Environmental Modelling of Remediation of Urban Contaminated Areas

Report of the Urban Remediation Working Group of EMRAS Theme 2

Environmental Modelling for RAdiation Safety (EMRAS) Programme

FOREWORD

Environmental assessment models are used for evaluating the radiological impact of actual and potential releases of radionuclides to the environment. They are essential tools for use in the regulatory control of routine discharges to the environment and also in planning measures to be taken in the event of accidental releases; they are also used for predicting the impact of releases which may occur far into the future, for example, from underground radioactive waste repositories. It is important to check, to the extent possible, the reliability of the predictions of such models by comparison with measured values in the environment or by comparing with the predictions of other models.

The International Atomic Energy Agency (IAEA) has been organizing programmes of international model testing since the 1980s. The programmes have contributed to a general improvement in models, in transfer data and in the capabilities of modellers in Member States. The documents published by the IAEA on this subject in the last two decades demonstrate the comprehensive nature of the programmes and record the associated advances which have been made.

From 2002 to 2007, the IAEA organised a programme titled “Environmental Modelling for RAdiation Safety” (EMRAS). The programme comprised three themes:

Theme 1: Radioactive Release Assessment

Working Group on the revision of IAEA Handbook of parameter values for the prediction of radionuclide transfer in temperate environments (Technical Reports Series (TRS) 364).

Working Group on model testing related to countermeasures applied to the intake of iodine-131 from the Chernobyl accident.

Working Group on testing of models for the environmental behaviour of tritium and carbon-14 following routine and accidental releases.

Working Group on testing of models for predicting the behaviour of radionuclides in freshwater systems and coastal areas.

Theme 2: Remediation Assessment

Working Group on testing of models for the remediation of the urban environment.

Working Group on modelling the transfer of radionuclides from naturally occurring radioactive material (NORM).

Theme 3: Protection of the Environment

Working Group on the review of data and testing of models for predicting the transfer of radionuclides to non-human biological species.

This report describes the work of the Urban Remediation Working Group under Theme 2. The IAEA wishes to acknowledge the contribution of the Working Group Leader, K. Thiessen of the United States of America, to the preparation of this report. The IAEA Scientific Secretary for this publication was B. Batandjieva of the Division of Radiation, Transport and Waste Safety.

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SUPPORTING INFORMATION

Bibliographic survey of modelling approaches for radionuclide transfer in contaminated urban environments, associated dose calculations and assessment of rehabilitation strategies. Report by F. Gallay, IRSN, France – versions in French and English.

Ukrainian scenario (complete version, including Geographic Information System (GIS) files).

Pripyat scenarios (Districts 1 and 4 of Pripyat), with supporting files.

Hypothetical scenario, with supporting files.

SUMMARY

The Urban Remediation Working Group of the International Atomic Energy Agency's EMRAS (Environmental Modelling for RAdiation Safety) programme was concerned with remediation assessment for urban areas contaminated with dispersed radionuclides. Types of events that could result in dispersal or deposition of radionuclides in an urban situation include both intentional and unintentional events, and releases could range from major events involving a nuclear facility to small events such as a transportation accident. The primary objective of the Urban Remediation Working Group was (1) to test and improve the prediction of dose rates and cumulative doses to humans for urban areas contaminated with dispersed radionuclides, including prediction of changes in radionuclide concentrations or dose rates as a function of location and time; (2) to identify the most important pathways for human exposure; and (3) to predict the reduction in radionuclide concentrations, dose rates, or doses expected to result from various countermeasures or remediation efforts. Specific objectives of the Working Group have included (1) the identification of realistic scenarios for a wide variety of situations, (2) comparison and testing of approaches and models for assessing the significance of a given contamination event and for guiding decisions about countermeasures or remediation measures implemented to reduce doses to humans or to clean up the contaminated area, and (3) improving the understanding of processes and situations that affect the spread of contamination to aid in the development of appropriate models and parameter values for use in assessment of these situations.

The major activities of the Working Group have included three areas. The first of these was a review of the available modelling approaches and computer models for use in assessing urban contamination and potential countermeasures or remediation activities. The second area of work was a modelling exercise based on data obtained in Ukraine following the Chernobyl accident. This exercise provided an opportunity to model large-scale contamination events such as the result of a nuclear accident. The exercise was designed to permit intercomparison of model results from different participants as well as, for some endpoints, comparison of model results with actual measurements. The third area was a modelling exercise based on a hypothetical situation involving a point-release of a radionuclide in an urban setting, specifically a release resulting from a radiological dispersal device involving an explosion. This exercise was intended to provide an opportunity for intercomparison of model results among participants. For both modelling exercises, the intent was to model the radiological situation over time in the absence of any remediation and with the effects of selected remedial measures. This approach was intended to permit comparison of the effects of various remedial measures in terms of their short- or long-term effect on dose rates and resulting doses in the areas of interest, for the purpose of aiding decisions about when to remediate and which remedial measures to use.

The Urban Remediation Working Group's final report includes an overview and discussion of the major modelling approaches and computer models presently available for use in assessing urban contamination situations. The models actually used in the Working Group's exercises are described in detail, including the parameterization for each of the exercises. Basic considerations in characterizing an urban environment have been summarized. The application of computer models to assess potential countermeasures or remediation measures is less well developed; therefore, the Working Group has summarized the available literature on countermeasures and their effectiveness and has developed some guidance for implementing countermeasures or remediation measures in computer models. An important caveat is that much of the information base on urban modelling generally and application of countermeasures more specifically has come from the Chernobyl experience; some

information might not be generally applicable for other types of contamination events or other geographical situations.

The first of the Working Group's two model intercomparison exercises was the Pripyat scenario, based on Chernobyl fallout data for the town of Pripyat in Ukraine, 3 km from the site of the accident. Deposition from the accident contained a wide spectrum of nuclear fission products, activation products, and transuranium elements. The scenario involved several radionuclides (^{95}Nb, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{141}Ce, and ^{144}Ce). Measured deposition of these radionuclides in District 1 and District 4 was provided as input information (e.g., for ^{137}Cs, 1.4 MBq m^{-2} in District 1 and 0.52 MBq m^{-2} in District 4). Pripyat was evacuated soon after the Chernobyl accident and has remained essentially uninhabited since that time.

The spread of the predictions from the four models for a given endpoint is more than an order of magnitude in many cases, and in some cases, up to 3–4 orders of magnitude. These large differences among results reflect the current uncertainty associated with modelling the behaviour of urban contamination. Much of this uncertainty is likely to be related to issues such as identifying the surfaces to be included in a model, the weathering of radionuclides from surfaces and transfer between surfaces, and the behaviour of different types of surface as contaminant collectors over long periods. The models used in the Pripyat scenario include different combinations of surfaces (e.g., interior surfaces of buildings were included in some models but not in others. Trees were included as surfaces in some models but not in others) or treat some surfaces differently (e.g., artificial surfaces were considered permeable in some models but impermeable in others). Thus, even when models gave similar results for a given endpoint (e.g., radiation dose rate at a given time and location), the relative contributions of surfaces to those results were often different. The examination of predictions of interim points in the overall dose assessment (e.g., the contributions to dose rate from specified surfaces) has enabled the Working Group to identify and understand the differences between models.

Predicted external doses to an outdoor worker (not a remediation worker) over the first time period in the modelling exercise varied from about 85 mGy to 200 mGy and predicted cumulative doses over 20 years varied from about 160 mGy to more than 4000 mGy, in the absence of countermeasures. Individual decontamination measures were estimated to reduce the dose over the first time period by a few percent to as much as 79%, depending on the model, the target person, and the importance of the decontaminated surface to that person's estimated dose in the given model. The short-lived radionuclides were very important contributors to the external dose from all surfaces in this scenario. Relocation of a target person during the first 6 months after the accident produced a 70–85% reduction in cumulative (20 year) dose, according to most of the models. Decontamination measures that physically removed contamination from the scene (e.g., cutting and removal of grass, removal of soil) had lasting effects in terms of dose reduction even 20 years later.

A number of measurements of dose rates were available for the Pripyat scenario. These were compared with the model predictions for the relevant locations and dates. Most of the models tended to underestimate the dose rates for outdoor locations, in part because the absence of human activity in the town appears to have resulted in slower loss of activity from surfaces. In addition, the initial deposition was considerably more uneven than the deposition assumed for the modelling exercise. Locations with mostly soil surfaces were modelled more successfully than those with mostly paved surfaces, but for a number of reasons, all of these comparisons include substantial uncertainty.

The Working Group's second modelling exercise was a scenario based on a hypothetical radiological dispersal device event. Using computer simulations of an explosive event involving a 50 TBq ^{137}Cs source, a set of reference surface contamination data was prepared for use as model input, together with concentrations of ^{137}Cs in air as a function of height at selected locations. Based on this input information, modellers were asked to predict contamination densities and dose rates over time at selected indoor and outdoor locations, doses for defined exposure situations, and the effects of selected countermeasures on the doses.

The highest predicted doses from occupational exposures during the first year after the RADIOLOGICAL DISPERSAL DEVICE event were about 7 mGy for exposure on the first floor of buildings very close to the site of the explosion; the highest predicted doses from residential exposures (approximately 1.5 km downwind) were about 5 mGy. The corresponding highest predicted cumulative doses over 20 years were about 70 and 30 mGy for occupational and residential exposures, respectively, in the absence of countermeasures. For any given location and type of exposure, predictions from the three models typically varied over a factor of 10–100. In all models, relocation for 6 months led to a large reduction in dose during the first year, but a much smaller reduction in cumulative dose over 20 years. Individual decontamination measures led to predicted reductions in cumulative doses of 0 (no effect) to about 80%, depending on the contribution of a given surface to the predicted dose and the estimated effect of the countermeasure on that surface. Decontamination measures such as cutting and removal of grass and removal of the top layer of soil continued to have an effect on annual dose for many years and had the greatest effect in terms of reducing cumulative (20 year) doses to individuals.

By comparing results from several modellers and models for the same endpoints, participants in the exercises were able to identify differences in the modelling approaches or parameterization and the effects of these differences on the model endpoints, to evaluate the effects of various countermeasures in terms of short-term and long-term dose reductions, and to justify selected revisions to the models. The differences in the modelling results to date provide an indication of the amount of uncertainty that currently exists in modelling urban contamination situations. The Working Group has identified a number of areas where more information needs to be obtained to improve predictive capabilities and reduce uncertainties. These include improved information about initial distribution of contamination, contaminant transport processes, and the nature of various urban surfaces in different countries or situations. From the exercises, the Working Group has prepared recommendations for improvement of both models and modelling exercises, in the context of assessing urban contamination. In addition, the Working Group prepared some practical considerations for decision makers, both for general preparedness and for addressing specific situations.

CHAPTER 1. INTRODUCTION

1.1. Background

The Urban Remediation Working Group is concerned with remediation assessment for urban areas contaminated with dispersed radionuclides. There are several types of events that could result in dispersal or deposition of radionuclides in an urban situation. These include both intentional and unintentional events, and releases could range from major events involving a nuclear facility or a nuclear weapon to small events such as a transportation accident. The extent of the contamination and impact on the environment would depend greatly on the specific event and the radionuclides involved. However, many aspects of assessing and remediating the situation will be the same or similar regardless of the spatial scale and specific radionuclides involved.

The intent of the Urban Remediation Working Group is to compare and test approaches and models to describe the behavior of radionuclides in an urban setting. The Working Group has sought to develop realistic scenarios for use in comparing and testing modelling approaches and models. Major issues that must be considered include a high density of buildings, relative lack of importance of agricultural issues, disposal of contaminated debris or water as a result of remediation measures, high potential for resuspension due to vehicular traffic, and movement of contamination within and outside the initial area of contamination due to human, vehicular or other means.

1.2. Objectives

The primary objective of the Urban Remediation Working Group is to test and improve the prediction of dose rates and cumulative doses to humans for urban areas contaminated with dispersed radionuclides, including (1) prediction of changes in radionuclide concentrations or dose rates as a function of location and time, (2) identification of the most important pathways for human exposure, and (3) prediction of the reduction in radionuclide concentrations, dose rates, or doses expected to result from various countermeasures or remediation efforts. Specific objectives include (1) the identification of realistic scenarios for a wide variety of situations, (2) comparison and testing of approaches and models for assessing the significance of a given contamination event and for guiding decisions about countermeasures or remediation measures implemented to reduce doses to humans or to clean up the contaminated area, and (3) improving the understanding of processes and situations that affect the spread of contamination to aid in the development of appropriate models and parameter values for use in assessment of these situations. The Working Group’s report is intended to describe what models are currently available and in what situations they might be useful, and to assist in the development of tools to be used for assessing the radiological impact (in terms of dose rates and doses) of a situation, for determining when remediation is required, and for evaluating proposed remediation measures in terms of the expected reduction of dose rates and doses.

1.3. Scope

The major activities of the Working Group have included three areas. The first of these is a review of the available modelling approaches and computer models for use in assessing urban contamination and potential countermeasures or remediation activities. The second area of work is a modelling exercise based on data obtained in Ukraine following the Chernobyl accident. This exercise provides an opportunity to model large-scale contamination events such as the result of a nuclear accident. The exercise is designed to permit intercomparison of model results from different participants as well as, for some endpoints, comparison of model results with actual measurements. The third area is a modelling exercise based on a hypothetical situation involving a point-release of a radionuclide in an urban setting, specifically a release resulting from a radiological dispersal device involving an explosion. This exercise is intended to provide an opportunity for intercomparison of model results among participants. For both modelling exercises, the intent is to model the radiological situation over time in the absence of any remediation and with the effects of selected remedial measures. This approach is intended to permit comparison of the effects of various remedial measures in terms of their short- or long-term effect on dose rates and resulting doses in the areas of interest, for the purpose (in part) of aiding decisions about when to remediate and which remedial measures to use.

1.4. Structure of the report

Chapter 1 provides a brief description of the background of the Urban Remediation Working Group, the Working Group's objectives, and the scope of its activities. Chapter 2 provides a summary of major models and modelling approaches designed for assessment of urban contamination situations. This section also includes a brief description of the models used by participants in the Working Group's modelling exercises. Chapter 3 describes the first modelling exercise, based on Ukrainian data following the Chernobyl accident. Chapter 4 describes the second modelling exercise, based on a hypothetical situation of a point release of a radionuclide in an urban setting. Chapters 3 and 4 include comparative analyses of model predictions and reasons for agreements or discrepancies. Chapter 5 provides the conclusions and recommendations of the Working Group based on the model review and the modelling exercises. Appendices I and II include the scenario descriptions and documentation for each of the modelling scenarios. Appendix III includes more detailed descriptions of the models used in these exercises by Working Group participants, including individual evaluations of their model performance. Appendix IV includes summaries of the model predictions and (where available for the Ukrainian scenario) measurements. Appendix V contains supplementary material about remediation activities that were actually undertaken in Pripyat or surrounding areas. The CD containing this report also contains full scenario descriptions and supporting information (electronic files) for both scenarios, as well as a complete report (in French and English) on available models and modelling approaches for assessing urban contamination and remediation measures.

CHAPTER 2. MODELLING OF CONTAMINATED URBAN ENVIRONMENTS

2.1. Recent international experience

In most developed countries, more than 70% of the population lives in urbanized areas; therefore, the assessment of the radiological consequences of contamination of this environment is today an issue of risk analysis during the recovery phase. In this context, therefore, the aims of the Urban Remediation Working Group are to make an inventory and an intercomparison of the models available for assessing the radiological consequences for the population of the contamination of an urban environment following an accident, as well as the appraisal of possible rehabilitation strategies for these areas. A recent report by Gallay [1] (copy available on the CD containing this report), summarized below, aims to provide a first statement of the international experience, based on a bibliographical synthesis of the main results published on the subject.

In case of a reactor accident, the external exposure to radionuclides deposited on urban surfaces would represent, during the post-accident phase, a major exposure pathway for the population living in the contaminated areas [2]. Therefore, this pathway has been more thoroughly studied than other exposure pathways to be considered in such situations, such as internal exposure via inhalation of resuspended particles in the air.

The first surveys of the consequences of an accidental deposit of radionuclides in an urban environment covered, in the early 1950s, the assessment of the shielding properties offered by buildings against external exposure to the radiation emitted by radionuclides deposited on urban surfaces. The results from building contamination experiments, conducted in Nevada (United States) during the 1950s and 1960s, as well as in-depth research, allowed the development of the first computational methods. Then, from the 1980s to the present, new computational methods have emerged, especially in Europe, in order to expand the initial results to various types of buildings, and to incorporate the heterogeneous distribution of radionuclides in an urban environment. These various methods may be based either on the point-kernel build-up method or on Monte Carlo simulations [3–5].

Studies of radionuclide transfers within the urban environment in a post-accident situation began later, essentially since the 1980s following the Chernobyl accident (26 April 1986 in Ukraine). This subject had not been very well explored before this period, since research on the consequences of a nuclear accident was primarily focused on rural areas before these events [6]. Furthermore, before 1986, the development of radionuclide transfer models for an urban environment was impaired due to a lack of experimental data and to the complexity of the subject. By now, numerous measurement results have been published, thus allowing characterization of the phenomena impacting the evolution in space and time of radionuclides deposited in an urban environment.

The Chernobyl accident also allowed the assessment of the importance, in case of a reactor accident, of other exposure pathways for the population in addition to external exposure to particles deposited on urban surfaces, especially internal exposure via inhalation of resuspended particles. It also highlighted the need for identifying and assessing the effectiveness of recovery strategies to allow the management of major contamination of the urban environment [7–12]. Numerous actions aimed at the decontamination of urban areas were indeed implemented following this accident. The results of these experiments then allowed development of models for assessing the post-accident rehabilitation strategies in urban space which, combined with radioecological and dosimetric models, currently allow a comprehensive assessment of the risks for the population living in urban spaces contaminated after an accident.

A number of issues must be considered in modelling urban contamination situations [1], including characterization of the contaminated urban environment, modelling of human exposures, and modelling of various rehabilitation strategies (countermeasures). Each of these is discussed briefly below.

Characterization of a contaminated urban environment includes the type of deposition, contaminant transport processes both pre- and post-deposition, the exposure pathways to be included, the radionuclides of concern and their physico-chemical characteristics, the location of an individual with respect to contaminated surfaces, shielding factors to account for attenuation of activity by various structures, occupancy factors (proportion of time spent in specific locations), and types of contaminated surfaces. For most situations, external exposure to radionuclides deposited on surfaces is expected to be the most important pathway; for some situations, important pathways could include inhalation from the plume, inhalation of resuspended radionuclides, or deposition on skin. For reactor accidents such as Chernobyl, ^{137}Cs is expected to be the major radionuclide of concern for the long term, but omission of shorter-lived radionuclides can contribute to a significant underestimate of short-term dose.

Urban environments are variously defined in terms of population density, land use (e.g., residential and occupational), and the kinds and sizes of buildings and surfaces. Dosimetric models typically describe a “location” or “environment” in terms of the structures and surfaces in the immediate vicinity of an individual and the contributions to that individual’s dose from each contaminated surface. Surfaces vary with respect to their retention of radionuclides and how effectively radionuclides are removed.

The rehabilitation of an accidentally contaminated urban environment is a complex topic, and some simplifications need to be applied for modelling purposes. However, at present, numerous relatively recent experimental results allow identification of the main parameters to be considered for this purpose. Furthermore, various models (summarized in Table 2.1) have been developed, especially in Europe, based on these data, for which a relatively rich feed-back experience is now available.

A summary of data available for post-accident rehabilitation of the urban environment currently highlights the following gaps:

- Parameters governing the deposition and distribution of radionuclides on different surfaces, especially for situations other than reactor accidents;
- The long-term behaviour of radionuclides deposited on urban surfaces, especially for situations other than reactor accidents;
- The attenuation properties of the wide variety of buildings encountered within urban environments worldwide;
- The effectiveness of post-accident rehabilitation actions in case of an accident from a facility other than a reactor; and
- The global effectiveness of the various combinations of rehabilitation actions.

Furthermore, numerous parameter values used in current models are associated with a high uncertainty, because these are often average values of results from independent measurements, in different conditions, and on different types of materials [13]. Results of calculations based on these values need to therefore be interpreted with caution, especially for the long term following an accident.

Table 2.1. Summary of the main characteristics of calculation codes for assessment of the recovery phase in urban areas (from Gallay [1]).

Models	**CONDO**[a]	**EXPURT**[b]	**LCMT**[c]**/RODOS**	**TEMAS Urban model**	**PARATI**[d]
Origin	**HPA/NRPB (UK)**	**HPA/NRPB (UK)**	**European Community**	**GSF (Germany) CIEMAT (Spain)**	**Instutito de Radioproteçao e Dosimetria (Brazil) GSF (Germany)**
References	[14, 15]	[16, 17]	[18]	[19]	[20, 21]
Objective	Multicriterion assessment of recovery options	External dose calculations and recovery option assessment	External dose calculations and recovery option assessment	External dose calculations and recovery option multicriterion assessment	External dose calculations
Component of another code	–	CONDO	–	TEMAS	–
Radionuclides included	^{241}Am, ^{140}Ba, ^{140}La, ^{60}Co, ^{134,136,137}Cs, ^{131}I, ^{95}Nb, ^{239}Pu, ^{103,106}Ru, ^{95}Zr + possible insertion of other radionuclides	^{241}Am, ^{140}Ba, ^{140}La, ^{60}Co, ^{134,136,137}Cs, ^{131}I, ^{95}Nb, ^{239}Pu, ^{103,106}Ru, ^{95}Zr	4 groups represented by ^{140}Ba, ^{106}Ru, ^{137}Cs, ^{131}I	^{134,137}Cs, ^{90}Sr	^{137}Cs (+ recent additions)
Radioecological approach	– (realized by EXPURT)	Dynamic compartment model	–	No compartment	Retention functions
Dosimetrical approach	– (realized by EXPURT)	Global and complex approach	Global and simple approach	Local and complex approach	Global and complex approach
Environments	–	5	–	2	9
Inhalation of resuspended particles	Resuspension: Garland's formulae	–	–	–	Yes
Recovery options	Yes	Yes	Yes	Yes	Yes
Optimisation of the assessment of recovery options	Costs, wastes, time for implementation, required skills and material, additional doses to the workers	–	Costs, wastes, additional doses to the workers	Yes	–

[a] CONDO: Software for estimating the consequences of decontamination options.
[b] EXPURT: Exposure from Urban Radionuclide Transfer.
[c] LCMT: Late Countermeasures Module for terrestrial environments.
[d] PARATI: Programme for the assessment of radiological consequences in a town and of intervention after a radioactive contamination.

Table 2.1. Summary of the main characteristics of calculation codes for assessment of the recovery phase in urban areas (from Gallay [1]) (cont.).

Models	**URGENT**[e]	**JSP-5 model**	**METRO-K**[f]	**MUD**[g]	**RESRAD-RDD**[h]
Origin	**RISØ National Laboratory (Denmark)**	**CEI – European Union**	**Korea Atomic Research Institute (South Korea)**	**Universidad Politecnica de Madrid (Spain)**	**Argonne National Laboratory (USA)**
References	[22]	[23]	[24]	[25]	[26]
Objective	External dose calculations and recovery option assessment	External dose calculations	External dose calculations	Radionuclide transfers in urban environment and to sewage system	Operational Guidelines for use in emergency preparedness and response to a radiological dispersal device incident. Doses from multiple exposure pathways (external, inhalation, ingestion, and submersion) are calculated.
Component of another code	–	–	–	MOIRA	–
Radionuclides included	^{137}Cs	$^{134, 137}$Cs, ^{132}Te, $^{131, 132}$I, ^{140}Ba, ^{140}La, ^{103}Ru (+ recent additions)	^{137}Cs, ^{131}I, ^{106}Ru	^{137}Cs	^{137}Cs, ^{241}Am, ^{252}Cf, ^{244}Cm, ^{60}Co, ^{192}Ir, ^{210}Po, ^{238}Pu, ^{239}Pu, ^{226}Ra, ^{90}Sr
Radioecological approach	Dynamic compartment model	Retention function for migration into soils	Dynamic compartment model	Dynamic compartment model	Dynamic compartment model
Dosimetrical approach	Global and complex approach	Global and simple approach	Global and complex approach	–	Global and complex approach
Environments	4	–	7	–	2
Inhalation of resuspended particles	–	–	–	–	Yes
Recovery options	Yes	–	–	–	Yes
Optimisation of the assessment of recovery options	–	–	–	–	Yes

[e] URGENT: Urban gamma exposure normative tool.
[f] METRO-K: Model for Estimating the Transient Behaviour of Radioactive Material in the Korean Urban Environment.
[g] MUD: Model to investigate the migration of ^{137}Cs in the urban environment and drainage and sewage treatment systems.
[h] RESRAD-RDD: RESRAD – Radiological dispersion device. RESRAD-RDD was not included by Gallay [1], but is included here for completeness.

Certain modelling approaches in current use are relatively simple and involve a limited number of parameters, while others are much more complex. However, both types of approaches include advantages and drawbacks. Complex models require a large quantity of experimental data to provide values for the numerous parameters used. If this information is available, the complex models may generate very good predictions. However, the experimental data currently available show that the values of certain parameters may demonstrate relatively high variability depending on the type of accident and on the type of urban environment being considered. Also, certain gaps have been identified with regard to the experimental results. Finally, the importance of technical resources and human skills required, as well as the time required for calculations, increases with the model complexity. In contrast, for simple models, a number of approximations are made in the calculations, such that the uncertainty in their results may sometimes be difficult to assess. Also, simple models are usually less flexible than complex models.

Selection of the type of model to be used is highly dependent on the calculation objective, the information available, and the time available to do the assessment. For example, models for use in emergency preparedness and planning could include detailed location-specific information such as building types but use average weather conditions. At the beginning of the post-accident phase in case of an actual event, few measurement results will be available: the use of simple models, applying relatively conservative assumptions, then permits the provision of first indications to decision-makers with regard to the exposure of the urban population living in the contaminated area in order, for instance, to assess the opportunity to implement population-protective actions in the post-accident phase, such as temporary relocation. Realization of the full potential of complex models may be difficult at this stage, as the large amount of input data required for calculations might not be available, although some models may be able to make use of real-time data for parameters such as meteorological variables. As data become available, use of data assimilation techniques can be applied to combine measurements with model results to improve the predictive power of the assessment models. In the medium and long term after the deposit, results of measurement campaigns may allow a finer assessment of risks, based on calculations performed with more complex models. For example, a growing number of reliable measurements can be used for updating parameter values, reassessing initial estimates of deposition, or re-evaluating a conceptual model. It may be necessary to use different models at different stages of an assessment.

2.2. Sources of information on urban recovery countermeasures for use in models

2.2.1. Literature on urban recovery countermeasures

In order to model the effect and consequences of recovery options, information is required. Many reports and papers have been generated regarding recovery countermeasures. These can be divided into two types. The first type includes those that present basic data such as the results of experiments and field trials, or real decontamination efforts following accidents such as Chernobyl and Goiânia (e.g. [27]). The second type includes those that are compilations or catalogues of recovery options generated for the purposes of emergency preparedness at a national or international level (e.g. [7–12]). As the second type generally refers back to the first type, they are an appropriate place to begin looking for information about countermeasures.

Compilation reports contain information relating not only to the effectiveness but also the cost and practicability of countermeasures that would allow a decision-maker to evaluate and compare different recovery strategies. Some go further and apply the countermeasures to hypothetical situations using urban models and stakeholder involvement in order to explore the consequences of different strategies and highlight less tangible but important considerations such as public acceptability (e.g. [28]). Others are presented as a decision framework, not only providing the information needed by the decision-makers but also guiding them through the decision-making process, often using aids such as flow-charts and decision trees (e.g. [8]).

Inevitably these compilations draw information from earlier reports, updating, adding to, amalgamating and refining the data within. They also draw from the body of basic data extrapolating from the specific to the general where possible to allow countermeasures to be compared.

In Europe, this process has culminated in a compendium [7] and a generic European handbook for the management of recovery options in contaminated inhabited areas following a radiological incident, generated under the European Commission (EC) 6th Framework Prgramme [29]. The compendium includes 52 recovery options as well as countermeasures for the pre-release and release phases of an incident. The examples in this report are drawn from this compendium.

A common aim in the various compendia is to present a consistent set of attributes for each recovery option. This allows comparison among the countermeasures and use of situation-specific criteria in the selection of appropriate options. Brown et al. [7] include the following classes of attribute in a standard countermeasure template:

- Objectives of the option;
- A short description of the option;
- Constraints on its implementation;
- Effectiveness;
- Requirements;
- Waste generated;
- Doses received by those implementing the option;
- Costs;
- Side-effects; and
- Practical experience.

Each of these classes is divided into a number of attributes. Most of the classes are fairly self-explanatory. Of particular interest to the modelling of countermeasures is the effectiveness.

2.2.2. Effectiveness of countermeasures

In Brown et al. [7] the effectiveness of a countermeasure is divided into the following attributes:

- Reduction in contamination on the surface;
- Reduction in surface dose rates;
- Reduction in resuspension;
- Averted doses;
- Additional doses (doses to workers implementing the countermeasure);
- Factors influencing the effectiveness of the procedure (technical); and
- Factors influencing the effectiveness of the procedure (social).

Some or all of these attributes will be found in the various other compendia, but the information is derived primarily from Chernobyl data and might not be applicable for other types of situations. Whilst most of the attributes can be derived from experimental data or consideration of the practical details of the option, the attributes of averted doses and additional doses can only really be evaluated using a model or, less practically, the measurement of real personal doses following a real incident. This is because the averted doses depend not only on the countermeasure, but also on the radionuclides deposited, the geometry and properties of the surfaces in the environment, and the behaviour of the population exposed. The additional doses depend on the above factors and on the nature of the countermeasure, such as the work-rate and where it places the worker within the contaminated environment. These values are therefore not inputs to a model but can be among the outputs.

2.2.2.1. Decontamination factor

The effectiveness of recovery options that decontaminate a surface can be described with a decontamination factor (DF). A DF represents the efficiency of removing activity from a surface:

$$Activity_{after}\ (Bq\ m^{-2}) = Activity_{before}\ (Bq\ m^{-2})\ /\ DF \qquad (2.1)$$

Thus a countermeasure with a DF of 2 will reduce the contamination on a surface by 50%. A DF of 10 indicates a 90% reduction, and a DF of 100 indicates a 99% reduction. A DF quoted for a countermeasure strategy is the DF for the first application of a countermeasure. It is generally not reasonable to assume that the second or subsequent applications will be equally as effective, particularly for cleaning techniques.

A DF of 2 does not imply an overall dose reduction of 50%, as it depends how much the particular surface contributes to the total external dose from all surfaces. This in turn depends on the contamination on the surface and the relationship between where the population spend time and the location and orientation of the surface.

A quoted DF must be interpreted correctly to ensure that it is used appropriately within a model. For example, the DF for a countermeasure may change as a function of time, becoming less effective at increasing times after the initial deposition. There are several reasons for this. Contamination may become increasingly tightly bonded with the surface, e.g. pavement, as time progresses. In this situation cleaning techniques such as fire-hosing become increasingly ineffective within a few days of deposition. However, the effectiveness of a removal technique such as road removal will not change with time. A second cause of DF time dependency is the movement of contamination to a part of the surface less affected by the countermeasure. For example, material deposited on grass will in time migrate to the base of a plant and into the leaf litter on the soil surface. A countermeasure such as mowing will take an increasingly smaller proportion of the total material that is on soil and grass as time continues. It is common for compendia to describe time dependency in qualitative terms. For example Brown et al. [7] describe the DF of fire hosing paved areas as:

> *"a decontamination factor between 2–4 can be achieved if this option is implemented within one week of deposition, and there has not been any significant rainfall. DFs at longer times will be significantly lower unless the surface has not been subject to any traffic and there has been no rainfall."*

The model user must consider which value in the range, if any, is most appropriate for the situation he or she is addressing.

For the purposes of interpretation of the quoted DF, it is convenient to subdivide decontamination techniques into those that clean a surface of contamination and those that remove a part of the surface and the contamination along with it. For removal techniques, high DFs are common; for example, Brown et al. [7] give a DF of between 10 and 30 for 'turf and top-soil removal'. This means that some 90% to 97% of the contamination is removed. In practice, the techniques are likely to be less effective because some of the removed material is likely to fall back onto the surface as it is taken away and because inevitably not all the contaminated surface will be removed. Generally a surface removal technique will exhibit less time dependency than a cleaning technique. However, particularly in connection with late implementation of surface removal techniques, it is always recommended to first assess the depth profile of the key contaminants in the material. In an attempt in 1989 to reduce external dose in 93 Chernobyl-contaminated settlements of the Bryansk region, the Russian army introduced the reasonable countermeasure of removing a topsoil layer, supposedly containing (most of) the contamination. However, at that time, vertical soil profiles of radiocesium in the area were sometimes recorded to peak at a depth of some 5–10 cm [30, 31]. This means that an uncritical scraping off of the top, say, 5 cm layer would in fact remove a shielding soil layer containing very little contamination. Therefore, the dose rates in some cases were found to increase, and the decontamination work was stopped [32]. Also, migration into construction materials can increase somewhat with time [33, 34], and the thickness of surface to be removed to obtain a given decontamination factor on such a surface will increase accordingly.

2.2.2.2. Dose rate reduction factor

A dose rate reduction factor (DRF) describes the reduction in external gamma and beta dose rate immediately above a surface following application of *a countermeasure:*

$$\textit{Dose rate}_{after}\ (Sv\ s^{-1}) = \textit{Dose rate}_{before}\ (Sv\ s^{-1})\ /\ DRF \qquad (2.2)$$

A DRF can be used to describe the effectiveness of decontamination techniques, techniques that mix or bury the contamination in the soil column, and techniques that place shielding between the source and the population. A DRF can be radionuclide specific; this is particularly true for shielding techniques which, when applied to contamination including beta emitters and less energetic gamma emitters, will give a higher DRF than when applied to contamination involving higher energy gamma emitters.

Quoted DRFs may be derived experimentally, derived from consideration of the mechanics of the countermeasure, or derived by modelling or calculation methods. For example, in Brown et al. [7], it is assumed for many decontamination techniques that the DRF is the same as the DF, based on consideration of the mechanics of the countermeasure. Derivation by modelling or calculation methods is particularly true for shielding techniques.

As with a DF, the DRF does not relate directly to external dose reduction, which also depends on how much that surface contributes to overall external dose.

2.2.2.3. Resuspension reduction factor

A resuspension reduction factor (RRF) describes the reduction of respirable material available from a surface immediately following application of a countermeasure:

$$\textit{Material Available}_{after}\ (Bq\ m^{-2}) = \textit{Material Available}_{Before}\ (Bq\ m^{-2}) /\ RRF \qquad (2.3)$$

A RRF can be used to describe the effectiveness of decontamination techniques, techniques that mix or bury the contamination in the soil column, techniques that place shielding between the source and the population, and tie-down techniques.

A resuspension reduction factor is a difficult quantity to measure and a difficult quantity to use. Generally it will be an assumed value for the purposes of dose assessment, derived from consideration of the countermeasure mechanics. For example, it would be a conservative assumption to assume that a decontamination technique had an RRF the same as the DF. This is conservative, because one might expect the fraction of material remaining following a decontamination technique to be that most difficult to remove and therefore not available for resuspension. It also assumes that all the remaining material is of a particle size that is respirable. According to the International Commission on Radiological Protection (ICRP) [35], 'inhaled particles larger than 10 μm would be cleared rapidly by ciliary action'. This, for instance, excludes sand particles and most silt particles, to which contaminants may be attached. It would also exclude a large proportion of the initial particles deposited after a 'dirty bomb' detonation [36].

As with a DF, the RRF does not relate directly to dose reduction, which also depends on how much that surface contributes to the overall resuspension dose.

2.2.2.4. Dose reduction

The dose reduction (DR) is the reduction in overall exposure from deposited material within the environment, including external irradiation and inhalation pathways, taking into account all the countermeasures that have been applied. A DR can be used to describe the effectiveness of all recovery options, including relocation and restriction of access options. However, it will be situation specific and dependent on the characteristics of the deposition, the environment and the population. Indeed, for many of the options in Brown et al. [7], no DR is quoted, because it is considered too situation-dependent to usefully quantify (see Table 2.2).

The dose reduction may be established in a real situation by giving the population of the region personal dosimeters. More commonly it is assessed using a model. In order to interpret the DR, some knowledge of the model and how it was used is required, for example, whether a specific radionuclide mix was assumed.

2.2.2.5. Summary of countermeasure effectiveness

Table 2.2 gives a summary of some of the countermeasure effectiveness information from Brown et al. [7].

Table 2.2. Summary of recovery countermeasure effectiveness (extracted from Brown et al. [7]).

Recovery option	DF	DRF	RRF	DR
Fire-hosing buildings	1.3[a]	As DF	As DF	Few %
Roof brushing	2–7	As DF	As DF	5–10%
Sandblasting walls	4–10[b]	As DF	As DF	6–8%[c]
High pressure hosing buildings	1.5–5[b] 2–10 (Pu)	As DF	As DF	6–7%[c]
Roof cleaning, pressurised hot water	2–7[b]	As DF	As DF	7–8%
Roof replacement	Effectively all	Effectively all	Effectively all	9–11%
Treatment of walls with ammonium nitrate	1.5–2 (Cs only)[b]	As DF	As DF	4%[cd]
Mechanical abrasion of wooden walls	1.5–2.5[a]	As DF	As DF	5%[c]
Tie-down to buildings	1[e]	1[f]	Effectively all[g]	Situation dependent
Vacuuming indoors	5–10[h]	As DF	As DF	15%[c]
Washing indoor surfaces	1.3–3[h]	As DF	As DF	5–10%[c]
Fire hosing paved areas	2–4[a]	As DF	As DF	5–10%
Vacuum sweeping paved areas	2–3[a]	As DF	As DF	5–10%
High pressure hosing paved areas	3–7[a]	As DF	As DF	5–10%
Surface removal paved areas	5–10	As DF	As DF	5–15%
Turning paving slabs	1	4–6[i]	Effectively all	Situation dependent
Tie-down to paved areas	1[e]	1[f]	Effectively all[g]	Situation dependent
Grass cutting	2–10[a]	As DF	As DF	About 25%[c]
Plant and shrub removal	2–10[a]	< DF[j]	< DF[j]	Situation dependent
Turf harvesting	3–10[k]	As DF	As DF	28%[cm] 65%[lm]
Top soil and turf removal	10–30	As DF	As DF	30%[cm] 65%[lm]
Cover soil/grass with clean soil	1	4–5[n]	Effectively all	Situation dependent
Tie down to soil, grass and plants	1e	1[f]	Effectively all[g]	Situation dependent
Rotovating	1	2–3[o]	10–20	Situation dependent
Manual digging	1	2–4[o]	< DRF	Situation dependent
Cover soil/grass with asphalt	1	2–3[q]	Effectively all	Situation dependent
Triple digging	1	5–10[r]	Effectively all	Situation dependent
Ploughing	1	2–5[r]	> DRF[s]	Situation dependent
Deep ploughing	1	5–10[r]	> DRF[s]	Situation dependent
Skim and burial ploughing	1	5–10[r]	> DRF[s]	Situation dependent
Peelable coatings, all outside areas	5[h]	As DF	As DF[t]	Situation dependent
Snow removal	10–30	As DF	As DF	35%[c] 80%[l]
Collection of leaves	As tree removal	Significantly reduced	Significantly reduced	As tree removal
Tree and shrub removal/pruning	Up to 50	As DF	As DF	20%[c]

[a] DF can be achieved if this option is implemented within 1 week of deposition and before significant rain.
[b] DF can be achieved if option is implemented soon after deposition.
[c] DR achievable under dry deposition conditions.
[d] DR achievable if significant Cs component to contamination.
[e] Tie-down techniques are not applied for the purpose of decontamination; in practice some contamination may be removed along with the tie-down material.
[f] Tie-down techniques are not applied to reduce external dose rates; however, beta rates may be reduced dependent on energy, tie-down material and tie-down material thickness, whilst material is in place.
[g] Resuspension inhibited whilst tie-down in place.
[h] DF can be achieved if implemented within a few weeks of deposition.
[i] DRF achievable for medium to high energy gamma emitters.
[j] The DRF and RRF are less than the DF because of contamination on the underlying soil.
[k] DF can be achieved if applied in first few years after deposition, effectiveness decreases as material migrates to deeper layers.
[l] DR achievable under wet deposition conditions.
[m] DR assumes all grass/soil areas treated, not just large areas such as parks.
[n] Example DRF for ^{137}Cs assuming clean soil to depth of 10 cm, beta dose rates reduced by effectively 100%.
[o] DRF achievable in the medium term depending on success of mixing within soil, technique will be more effective for beta dose rates.
[p] Example DRF for ^{137}Cs dependent on success of burying top layer, technique will be more effective for beta dose rates.
[q] Example DRF for ^{137}Cs assuming 5–6 cm of asphalt, beta dose rates reduced by effectively 100%.
[r] Gamma dose rate reduction dependent on energy, beta dose rates reduced by effectively 100%.
[s] Significantly better at reducing resuspension than external dose rate.
[t] RRF will be effective 100% while coatings are in place.

2.2.3. *Using recovery countermeasure information in models*

How a recovery option is included within a model depends on the way the model works and the endpoints required from that model.

At the simplistic end a DR can be applied to a calculated dose in the absence of countermeasures. This is essentially how the LCMT (Late Countermeasure Module Terrestrial) in the RODOS nuclear emergency decision support system works (see [12]). LCMT applies a library of DRs to the output of the dose module of RODOS. The DRs used were precalculated using an early version of the EXPURT model. Therefore, the user of LCMT is a step removed from the need to interpret countermeasure effectiveness as this has been done in advance by the developers of the DR library and the LCMT interface. The result is an application that is simple to use, and 'safe' for non-experts but is somewhat inflexible in that the user is restricted to scenarios that have been pre-calculated.

At the more complex end, a DF or other measure of effectiveness can be applied to a model that simulates the retention of radionuclides and calculates the dose contribution from each surface explicitly. EXPURT is an example of this type of model (see [17]). For this type of model, the user needs to interpret a quoted DF carefully before attempting to represent a particular countermeasure. The following questions must be asked: Is the DF appropriate for the countermeasure one is intending to represent? Does it account for time dependency? Is it applicable to the radionuclide contamination? Is it applicable to the whole surface (e.g. all grass-soil surfaces or both grass and soil) or just a part (e.g. only large areas of grass such as parks but not small areas, or only grass and not the underlying soil)? The result is a model that is very flexible but not necessarily simple to use, and therefore inappropriate for non-experts.

CONDO is an example of an application that embeds a model (EXPURT). By providing a front end it becomes easier and more robust to use whilst retaining most of the flexibility (see [15]). For example, CONDO applies a linear function to represent time dependent DFs in order to simulate the way some decontamination methods become less effective with time. CONDO calculates the RRF for decontamination techniques and tie-down techniques in run-time, based on knowledge of the countermeasure mechanics and the surface activity results of EXPURT.

2.2.4. *Comments on the countermeasures selected for the Pripyat scenario and their effectiveness*

The following countermeasures were specified for consideration in the modelling of the Pripyat scenario (Chapter 3 and Appendix I):

2.2.4.1. *Washing of roads*

This countermeasure needs to be applied early to save significant dose. This is because experience from Chernobyl has shown that some 70% of the contamination on a road would be removed by 'natural' weathering processes with a half life of some 120 days (the rest with a half-life of ca. 3 y). Also the effect would be less if implementation occurs later than suggested in the scenario description because of contamination fixation. If the condition of the roads is reasonable (with respect to, e.g., holes and evenness) a decontamination factor at the high end (of the order of 4) would be expected from trials outside the vicinity of the Chernobyl Nuclear Power Plant (NPP), if the job is done fairly thoroughly (0.01–0.02 h per m^2). However, a significant part of the contamination so close to the NPP would be associated with large, not readily soluble, particles which settle at short distances. Such large particles would be considerably easier to wash away from the surface. For instance, Clark and Cobbin [37] obtained a DF of 50 when hosing a street contaminated by particles in the 44–100 µm range [7, 9–11, 33, 38–42].

2.2.4.2. Washing of roofs and walls

On a clay roof tile (as stated in the scenario description), much of the contamination (particularly cesium) will be retained and fixed over a period of time. Again, since the method is applied early, there is hope of a comparatively high DF. Judging from field trials, the method would be likely to remove about 70–80% of small (ca. 1 µm) condensation particle contamination on these types of surfaces, assuming water consumption of 10–20 L m^{-2}. The much higher DF reported in Section I.4 of the scenario description (Appendix I) could reflect two different things: (1) The association of the contamination with large, not readily soluble particles. A considerable difference was found in 1993 between the binding strength of cesium in the town of Pripyat and that in the village of Vladimirovka, at a distance of some 65 km from the power plant. Spraying of inert water solutions on similar limestone walls removed two-thirds of the cesium contamination in Pripyat, but only about one-fifth of the cesium contamination in Vladimirovka. (2) The early assessments of DF in Pripyat were most likely based on beta monitoring. As much of the contamination on the very surface would be removed by washing, the beta signal would be greatly reduced, but as a considerable part of the contamination would have penetrated slightly, such measurements would not be representative [7, 9–11, 28, 33, 40, 41, 43, 44].

2.2.4.3. Cutting and removal of grass

We will assume that the grass is cut as tightly as possible, and the grass carefully removed. Then it would be possible to reduce the contamination by a factor of 8–10 (as we are dealing with dry deposition). The effectiveness of this countermeasure is critically dependent on time (particularly heavy rain showers washing contamination into the soil). Average half-lives of the transfer from grass to soil have been reported to be of the order of 2 weeks [45], and since the weather started out dry, probably very little contamination reached the soil over the first 2 weeks, when the method is assumed to have been implemented [7, 9, 11, 33, 46].

2.2.4.4. Removal of trees

Removal of deciduous trees would make sense only if applied very early. By the end of the suggested implementation period it would be autumn, and leaves would have been shed completely from deciduous trees. According to the findings of Roed [47], the leaves receive some 98% of the bulk aerosol deposition on a tree. For elemental iodine, this value is 75%. For coniferous trees, needles can be assumed to be shed evenly over some 2–6 years. A complete removal of a tree would mean a virtually complete removal of the contamination on it [7, 9, 10, 48].

2.2.4.5. Removal of soil (5 cm)

A removal layer of 5 cm thickness is expected to be sufficient to ensure optimal effect, particularly as the method is applied over the first 6 months. For instance, ruthenium is significantly more mobile in soil than cesium, but soil samples near Chernobyl showed that four years after the Chernobyl accident, virtually all the ruthenium still lay in the upper 10 cm of the soil. Within the first 6 months the penetration of such relatively mobile radionuclides would be much more limited. Based on field trials, a maximum estimate for the DF would be 10, as some mixing or smearing would be likely to occur. Also, in reality, removal depth would be somewhat inhomogeneous. This DF estimate seems to be in reasonable agreement with the DRFs reported in Section I.4 of the scenario description (Appendix I). By removing only 5 cm of topsoil, the potential for creating fertility or erosion problems has been minimised [7, 9, 11, 30, 31, 49, 50].

2.2.4.6. Ploughing (50 cm)

It should be noted that this requires much open space, and could not be accomplished on small land lots. Deep ploughing will under optimal conditions be expected to result in a DRF of about 10, if carried out early, while the contamination is at the very top of the soil profile. However, since the soils in the area are rather sandy, a degree of mixing of soil layers is likely to occur, and the DRF might well be in the range of only 4–6 [7, 9, 30, 33, 50–52].

2.2.4.7. Washing indoor surfaces

The particles that contaminated Pripyat would have been relatively large compared with, e.g., the radiocesium particles recorded in Western Europe after the Chernobyl accident. Many of the particles in Pripyat would still be sufficiently small to penetrate into buildings in large quantities (although the building filter factor for 5 µm particles is only about half of that of 1 µm particles), where they would have high deposition velocity. Due to gravitational settling of these supermicron particles, floors of buildings (and other horizontal surfaces) would be particularly important to wash. For such particles in the early phase, thorough washing/scrubbing with hot water and detergent would be likely to result in a reduction of the contamination level by a factor of 3–5. For very smooth surfaces without cracks, the effect could be higher [7, 9, 53–55].

2.2.4.8. Vacuum-cleaning indoor surfaces

As stated above, the most important surfaces to treat would be the horizontal ones. The smallest of the primary contaminant particles will, according to experiments, over a day or two agglomerate/attach to larger house dust particles, whereby they become much easier to remove with a vacuum cleaner. The larger particles that can enter a dwelling (5–10 µm) would be readily picked up by a vacuum cleaner with good effect. If it is done around day 14, as stated in the scenario description (Appendix I), a reduction of the contamination on the treated surface by a factor of 10 is realistic. For ca. 5 µm particles, the deposition velocity to the floor is 5–10 times as great as that to the wall or ceiling, so clearly this is the important surface to treat [7, 9, 53, 55, 56].

2.3. Description of models used in these exercises

Five models were used by participants in the Urban Remediation Working Group’s modelling exercises. These are summarized briefly below and described in more detail in Appendix III. A general comparison of key features of the models is provided in Table 2.3. Comparisons of the models as actually applied in the two modelling exercises are provided in Tables 2.4 and 2.5. Parameter values for environmental removal of contamination are summarized by model in Table 2.6. Decontamination factors used for specific countermeasures are summarized by model in Table 2.7. (Note that the decontamination factors actually applied do not necessarily agree with the information provided in Section 2.2; individual modellers were free to select their own values.)

2.3.1. EXPURT

EXPURT calculates surface activity densities and external gamma doses and dose rates as a function of time in built environments with a mixture of urban surfaces including roads, trees, walls, roofs, grass, etc. The current version 3.02 is largely unchanged from version 3.0 described by Jones et al. [17]. It is a compartment model that simulates the movement of radionuclides between surfaces in inhabited areas as first order differential equations. EXPURT uses a library of unit dose rates for different energies and different urban surfaces calculated by a Monte Carlo code. It can represent the implementation of several countermeasures including decontamination and soil mixing.

EXPURT is used for research purposes and for the purposes of generating advice. In addition it has been used to produce data libraries for the probabilistic risk assessment prgramme COSYMA [57] and a data library of dose reduction factors for use in the Late Countermeasures Module –Terrestrial of the Emergency Response Decision Support system RODOS [58]. EXPURT is embedded within CONDO (CONsequences of Decontamination Options), a software tool developed to assist decision-makers in the event of a radiation emergency. The current version of CONDO is 3.1; version 2.1 is described in detail by Charnock et al. [15]. CONDO uses the EXPURT 3.02 model, as well as a database of recovery options (mainly extracted from [12, 43]), summary calculations and default values to present the decision maker with a number of specific results including estimates of normal living doses, doses from inhalation of resuspended activity and waste activity concentrations.

2.3.2. METRO-K

METRO-K has been developed for dose assessment due to radioactive contamination in the Korean environment. It is an analytical compartment model with a simple mathematical structure, using a relatively small number of parameters. It uses five different surfaces (roofs, paved roads, outer walls, lawn or soil, trees) for constructing an environment of interest. Outputs of METRO-K are concentrations of radioactive material at receptor locations and associated exposure doses, expressed as a function of time.

The major contribution to deposition of radionuclides comes from dry and wet deposition. Furthermore, dry deposition is fractioned into fixed and mobile parts. It is assumed that regardless of the surface and radionuclide in question, 90% of the initial deposition is fixed and 10% is in the mobile fraction. Due to the Korean environment, further fixation of the mobile fraction happens at the rate of 70% per day. In the case of wet processes, a critical amount of precipitation (CAP) characterizes deposition processes. Weathering and time decay within a compartment are accounted for, but not transport between compartments.

Assessment of doses from deposition concentration is done using Meckbach et al.'s kerma values [4] according to the receptor location. METRO-K considers seven types of representative Korean buildings. To model an environment in question for the Korean case, Meckbach et al. kerma values were rearranged using kerma values derived for seven Korean buildings, assuming three gamma energies (0.3 MeV, 0.662 MeV, 3 MeV). Kerma values for other energies and locations, not covered by a Korean scenario, are found by logarithmic interpolation. Exposure doses as output of the model include local situations for the receptor locations and the influence on dose of surrounding buildings and surfaces.

Countermeasures considered by METRO-K are cutting and removal of grass; removal of trees, leaves, and soil; relocation; and washing of roads, roofs and walls. Scenarios of internal exposure due to inhalation or exposure to contaminated inner surfaces are not considered in the model.

2.3.3. EDEM

The EDEM model is an analytical model developed for assessing external dose to a population due to the Chernobyl accident. It consists of four sub-models: absorbed dose rate in air, location factors, occupancy times for different population groups and conversion factors for effective dose rate in air.

Exposure at a receptor site is obtained by multiplying the dose at the receptor location with location factors derived from dose rate measurements performed in Russia after the Chernobyl accident. The major input parameter for the model is air kerma rate at 1 m height above the ground, and an attenuation function derived by following migration of the radioactive material down the soil column (based on measurements performed in Russia, Ukraine, USA, and Germany).

For accounting for decontamination measures, a compartment model similar to EXPURT or URGENT was used. There are seven compartments one can choose from (grass, soil, internal surfaces, hard surfaces, walls, trees, roofs). The model considers transport of contaminants between compartments by weathering to grass or sewers, and from grass down a soil column. Decontamination measures are represented by a one-time change in location factors. Weathering processes are modelled by fractioning into fixed and mobile components. Countermeasures considered by this model are cutting and removal of grass; removal of trees, leaves, and soil; washing of roads, roofs and walls; and relocation. Scenarios of internal exposure due to inhalation are not considered in the model.

2.3.4. CPHR

CPHR is a compartment model, developed as a support to emergency response in the Republic of Cuba. It is based on the Ecolego® code developed by Facilia AB Company[1], and it is used to assess time dependence of radioactive contamination and associated dose rates due to environmental processes.

Compartments are represented by “clusters” specified by a characteristic radius, with the receptor located in the centre of the cluster. Compartments considered include paved surfaces, surface soil, roofs, trees, walls and deep soil. Contaminant transport routes considered are from walls, trees and roofs to soil or paved surfaces and from there to deep soil or fixed fraction on paved surfaces. Fractioning to fixed and mobile components has been done for each compartment.

Input data for the model consist of initial deposition for each compartment considered, the ratio of paved and soil surfaces for the environment and the contribution of each compartment to each receptor’s dose. Initial deposition for compartments does not have to be homogeneous.

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[1] http://www.facilia.se/products/ecolego.asp
http://www.facilia.se/products/ecolego_radioecological_risk_assessment_toolbox.pdf

The probabilistic approach of the Ecolego® code allows assessment of uncertainties according to the initial deposition distribution used (normal or log-normal). Countermeasures considered by this model are cutting and removal of grass; removal of trees, leaves, and soil; washing of roads, roofs and walls; and relocation. Scenarios of internal exposure due to inhalation or exposure to contaminated inner surfaces are not considered in the model.

2.3.5. RESRAD-RDD

The RESRAD-RDD model is a compartment model that considers dispersion of eleven radionuclides and their partitioning in the environment following a radiological dispersal device event [26]. It assumes that the radiological dispersal device event has happened outdoors and resulted in contamination on outdoor and indoor surfaces. Indoor surfaces could be contaminated by the event itself or by additional transport of the contaminant by human activity or by indoor/outdoor air exchange.

Available compartments are soil, street, outdoor/indoor walls, roof, indoor floor, indoor/outdoor air and plants. The code uses the partitioning factors to consider differences in the initial radionuclide concentrations on different surfaces, and employs the weathering parameters to consider the changes in radionuclide concentrations on various surfaces as time progresses. Partitioning to fixed and mobile components has been implemented according to the Chernobyl experience, and average correction factors have been derived for different surfaces, including weathering and radioactive decay. Contaminant transport routes considered are from the radiological dispersal device event to soil, streets, outdoor/indoor walls, roofs and indoor floor; from soil and streets to plants and outdoor air; and from indoor floor and outdoor air to indoor air.

Outputs are external exposure rates at receptor locations from all surfaces, contribution to the dose rates from each surface, annual and cumulative external doses for receptors, and radionuclide surface concentrations for each outdoor location. RESRAD-RDD also outputs outdoor inhalation dose from breathing of resuspended contaminants from streets and soils, indoor inhalation dose from breathing indoor contaminated air, submersion in contaminated indoor air, ingestion of dust particles from streets and soils while staying outdoors, and ingestion of dust particles while staying indoors. These exposure pathways were not included in the present exercise.

Shielding factors for buildings have been expressed in terms of concrete equivalent for typical USA houses adequate for the modelling exercise and applied to dose rate calculations for the receptor locations. Considered countermeasures are cutting and removal of grass; removal of soil; washing of roads, roofs, walls and indoor surfaces; and relocation. The first year is divided into two parts. The first part considers the time from the event to the application of countermeasures, and the second part covers the period to the end of the first year. External doses for these two periods were calculated separately and then added together to give the total external dose for the first year.

Table 2.3. General comparison of the models used in the Urban Remediation Working Group's modelling exercises.

Model	EXPURT	METRO-K	EDEM	CPHR	RESRAD-RDD
Purpose	– to assess average doses and dose rates from external gamma radiation in habitat areas – to represent impact of remedial actions – for research purposes	– to assess external dose due to radioactive contamination in Korean environment (wet environment)	– to calculate external exposure due to Chernobyl accident	– support to emergency preparedness in Cuba	– modelling of changes in radionuclide concentrations due to dispersion caused by radiological dispersal device event – modelling of doses from different exposure pathways after a radiological dispersal device event
Type of model	– compartment model – transfer of radiation between surfaces as first order differential equations	– analytical compartment model – no transfer of material between compartments	– analytical model – additional compartment model similar to EXPURT and URGENT was used for simulation of decontamination	– compartment model – transfer of radioactivity between surfaces as first order differential equations	– compartment model – no transfer of radioactivity between surfaces
Compartments considered	– roofs, exterior walls, paved surfaces, interior surfaces, trees and drains, grass with top soil layer, four soil layers	– roofs, paved roads, outer walls, lawn or soil, trees	Additional model – grass, soil, internal surfaces, hard surfaces, walls, trees, roofs	– paved surface, surface soil, roofs, trees, walls, deep soil	– soil, street, outdoor and indoor walls, roof, indoor floor, indoor and outdoor air, plants
Transport scenarios considered	– transfer of radioactive material between surfaces and down soil column because of weathering processes – rearrangement of material in soil column by soil mixing	– wet and dry deposition processes (CAP – critical amount of precipitation) – weathering processes within compartments – 90% of initial deposition fixed regardless of radionuclide; mobile fraction fixed at the rate of 70% per day	Additional model – from grass down soil column; between compartments by weathering to grass or sewers	– from walls, trees, roofs to surface soil or paved surface, from surface soil to deep soil and exchange between labile fractions of surface soil and paved surfaces – weathering – exchange between subzones for the case of nonhomogeneous distribution of contamination	– from radiological dispersal device event to soil, street, outdoor/ indoor walls, roofs and indoor floor – from soil and street to outdoor air and to plants – from indoor floor and outdoor air to indoor air – from weathering

Table 2.3. General comparison of the models used in the Urban Remediation Working Group's modelling exercises (cont.).

Model	EXPURT	METRO-K	EDEM	CPHR	RESRAD-RDD
Endpoints considered	EXPURT: – effective external dose and dose rate from each urban surface, indoors and outdoors, as a function of time, with and without countermeasures – contamination of each urban surface as a function of time CONDO – *effective dose from external exposure to public and workers, with and without countermeasures* – *committed effective dose to public and workers from inhalation of resuspension, with and without countermeasures* – *financial burden of countermeasures* – *waste produced (kg) and activity concentration (Bq/kg)*	– radionuclide concentrations on each surface – external exposure from different contaminated surfaces as a function of time and the location of the exposure receptor	– absorbed dose rate in air at 1 m height – absorbed dose rate in air at urban locations (location factors) – dose rate in air for population groups (occupancy factors) – effective dose rate to population group	– radioactive contamination of areas of interest and associated external exposure dose rates	– external exposure rates by surface and total – contribution to the dose rates from each surface – annual and cumulative external doses – radionuclide surface concentrations – inhalation, submersion, ingestion, radon inhalation doses
Uncertainties	– no estimates of uncertainties	– no estimates of uncertainties	– no estimates of uncertainties	– associated with initial deposition values (normal or log-normal distribution)	– no estimates of uncertainties

Table 2.4. Comparison of the models as applied for the Pripyat scenario.

Model	EXPURT	METRO-K	EDEM	CPHR
Key assumptions	– homogeneous deposition on each surface – user specified period without rain, otherwise continuous rainfall	– after initial deposition, 90% of radioactive material is fixed and 10% is mobile, with fixation rate of 70% per day – wet and dry deposition in place – gamma energies and yields	– air kerma rate 1 m above ground is representative of compartment (location) – location factors characteristic for Russia after Chernobyl – migration of radioactivity into soil expressed by attenuation functions – Additional model – decontamination represented by one-time change in location factors	– initial deposition homogeneous, extrapolating proportionalities based on initial data for radionuclides other than ^{134}Cs, ^{137}Cs and ^{106}Ru
Modelling approaches – transfers between compartments – concentrations within compartments – temporal and spatial discretization – input data	– modelled by first order differential equations – surface radiation density and time integrated surface radiation density – initial deposition is instantaneous, and time integration for public is user defined; spatial conditions are homogeneous – environment, initial deposition, wet/dry component estimate, countermeasure effectiveness *CONDO: Initial deposition and conditions, environments combination, decontamination technique*	– transfer between compartments is not considered – aggregation of the concentrations due to wet and dry deposition and retained fraction of material due to run-off water, weathering within compartments – compartments are homogeneous in initial deposition; time interval is user defined – dry and wet deposition velocities, water run-off retention factors	– Additional model: from compartments by weathering to grass and down soil column or to sewers – Additional model: described by one time change in location factors; down soil migration described by attenuation function – occupancy factors, timeframes of interest for population groups, and homogeneous spatial distribution of contamination for compartments – air kerma rate 1 m above ground, attenuation function, location factors, decontamination factors	– modelled by transfer functions for each compartment – described by first order differential equations – temporal discretization is user defined, and spatial depends on location in question – timeframe of interest, radionuclides involved with respective initial deposition, surface proportions for compartments in environments, percentage of contribution of each compartment to exposure, timeframe of applied countermeasures

Table 2.4. Comparison of the models as applied for the Pripyat scenario (cont.).

Model	EXPURT	METRO-K	EDEM	CPHR
Parameter values	– initial deposition (iodine + other), environments, rate of material movement within environment, time interval	– environment, initial deposition, deposition velocities, retention factors, time interval, weathering terms, gamma energies and yields (of parent and daughter radionuclides)	– air kerma rate 1 m above ground – Additional model: initial distribution of radioactivity (dry deposition), weathering fractions, decontamination factors	– slow fixed and fast fraction values for compartments, fast and slow half lives for compartments, transfer coefficient for soil, dose conversion factors
Model scenario application – scenario data to drive a model – assumptions to match model	– environments were chosen to best match situation in Pripyat – no assumptions nor corrections of the existing model were made	– environments were chosen to best match situation in each scenario – measured radioactivity concentrations in soil were used to assess initial air concentration as input	– air kerma rate 1 m above ground, location factors derived in Russia after Chernobyl – no assumptions nor corrections of the existing model were made	– percentage of paved and soil areas in contribution to dose – homogeneous initial deposition
Countermeasures applied	– washing of roads, roofs, walls and indoors; cutting and removal of grass; removal of trees and soil; ploughing; vacuuming indoors; relocation.	– washing of roads, roofs, walls; cutting and removal of grass; removal of trees, leaves and soil; relocation of population	– washing of roads, roofs, walls; cutting and removal of grass; removal of trees or leaves and soil; relocation	– washing of roads, roofs, walls; cutting and removal of grass; removal of trees or leaves and soil; relocation
Radionuclides considered	^{95}Nb, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{141}Ce, ^{144}Ce	^{95}Nb, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{144}Ce (radiation effects of daughter products are included)	^{95}Nb, ^{95}Zr, ^{103}Ru, ^{106}Ru + ^{106}Rh, ^{134}Cs, ^{137}Cs + ^{137m}Ba, ^{141}Ce, ^{144}Ce + ^{144}Pr	^{134}Cs, ^{137}Cs, ^{106}Ru, other proportionally extrapolated according to initial data

Table 2.5. Comparison of the models as applied for the hypothetical scenario.

Model	METRO-K	CPHR	RESRAD-RDD
Key assumptions	– after initial deposition, 90% of radioactive material is fixed and 10% is mobile, with fixation rate of 70% per day – wet and dry deposition in place – gamma energies and yields (of parent and daughter radionuclides)	– non-homogeneous initial deposition	– homogeneous deposition on each surface – radiological dispersal device event occurred outdoors resulting in outdoor surface contamination (contaminants are assumed to get inside) – partitioning to account for different initial depositions on surfaces
Modelling approaches – transfers between compartments – concentrations within compartments – temporal and spatial discretization – input data	– transfer between compartments is not considered – aggregation of the concentrations due to wet and dry deposition and retained fraction of material due to run-off water, weathering within compartments – compartments are homogeneous in initial deposition; time interval is user defined – dry and wet deposition velocities, water run-off retention factors	– modelled by transfer functions for each compartment – described by first order differential equations – temporal discretization is user defined, and spatial depends on location in question: does not need to be homogeneous – timeframe of interest, radionuclides involved with respective initial deposition, surface proportions for compartments in environments, percentage of contribution of each compartment to exposure, timeframe of applied countermeasures	– partitioning initial depositions – weathering correction factor (WCF) including decay – occupancy factors for locations; geometrical characteristics of the locations with homogeneous contamination – partitioning and weathering factors for compartments
Parameter values	– environment, initial deposition, deposition velocities, retention factors, time interval, weathering terms, gamma energies and yields	– slow fixed and fast fraction values for compartments, fast and slow half lives for compartments, transfer coefficient for soil, dose conversion factors	– initial outdoor ground surface contamination, initial partitioning factors, weathering coefficients, buildings shielding factors
Model scenario application – scenario data to drive a model – assumptions to match model	– environments were chosen to best match situation in each scenario – initial air concentration from HOTSPOT	– percentage of paved and soil areas in contribution to dose – non-homogeneous initial deposition	– Inverse distance weighting (IDW) interpolation by inhabited area monitoring module (IAMM) – occupancy factors, geometrical characteristics of locations of interest, wall/floor thickness in concrete equivalent for buildings
Countermeasures applied	– washing of roads, roofs, walls; cutting and removal of grass; removal of trees, leaves and soil; relocation of population	– washing of roads, roofs, walls; cutting and removal of grass; removal of trees or leaves and soil; relocation	– washing of roads, roofs, exterior walls, indoor surfaces; grass removal, soil removal, relocation

Table 2.6. Comparison of parameter values for environmental removal of contamination.

Surface	Half-life for removal	EXPURT [a]		METRO-K		EDEM (compartment model)		CPHR		RESRAD-RDD	
		Fraction	**Half-life [b]**	**Fraction**	**Half-life [c]**	**Fraction**	**Half-life [d]**	**Fraction**	**Half-life**	**Fraction**	**Half-life**
Roofs	Fast		–	0.5	1 y	0.5	0.096 y	0.5	0.93 y	0.5	4 y
	Slow		2.5 y	0.5	37.5 y	0.5	4 y	0.5	4.11 y	0.5	50 y
Paved surfaces	Fast	0.67	0.24 y	0.7	0.33 y	0.5	0.19 y	0.5	0.19 y	0.5	0.2 y
	Slow	0.33	2.5 y	0.3	3 y	0.5	5 y	0.5	18.9 y	0.5	2 y
Outer walls	Fast		–		–	0.2	0.16 y	0.2	0.19 y	0.2	0.2 y
	Slow		7.5 y		7.5 y	0.8	10 y	0.8	18.9 y	0.8	20 y
Lawn or soil	Fast		–	0.575	3.3 y		0.041 y (grass)	0.2	0.2 y [g]	0.46	1.5 y
	Slow		–	0.425	21 y		5-30 y (soil [f])	0.8	20.0 y [g]	0.54	50 y
	Migration rate [e]	6.65×10^{-4} d^{-1}									
Trees			0.5 y		0.27 y		2 y	0.9	0.5 y		–
Interior floors	Fast		0.055 y		–		–		–	0.5	0.2 y
	Slow		–		–		–		–	0.5	2 y
Interior walls	Fast		0.055 y		–		–		–	0.5	0.2 y
	Slow		–		–		–		–	0.5	20 y

[a] EXPURT used migration rates or fractional transfers between compartments, rather than environmental half-lives. Approximate environmental half-lives were calculated for several surfaces.
[b] Reported as 6 months for trees and 20 days for interior floors and interior walls.
[c] Reported as 365 days (fast) and 13,700 days (slow) for roofs, 120 days (fast) and 1100 days (slow) for paved surfaces, 2740 days for outer walls, 1200 days (fast) and 7670 days (slow) for lawn or soil, and 100 days for trees.
[d] Reported as 35 days (fast) for roofs, 70 days (fast) for paved surfaces, 60 days (fast) for outer walls, and 15 days for grass.
[e] Value shown is for 0-1 cm soil layer; values for other layers range from 1.72×10^{-4} to 4.03×10^{-6} per day.
[f] Value depends on depth of soil: 0-2 cm, 5 y; 2-5 cm, 6 y; 5-15 cm, 30 y.
[g] Used for movement from surface soil to paved surfaces; for movement from surface soil to deep soil, CPHR uses a transfer coefficient of 0.01.

Table 2.7. Comparison of decontamination factors used and times of application of remediation measures for both scenarios[a].

Decontamination measure	Model									
	EXPURT		METRO-K		EDEM		CPHR		RESRAD-RDD	
	DF[a]	Time[c]	DF	Time	DF	Time	DF	Time	DF	Time
Cutting and removal of grass	8	Day 7	5	Day 7	2	Day 15	50	Day 7	3	Day 7
Washing of roads	7	Day 14	3	Day 14	5	Day 15	4	Day 14	5	Day 14
Washing of roofs and exterior walls	1.3	Day 14	5 (roofs) 7 (walls)	Day 14	10	Day 15	7 (roofs) 1.3 (walls)	Day 14	1.4 (roofs) 10 (walls)	Day 14
Removal of trees and leaves	50	Day 30	20	Day 30	10	Day 15	50	Day 30	–	
Removal of soil (5 cm)	All	Day 180	20	Day 180	6	Day 15	50	Day 180	10	Day 180
Vacuuming indoors	10	Day 14	–[d]		–		–		5	Day 14
Washing indoors (interior walls)	3	Day 14	–		–		–		5	Day 14

[a] METRO-K used dose rate reduction factors rather than decontamination factors. For the decontamination measures in this table, which involve removal of activity, the two types of factors are equivalent.
[b] Decontamination factor.
[c] Days after accident.
[d] Decontamination measure not considered in the model.

CHAPTER 3. SCENARIO 1 – PRIPYAT SCENARIO, NPP ACCIDENT

3.1. Overview and rationale

This scenario is based on Chernobyl (Chornobyl) fallout data for Pripyat, a town in Ukraine near Chernobyl. The Chernobyl accident and the following spread of radioactive releases caused widespread contamination in Europe, including several urban areas. Deposition from the accident contained a wide spectrum of nuclear fission products, activation products, and transuranium elements. Fallout in the town of Pripyat was mainly in the form of finely dispersed fuel. The total level of deposition reached up to 80–24 000 kBq m^{-2} of ^{137}Cs, 50–6660 kBq m^{-2} of ^{90}Sr, and 1.5–200 kBq m^{-2} of $^{239+240}Pu$ [59]. Pripyat was evacuated soon after the Chernobyl accident and has remained essentially uninhabited since that time.

The Pripyat scenario was designed to allow modelling of the changes over time of external exposure rates and concentrations of radionuclides in different compartments of an urban environment. Information was provided to support modelling for two districts of Pripyat, District 1 and District 4 (Figure 3.1). For each district, participants were asked to model the effects of no remediation (only natural processes and any human activity) and of various specified remediation efforts on the changes over time of the radiological situation. Participants were also asked to estimate external doses received by reference individuals in District 4.

A set of input information (measurements of deposition and of radionuclide composition for specific districts) was provided for use for all phases of the scenario, to provide a common starting point. Some additional data were provided for use in model calibration for participants desiring to do so. Test data (measurements) are available for some modelling endpoints; additional endpoints were also used for model intercomparison. Complete details of the scenario, including input information, endpoints to be modelled, occupancy factors, and countermeasures to be included are given in Appendix I and the supporting files (included on the CD containing this report). Detailed background information about the town, the contamination situation, and the remedial measures is also given in Appendix I. Supplementary information describing various remedial activities carried out in Pripyat is provided in Appendix V. Figure 3.2 shows the sites where major decontamination activities were carried out.

The modelling endpoints for Districts 1 and 4 of Pripyat are as follows:

(1) External exposure rates (dose rates, mGy h^{-1}) at specified locations, from all relevant surfaces (by surface and by radionuclide, and total);
(2) Contributions to the dose rates (%) from each surface and each radionuclide, for the most important surfaces and radionuclides;
(3) Annual and cumulative external doses (mGy) to specified reference (hypothetical) individuals (District 4 only); and
(4) Radionuclide concentrations (Bq m^{-2}) at the outdoor locations.

Modellers were asked to provide results starting about 3–4 months after the Chernobyl accident and carried forward for at least 10 years, preferably 20 years. Results were requested as a time series.

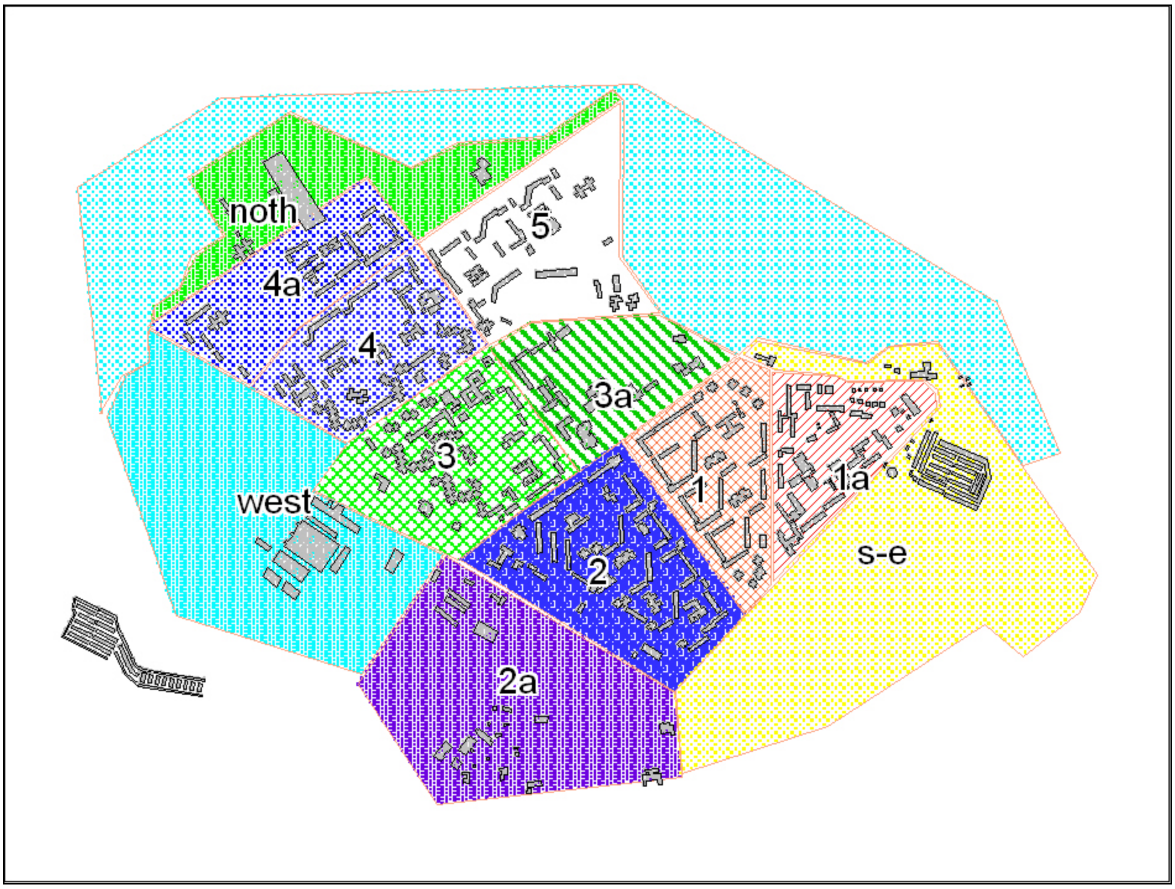

Fig. 3.1. Map of microdistrict locations in the town of Pripyat.

For dose calculations (District 4 only), the following (hypothetical) reference individuals were suggested:

(1) An adult, employed in indoor work;
(2) An adult, employed in outdoor work;
(3) A pensioner;
(4) A child, attending school or kindergarten; and
(5) A pre-school child.

The individuals were assumed to live and work in District 4 (detailed exposure situations are given in Appendix I). For reference children, predictions of annual dose were requested; for reference adults, annual and cumulative doses were requested.

All endpoints were used for model intercomparison. Test data (measurements) are available for a few locations and time points, which has permitted comparison of model predictions and measurements for selected situations.

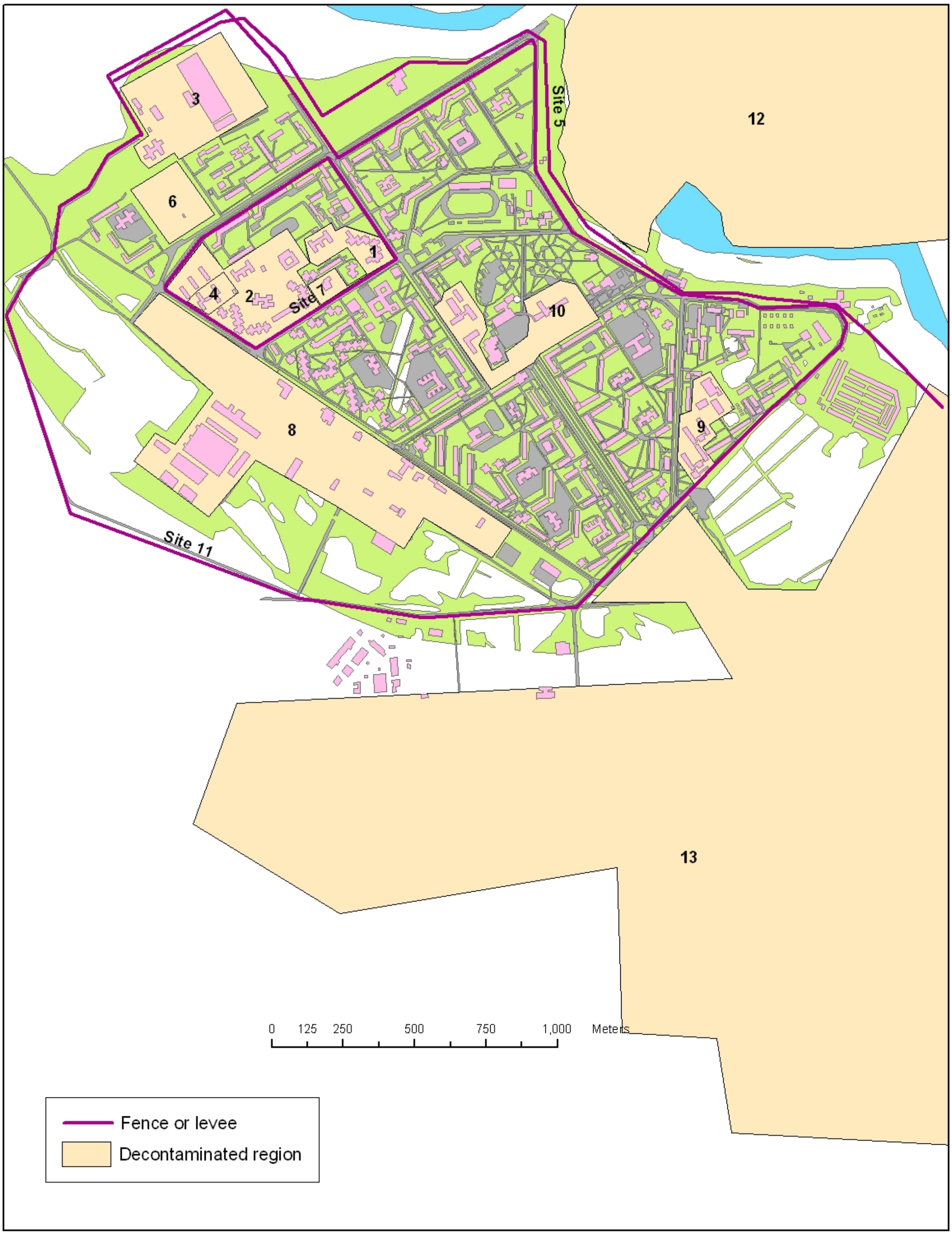

Fig. 3.2. Map of Pripyat showing the sites where major decontamination activities were carried out. For details of the activities in each area, by number, see Appendix I and the supporting files (Table 16 in the Excel workbook). Note that sites 5, 7, and 11 correspond to fences or levees, rather than areas.

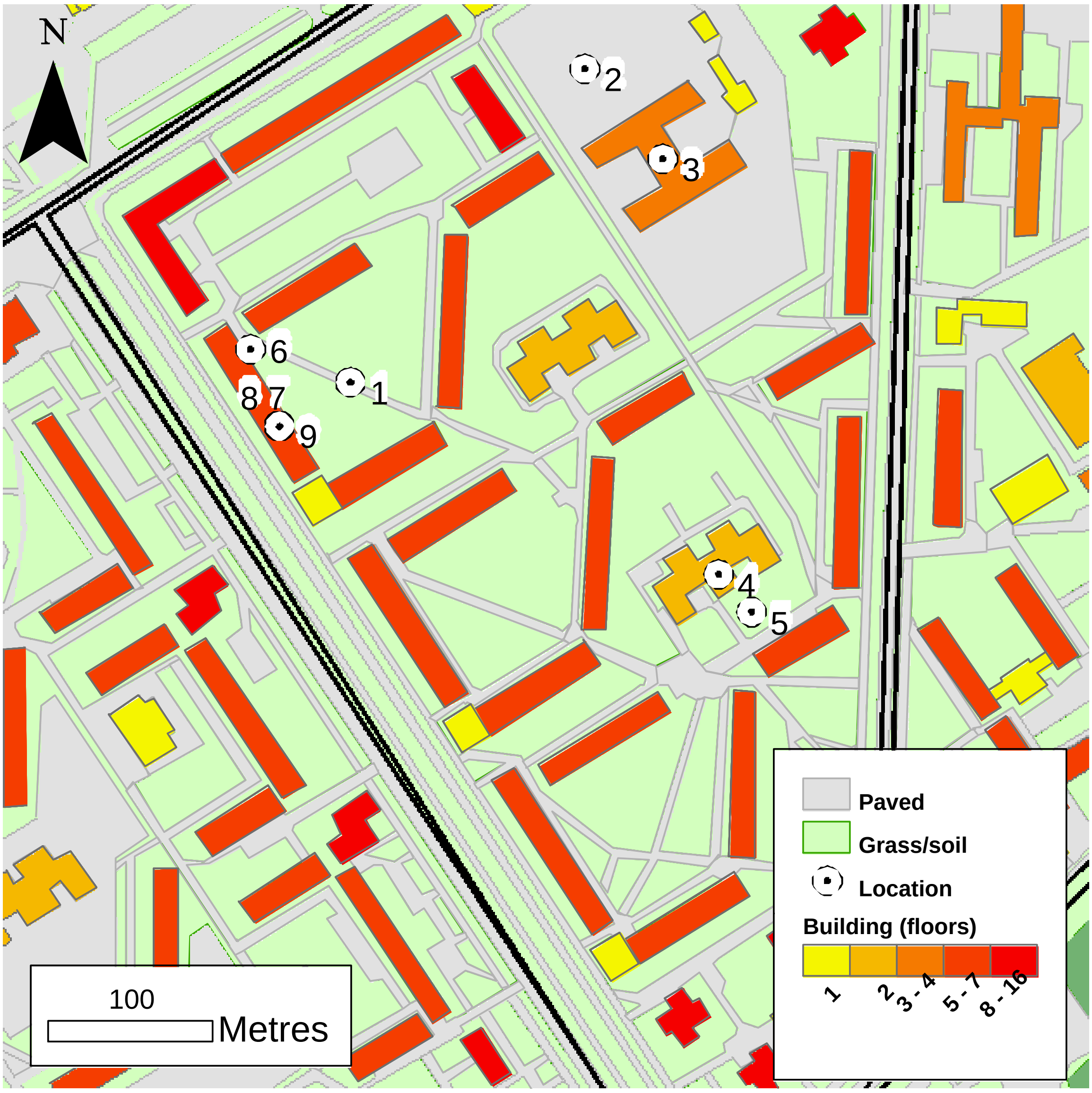

Fig. 3.3. Locations for model calculations in District 1 of Pripyat. Map positions of the locations are given in the accompanying material for Appendix I. Locations 1, 2, 5, and 6 are outdoors. Locations 3 and 4 are indoors in schools. Locations 7, 8, and 9 are on the 1st, 3rd, and 5th floors of a 5-story apartment building.

3.2. District 1

In District 1, the changes over time of actual external exposure rates and radionuclide concentrations are due primarily to natural processes (no human activity, no remedial measures). However, for the purposes of the modelling exercise, the effects of various countermeasures were also considered, i.e., if the countermeasure had been applied, what would have been the effect on dose rates and radionuclide concentrations.

For each test location in District 1 and for each applicable countermeasure, participants were asked to calculate the external exposure rates (mGy h^{-1}) and radionuclide concentrations (Bq m^{-2}) at nine specified locations (Figure 3.3). Locations 1, 2, 5, and 6 are outdoors, two of them next to a road, one on a natural surface, and one on an artificial surface. Locations 3 and

4 are indoors in schools. Locations 7, 8, and 9 are on the 1st, 3rd, and 5th floors of a 5-story apartment building.

3.3. District 4

In District 4, the changes over time of actual external exposure rates and radionuclide concentrations are due to both natural processes and human activity, including various remedial measures. The effects of various countermeasures were considered for the purposes of the modelling exercise, although not all countermeasures were applied in all locations.

For this phase, participants were asked to calculate the external exposure rates (mGy h^{-1}) and radionuclide concentrations (Bq m^{-2}) at fifteen specified locations in District 4 (Figure 3.4). Participants were also asked to calculate the doses to reference individuals, assuming that people had lived in District 4 for the entire period covered by the model calculations. The remedial measures (countermeasures, remediation measures) to be considered are listed in Table 3.1, together with the time of application to be assumed.

Five of the locations (Locations 10–14) are outside the areas where remedial activities were implemented; the other ten locations (Locations 15–24) are within the areas where remedial activities were implemented (Sites 2 and 4, Figure 3.2) and where people lived for several years after the accident. Locations 10, 11, and 12 are indoors on the 1st, 5th, and 7th floors of the unfinished end of an apartment building. Locations 13 and 14 are outdoors, one on a natural surface and one on an artificial surface. Locations 15, 20, 21, and 22 are outdoors; two of these are on natural surfaces, one on a road, and one on an artificial surface outside a kindergarten. Location 16 is indoors in a 1-floor kitchen. Locations 17, 18, and 19 are on the 1st, 5th, and 9th floors of a 9-story apartment building adjacent to the kitchen. Locations 23 and 24 are on the 1st and 2nd floors of a 2-story kindergarten building.

For each test location and each applicable countermeasure, participants were asked to calculate the dose rates and radionuclide concentrations first without any countermeasure and then with the indicated countermeasure. For dose calculations, participants were asked to predict the annual doses to each reference individual without countermeasures and then with the indicated countermeasure, assuming that the person lived and worked or went to school in District 4.

Information on effectiveness of various countermeasures is available in documents prepared by B. Zlobenko and V. Golikov (Appendix V of this report) and in other literature (see Section 2.2).

Table 3.1. List of countermeasures and the corresponding time of application for use with the Pripyat scenario.

Number	Countermeasure	Time of application(after the accident)
1	No remediation	–
2	Cutting and removal of grass	Day 7
3	Washing of roads	Day 14 (no rain)
4	Washing of roofs and walls	Day 14 (no rain)
5	Removal of trees (or leaves)	Day 30
6	Removal of soil (5 cm)	Day 180
7	Vacuuming indoors	Day 14
8	Washing indoor surfaces	Day 14
9(a)	Relocation of population (temporary):	For the first 2 weeks
9(b)		For the first 6 weeks
9(c)		For the first 6 months

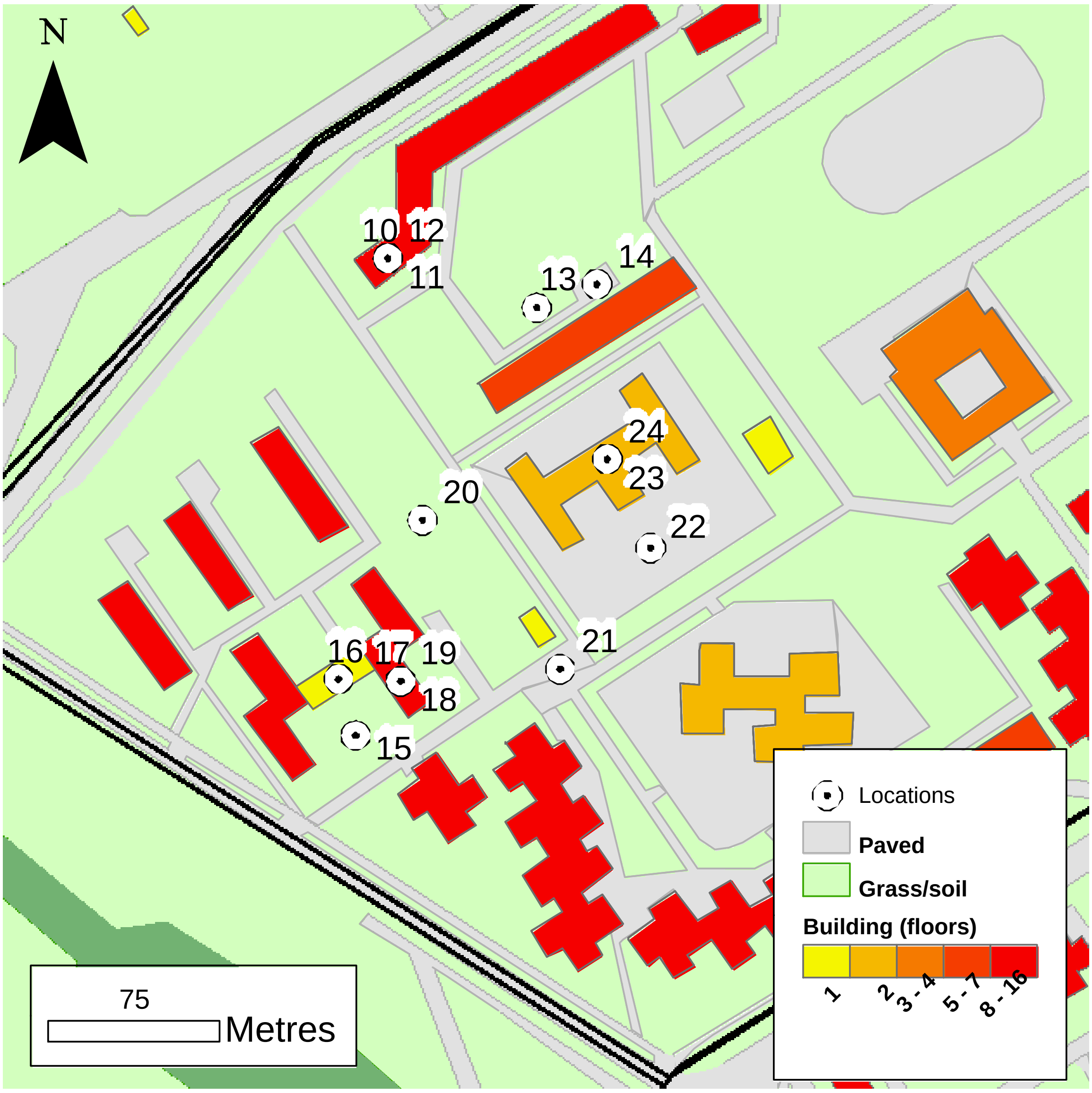

Fig. 3.4. Locations for model calculations in District 4 of Pripyat. Map positions of the locations are given in the accompanying material for Appendix I. Locations 13, 14, 15, 20, 21, and 22 are outdoors. Locations 10, 11, and 12 are indoors on the 1st, 5th, and 7th floors of the unfinished end of an apartment building, and locations 17, 18, and 19 are indoors on the 1st, 5th, and 9th floors of a 9-story apartment building. Location 16 is indoors in a 1-floor kitchen. Locations 23 and 24 are on the 1st and 2nd floors of a 2-story kindergarten building.

3.4. Results of model intercomparison exercise

This section reports the results of the model intercomparison exercise for the Pripyat scenario. Although the dose rate and dose are the principal endpoints, they represent a synthesis of several components that need to be examined to understand why models agree or disagree in particular situations. The components can be broadly classified in terms of the modelling approach, the model parameters, and the interpretation of the scenario by the modeller. Therefore it is important to look at the intermediate endpoints, particularly the contamination density and relative dose rate contribution of urban surfaces, to understand the interaction between these components.

Four models participated in the Pripyat scenario comparison exercise: EXPURT, METRO-K, CPHR and EDEM. The models are briefly described in Section 2.3, and detailed information is given for each model in Appendix III. The results shown in this section are the most recently submitted for each model (Spring 2007 for EDEM and CPHR, Summer 2007 for EXPURT, and November 2007 for METRO-K), although preliminary results for several models were presented as early as 2005 and 2006. A full set of information on model predictions, including examples of major revisions (EXPURT and METRO-K), is provided in Appendix IV.

The modellers were asked to make predictions of dose rate over time for several locations in District 1 and District 4 of Pripyat. The locations can be divided for convenience between those that were indoors and those that were outdoors. Additional endpoints for both districts included the percentage contribution to dose rate from various surfaces or individual radioisotopes (indoor and outdoor locations) and contamination densities (outdoor locations only). Dose endpoints were also requested for District 4. The modellers were also asked to consider the effect of a number of relocation and decontamination countermeasures on the dose rate and dose endpoints.

3.4.1. Outdoor locations

The Pripyat scenario includes several outdoor locations in District 1 and District 4 to be simulated by the participating models. The locations vary in the relative proportions of urban surfaces present and the proximity of various building types. There are differences between the districts in the amount of deposition and the degree of tree cover.

3.4.1.1. Predicted dose rates, District 1

The dose rate results for the four outdoor locations in District 1 are shown in Figure 3.5 for all four participating models. Location 1 in District 1 is in the middle of a large area of grass with large buildings beyond the grass but possibly not close enough to contribute more than a minor component of the total external dose. All the model predictions for dose rate at Location 1 are in reasonable agreement (within an order of magnitude) at the first time point calculated (1 August 1986; Figure 3.5, upper left). For subsequent years, three of the models, EXPURT, METRO-K and EDEM, are in reasonable agreement, while the fourth, CPHR, predicts somewhat higher values at each time step; however, all models show the expected reduction in dose rate with time. The larger dose rate for CPHR is explained as being a result of the calibration process, which used real measurements to establish the appropriate dose conversion factors (DCF). This may be too conservative because it does not account for the presence of short lived radionuclides [60]. This pattern of higher dose rates from CPHR is repeated for all the locations.

Location 2 is on a large paved area. There is a wider spread of results for this location, particularly at the longer times (Figure 3.5, upper right). Three of the models, EXPURT, METRO-K and EDEM, are initially in reasonable agreement although they diverge at later times. A difficulty with this location is that although the surface is artificial, it is permeable. However, EXPURT and METRO-K represent this surface as impermeable, i.e. there is no penetration of the surface by the radionuclides.

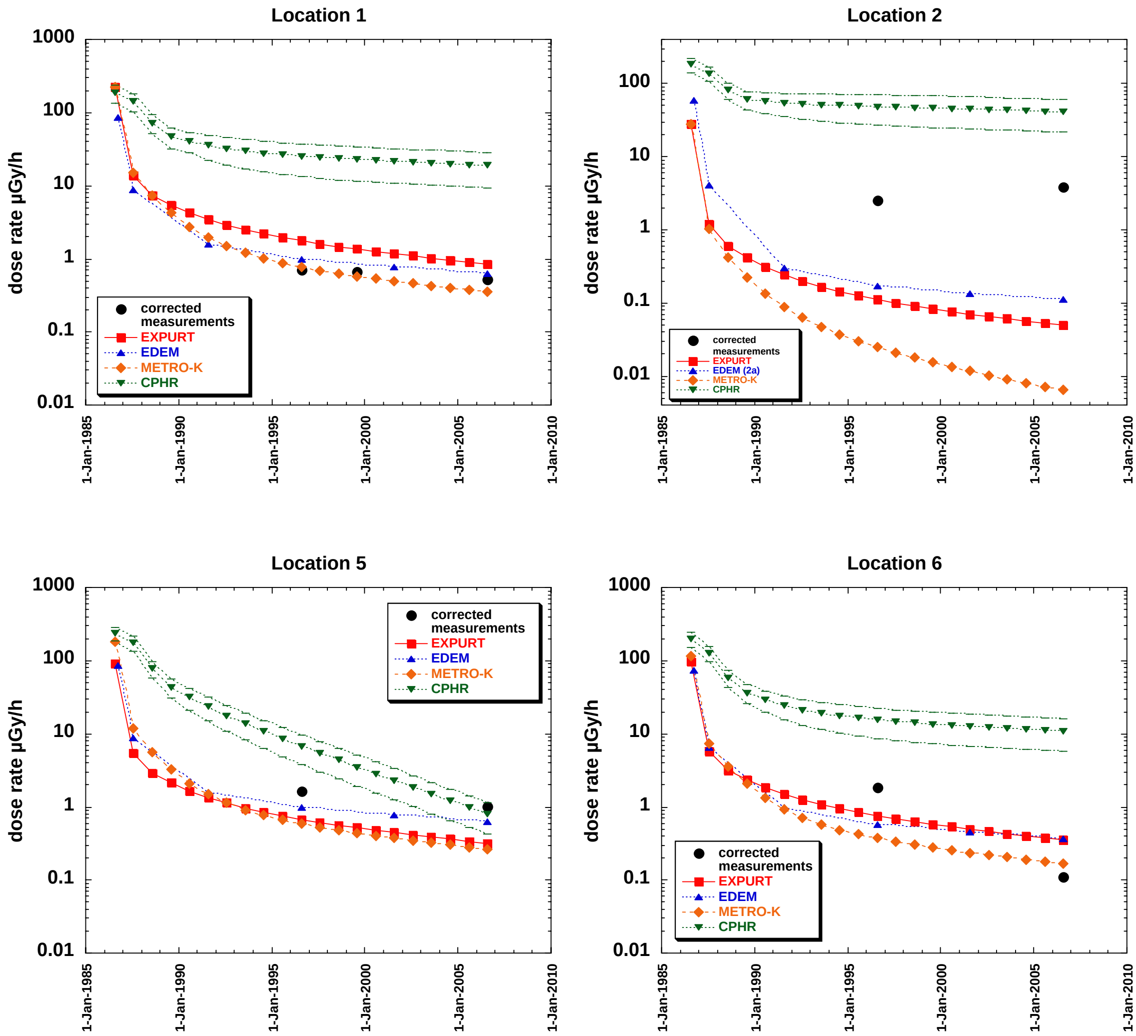

Fig. 3.5. Predicted and measured dose rates for outdoor locations in District 1 of Pripyat in the absence of countermeasures.

Location 5 is in an area of predominantly grass but close to a low school building, and Location 6 is in an area of predominantly grass but very close to a large multi-storey apartment building. The pattern of predicted dose rates is similar for both locations (Figure 3.5, lower left and right). Three of the models, EXPURT, METRO-K and EDEM, are in close agreement for all time steps. CPHR is consistently higher for the same reasons as given for Location 1. At Location 5 there is a convergence of all the models at later times that is not seen for Location 6.

3.4.1.2. Predicted dose rates, District 4

The dose rate results for the four outdoor locations in District 4 are shown in Figure 3.6 for all four participating models. Location 15 is in a predominantly grass area but close to buildings. The pattern of predicted dose rates (Figure 3.6, upper left) resembles that for Locations 5 and 6 (Figure 3.5), which was expected, as the situations are similar, although the overall deposition in District 4 is less and so the dose rates are correspondingly lower. It is noticeable that the EDEM model starts at a higher dose-rate than EXPURT or METRO-K and comparable to CPHR. This is explained in that the modeller assumed the same level of deposition in District 4 as District 1. In addition, the EDEM results started at an earlier date than the others (27 April 1986 vs. 1 August 1986), so they would include higher values for the earlier dates. The high starting value of EDEM is a pattern that is repeated in all District 4 outdoor and indoor locations.

Location 20 is in a predominantly grass area at some distance from buildings. The pattern of predicted dose rates (Figure 3.6, upper right) is similar to other locations, with three of the models, EXPURT, METRO-K and EDEM, in reasonable agreement at most time steps and CPHR somewhat higher.

Location 21 and Location 22 are similar; they are both on predominantly paved surfaces with few buildings close by. Again there is a very wide divergence in predicted dose rates (Figure 3.6, lower left and right) between CPHR and the other three models (EXPURT, METRO-K and EDEM), which are in good agreement.

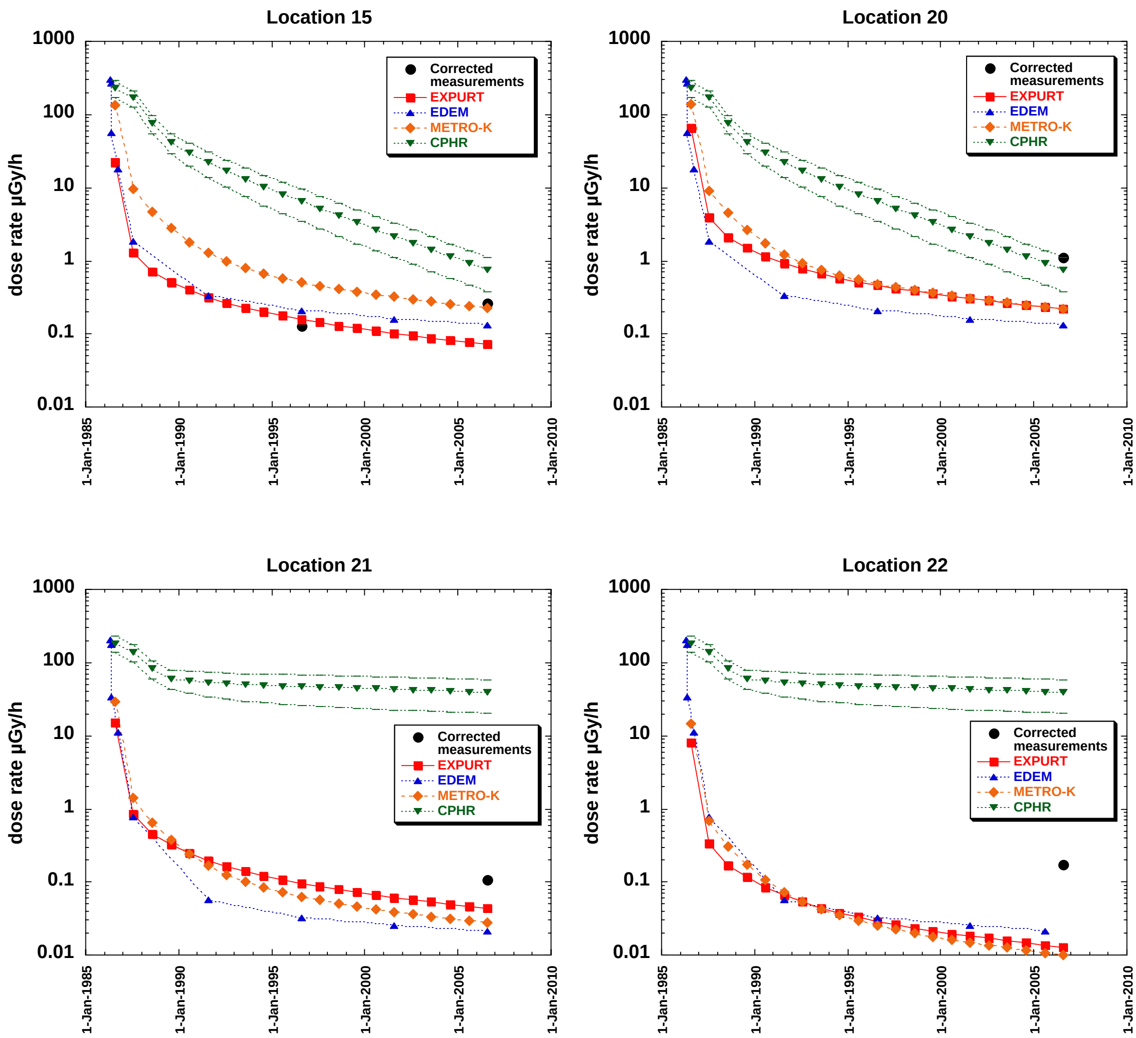

Fig. 3.6. Predicted and measured dose rates for outdoor locations in District 4 in the absence of countermeasures.

3.4.1.3. *Predicted contributions from surfaces*

To understand the differences in overall dose rates predicted by the models at the locations in Figures 3.5 and 3.6, it is necessary to look at the contributions to the overall dose rate from the individual surfaces as predicted by the models. Figures 3.7 and 3.8 show the relative contributions of the most important surfaces in each model to the predicted dose rate as a function of time for Locations in District 1 and District 4, respectively.

At Location 1 (Figure 3.7, upper left) for the first time point of 1 August 1986, all the models agree that soil is the main contributor to the dose rate. Three of the models, EXPURT, EDEM and METRO-K, agree that trees are the second biggest contributor. CPHR predicts that the paved surface is the second biggest contributor. For subsequent times there is no information for EDEM. For these times two of the models, EXPURT and METRO-K show an increasing proportion of the dose rate being contributed by the soil surface, while CPHR shows an increasing proportion of contribution from paved surfaces.

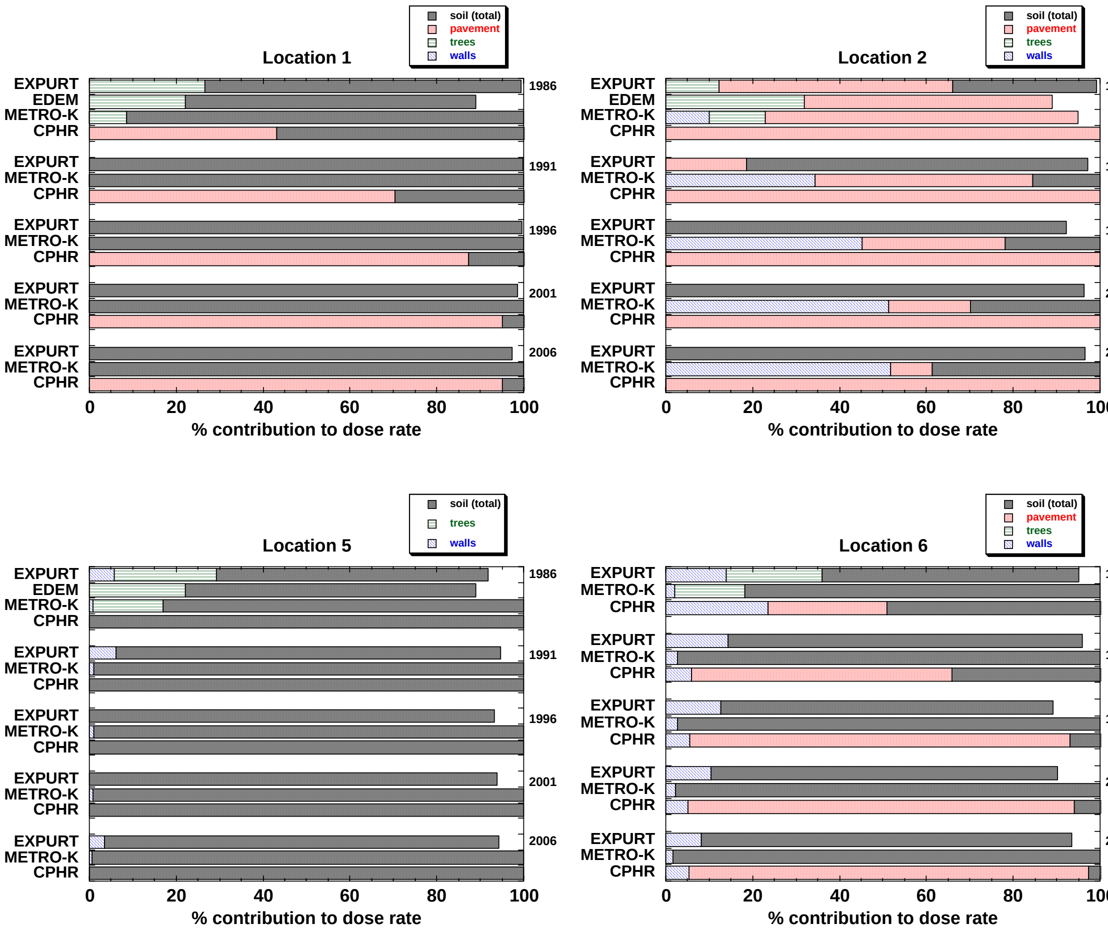

Fig. 3.7. Predicted contributions to dose rate over time from the most important surfaces for outdoor locations in District 1 of Pripyat in the absence of countermeasures.

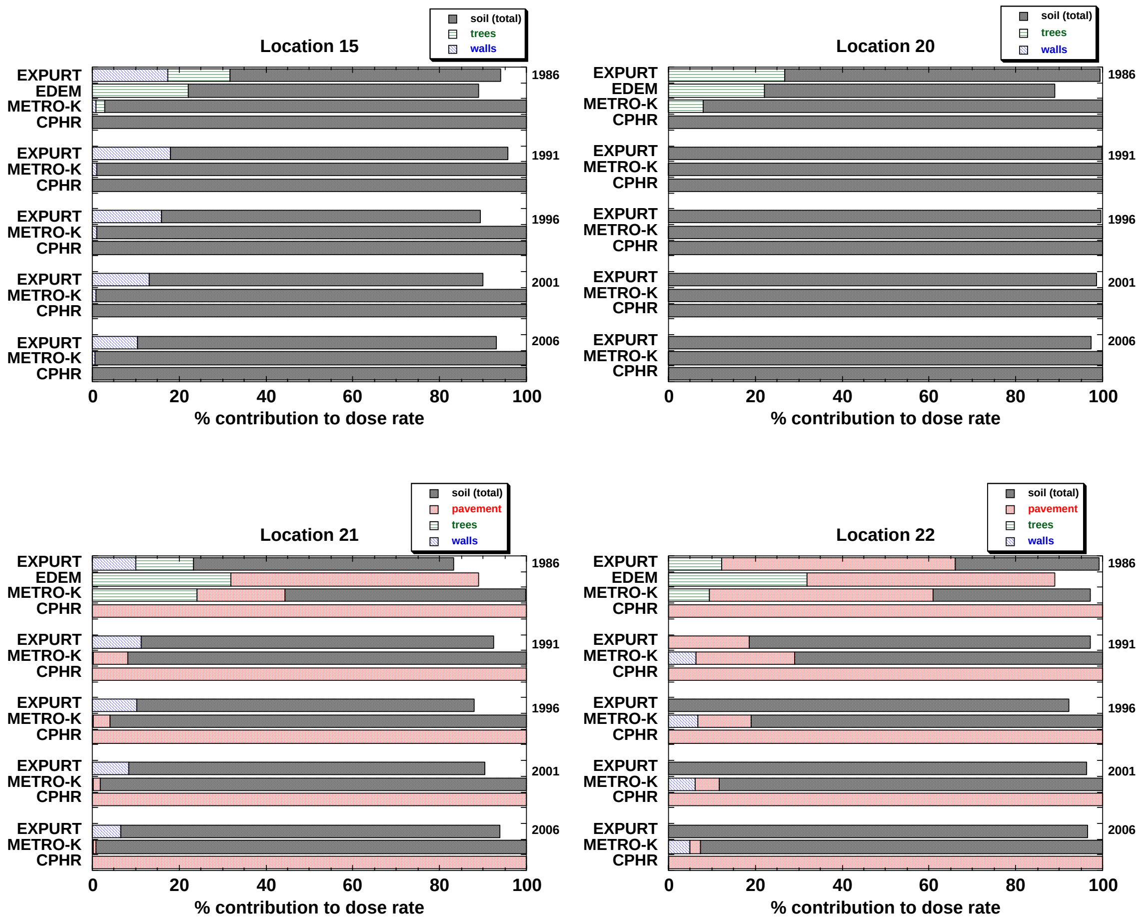

Fig. 3.8. Predicted contributions to dose rate over time from the most important surfaces for outdoor locations in District 4 of Pripyat in the absence of countermeasures.

At subsequent time steps, the differences for Location 1 among CPHR, EXPURT and METRO-K are due largely to the complex interaction of the assumptions made about the relative proportions of surfaces, the initial deposition and retention on surfaces, and transfers between those surfaces. CPHR assumes that a proportion (0.3) of material on paved surfaces is fixed and that this will only reduce with radioactive decay (trees, walls, and roofs also have such a fixed component). Furthermore, of the labile component of the compartment (i.e. material that migrates), a fraction (0.5) will migrate with a relatively long half of 18.9 y (the remainder with a half life of 0.19 y). CPHR has no fixed component for soil, and furthermore CPHR assumes a transfer from soil to the fixed fraction on pavement. So, although soil in CPHR has a slightly longer fast and slow half life than paved surfaces (at 0.2 and 20 y respectively) and a higher slow fraction (0.8), it is the paved surface that tends, if radionuclides with a sufficiently long half life are present, to become the dominant surface (this is not true for Locations 5, 15 and 20 because there is no paved surface present). In comparison, EXPURT also divides the contamination on the paved surface into fixed and mobile fractions, but there is a slow transfer from the fixed to other surfaces, with fast and slow components that have half-lives of approximately 0.24 y and 2.5 y respectively. In EXPURT there is assumed to be no transfer from soil to pavement (or to any other surface), but there is a transfer from paved surfaces to soil, so of the two surfaces of pavement and soil, if long lived radionuclides are present, soil will eventually become the dominant surface regardless of their relative proportions in terms of area. This is particularly noticeable in the EXPURT results for Location 2,where although paved surface is the largest proportion of surface area, over long times soil dominates. It is a constraint of EXPURT that although an environment may have small amounts of pavement or soil it cannot have a zero amount. METRO-K does not consider transfers between surfaces; material that is lost from a surface is lost from the system and makes no further contribution to dose.

For Location 2 for the first time point of August 1986 (Figure 3.7, upper right), all the models agree, as expected, that pavement is the main contributor to the dose rate. For CPHR pavement is the only contributor, whereas the other three models, EXPURT, EDEM and METRO-K, agree that trees are an important contributor, along with soil (EXPURT) and walls (METRO-K). At subsequent times the models diverge. There is no information for EDEM but for EXPURT, soil becomes the main contributor, while for METRO-K walls and soil become the main contributors. For CPHR paved surfaces are the only contributor at all times.

For both Location 1 and 2, the differences in contributing surfaces are due to different assumptions made about relative proportions of surfaces, migration and retention. In EXPURT all material ends in either soil or drains, which are treated as the lowest soil layer for the purposes of calculating dose rates; thus at long times regardless of which surface is most prevalent, the main contributor to dose rate is likely to be soil. For the reasons given for Location 1 CPHR tends towards paved surfaces as the main contributor at long times, and for Location 2, which is dominated by pavement, it is the only contributor. For Location 2 where the artificial surface is not impermeable as represented in METRO-K and EXPURT but is permeable, it may be that the ‘paved’ surface is acting as such a sink. METRO-K models the retention on each surface by dividing the material into fast and slow components and applying appropriate half lives to those components. In METRO-K, the wall surface has a half life of 7.5 y for the fast component and no slow component, whereas the paved surface has a fast fraction of 0.7 with a half-life of approximately 0.33 y and a slow fraction with a half life of approximately 3 y. Consequently at longer times walls become more significant than paved surfaces.

3.4.1.4. Predicted contributions from radioisotopes

Figure 3.9 shows the predicted contributions from each radionuclide for each of the participating models for Location 15. As the modellers were given the same deposition data as a starting point it is unremarkable that the patterns displayed by each are similar. Cesium-137 dominates in the long term because of its relatively long half life compared with the other radionuclides. The slight differences in the short term can be put down to the differences in the interpretation of the deposition data as well as internal model approximations and assumptions that represent such radionuclide-dependent properties as energy spectra, attenuation, and progeny. METRO-K, for example, requires air concentration as a starting point, whereas EDEM and EXPURT use surface deposition on a reference surface (a lawn surface). METRO-K and EXPURT use unit dose rates calculated for various energies and calculate the dose rate from the energy spectra of the radionuclides concerned. METRO-K uses results for idealized environments developed by Meckbach et al. [4] and generated by Monte Carlo modelling. EXPURT uses results for idealized environments developed by Jones et al. [17] and also generated by Monte Carlo modelling. In contrast EDEM uses empirical functions to generate time dependent location factors. EXPURT models those radionuclides with significant daughters, such as ^{95}Zr and its daughter ^{95}Nb, by creating a ‘composite’ radionuclide (See Appendix III.1).

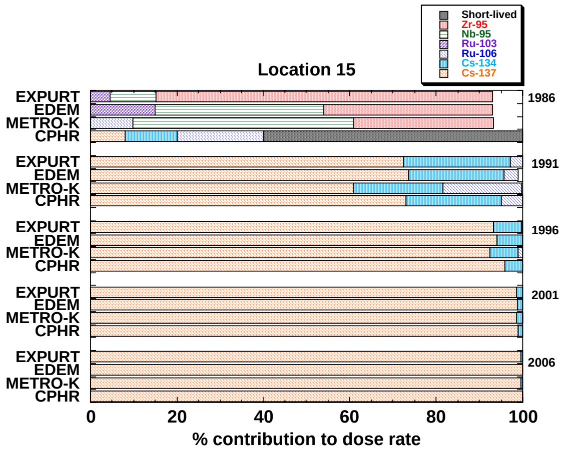

Fig. 3.9. Predicted contributions to dose rate over time from the most important radioisotopes for Location 15 in District 4 of Pripyat in the absence of countermeasures.

None of the participating models has used radionuclide specific deposition or retention parameters for the Pripyat scenario. However, modellers for METRO-K and to a lesser extent for EXPURT do give some radionuclide specific data in the detailed descriptions (see Appendix III). Because all radionuclides on the same surface behave in the same way in any given model, and because the radionuclide mix is the same at all locations, at all locations the pattern of radionuclide contribution apparent in Figure 3.9 is repeated.

3.4.1.5. Predicted contamination densities

Figure 3.10 shows the predicted contamination densities of ^{137}Cs on the soil surface at Location 1 for three of the participating models, both as predicted and normalized for the predicted values at 1 August 1986. (Appendix IV also contains predicted contamination densities for ^{134}Cs and ^{106}Ru.) There is good consistency between the models. CPHR and EXPURT show initial rises due to inputs from other surfaces: in the case of EXPURT, from the tree surface and also, of less importance, from the walls and paved surfaces, and in the case of CPHR, from trees, roofs, walls and paved surfaces (there is also a loss to paved surfaces).

After a period of time, the transfers to soil in EXPURT become negligible, and as EXPURT represents soil as 5 layers with a very slow downward migration, the loss from soil is also negligible; therefore the dominant process visible in Figure 3.10 is radioactive decay. The curves for CPHR and METRO-K fall marginally more steeply, indicating that some other loss process is operating in addition to radioactive decay. METRO-K represents loss from soil with a half life of approximately 3.3 y for a fast fraction (0.575) and a half life of approximately 21.5 y for a slow fraction. CPHR has transfers to and from paved surfaces as well as to deep soil at all times.

A similar pattern is seen for other locations; for example Figure 3.11 shows the surface contamination with ^{137}Cs at Location 2 in District 1. CPHR shows the initial rise identified for Location 1 (Figure 3.10), but the rise continues over the whole period, indicating that inputs of ^{137}Cs to this surface (pavement) are larger than the loss through radioactive decay. EXPURT shows a decline only slightly faster than radioactive decay, while METRO-K shows a steeper decline for Location 2 than for Location 1.

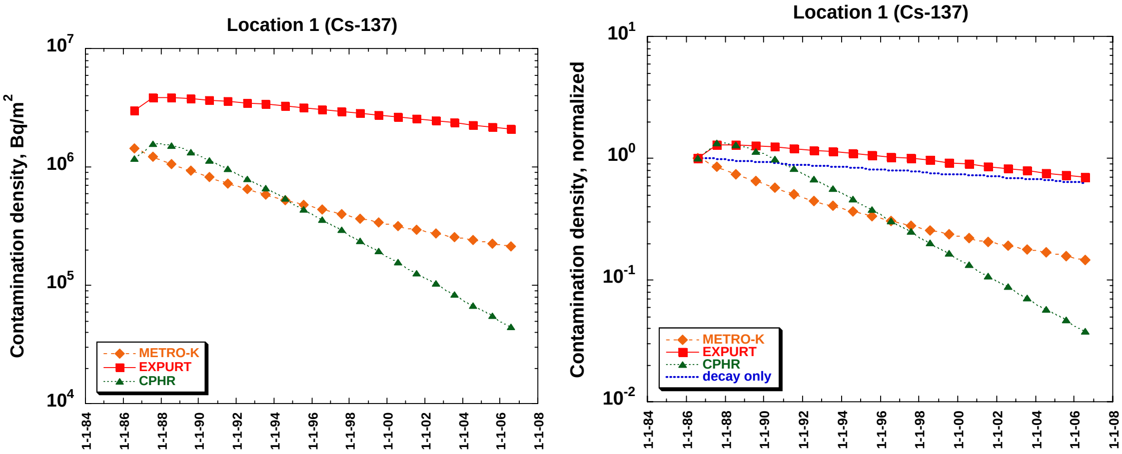

Fig. 3.10. Predicted ^{137}Cs contamination densities over time at Location 1 in District 1, in the absence of countermeasures. Predictions are shown as submitted (Bq per m^2; left) and normalized to the predicted value for 1 August 1986 (right). The change in contamination density over time due solely to radioactive decay is also shown (right). For EXPURT, the contamination density includes all lower soil layers; for METRO-K and CPHR the contamination density represents the soil surface.

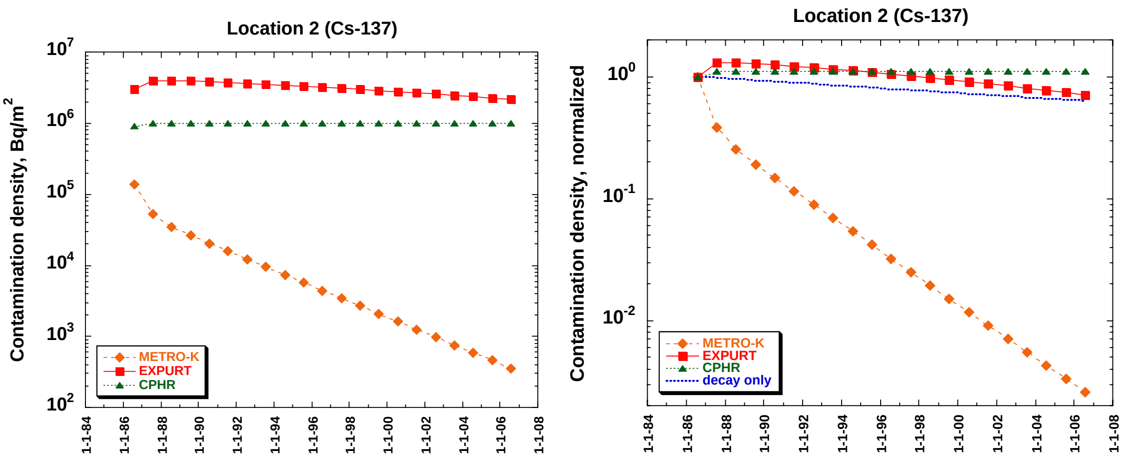

Fig. 3.11. Predicted ^{137}Cs contamination densities over time at Location 2 in District 1, in the absence of countermeasures. Predictions are shown as submitted (Bq per m^2; left) and normalized to the predicted value for 1 August 1986 (right). The change in contamination density over time due solely to radioactive decay is also shown (right). For EXPURT, the contamination density includes all lower soil layers; for METRO-K, the contamination density represents soil and paved surfaces; for CPHR, the contamination density represents the paved surface. Note the differences in vertical scale between the two graphs.

3.4.2. *Indoor locations*

The Pripyat scenario includes several indoor locations in District 1 and District 4 to be simulated by participating models. The locations vary in the type of buildings, the floor on which they are positioned, and the relative proportions of surfaces that surround the building. There are differences between the districts with regard to the amount of deposition and the degree of tree cover.

3.4.2.1. Predicted dose rates, District 1

The dose rate results for the five indoor locations in District 1 are shown in Figure 3.12 for all four participating models. Location 3 in District 1 is in a low school building set in a large expanse of paved surface. Location 4 is similar, but it is set in a region that is predominantly grass. At Location 3 (Figure 3.12, upper left), three of the models (EXPURT, METRO-K and EDEM) are in very close agreement. CPHR has somewhat higher doses at all times for the reasons specified in Section 3.4.1.1 with respect to outdoor locations. At Location 4 there is close agreement between EXPURT and EDEM, and these results are not very different from Location 3; however, METRO-K predicts higher doses rates and CPHR is higher still.

Locations 7, 8 and 9 in District 1 are on the 1st (ground), 3rd and 5th floors of a 5-storey apartment building. For all the models the dose rates are marginally higher at all times on the 1st (ground) floor than the other floors (Figure 3.12). This is expected as the 1st floor is closer to exterior surfaces of pavement and soil than the higher floors. METRO-K and CPHR give marginally higher dose rates for the top floor (Location 9) than for the middle floor (Location 8); again this might be expected because of an additional component from the roof. EXPURT cannot distinguish between Location 8 and Location 9, so the dose rate curve for EXPURT is the same in Figure 3.12 for both locations. EDEM also gives similar results for Locations 8 and 9, although slightly different parameters were used to calculate the time dependent location factor for these two different locations (see Appendix III.3); this is expected to give marginally higher dose rates for Location 8 compared to Location 9, but this is not discernable in Figure 3.12.

3.4.2.2. Predicted dose rates, District 4

The dose rate results for the six indoor locations in District 4 are shown in Figure 3.13 for all four participating models. Location 16 is in a low building set between two high apartment buildings in an expanse of predominantly grass surface. It is a somewhat complex situation as it is possible that there could be a significant contribution to dose from the walls of the large buildings penetrating through the rubberoid roof of the lower building. For this location (Figure 3.13, upper left), METRO-K and CPHR begin at a similar level, but METRO-K drops more rapidly in the following years. EXPURT and EDEM predict dose rates that are lower than METRO-K and CPHR. EDEM begins at a higher level because an earlier date is shown and also because the modeller assumed that the deposition in District 4 was the same as District 1; however EXPURT and EDEM are in good agreement for the subsequent years.

Locations 17, 18 and 19 are on the 1st (ground), 5th and 9th floors of a nine-storey apartment block set in an expanse of predominantly grass surface. The pattern of predicted dose rates (Figure 3.13) between these locations is the same as for the five-storey apartment block (Locations 7, 8 and 9); all models predict the highest dose rates on the 1st (ground) floor (Location 17). METRO-K and CPHR give slightly higher dose rates on the top floor (Location 19) than the middle floor (Location 18), whereas EDEM gives very marginally lower doses on the top floor compared to the middle floor. EXPURT cannot distinguish between Locations 18 and 19 and so the curve for EXPURT is the same for both locations.

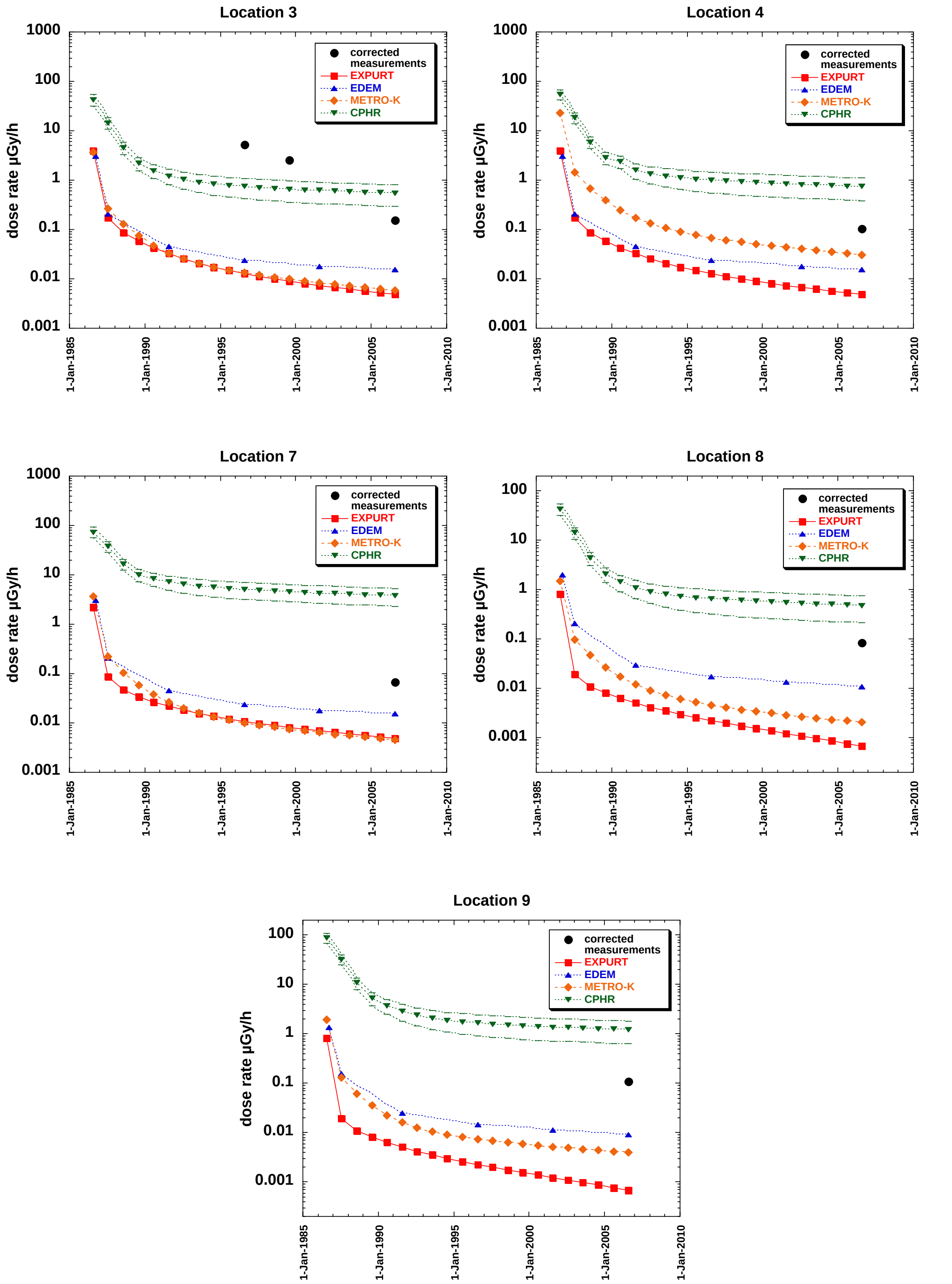

Fig. 3.12. Predicted and measured dose rates for indoor locations in District 1 of Pripyat in the absence of countermeasures. (NB that the vertical axis is rescaled for Locations 8 and 9, but the relative proportions are the same for all five graphs.)

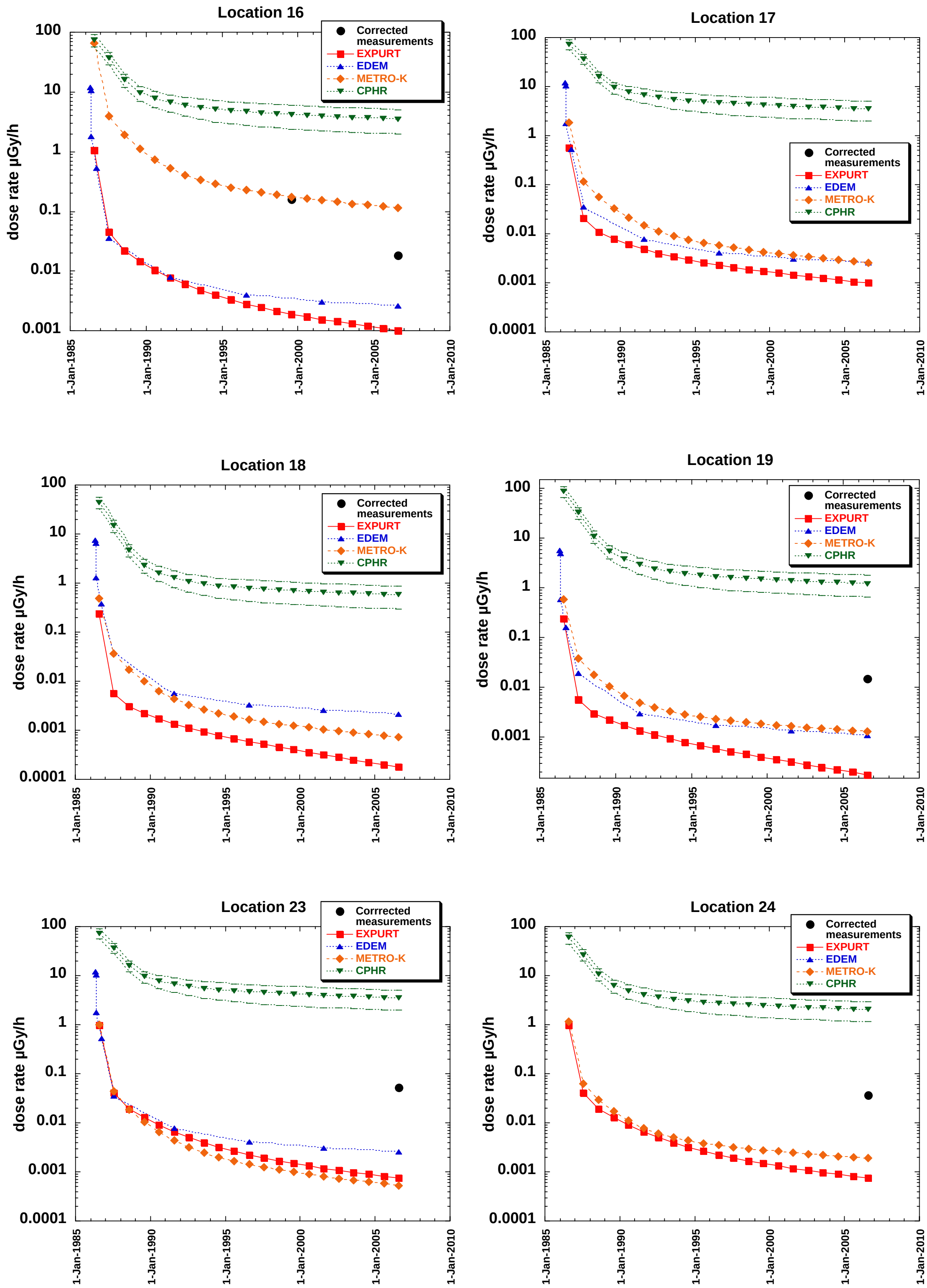

Fig. 3.13. Predicted and measured dose rates for indoor locations in District 4 of Pripyat in the absence of countermeasures. For locations 17 and 18, corrected values for the measurements in 2006 were negative and are not shown.

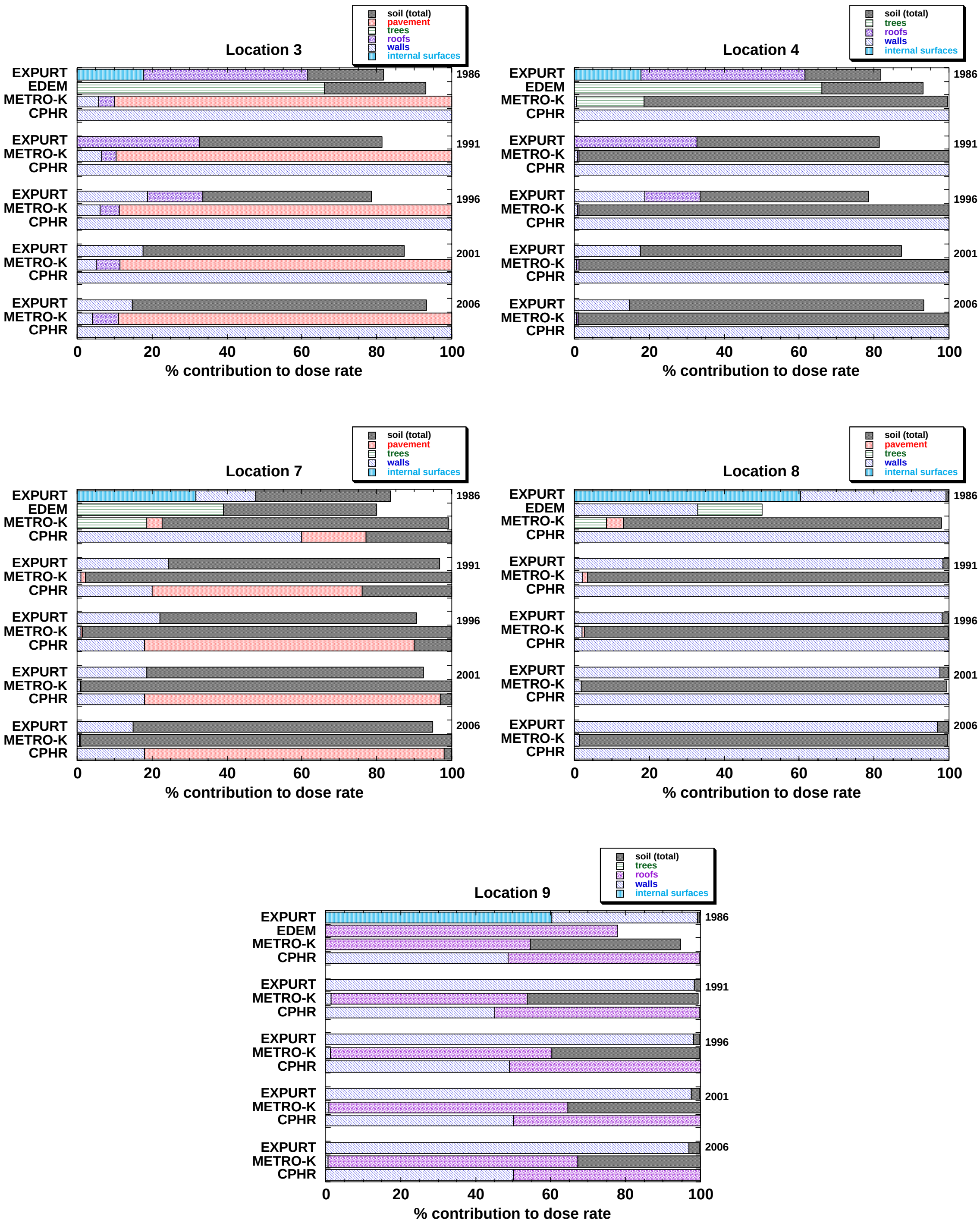

Fig. 3.14. Predicted contributions to dose rate over time from the most important surfaces for indoor locations in District 1 of Pripyat in the absence of countermeasures.

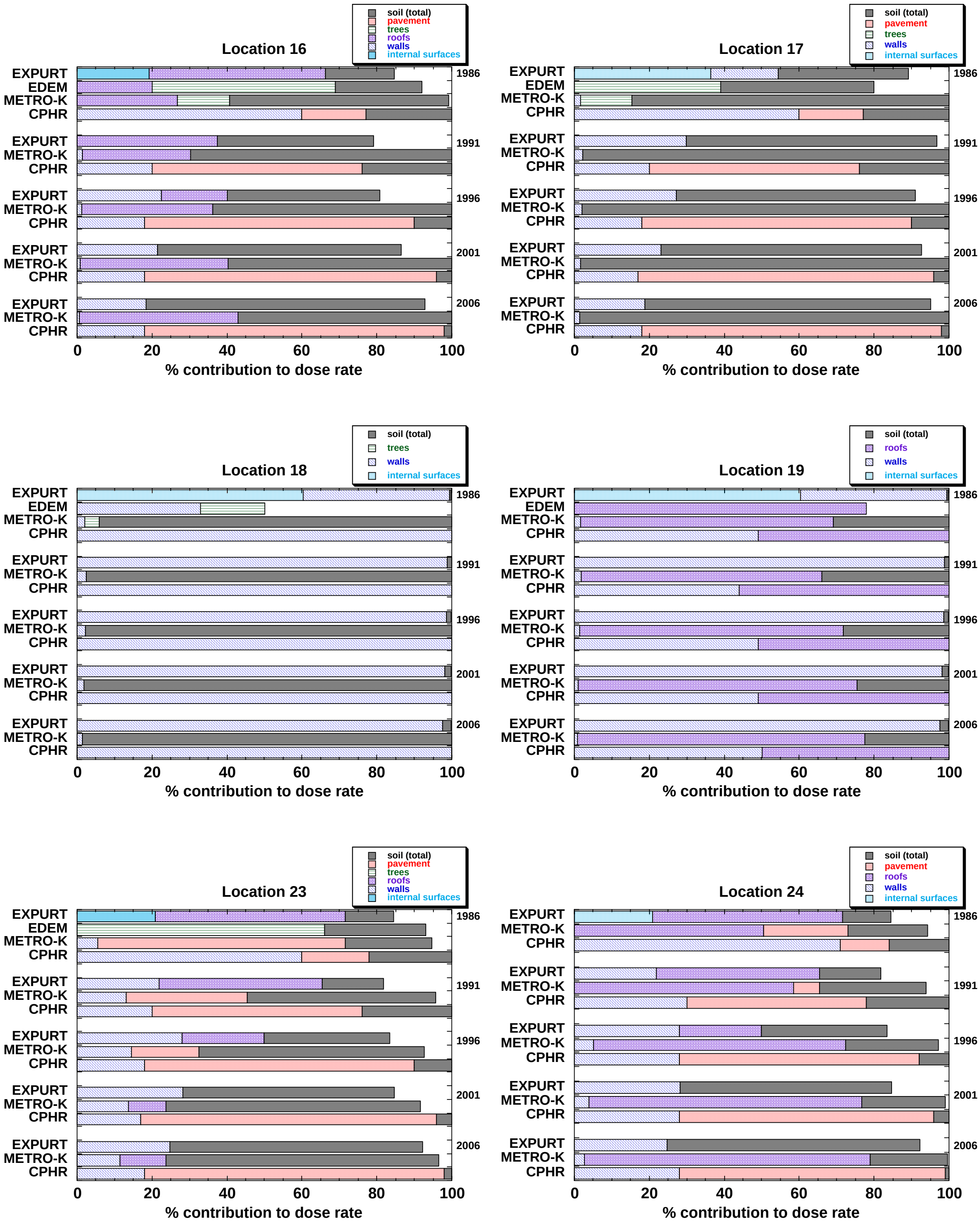

Fig. 3.15. Predicted contributions to dose rate over time from the most important surfaces for indoor locations in District 4 of Pripyat in the absence of countermeasures.

Locations 23 and 24 are on the 1st (ground) and 2nd floor of a school that is set in a large expanse of paved area. METRO-K and CPHR predict slightly higher dose rates for the 1st (ground) floor than the 2nd floor (Figure 3.13, bottom). EXPURT cannot distinguish between the two locations, and EDEM has not been applied to Location 24. Although there is sometimes good agreement between the models for indoor locations, the predicted dose rates are attributable to different combinations of surfaces in different models (next section).

3.4.2.3. Predicted contributions from surfaces

Figures 3.14 and 3.15 show the relative contributions of the most important surfaces in each model to the predicted dose rate as a function of time for indoor locations in District 1 and District 4, respectively. The EXPURT model did not distinguish between Locations 3 and 4 (Figure 3.14, top graphs), both of which are indoors in schools. In the first year, EXPURT predicts that the main contribution to dose rate is from roofs, but with significant contribution from soil and from internal surfaces. EXPURT is the only model to explicitly include internal deposition, although EDEM may be argued to implicitly include it within the empirical location factors. At subsequent times EXPURT predicts that soil will become the dominant surface, with walls making a significant contribution because of the long retention times. The EXPURT results are more convincing for Location 4 than Location 3, which has a much smaller proportion of soil in the vicinity. The EDEM predictions for both locations show that trees contribute most in the first year, with a significant contribution from soil. No EDEM results were provided for subsequent years. METRO-K consistently predicts for all times that most dose is contributed by paved surfaces at Location 3 and soil surface at Location 4 with minor components from walls and from roofs. CPHR consistently predicts that walls are the dominant surface at both locations and at all times.

Figure 3.14 (lower three graphs) also shows the surface contributions predicted by each participating model for Locations 7, 8 and 9, which are the 1st (ground), 3rd and 5th floors of a five-storey apartment block. EXPURT predicts for the first year, for the 1st (ground) floor (Location 7), that there will be roughly equal contributions from internal surfaces and from soil with a significant component from exterior walls. In subsequent years the internal surface contribution is gone, and soil makes the largest contribution with a persistent significant contribution from walls. EXPURT cannot distinguish between Locations 8 and 9 (middle and top floor). For these locations in the first year, EXPURT predicts that most of the dose is contributed by material deposited on internal surfaces with a significant component from external walls; in subsequent years the walls dominate with a minor component from soil.

METRO-K predicts that in the first year, for the 1st (ground) floor (Location 7), most of the dose will come from soil with a significant component from trees, and also a minor component from paved surfaces. In subsequent years the relative contribution from soil increases, and trees and walls become increasingly minor components. METRO-K predicts a similar pattern for the middle floor (Location 8), with soil being generally more significant in subsequent years. However, absolute dose rates from all these surfaces must be less on the 3rd floor than the 1st floor because of the increased distance, giving the reduction in dose rate that is seen when comparing these two locations in Figure 3.12. For the top floor (Location 9) METRO-K predicts that most of the dose rate will come from roofs, but still with a significant component from soil; the relative contribution from roofs increases in subsequent years. METRO-K predicts a slight rise in dose rate from the middle floor (Location 8) to the top floor (Location 9), with the increased component from the roof more than compensating for the increased distance from the soil surface.

EDEM predicts for the first year for the 1st (ground) floor (Location 7) roughly equal contributions from trees and soil; for the middle floor (Location 8) most of the dose rate is predicted to be from external walls with a significant component from trees, and for the top floor (Location 9) EDEM predicts that roofs dominate. CPHR predicts for the first year, for the 1st (ground) floor (Location 7), that most of the dose will come from exterior walls with significant components from paved surfaces or soil; in subsequent years the relative contribution from paved surfaces increases. For the middle floor (Location 8) CPHR predicts that the external walls surface will dominate at all times and that the soil and paved surface are sufficiently distant not to contribute. For the top floor (Location 9), CPHR predicts that roughly equal contributions to dose rate will be made by roofs and external walls at all times. The component from walls will be similar to that on the middle floor (Location 8), so the roof is an additional component, as with METRO-K. This explains why there is the slight increase in dose rate from the middle floor to the roof that can be seen when comparing these locations in Figure 3.12.

For Location 16 in District 4, in the first year, EXPURT predicts that the main contribution to dose rate is from roofs, but with significant contributions from soil and from internal surfaces (Figure 3.15, upper left). At subsequent times EXPURT predicts that soil will become the dominant surface, with roofs and later walls also making significant contributions. The EDEM predictions for Location 16 indicate that trees contribute most in the first year, with significant contributions from soil and from roofs. No EDEM results were provided for subsequent years. METRO-K consistently predicts for all times that the most dose is contributed by the soil surface with significant components from roofs, which increases in subsequent years, and from trees, which decreases in subsequent years. CPHR predicts that walls contribute the most to dose rate in the first year with significant contributions from paved surfaces and from soil. In subsequent years the predicted relative contributions from paved surfaces increases, while there is a persistent significant component from walls and an increasingly small relative component from soil.

The pattern of contributing surfaces predicted by EXPURT, EDEM and CPHR for Locations 17, 18, and 19 (the 1st, 5th and 9th floors of a 9-storey apartment block; Figure 3.15) is essentially the same as that predicted for Locations 7, 8 and 9, the 1st (ground), 3rd and 5th floors of a 5-storey apartment block. METRO-K predicts for the first year, for the 1st (ground) floor (Location 17), that most of the dose will come from soil with a significant component from trees, and also a minor component from wall surfaces. In subsequent years the relative contribution from soil increases, and trees and walls become minor components. METRO-K predicts a similar pattern for the middle floor (Location 18) with soil being generally more significant at all times. For the top floor (Location 19), METRO-K predicts that most of the dose rate will come from roofs with a significant component from soil; the relative contribution from roofs increases in subsequent years.

The remaining graphs in Figure 3.15 show the surface contributions predicted by each participating model for Locations 23 and 24, the 1st (ground) and 2nd floors of a school. EXPURT cannot distinguish between these two locations. In the first year EXPURT predicts that most of the dose is contributed by roofs with significant contributions from internal surfaces and from soil. In subsequent years the relative contribution from soil grows, and there is a significant persistent contribution from walls. METRO-K predicts that the 1st (ground) floor (Location 23) will in the first year receive most dose from paved surfaces with a significant component from soil and less from walls; in subsequent years the relative contribution from soil increases, whilst the contribution from paved surfaces disappears and there is a persistent significant contribution from walls and roofs. METRO-K predicts that the

2nd floor (Location 24) will in the first year receive most of the dose from the roof with significant and roughly equal components from paved surfaces and soil. In subsequent years the relative contribution from the roof increases, whilst there is a persistent significant contribution from soil and a persistent minor contribution from walls. For the 1st (ground) floor (Location 23), EDEM predicts that trees will make the largest contribution to dose with a significant component from soil. No EDEM results are given for the top floor (Location 24) or for subsequent times in either location. CPHR predicts that external walls will make the largest contribution to the dose rate on the 1st (ground) floor (Location 23) with significant components from both paved surfaces and soil; this pattern is repeated on the top floor (Location 24) but with external walls more dominant, as this location is further from the paved and soil surfaces. At subsequent times in both locations the paved surface becomes increasingly important, with a persistent significant component from walls and an increasingly minor component from soil.

3.4.3. Comparison of indoor and outdoor dose rates

Generally outdoor dose rates are greater than indoor dose rates at corresponding times by factors that range from less than an order of magnitude to greater than two orders of magnitude within a District, where the deposition on any given surface is, for the purposes of this comparison exercise, being considered uniform. Only one example can be found of where the indoor dose rate was comparable with the outdoor dose rate predicted by the same model. Figure 3.16 shows the situation for METRO-K; at around 20 y after deposition the dose rate at Location 2 outdoors is roughly the same as that at Location 3 indoors. This may reflect the much lower predicted contribution to dose rate from soil at Location 2 than at other outdoor locations (Figure 3.7, METRO-K predictions).

3.4.4. Dose endpoints in District 4

An additional set of dose endpoints was requested for District 4. Five hypothetical individuals were specified, and the modellers were required to generate estimates of cumulative and annual external dose. In order to calculate dose, modellers need information on the amount of time the typical individuals spent in different locations. In an earlier version of the scenario, a description of the basic occupancy of the individuals was provided in terms of their time spent on different surfaces. The results from EXPURT and EDEM are based on the modellers' own interpretations of this information (see Appendix I, Table I.5). In order to assist modellers, the scenario description was modified to explicitly relate the typical individuals' behavior to the test locations identified for District 4 (see Appendix I, Section I.7). The estimates generated with METRO-K and CPHR use this information. Figures 3.17 and 3.18 illustrate the estimated annual doses and cumulative doses, respectively.

Three of the models, EXPURT, METRO-K and CPHR, used time steps as follows: the first integration period was from the time of deposition to 1st of August 1986 (approximately 3 months), and subsequent integration periods are for 12 month intervals from 1st August to 31st July. For EDEM the first integration period is from the time of deposition to the end of the year (approximately 8 months); the subsequent integration periods are for 12 month intervals from 1st January to 31st December.

All the models predicted that the outdoor worker would receive the highest annual doses. For the remaining hypothetical individuals the results are generally similar for any given model. CPHR gave the highest results for all individuals, due to predicting the highest dose rates, for reasons discussed in Section 3.4.1.1. EXPURT generally gave the lowest dose for the first period (which is not an annual dose but is integrated from the time of deposition to 1st August

1986). For subsequent years EXPURT, METRO-K and EDEM are in reasonable agreement, being generally within an order of magnitude. CPHR shows a rise in dose between the first and second time period; this can be explained because the first period is approximately 3 months and the second and subsequent periods are 12 months. For the models EXPURT and METRO-K, the effect of this shorter integration period is masked by the much higher dose rates predicted for the initial period, and EDEM uses an initial integration period of 8 months.

A pattern is very clear in the cumulative dose results (Figure 3.18); CPHR gives the highest and EXPURT the lowest predicted doses at all times, while METRO-K and EDEM are in generally good agreement. It is clear from Figure 3.18 and the dose rate results described in Sections 3.4.1.1 and 3.4.1.2 that the highest dose rates occur in the first 3 months; therefore EXPURT predicts a lower cumulative dose at all subsequent times because of the relatively low estimate of dose for that first three month period (Figure 3.17).

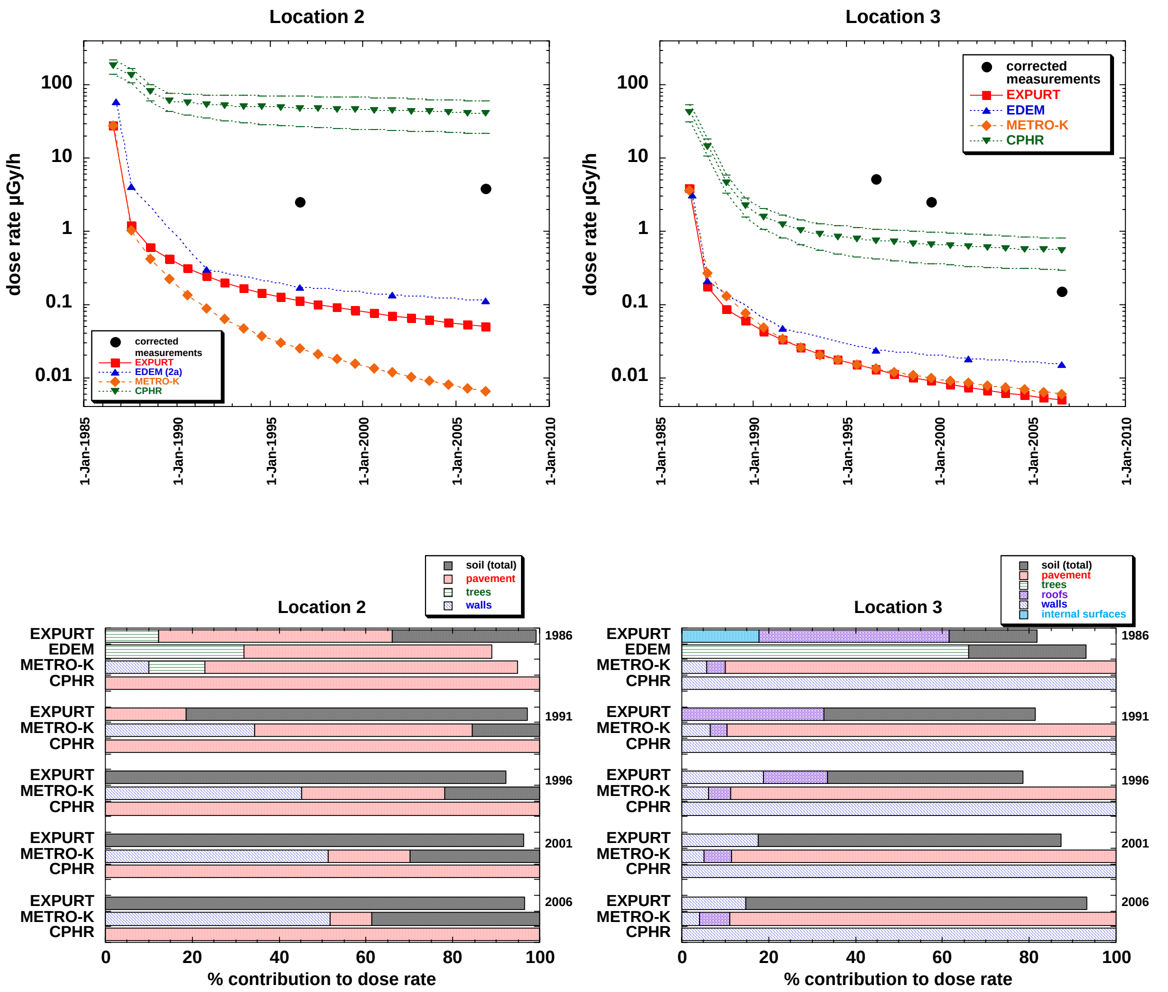

Fig. 3.16. Predicted and measured dose rates (top) for outdoor Location 2 (left) and indoor Location 3 (right), and the corresponding predicted contributions to dose rate over time from the most important surfaces (bottom) for Location 2 (left) and Location 3 (right) of District 1 of Pripyat in the absence of countermeasures.

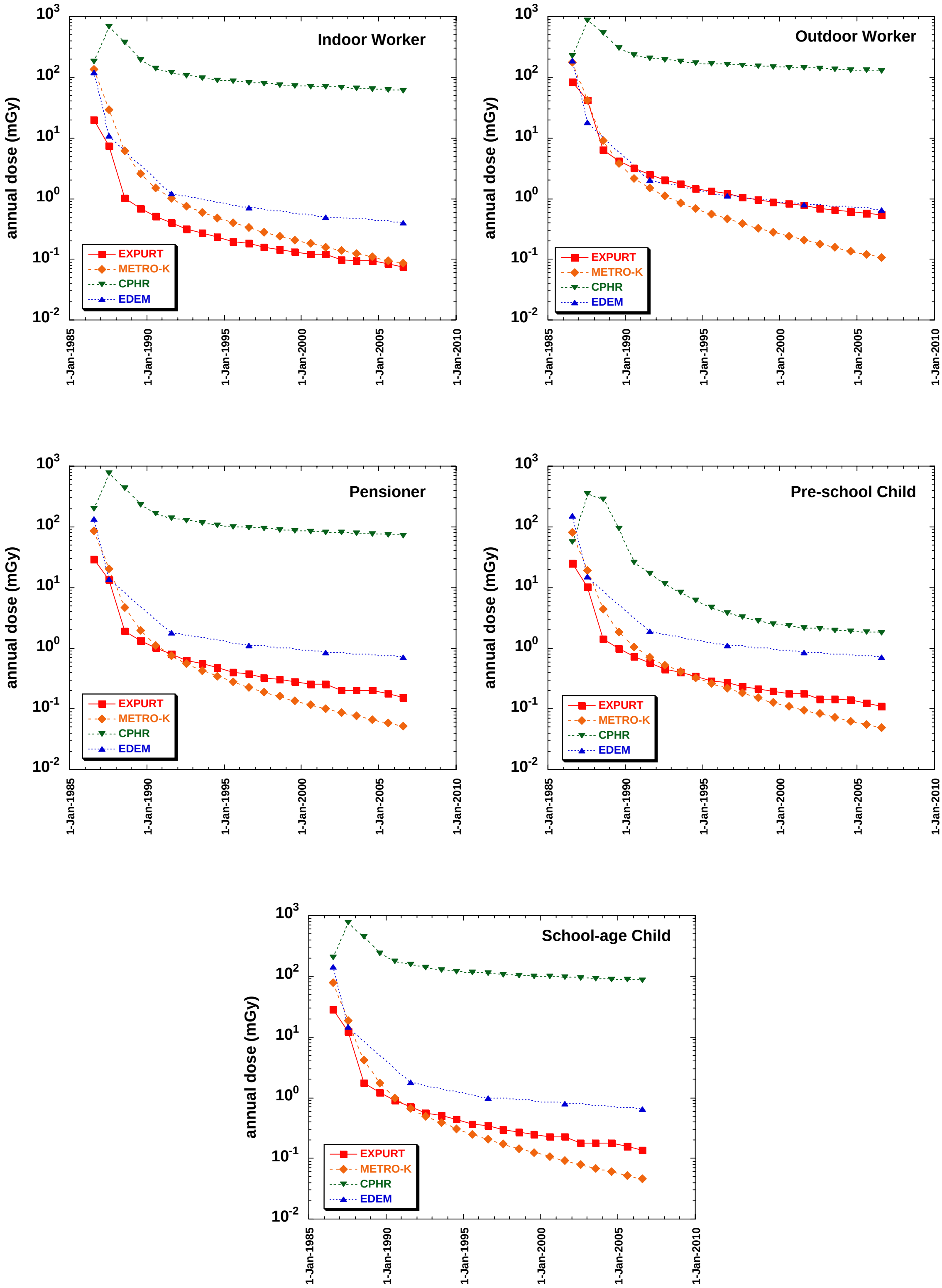

Fig. 3.17. Predicted annual doses to specified reference individuals, assuming no countermeasures.

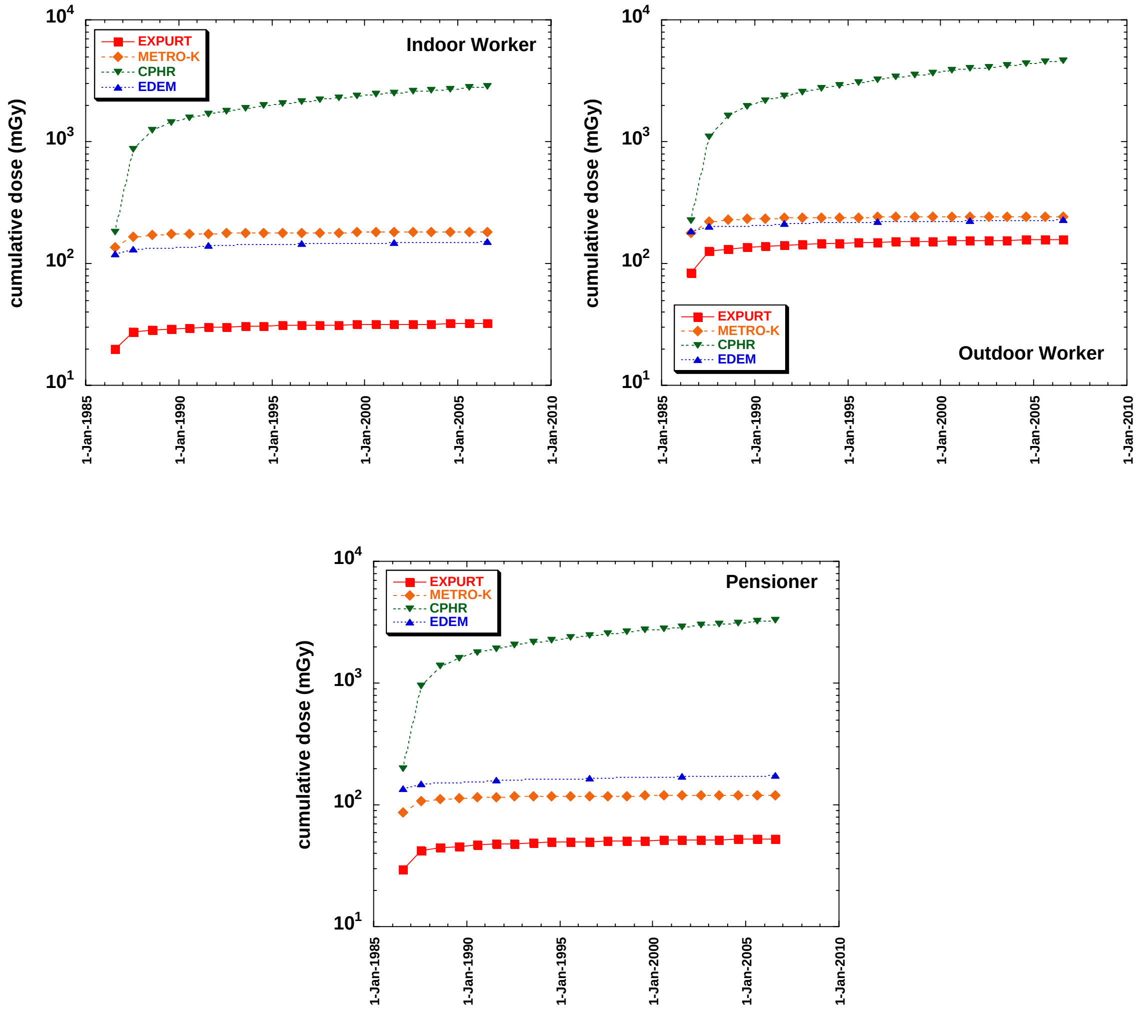

Fig. 3.18. Predicted cumulative doses to specified reference individuals, assuming no countermeasures.

3.4.5. Countermeasures within Districts 1 and 4

A number of hypothetical countermeasures were specified in the modelling scenario to test the models in both Districts 1 and 4. For District 1, one set of predictions (EXPURT) examines the effect of countermeasures on dose rates. For District 4, all four modellers predicted the effects of countermeasures on annual and cumulative doses to the reference individuals.

3.4.5.1. Predicted effects of countermeasures on dose rates

Figures 3.19 and 3.20 give example results generated by EXPURT for dose rates at locations in District 1. Location 1 is outdoors in the middle of a large area of grass or soil surface. EXPURT predicts that most of the dose rate at Location 1 is contributed by the soil surface with a significant component in the first year from trees (Figure 3.19, lower left). It is clear that countermeasures that treat the soil surface (grass cutting, soil removal, or ploughing) and the tree surface (tree removal) are the most effective at reducing dose in this location (Figure 3.19, upper left). In contrast Location 2 is outdoors in a mainly paved area. Countermeasures that treat the paved surface (e.g., hosing roads or high pressure hosing roads) have greater effect than they have at Location 1 (Figure 3.19, upper right); however, the effect diminishes with time; the contribution to dose rate from paved surfaces predicted by EXPURT (Figure 3.19, lower right) is only significant for the first few years following deposition, and at longer times soil is again the dominant surface.

Locations 7, 8 and 9 in District 1 are on the 1st (ground), 3rd and 5th floors of a 5-storey apartment building. EXPURT predicts that each of these locations will receive a significant component of the total dose rate from internal deposition (Figure 3.20). However, this contribution is temporary, and EXPURT predicts that internal material is removed very rapidly. Consequently countermeasures that treat internal surfaces (vacuuming or washing) have an effect, but it is temporary and hardly discernable in Figure 3.20 because of the steep decline in dose rates in this period. The 1st (ground) floor (Location 7) is also predicted to receive a significant contribution from soil, and the relative contribution of this surface to the dose rate at this location increases at subsequent times; consequently countermeasures that treat soil have a noticeable and lasting effect. EXPURT does not predict that trees make a significant contribution to dose rate in Location 7. However there is a large transfer from trees to soil, so treatment of trees does have a discernable effect. The 3rd and 5th floors are predicted by EXPURT to receive a significant persistent component of the dose rate from walls, and this is reflected in the effectiveness of the technique that treats this surface (washing walls). METRO-K, EDEM and CPHR each predict a large and persistent component on the top floor (Location 9) from the roof; for these models countermeasures that treat the roof will be the most effective.

The effectiveness of the various countermeasures in EXPURT in terms of the predicted reduction in dose rates at 1 August 1986 and 1 August 2006 is summarized in Table 3.2. The ranges are summarized separately for outdoor and indoor locations. The ranges given for outdoor locations reflect the different contributions of soil and paved surfaces at different locations. For indoor locations, the ranges reflect the relative importance of various surfaces for ground floor and upper floor locations.

3.4.5.2. Predicted effects of countermeasures on annual and cumulative doses

Figures 3.21 and 3.22 display the predictions from the four participating models of the effect of different countermeasures on the annual dose estimates for the indoor worker and outdoor worker, respectively. Unsurprisingly the relocation countermeasure gives the biggest reduction in the first period. Because the first integration period is approximately 3 months for the EXPURT, METRO-K and CPHR results, the predicted dose is nothing when a relocation of 6 months is assumed, and the effect of this countermeasure extends into the second period. For EDEM which has a first integration period of 8 months, a dose with 6 month relocation assumed is very low but not zero.

Relocation is a particularly appropriate countermeasure for the Pripyat scenario with the presence of short-lived radionuclides that are predicted to give a very high initial dose rate that drops rapidly in the first few weeks and months (see Figures 3.5, 3.6, 3.9 and 3.10). Of the decontamination countermeasures, the models generally agree that even for the indoor workers it is techniques that treat the soil or paved surfaces that give the most significant reductions. Techniques that physically remove contamination from the area (e.g., removal of soil, grass, or trees) continue to reduce dose even years later.

Table 3.2. Summary of predicted effectiveness of countermeasures for District 1 of the Pripyat scenario from EXPURT, in terms of the percent reductions in dose rate at 1 August 1986 and 1 August 2006.

Countermeasure	1 August 1986		1 August 2006	
	Outdoors	**Indoors**	**Outdoors**	**Indoors**
Cutting and removal of grass (at 1 week)	21–45	0.3–23	39–45	1–38
Hosing of roads (at 2 weeks)	1–27	0–1	0.1–3	0–0.5
High pressure hosing of roads (at 2 weeks)	1–47	0.1–2	0.1–4	0–1
Washing of roofs and walls (at 2 weeks)	0–3	3–12	0–3	4–22
Removal of trees and leaves (at 30 days)	19–40	0.3–21	35–40	1–34
Removal of soil (5 cm at 6 months)	0	0	65–76	2–64
Ploughing (30 cm at 6 months)	0	0	57–67	2–56
Vacuuming of interior (at 2 weeks)	0	16–54	0	0
Washing of interior (at 2 weeks)	0	12–40	0	0

EXPURT tends to favour techniques that treat the soil surface over the those that treat paved surfaces for both the indoor and outdoor workers (Figures 3.21 and 3.22, upper left). This result is not surprising after considering the predicted relative dose contributions in Figures 3.7, 3.8, 3.14 and 3.15. EXPURT predicts that grass cutting is the most effective technique for both the indoor and the outdoor worker. Generally grass cutting is considered less effective at dose reduction than other countermeasures such as soil removal or ploughing. But in this scenario grass cutting is applied early at one week, compared to 6 months for soil removal and ploughing, and EXPURT predicts that it has a large reduction that is only exceeded by ploughing by the third year for either the indoor worker or the outdoor worker. The effect of occupancy is apparent when looking at the predictions for high pressure hosing of roads; for the indoor worker EXPURT predicts that high pressure hosing of roads makes a small but clear reduction, however for the outdoor worker the reduction is barely discernable. The reason for this is clear from the description provided by the modeller (Appendix III.1, Table III.12). The modeller has assumed that the indoor worker spends roughly 8% of the time outdoors (where a significant proportion of the dose is accrued because of the relatively higher dose rates compared to indoor locations), and of this nearly 50% is within highly paved areas. In contrast the worker spends 39% of the time outdoors but only 5% of this is within a highly paved area.

METRO-K also favours the techniques that treat soil surfaces and predicts that grass removal is more effective than 2 weeks of relocation for both indoor and outdoor workers (Figures 3.21 and 3.22, upper right). METRO-K predicts that the washing of roofs and walls has a small effect for the indoor worker that persists until the third period, but no significant effect for the outdoor worker. Washing of roads has no discernable effect for either the indoor or the outdoor worker. This result is not surprising when considering the relative dose contributions in Figures 3.7, 3.8, 3.14 and 3.15 predicted by METRO-K, which indicate that very few locations are dominated by the paved surfaces.

In contrast CPHR predicts that washing roads is one of the most effective techniques, particularly for the outdoor worker (see Figures 3.21 and 3.22, lower left). For both the indoor and outdoor worker the effect of washing roads is persistent, reflecting the assumptions about retention on this surface made by CPHR (see Section 3.4.1.1). However, CPHR also predicts that soil removal will be the most effective technique at most times. This is explained because although soil is often a less important surface than pavement in CPHR (see Figures 3.6, 3.7, 3.14 and 3.15), soil removal removes a larger proportion of contaminated material from the soil surface than washing of roads removes from the paved surface.

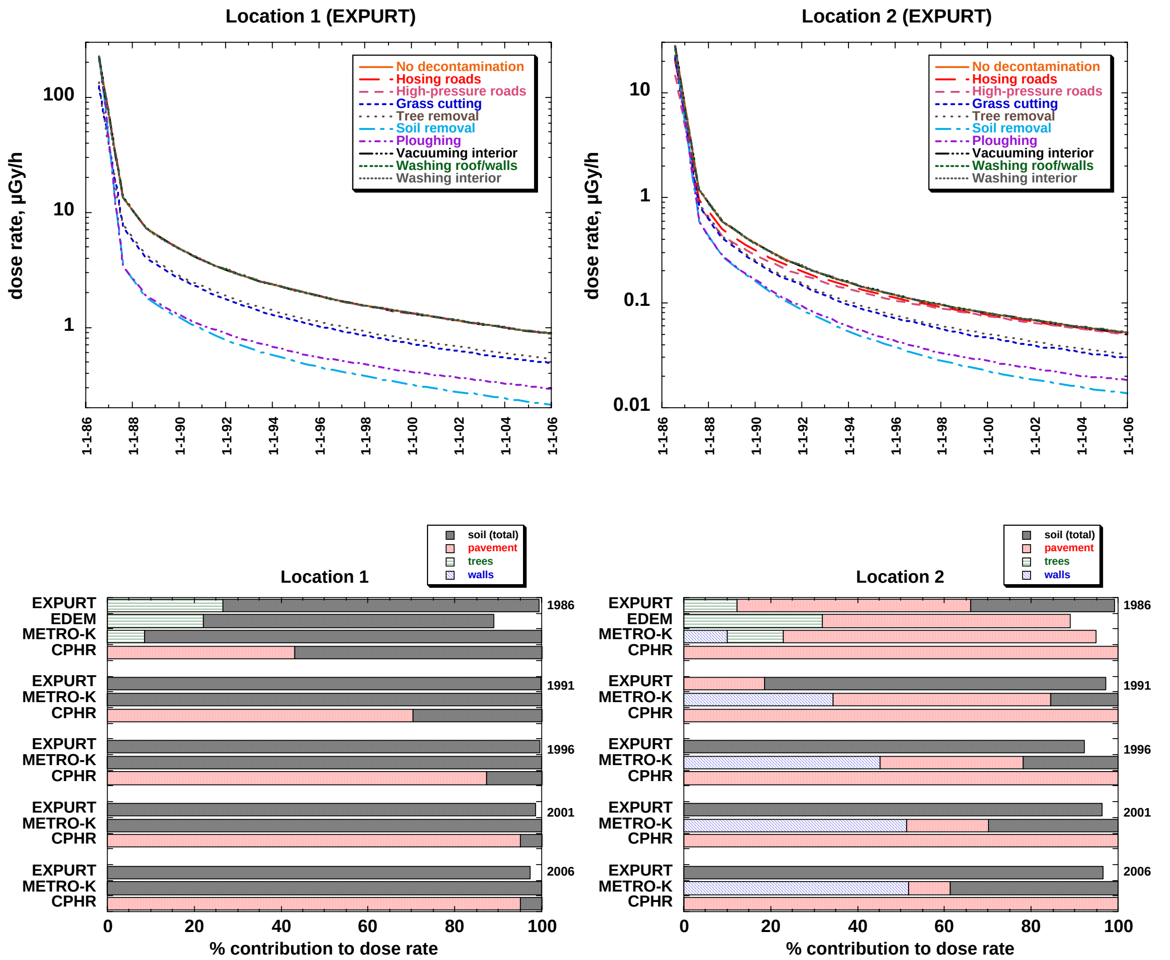

Fig. 3.19. Predicted effects of countermeasures on dose rates over time (top) at Location 1 (left) and Location 2 (right), and predicted contributions to dose rate over time (in the absence of countermeasures) from the most important surfaces (bottom) for Location 1 (left) and Location 2 (right) in District 1. Predictions from EXPURT. (Vertical scales in the top two graphs are scaled differently, but the relative proportions are the same.)

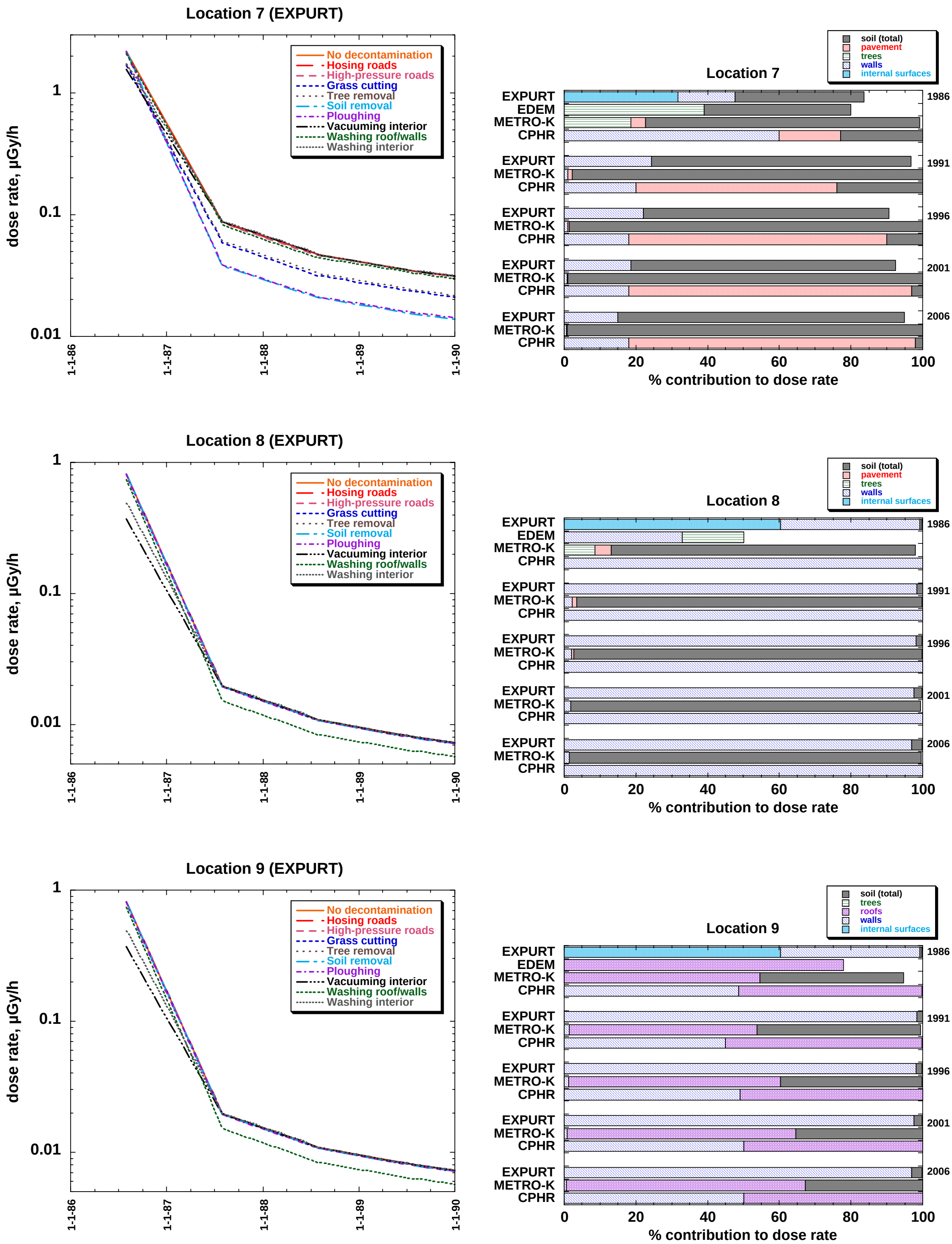

Fig. 3.20. Predicted effects of countermeasures on dose rates over time (left) at Location 7, Location 8 and Location 9, and corresponding predicted contributions to dose rate over time from the most important surfaces (right) for the same locations, in District 1. Predictions from EXPURT.

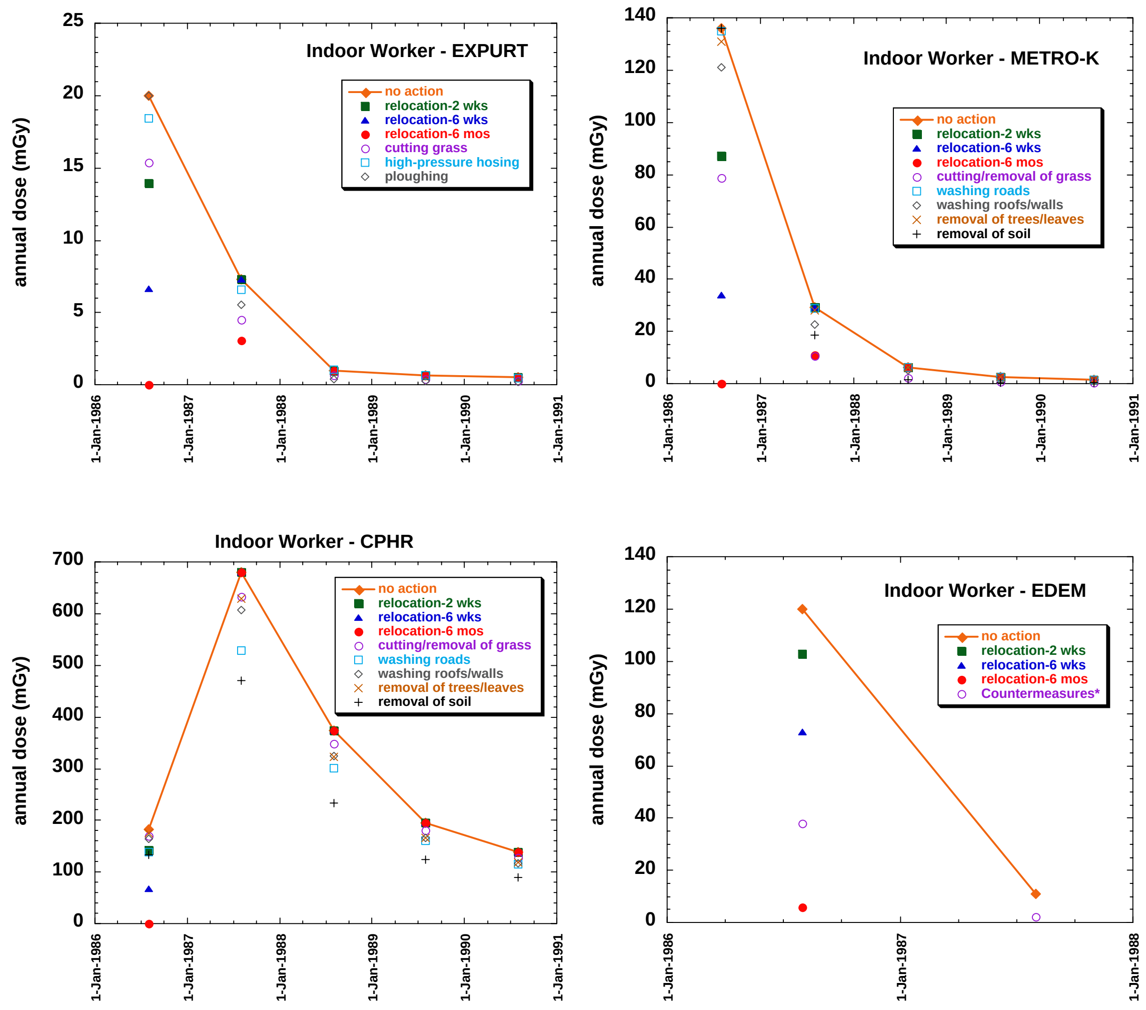

Fig. 3.21. Predicted annual doses (mGy) to a reference indoor worker for the first 5 years for EXPURT, METRO-K and CPHR and the first 2 years for EDEM, showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear. Scales for METRO-K and EDEM are identical to each other but not to scales for EXPURT or CPHR.)

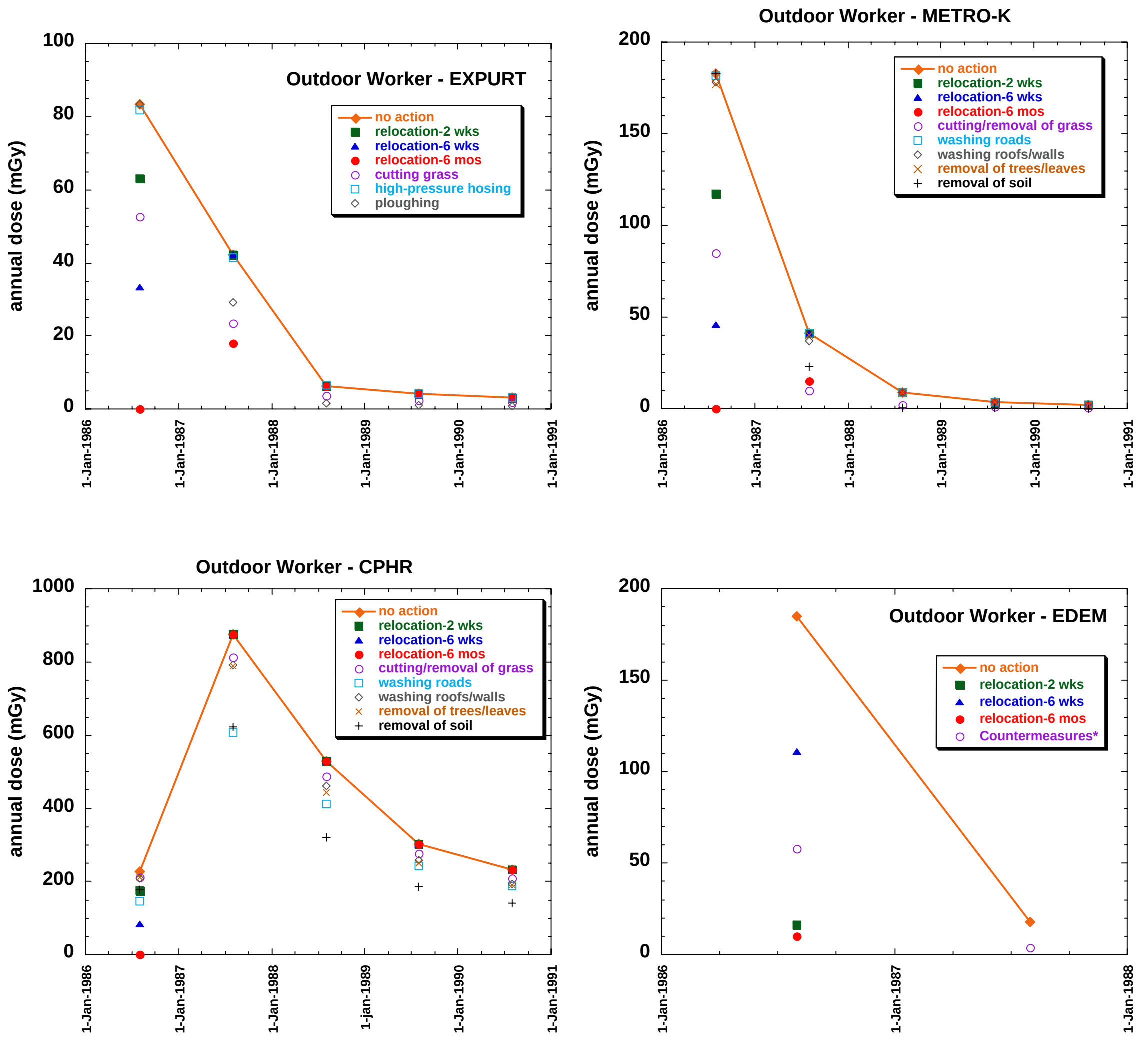

Fig. 3.22. Predicted annual doses (mGy) to a reference outdoor worker for the first 5 years for EXPURT, METRO-K, and CPHR and the first 2 years for EDEM, showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear. Scales for METRO-K and EDEM are identical to each other but not to scales for EXPURT or CPHR.)

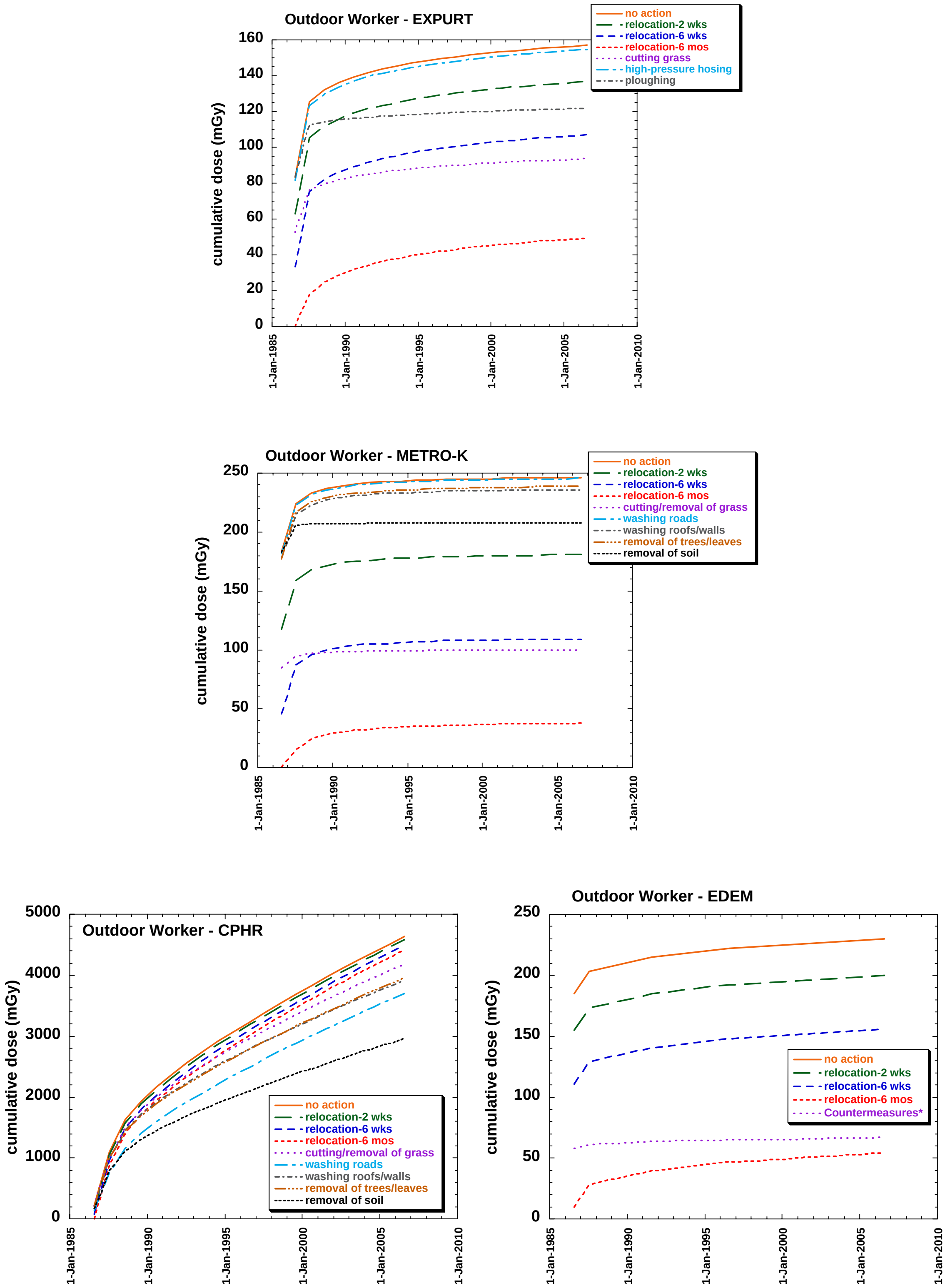

Fig. 3.23. Predicted cumulative doses (mGy) to a reference outdoor worker, showing the predicted effects on the cumulative dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not comparable.)

The combined effects of decontamination techniques predicted by EDEM have been lumped into a single dose reduction (Figures 3.21 and 3.22, lower right). Taken together the countermeasures are more effective than two or six weeks relocation, and the effect persists into the second time period and presumably beyond.

The predicted effects of various countermeasures on the cumulative dose to an outdoor worker are shown in Figure 3.23. For three of the models (EXPURT, METRO-K, and EDEM), relocation for 6 months during the initial post-accident period produces a substantial decrease in the cumulative dose over 20 years, more so than any other single countermeasure. For EXPURT and METRO-K, cutting and removal of grass reduces the cumulative dose by a slightly larger amount than does relocation for 6 weeks. The combination of countermeasures used by EDEM is almost comparable with relocation for 6 months in terms of the effect on cumulative dose. CPHR differs from the other three models in showing greater effects from decontamination than from relocation, with the greatest effects on cumulative dose from removal of soil and washing of roads.

The effectiveness of the various countermeasures in terms of the predicted reduction in annual and cumulative doses is summarized for each model in Table 3.3. The ranges given for many countermeasures depend on the reference individuals; for example, cutting and removal of grass gives a smaller reduction in dose for an indoor worker than for an outdoor worker. As shown in the table and described above, relocation produces a substantial reduction in the dose over the first time period and, because of the high contribution from short-lived radionuclides, to the cumulative dose, but not to annual doses after the initial relocation period. Countermeasures involving removal of grass or soil may reduce the annual doses for years to come, as well as reducing the cumulative doses. The predicted effectiveness of countermeasures varies among the models, especially for the decontamination measures.

3.5. Comparison of modelling results with data

A number of measurements of dose rate are available at or near the locations in District 1 and District 4. Some of the measurements are included in the figures in Sections 3.4.1 and 3.4.2. Caution must be exercised when comparing the measurements to the model predictions.

The models predict gamma dose rates due to the radionuclides released by the Chernobyl accident and do not include background radiation. However, the measurements were not carried out in a spectrometric mode, and consequently they will include the background radiation. They also include a contribution from the inherent background of the device. Calibration of the measurement instrument (DBG-06t; used for the 2006 measurements) inside a thick lead wall camera indicated an inherent background of mean 0.064 µSv h^{-1}. This instrument is similar to the model DRG-01T, which incorporates energy-compensated Geiger-Müller tubes. On the basis of experience with DRG-01T use in Russia [30, 61], it is possible to estimate the contribution of cosmic radiation and inherent background to readings of the DBG-06T as 70–75 nGy h^{-1}. Considering the additional contribution of gamma radiation from natural radionuclides in soil, the total contribution to the device reading from those components which are not taken into account within the model calculations is approximately 120 nGy h^{-1} over soil (dependent on the geology). As a rule, this value will be greater inside, or near to, structures. So, for example, the comparison of model predictions of dose rates with measurements taken inside buildings is not meaningful, as after the subtraction of the estimate of background from the measurement, the final result may be very close to zero or even negative, and will certainly include a very large uncertainty.

Table 3.3. Comparison of model predictions for District 4 of the Pripyat scenario, in terms of the percent reduction in annual dose and cumulative dose due to countermeasures.

Countermeasure	Model											
	EXPURT			**METRO-K**			**EDEM**			**CPHR**		
	Annual		**Cumu-lative**	**Annual**		**Cumu-lative**	**Annual**		**Cumu-lative**	**Annual**		**Cumu-lative**
	1st year[a]	**20th year**	**20 years[b]**	**1st year**	**20th year**	**20 years**	**1st year**	**20th year**	**20 years**	**1st year**	**20th year**	**20 years**
Cutting and removal of grass	23–36	33–48	29–40	42–60	53–80	47–65	–	–	–	6.7–7.4	11.3–13	9–10
Washing of roads[c]	2–8	0.1–2	2–7.4	0.5–1.3	0	0.4–0.6	–	–	–	24–35	13.7–14.5	18–20
Washing of roofs and walls	–[f]	–	–	0.5–11	0.3–27	4–13	–	–	–	8–10	18–19	14.7–15.4
Removal of trees and leaves	–	–	–	1.2–4	0	1.6–4	–	–	–	4.3–6.2	14.6–15.3	12–15
Removal of soil (5 cm)	–	–	–	0	63–95	12–17	–	–	–	21–79	38–99	35–36
Ploughing (30 cm at 6 mo.)	0	50–67	14–23	–	–	–	–	–	–	–	–	–
Combination[d]	–	–	–	–	–	–	68–71	80–89	71–72	–	–	–
Relocation (2 weeks)	24–30	0	13–19	35–36	0	26–27	12–16	0	11–13	22–79	0	1–1.4
Relocation (6 weeks)	60–67	0	32–42	74–75	0	55–57	32–40	0	30–32	63–90	0	3.1–4
Relocation (6 months)	100	0	68–75	100	0	84–85	93–95	0	74–76	100	0	5–6
Relocation (6 months) + 1 additional countermeasure[e]	100	0.1–67	0.8–71	–	–	–	–	–	–	–	–	–

[a] The "annual dose" for the first year is actually the dose over the first time period, until 1 August 1986 (31 December 1986 for EDEM).
[b] Cumulative dose over 20 years (range of predicted reductions for adults).
[c] For EXPURT, "High pressure hosing".
[d] Combination of countermeasures, including cutting and removal of grass, washing of roads, washing of roofs and walls, removal of trees, and removal of soil (5 cm).
[e] Relocation for 6 months plus one of the following countermeasures: cutting and removal of grass, washing of roads, or ploughing.
[f] Specified countermeasure not used by modeller in this exercise.

Another important consideration is that, as a rule, the parameters of models were estimated on the basis of long-term measurements within inhabited locations at long distances from Chernobyl, while Pripyat has been uninhabited since the accident and is very close to the point of release. The parameters will implicitly include activities and processes such as traffic, everyday grass cutting, road sweeping, cleaning building interiors, etc. So it can be expected that removal of activity from surfaces is generally slower in an uninhabited environment than one with an active population. For example, the observed build up of debris on paved surfaces in Pripyat suggests weathering and removal processes very different from those assumed by the models. Thus, dose rates measured many years after the deposition can be expected to be higher than those predicted by the participating models. On the other hand, because Pripyat is close to the point of release, larger and less readily soluble particles (e.g., fuel fragments) would be expected, which would have had more heterogeneous deposition and shorter retentions.

Another source of uncertainty is that the scenario presented in Appendix I is a necessary simplification of reality for the purpose of providing a basis for the model test. In reality the deposition varied quite markedly across the regions, as appears to be indicated by the dose rates taken in the summer of 1986 (see Appendix I, Figure I.9), and more distant locations can be expected to have different isotopic composition and particle sizes than those closer to the source of the release. Furthermore, some parts of District 4 were subjected to remediation efforts, which have been ignored in this comparison.

Figures 3.24 and 3.25 show the predicted and measured dose rates for outdoor locations in District 1 and 4 in 1996, 1999 and 2006. Measured dose rates are shown directly and corrected for an estimated contribution of 0.1 μGy h^{-1} from background (non-Chernobyl) sources of radiation. The most obvious feature is that even taking into account the estimated background, the measurements are generally higher than the predictions from EXPURT, METRO-K and EDEM. CPHR predicts dose rates generally higher than the measurements, probably for the reasons discussed in Section 3.4.1.1.

For the four outdoor locations in District 1 (Locations 1, 2, 5 and 6, Figure 3.24), the predicted results for 1996 from EXPURT, METRO-K and EDEM look in reasonable agreement with the measurements, particularly for Locations 1, 5 and 6. The only outdoor locations in District 4 with measurements in 1996 are Locations 13 and 15 (Figure 3.24); here too, EXPURT, METRO-K and EDEM (Location 15) are in reasonable agreement. (EDEM and CPHR did not provide predictions for Location 13.)

Locations 1 and 13 are the only outdoor locations with measurements in 1999 (Figure 3.24). The METRO-K prediction is particularly close to the measured value (corrected for the estimated background) at Location 1. The dose rate at Location 13 appears to have risen since 1996, which underlines the caution with which such measurements need to be treated, particularly in District 4 where the deposition is less than District 1 and consequently the proportion from background radiation in the measurements will be greater. METRO-K and EXPURT are less in agreement with the 1999 measurement at Location 13, as they predict a drop in dose rate between 1996 and 1999. (EDEM did not provide predictions for 1999.)

Measurements were made in 2006 at all outdoor Locations (Figure 3.25). As with 1996, the EXPURT, METRO-K and EDEM models (and CPHR for Location 5) appear to simulate Locations 1, 5 and 6 more successfully than Location 2. Locations 1, 5 and 6 have a much larger proportion of soil surface than Location 2. It is possible that either the models are better at representing soil surfaces than paved surfaces, or the accumulation of debris on the paved surface at Location 2 because Pripyat is uninhabited is giving a much different result than would be measured if Pripyat were inhabited and Location 2 were clear of debris. It is probably not useful to attempt to draw conclusions from the measurements at Location 2, as they appear to indicate a distinct rise in dose rate between 1996 and 2006.

The most obvious features of the measurements made in 2006 (Figures 3.25 and 3.26) are that the variation between them is little more than an order of magnitude and there appears to be little correlation between dose rate and position indoor or outdoors, although the highest dose rates were taken at outdoor locations. The most successfully simulated outdoor locations appear to be Locations 5, 15 and 20, with all the models within an order of magnitude. The least well simulated appear to be Locations 2, 14, 21 and 22. Again it would appear that locations with more soil are generally more successfully modelled than those with more paved surfaces. But, given the sources of uncertainty discussed above, this can only be a very tentative conclusion.

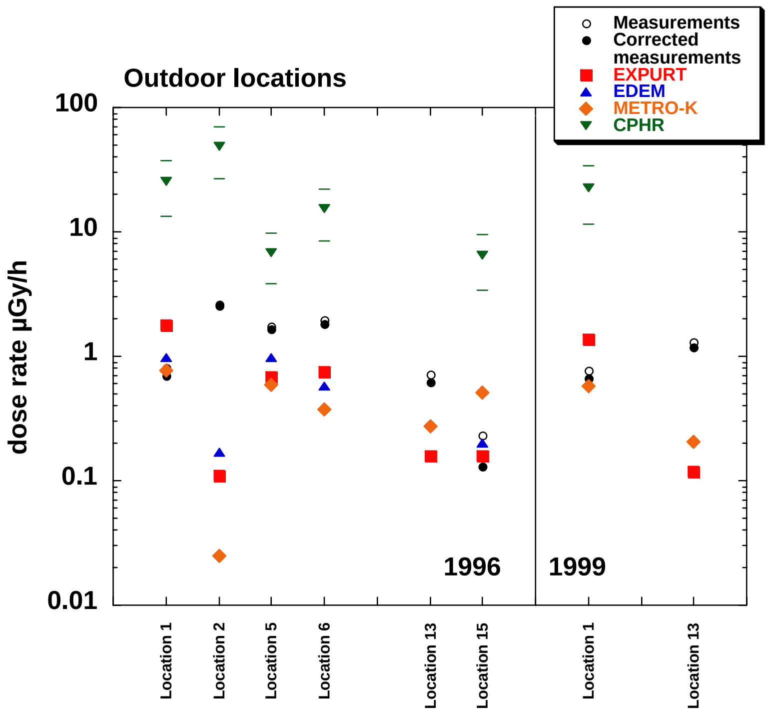

Fig. 3.24. Comparison of model predictions and test data (measurements) by location for Districts 1 and 4 of Pripyat for 1 August 1996 and 1 August 1999. Locations 1, 2, 5, and 6 are in District 1; Locations 13 and 15 are in District 4. Measured dose rates are shown directly and corrected for an estimated contribution of 0.1 µGy h^{-1} from background (non-Chernobyl) sources of radiation.

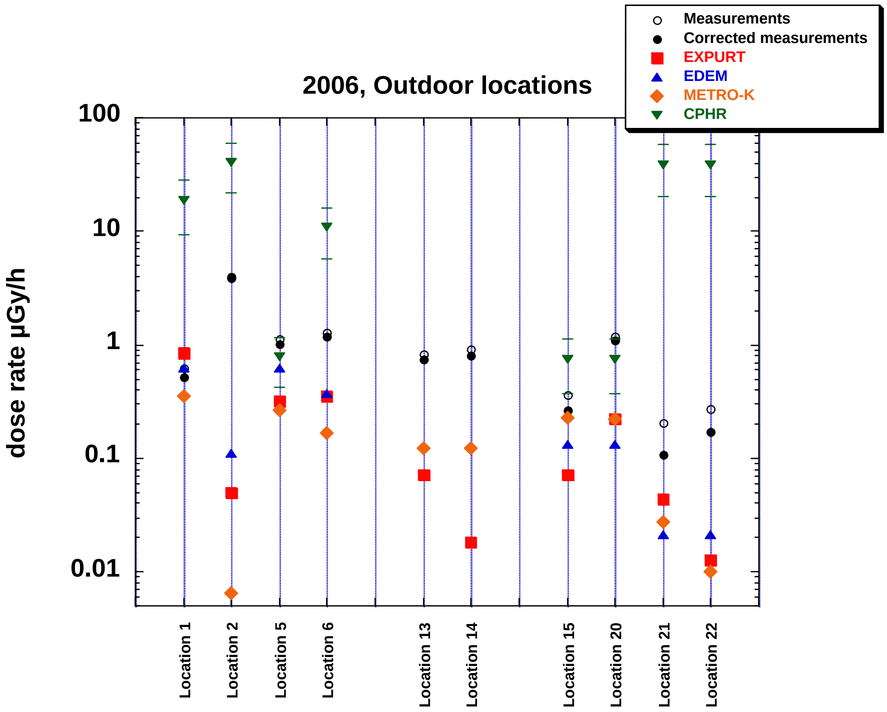

Fig. 3.25. Comparison of model predictions and test data (measurements) by location for Districts 1 and 4 of Pripyat for 1 August 2006. Locations 1, 2, 5, and 6 are in District 1. Locations 13 and 14 are in the unremediated part of District 4. Locations 15, 20, 21, and 22 are in the remediated part of District 4. Locations 1, 5, 6, 13, 15 and 20 are in locations with a larger proportion of soil than pavement in the immediate vicinity. Locations 2, 14, 21 and 22 are in locations with a smaller proportion of soil than pavement. Measured dose rates are shown directly and corrected for an estimated contribution of 0.1 µGy h^{-1} from background (non-Chernobyl) sources of radiation.

3.6. Conclusions from the Pripyat scenario modelling exercise

The Pripyat scenario presents a challenge to modellers. Generally the models compared well together, although CPHR was somewhat higher than the other models (for the reasons discussed in Section 3.4.1.1). Lessons learned about constructing and using models on a Pripyat-like scenario are described here; lessons learned about conducting a model comparison exercise or planning a real-world response are described in Chapter 5.

Three of the models, EXPURT, METRO-K and CPHR, had a similar modelling approach in that they explicitly represented several typical urban surfaces. EDEM used a different, rather elegant, approach based on an empirical function for time-dependent location factors. For the purposes of calculating dose rate, EDEM was generally in close agreement with most of the other models in both indoor and outdoor locations (see Figures 3.5, 3.6, 3.12 and 3.13) and gave as good agreement or better with the outdoor measurements as any of the other models (see Figures 3.24 and 3.25). However, EDEM is less amenable for calculating contributions from different surfaces or the effect of countermeasures, and the EDEM modeller used a compartmental model that is similar to EXPURT (see Appendix III.3), to calculate step changes in the location factors to use within EDEM to represent countermeasures.

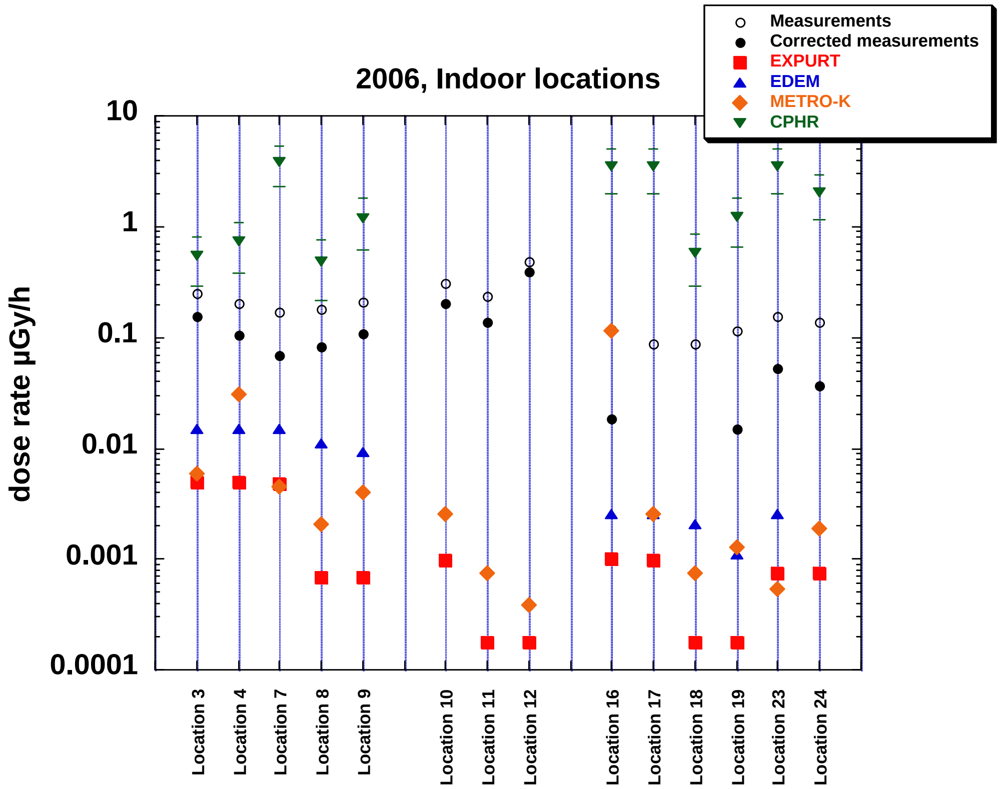

Fig. 3.26. Predicted and measured dose rates at indoor locations in Districts 1 and 4 of Pripyat, for 1 August 2006. Locations 3, 4, 7, 8 and 9 are in District 1. Locations 10–12 are in the unremediated part of District 4. Locations 16–19, 23 and 24 are in the remediated part of District 4. Measured dose rates are shown directly and corrected for an estimated contribution of 0.1 µGy h^{-1} from background (non-Chernobyl) sources of radiation. Corrected values below zero (negative values) were obtained for Locations 17 and 18 in District 4, and these are not shown.

The time-dependent location factor functions in EDEM were derived from results of dose rate measurements performed in Russia over a ten-year period after the Chernobyl accident [4]. The measurement locations are much more remote from the Chernobyl site than Pripyat, which is only about 3–4 km from the power plant, and it might be expected that the deposition and subsequent retention characteristics in these far and distant locations could be sufficiently different that the empirical functions would not apply. However, there is no indication of this in the EDEM predictions, which are compatible with the results of other models and with the available measurements. Being empirical it would probably not be appropriate to apply EDEM to scenarios very different from Chernobyl in radionuclide composition or chemistry, or in environments that are very different from those in which the measurements were made from which the location factors were derived. However, the same argument could be made for the other models, which use parameters for deposition and retention, and in some cases dose rate, largely derived from the Chernobyl experience.

EXPURT and CPHR explicitly model transfers between surfaces, whereas METRO-K does not. Some of the big differences between the EXPURT and CPHR predictions of contributing surface at long times can be put down in part to these transfers (see for example the discussion of contributing surfaces at Location 1, Section 3.4.1.1). It might be argued that ignoring these transfers makes for a more robust model; certainly no surface in METRO-K acts as a sink for other surfaces. Indeed for a new model ERMIN, which is in development and not available for this comparison exercise, the model developers have chosen to ignore transfers between surfaces, other than the major transfer from trees to soil which is principally by leaf fall [62] and is too large to be ignored.

By explicitly representing surfaces, the models can also explicitly represent the application of countermeasures to those surfaces. It is relatively straightforward, for example, to apply an arbitrary DF to a surface in EXPURT, METRO-K and CPHR, whereas it is more complex to apply one for EDEM, as it requires a compartmental model to generate the step reduction in the location factor. An advantage of explicit surfaces is that it is possible to extract additional useful endpoints other than dose rate. Such endpoints include the surface contamination (useful in the process of establishing directly measurable action levels in terms of Bq cm^{-2} for triggering remediation) and activity removed (useful for calculating the activity concentration of waste and so evaluating disposal routes and costs). EXPURT, METRO-K and CPHR represent approximately the same set of urban surfaces: soil (and grass), paved surfaces, exterior walls, roofs and trees. In addition EXPURT has a compartment representing interior surfaces and also divides soil into five layers.

It became clear in this comparison exercise that it is important to look at the contribution from different surfaces; in several cases models were giving comparable overall dose rate estimates but due to contributions from completely different surfaces. A decision maker who based his decisions on one model might target completely different surfaces than if the decision were based on another model. Naturally, a decision-maker who bases his decision solely on a model that omits a particular surface will not consider countermeasures that apply to that surface. Therefore, model developers must try to include all surfaces that are expected to be relevant for their national or organizational purposes.

It could be argued that EXPURT has an advantage over the other compartmental models in the comparison in that it includes a compartment for internal surfaces, and the effect of countermeasures on internal surfaces can be seen in Figure 3.19. However it has to be acknowledged that the modelling of interiors within EXPURT is fairly simplistic; even making the assumption that most contamination is on horizontal surfaces, the compartment includes a multitude of surface types, such as concrete, ceramics, wood, carpet, vinyl, etc., and furthermore there will be a great variation in degree and frequency of regular cleaning. Nevertheless EXPURT does predict that internal deposition will be an important and even dominant surface at early times for a number of indoor locations (See Figures 3.14 and 3.15).

CHAPTER 4. SCENARIO 2 – HYPOTHETICAL SCENARIO, POINT RELEASE OF CONTAMINATION

4.1. Overview and rationale

The EMRAS Urban Remediation Working Group discussed a number of types of hypothetical situations that could result in the accidental or deliberate dispersal of radioactive material in urban settings. In addition to a nuclear power plant accident (Chapter 3 of this report), such situations include a radiological dispersal device using conventional explosives, deliberate or accidental dispersal of radioactive material without use of explosives, transport accidents, and accidents at facilities for waste storage or spent fuel storage. This hypothetical scenario is designed to provide an opportunity to model a radiological dispersal device situation, in particular, the effectiveness of various countermeasures in decreasing long-term radiation exposures and doses of persons living or working in the test area.

This scenario is based on a hypothetical event in a hypothetical city and is intended to represent the long-term consequences of a radiological dispersal device situation. The scenario was designed to allow modelling with and without the effects of various remediation efforts on the changes over time of the radiological situation. The primary input information for the modelling exercise is the reference surface contamination at six selected buildings. Concentrations of ^{137}Cs in air as a function of height at the building locations are also provided. A contour plot of the ground deposition and a plot of the plume centreline deposition are also included. A selected set of endpoints was used for model intercomparison.

For purposes of this scenario, the decision was made to select a section of an existing city that would provide a representative set of features, rather than to design a model city that was entirely hypothetical. In addition to providing a realistic geographical layout, this approach also permitted the collection of an internally consistent set of meteorological data and other physical data that correspond to that city. However, the Working Group did not attempt to develop complete site-specific information about the test site. In particular, building sizes, heights, and areas were approximated in many or most cases, and building uses and occupancy factors assumed for this scenario do not necessarily correspond to the real situation. Nothing in this scenario or report should be taken to mean that this city or any feature of this test site is considered to be a possible target for destructive activity. Rather, it has been selected simply to provide modellers with useful practice in modelling the long-term effects of a situation that we all hope never occurs.

The test site (Figure 4.1) was selected to provide a representative section of a major city; it includes large buildings (in terms of ground surface area covered, building height, or both), residential areas, a major highway, other roads, car parking areas, grassy park areas, and trees.

An open area (the fountain in the park in the centre of the picture; Figures 4.1 and 4.2) was selected as the origin of the event. An explosive event too close to major buildings would not be expected to disperse widely, due to the effects of the buildings; therefore, in the interest of a more useful situation for modelling purposes, the origin of the event was placed in an open area, so that there would be dispersion past the nearest buildings. Again in the interest of a useful modelling situation, most of the receptor locations were placed in the primary downwind direction, within a 2 km radius, so as to be in an area where the assumed contamination would clearly justify consideration of remedial measures. Appendix II contains complete information about the city, selected buildings, population, traffic, land use, tree cover, occupancy factors, and area meteorology.

Fig. 4.1. Aerial photograph of the centre of the test area. The hypothetical event is assumed to originate at the fountain in the park area in the centre of the photograph.

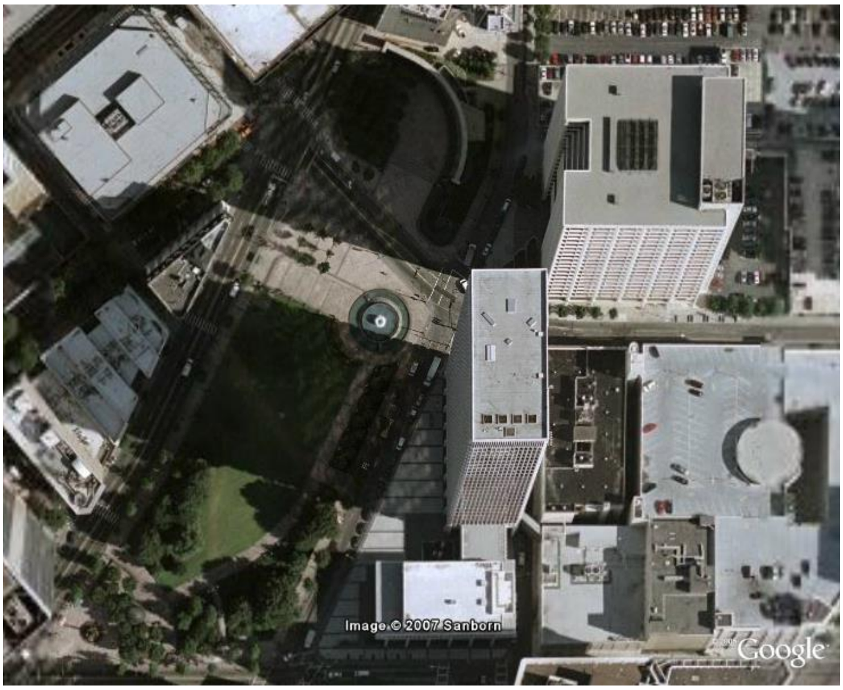

Fig. 4.2. Close-up photograph of the park shown in Figure 4.1.

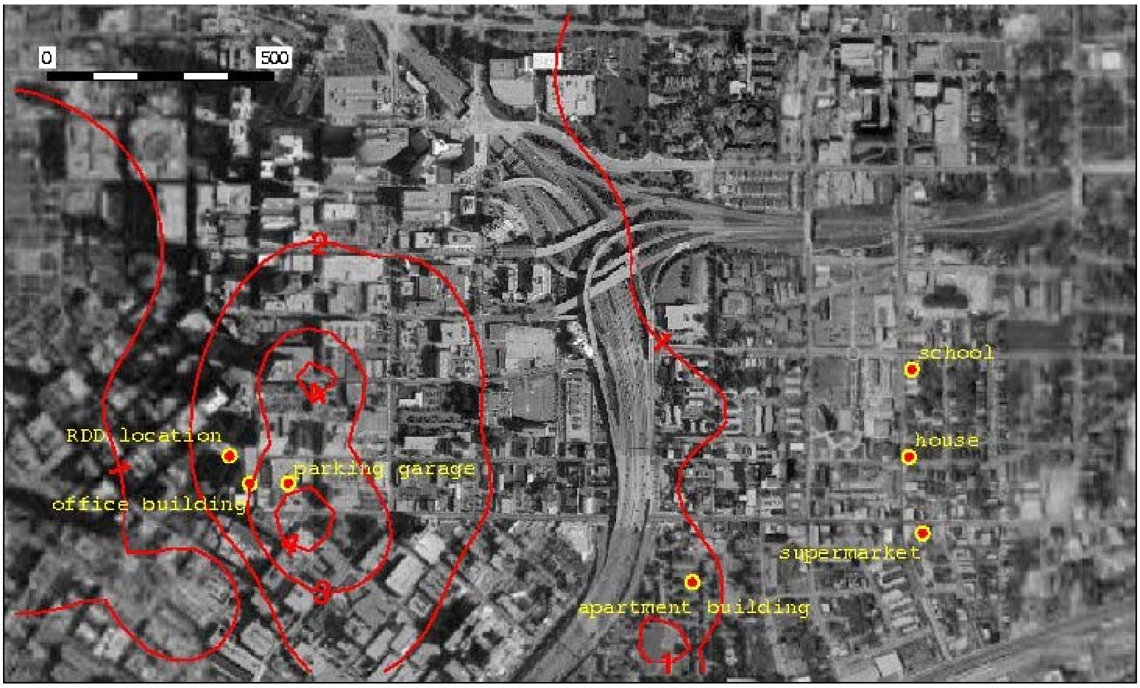

Fig. 4.3. Reference surface contamination with contour levels at 1, 2, 3 and 4 MBq m^{-2}. The buildings corresponding to the test locations are indicated.

For this scenario, we assumed a scenario similar to that suggested by Sohier and Hardeman [63]: a 5 kg conventional explosion of a radiological dispersal device containing 50 TBq of ^{137}Cs in powder form. The event was assumed to happen on 1 July of year 0. The weather at the time of the event was assumed to be dry, with a wind speed of 5 m s^{-1} in the prevailing direction (from west to east). Release height was assumed to be ground level. Deposition velocities were assumed to be 0.3 cm s^{-1} for the respirable fraction and 8 cm s^{-1} for the non-respirable fraction. The respirable fraction was assumed to be 0.5, and the airborne fraction (aerosolization fraction) was assumed to be 0.3. The hypothetical release was located in a park area surrounded by buildings.

Based on these assumptions, a simulation of the explosion event was carried out with the Hotspot code (described in Appendix II). Using the Hotspot results to represent the "true" contamination, further simulation with the IAMM code (also described in Appendix II) was carried out to generate realistic values for the "measured" surface contamination at selected building locations (Figure 4.3).

For a set of test locations (Figure 4.3) and countermeasures, participants were asked to calculate the dose rates and radionuclide concentrations, first without any countermeasures and then with the individual countermeasures. For dose calculations, participants were asked to predict the annual doses to specified reference individuals without countermeasures and then with the indicated countermeasure. All endpoints were used for model intercomparison.

The modelling endpoints for this scenario were as follows:

(1) External exposure rates (dose rates, mGy h^{-1}) at specified locations, from all relevant surfaces (by surface and total);

(2) Contributions to the dose rates (%) from each surface, for the most important surfaces;
(3) Annual and cumulative external doses (mGy) for specified reference (hypothetical) exposure scenarios; and
(4) Radionuclide surface concentrations (Bq m^{-2}) at each location (outdoors).

Model calculations were to start following the initial deposition from the radiological dispersal device event and be carried forward for 20 years. Results were to be presented as a time series. Where possible, uncertainties on the predictions were to be included.

For dose calculations, participants were asked to use the following (hypothetical) exposure scenarios:

(1) Occupational exposure (adult), Building 1, floor 1 (40 h wk^{-1}, residential and other exposures not included);
(2) Occupational exposure (adult), Building 1, floor 5 (40 h wk^{-1}, residential and other exposures not included);
(3) Residential exposure (adult, e.g., pensioner or housewife), Building 5, floor 1 (120 h wk^{-1} indoors and 15 h wk^{-1} outdoors, other exposures not included);
(4) School exposure (child), Building 3, floor 1 (35 h wk^{-1} indoors); and
(5) Occasional exposure (adult), Building 4 (store), floor 1 (1 h wk^{-1} indoors).

For reference children (school scenario), predictions of annual dose were requested; for reference adults (all other scenarios), annual and cumulative doses were requested.

Information about the six buildings at the test locations is given in Appendix II and the accompanying files. For each building, participants were asked to calculate the endpoints both inside (on specified floors) and outside the building (outside at ground level; near the entrance if that is known, otherwise the west side).

4.2. "No Action" scenario

For this phase, the purpose was to model the changes over time of external exposure rates and radionuclide concentrations due to natural processes and human activity, but without remedial measures. Participants were asked to calculate the external exposure rates (mGy h^{-1}) and radionuclide concentrations (Bq m^{-2}) at the specified locations.

4.3. Remediation actions

For this phase, the purpose was to model the changes over time of external exposure rates and radionuclide concentrations due to natural processes, human activity, and specified remedial measures. For this phase, participants were asked to calculate the external exposure rates (mGy h^{-1}) and radionuclide concentrations (Bq m^{-2}) at the specified locations. Participants were also asked to calculate the doses to the specified reference individuals.

The remedial measures (countermeasures, remediation measures) to be considered are listed in Table 4.1, together with the time of application to be assumed.

Table 4.1. List of countermeasures and the corresponding time of application for use in the modelling exercise.

Number	Countermeasure	Time of application (after the accident)
1	No remediation	–
2	Cutting and removal of grass	Day 7
3	Washing of roads	Day 14 (no rain)
4	Washing of roofs and walls	Day 14 (no rain)
5	Removal of trees (or leaves)	Day 30
6	Removal of soil (5 cm)	Day 180
7	Vacuuming indoors	Day 14
8	Washing indoor surfaces	Day 14
9(a)	Relocation of population (temporary):	For the first 2 weeks
9(b)		For the first 6 weeks
9(c)		For the first 6 months

4.4. Results of model intercomparison exercise

This section describes actual results of modelling runs carried out with three different models: METRO-K, CPHR and RESRAD-RDD. These models were originally created for different purposes, use different assumptions, simplifications and underlying datasets, and are in different ways and degrees adapted for description of scenarios involving radiological dispersal devices. Also, model scenarios essentially leave the interpretation of a rather wide range of factors to the judgment of the modeller. In this section an effort is made to explain possible reasons for discrepancies between the modelling results. The participating models are briefly described in Section 2.3, and detailed information is given for each model in Appendix III. The results shown in this section are the most recently submitted for each model (Summer 2007). A full set of information on the model predictions is provided in Appendix IV, including examples of major revisions between the results shown here and earlier submissions.

4.4.1. Outdoor locations

4.4.1.1. Predicted contamination densities

Predicted contamination densities at outdoor locations near six different buildings in the area (the test locations) are shown, both as submitted (Bq m^{-2}; Figure 4.4) and normalized for initial predictions (Figure 4.5). Also shown for reference is the change in contamination density due only to radioactive decay (Figure 4.5). As can be seen, there are considerable differences between the model results for any given location.

Looking at the results for the first building, it is clear that the starting points at time zero are less than an order of magnitude apart. This would be expected since the initial contamination levels on reference surfaces were given in the scenario description. It is not clear from the aerial photos (Appendix II) if the surfaces around this building are to be considered as grassed/soil reference surfaces or paved areas, and already at this stage, this difference is important. For the RESRAD-RDD model it is assumed that paved areas receive about the same level of initial contamination as the grassed/soil surfaces. This assumption seems to be valid also for the CPHR model, which gives a similar initial value. METRO-K assumes a deposition velocity to paved areas that is almost an order of magnitude less than that to the reference surface. A grassed surface might be expected to be significantly rougher than a paved surface, and particles might thus deposit with a higher deposition velocity on the former than on the latter. However, the significance of this would depend on the length of the grass and the texture of the paving, as well as on the particle size.

Particle sizes assumed to result from the radiological dispersal device incident are not given explicitly in the scenario description, although the rather high overall deposition velocities and significant fractions of both respirable (< ca. 10 microns) and non-respirable (> ca. 10 microns) aerosols on reference surfaces seem to suggest that the cesium contamination has not undergone phase transition during the blast. Even the smallest of the aerosolised particles may on this basis be expected to be supermicroneous, and deposition thus dominated by gravitational settling/impaction rather than Brownian movements (which was a dominant deposition mechanism for the small Chernobyl radiocesium condensation particles). The relative deposition pattern observed for Chernobyl radiocesium on the different types of surface in an inhabited area may therefore not apply in this case. The assumptions used in this scenario are expected to give a conservative estimate of the deposition resulting from the radiological dispersal device event.

The results of the CPHR model for the first two locations show a steady increase in the contamination level over the following six years. This is consistent with the CPHR predictions for the Pripyat scenario (Section 3.4). Weathering and migration parameter values applied in the CPHR model are given in Appendix III. The CPHR curves for Buildings 3–6 increase rapidly over a very short time period, by more than three orders of magnitude. This model considers dynamic effects of transport between zones of different contamination, and also within zones, that are not considered significant by the other modellers. Based on data from Allott et al. [53] on transport of contamination between outdoor and indoor surfaces, the CPHR model assumes that, at the longer distances from the origin of the radiological dispersal device event, there is transport of contamination between zones of different contamination levels, which produces secondary contributions to contamination at distant locations over the first year. For areas outside Buildings 1–4, the slow decline in contamination level seems to indicate that in the longer term, practically only the physical half-life of the contaminant (30 y) influences the contamination level on some of the horizontal surfaces. With this model, the open areas around Building 1 appear to act as a total sink for the deposited contamination (reasonably neglecting any possible redistributing influence of resuspension, which is not considered by CPHR). This is similar for all the first four outdoor locations, but for the areas near the houses (Buildings 5 and 6), the decline in contamination level assumed by the CPHR modeller is much steeper.

4.4.1.2. Predicted dose rates

Predicted dose rates at the six outdoor locations are shown as predicted (μGy h^{-1}; Figure 4.6) and normalized for initial predictions (Figure 4.7). As expected, the time-variation of these dose rates seems to follow that of the contaminant concentrations, as shown in Figures 4.4 and 4.5.

4.4.1.3. Predicted contributions from surfaces

Much of the explanation for the results shown for contamination densities and dose rates is found by examination of the relative importance of various surfaces for each set of predicted dose rates (Figure 4.8). For example, the initial steep decline in dose rate at Building 2 for METRO-K (Figure 4.6) is attributable to the large contribution to dose rate from trees during the first year but not subsequent years. The two locations with the steepest overall decline in dose rate in the METRO-K predictions, Buildings 2 and 4, have the major contributions over time from pavement and outer walls (Figure 4.8); the other locations, for which the main contribution to dose rate comes from soil (Figure 4.8), show a similar gradual decline in dose rate over time (Figure 4.6). RESRAD-RDD similarly shows a steep decline in dose rate at the location (Building 2; Figure 4.6) where the only contributor to dose rate is paved surfaces (Figure 4.8), but much slower declines in dose rate for the other locations (Figure 4.6), where the major contribution to dose rate comes from soil (Figure 4.8).

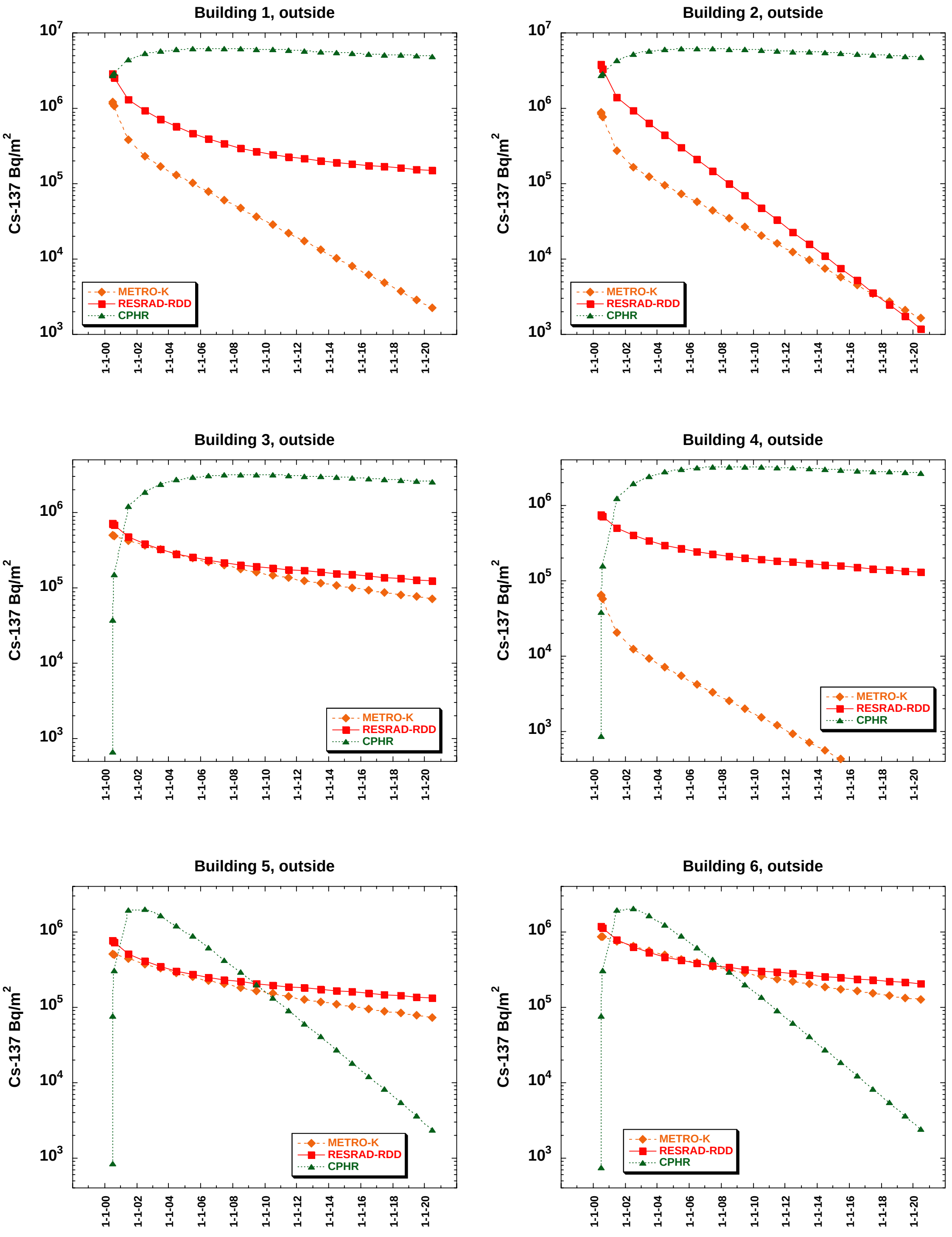

Fig. 4.4. Predicted contamination density (Bq m^{-2}) at outdoor locations.

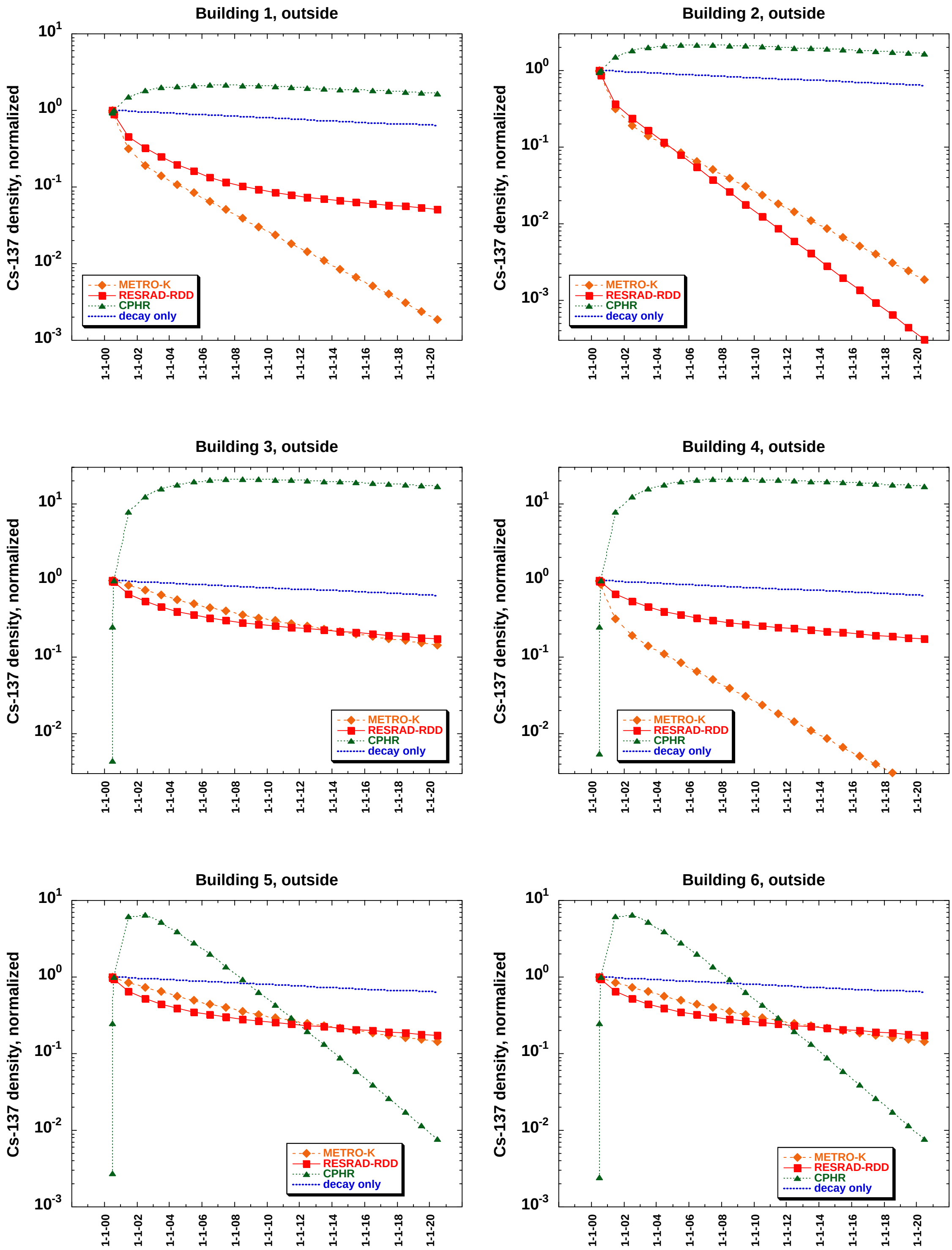

Fig. 4.5. Predicted contamination densities at outdoor locations, normalized for initial value (METRO-K, RESRAD-RDD) or value at one month (CPHR). The expected change in contamination density due only to radioactive decay of ^{137}Cs is also shown.

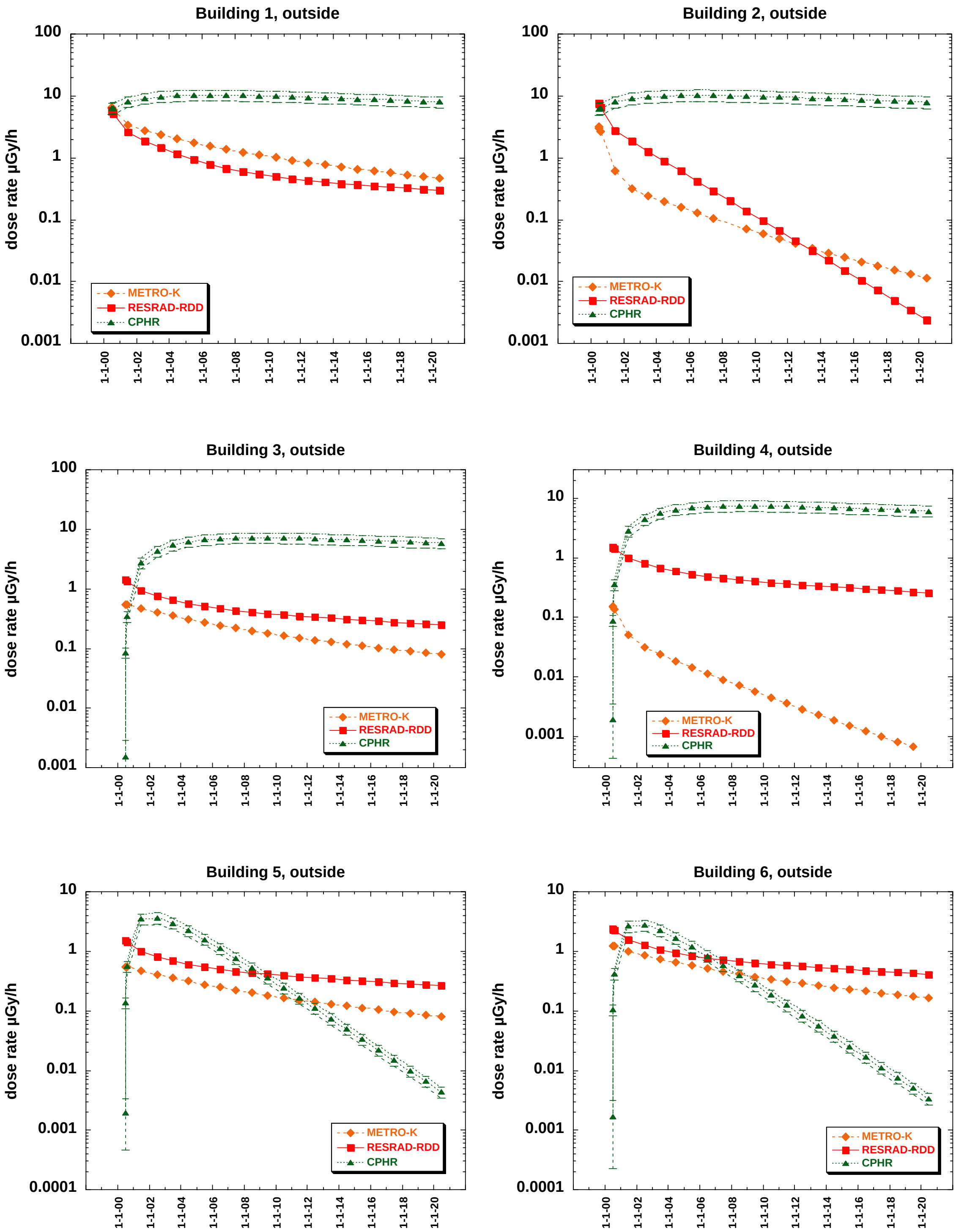

Fig. 4.6. Predicted dose rates (µGy h^{-1}) at outdoor locations.

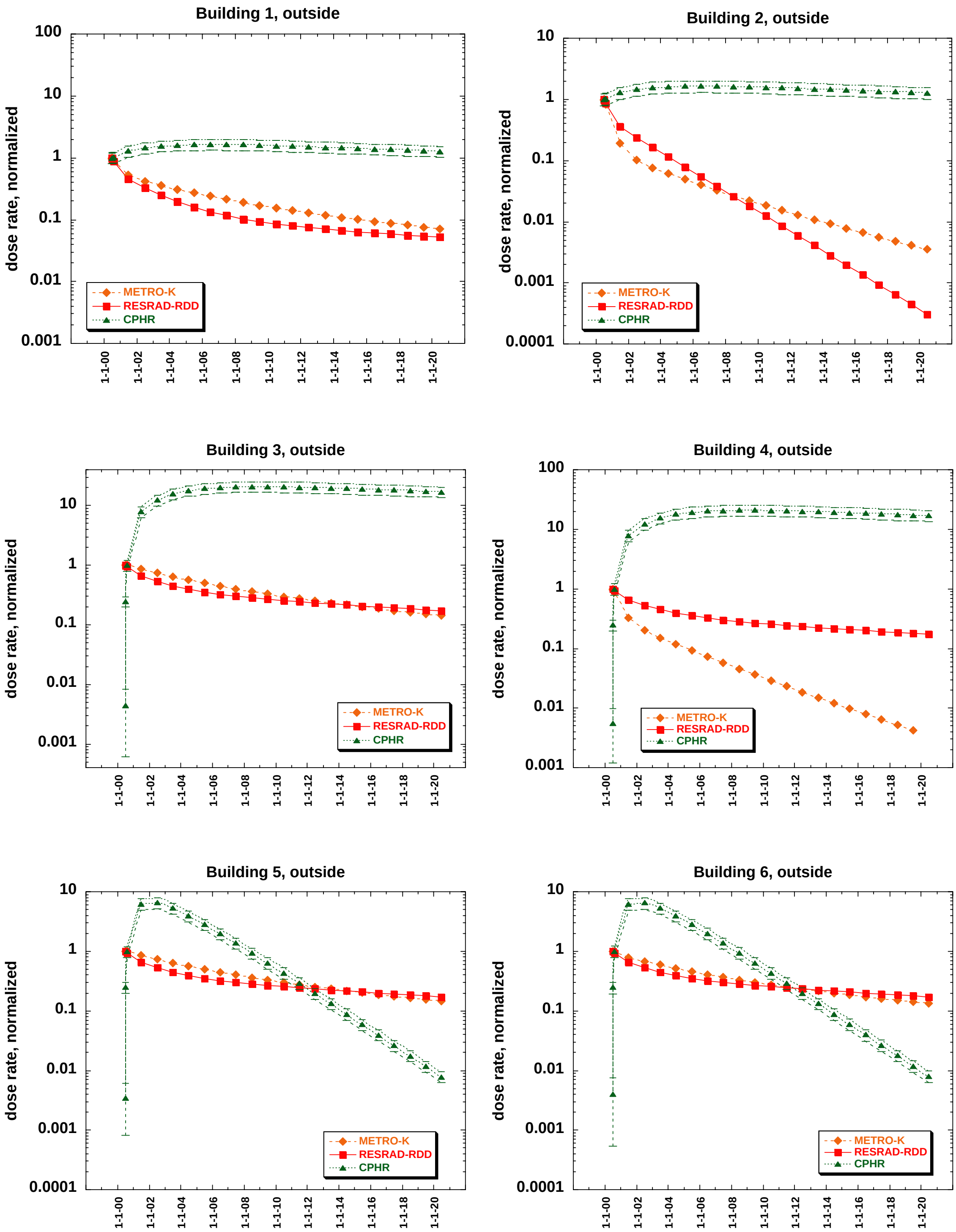

Fig. 4.7. Predicted dose rates (μGy h^{-1}) at outdoor locations, normalized for the initial value (value at 1 month for CPHR, Buildings 3–6).

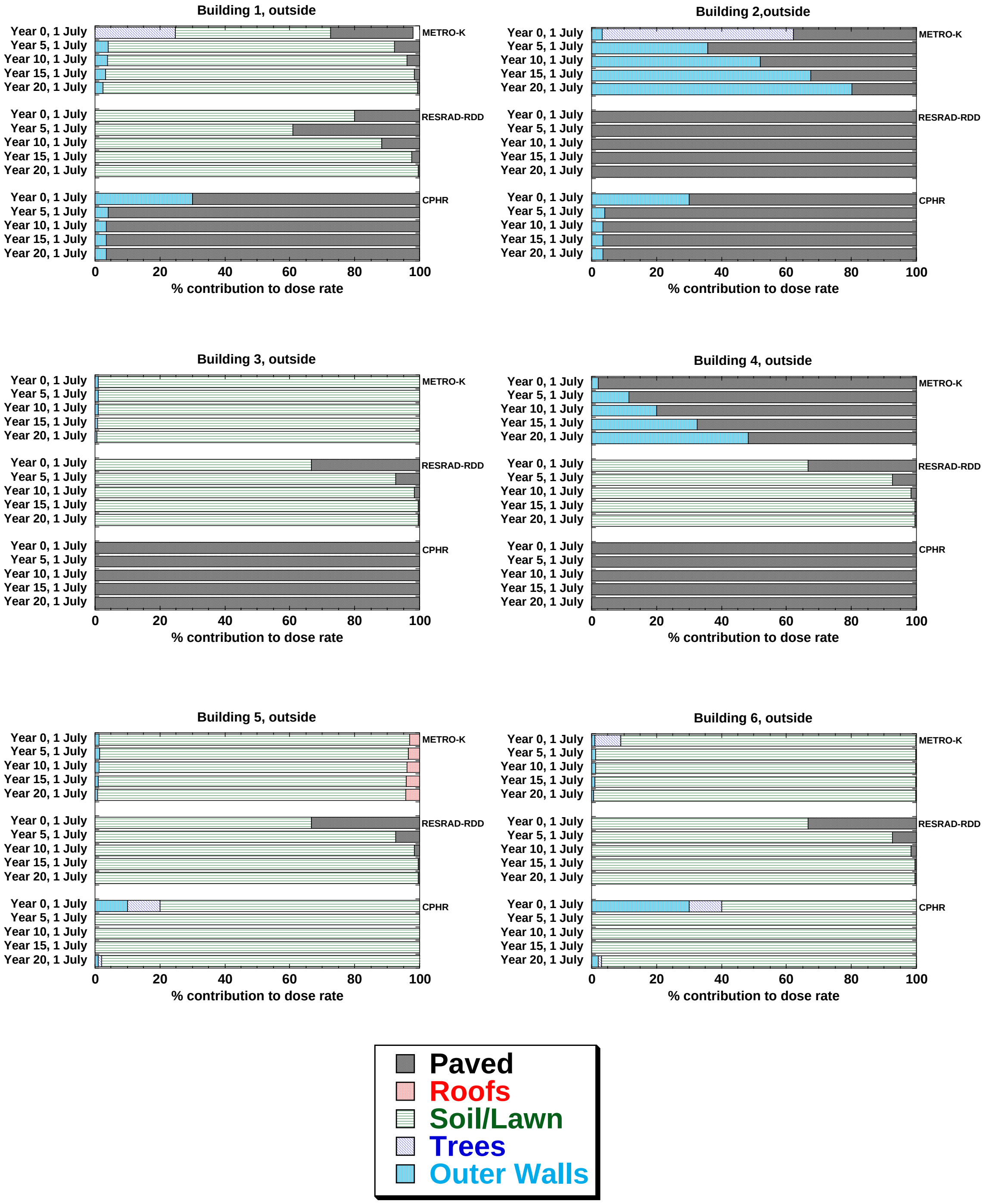

Fig. 4.8. Predicted contributions to dose rates (%) from different surfaces, for outdoor locations.

The results of the CPHR model show an opposite effect, where the steepest declines in dose rates (Buildings 5 and 6; Figure 4.6) are associated with a primary contribution from soil surfaces (Figure 4.8), and the slowest declines in dose rate (Buildings 1–4; Figure 4.6) are associated with a primary (or the only) contribution coming from paved surfaces (Figure 4.8). This effect was also seen in the Pripyat scenario (see Section 3.4), and is explained by the CPHR model tending toward pavement, rather than soil, as a sink for contamination over a long time period. From the model description it seems that CPHR assumes that 30% of the contamination on a paved surface is permanently fixed, whereas 50% of the contamination on a paved surface is weathered away with a slow half-life of 18.9 y. Since contamination also seems to be transferred to pavement from, e.g., soil, the pavement becomes increasingly important with time, with these assumptions. However, measurements made in different areas of the radiocesium contamination after the Chernobyl accident indicate that the weathering process on paved surfaces is much faster, and if large, insoluble particles are implied, it would be even faster.

4.4.2. Indoor locations

4.4.2.1. Predicted dose rates

Figure 4.9 shows comparisons of predicted dose rates at indoor locations and the top of Building 2. For Building 1, all the models show a similar slow decline in dose rate over time. CPHR and RESRAD-RDD show similar magnitudes of the dose rate at higher floors in the building; however, METRO-K shows a decrease up to several orders of magnitude between the first floor and the 60^{th} floor. For Building 2 (inside, floor 1), METRO-K predicts a somewhat steeper initial decline in dose rate than is seen for other models or locations. For Buildings 3–5, but not 6, CPHR predictions show an initial increase in dose rate, similar to the predictions for the outdoor locations.

Neither CPHR nor METRO-K considered indoor contamination. It would therefore be expected that METRO-K calculations, in particular, might underestimate the actual doses somewhat. However, if the aerosols were not submicroneous, indoor air concentrations would normally be quite low compared with outdoor air concentrations, and indoor contamination perhaps not the greatest contributor to dose rate, depending on the nature and orientation of outdoor surfaces that could contribute to dose rate, as well as on whether major ventilation ducts in buildings were closed during the passage of the plume. As would be expected, the differences in dose rate functions seem to be rather strongly dependent on the overall differences in retention functions, as observed for the outdoor locations.

The top of Building 2 is an open, flat surface used as the top floor of a parking garage. The predictions from CPHR and RESRAD-RDD are very close, with the predicted dose rate over time from METRO-K starting somewhat lower and declining much more steeply.

4.4.2.2. Predicted contributions from surfaces

As for the outdoor locations, much of the explanation for the predicted dose rate curves for indoor locations and the top of Building 2 is found in the predicted contributions to dose rate from various surfaces (Figure 4.10). Here it is very clear that these models, which were developed for different purposes and are only adaptable to the scenario within certain limits, have differences in their fundamental structure, which may lead to considerable differences in predictions. To an extent, for the lower floors, the major contributing surfaces are similar to those for the outdoor locations. For example, for CPHR, pavement contributes most to dose rate outside Buildings 1–4, and soil at Buildings 5 and 6; for indoor locations in Buildings 1 (lowest floors), 2, 3, and 4, the pavement is a substantial contributor to dose rate, along with contributions from outer walls (Figure 4.10). Soil continues to contribute to dose rate on the first floors of Buildings 5 and 6, but the roof is an additional, more important contributor to dose rate inside these buildings.

Only RESRAD-RDD considers indoor contamination, but in the tall Building 1, this gives an important contribution to the total dose rate, especially at high elevation, where the angle at which radiation from nearby ground contamination can enter through windows is small. In METRO-K, where trees are modelled and probably assumed to have their canopy at about floor 1 height, rather than floor 5 height, these can be major dose rate contributors (Figure 4.10, Building 1, floor 1; Building 2, floors 1 and 4; and Building 6, floor 1).

It is not surprising that outer walls contribute significantly to dose rate on the 20th floor of a building (particularly if indoor contamination is not modelled), nor that roofs give a high contribution at the top floor of a tall building. For the top floor of building 1 there are some discrepancies between the models in the relative contributions of roof and walls, but this may be due to different assumptions regarding roof construction or whether the building height exceeded the height of the contaminant plume. Also, METRO-K applies dose conversion factors calculated by Meckbach et al. [4] using the SAM-CE Monte Carlo photon transport code. Buildings corresponding to four different degrees of urbanization are here available, so simplifications and adaptations would be needed to make them applicable to the particular scenario. For instance, the tallest buildings modelled by Meckbach et al. have 5 storeys. RESRAD-RDD uses its own shielding factors, obtained with the RESRAD-BUILD code (see Appendix III). The dose rate conversion factors applied in CPHR are not described.

All three modellers predicted that essentially all of the dose rate on the top of Building 2 comes from the roof (acting as the floor of the parking area; Figure 4.10), although not all of the contributions to dose rate on the top of Building 2 would necessarily come from the contamination on this top floor of the parking garage. Nevertheless, the interpretation of surface types (presumably concrete on the top) to be considered is perhaps here more straightforward than in other places. However, as noted previously, the shape of the dose rate curve differs between METRO-K and the other two models.

4.4.3. Predicted annual and cumulative doses

The next series of modelling results (Figures 4.11–4.17) give predictions of annual and cumulative doses (mGy) for different population group exposures at various locations. Basically, this is a series of diagrams showing location- and time-averaged exposure in different places. Occupancy time varies between the “occupational”, “school”, “occasional”, and “residential” exposures. Differences between staying on different floors are illustrated, especially for Building 1, but the overall differences between results of the three models reflect the differences in the underlying contamination and dose rate functions, as described above. The cumulative doses (mGy) reflect a simple summing of the predicted annual dose rates.

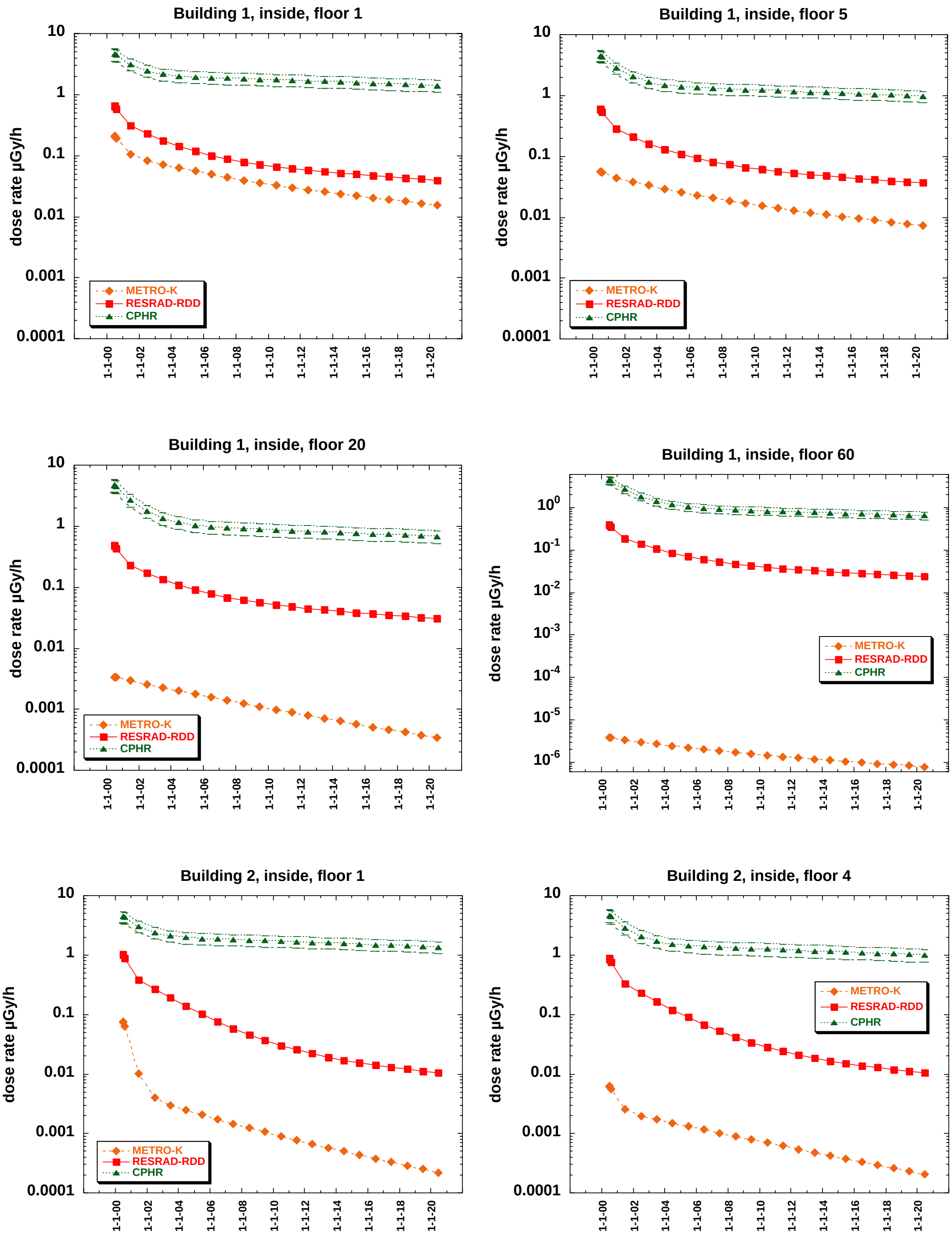

Fig. 4.9. Predicted dose rates (µGy h⁻¹) at indoor locations and the top of Building 2. (Scales are comparable, except for Building 1, Floor 60).

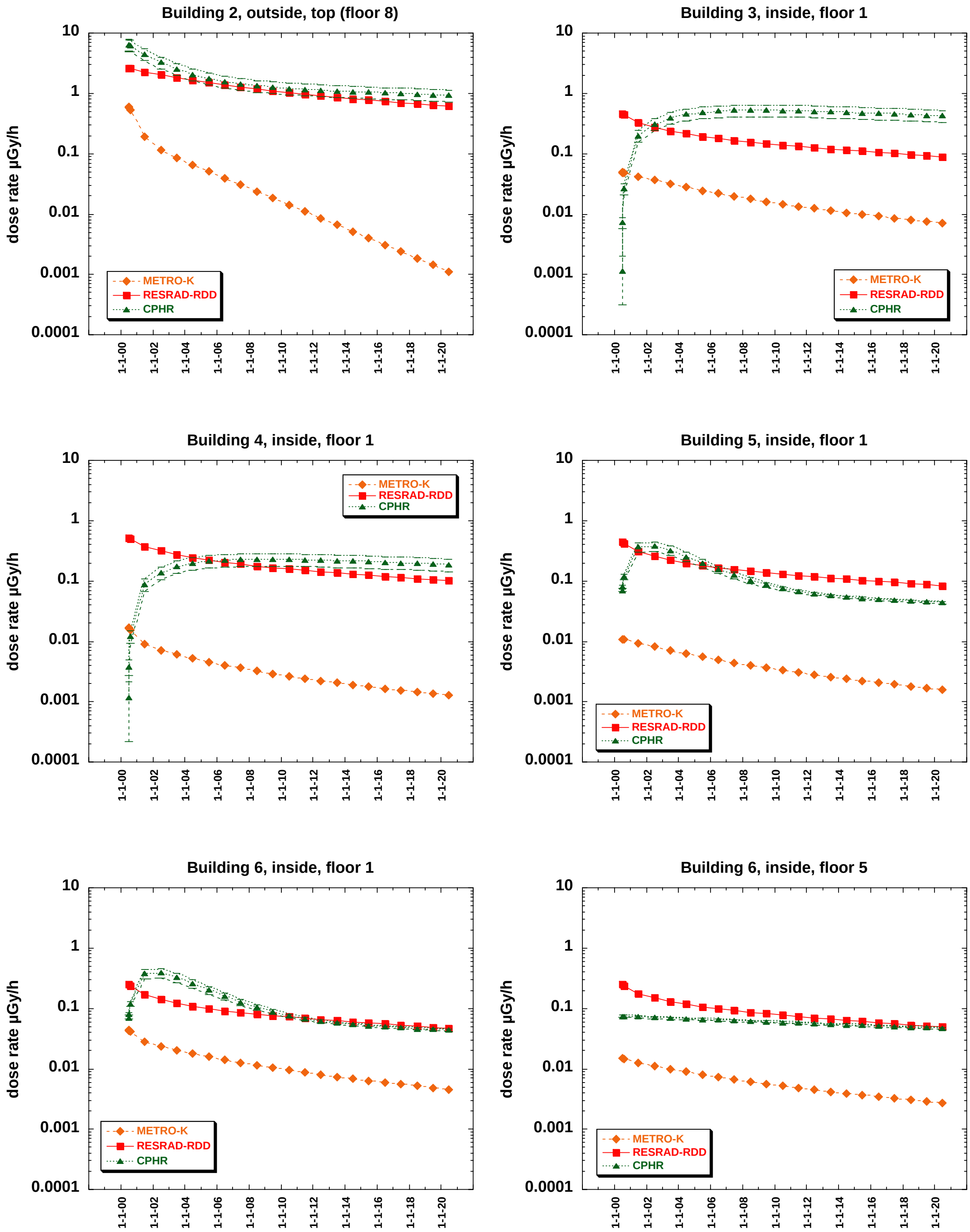

Fig. 4.9. Predicted dose rates (µGy h^-1) at indoor locations and the top of Building 2. (Scales are comparable, except for Building 1, Floor 60) (cont.).

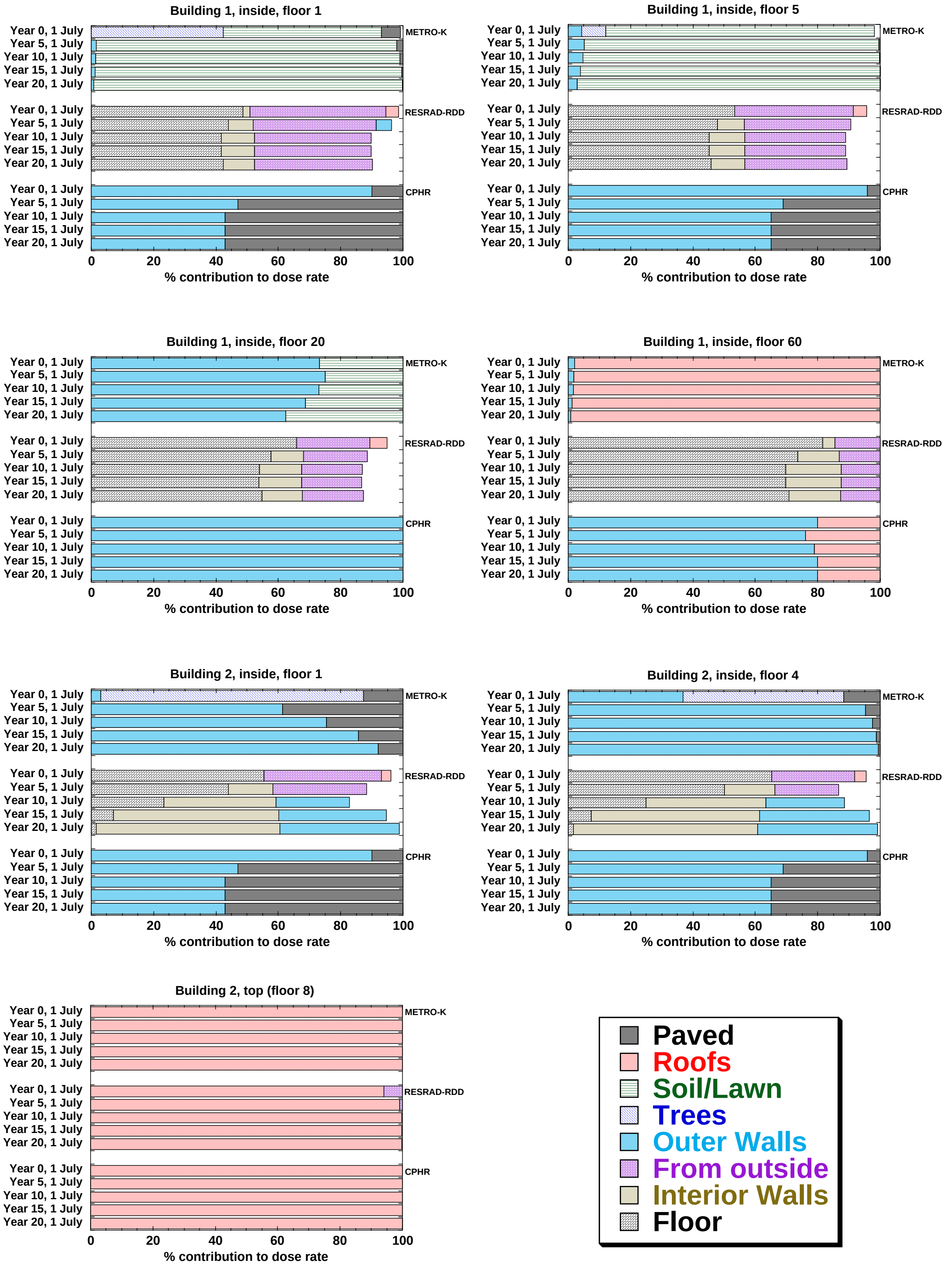

Fig. 4.10. Predicted contributions to dose rates (%) from different surfaces, for indoor locations and top of Building 2.

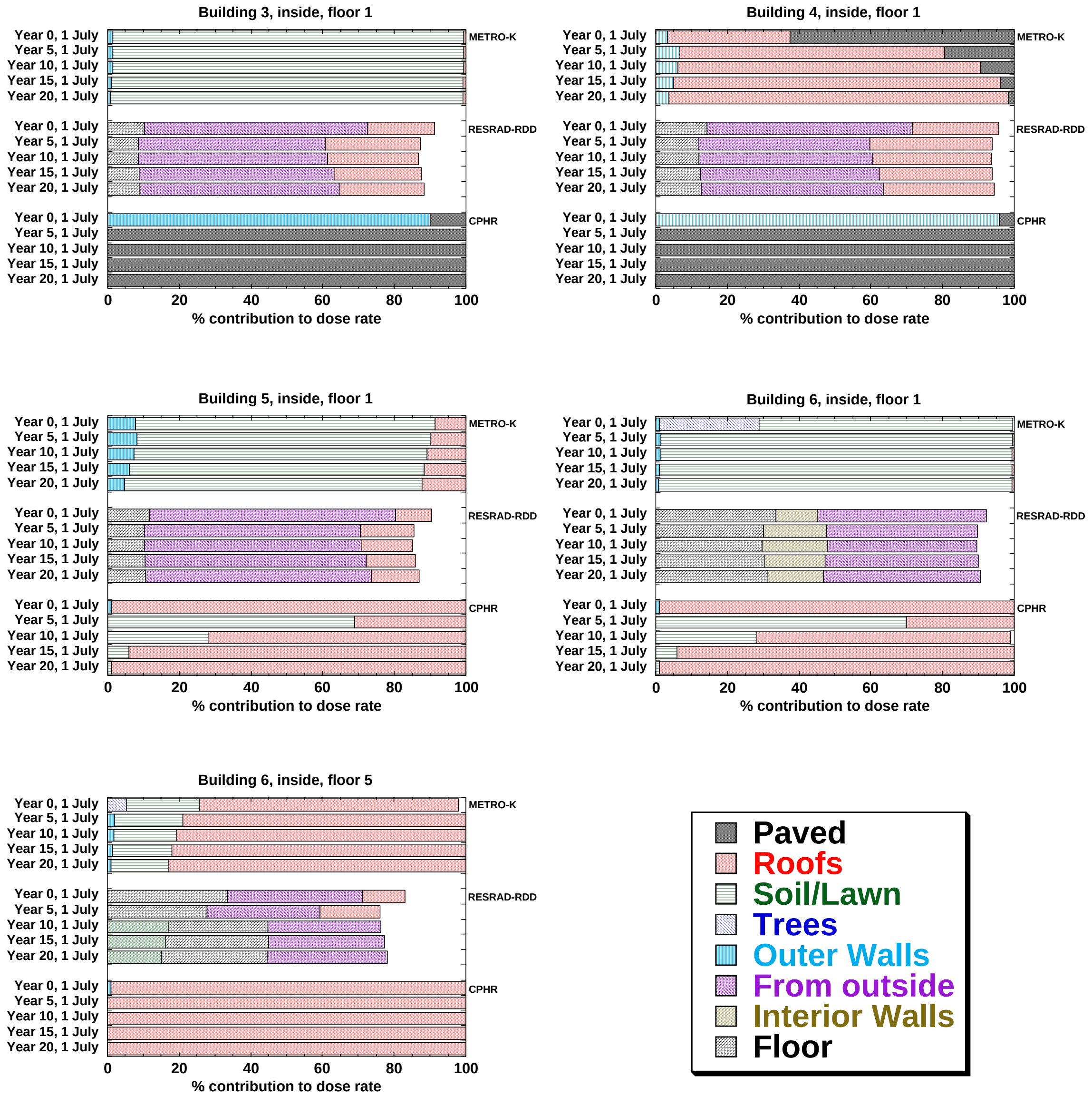

Fig. 4.10. Predicted contributions to dose rates (%) from different surfaces, for indoor locations and top of Building 2 (cont.).

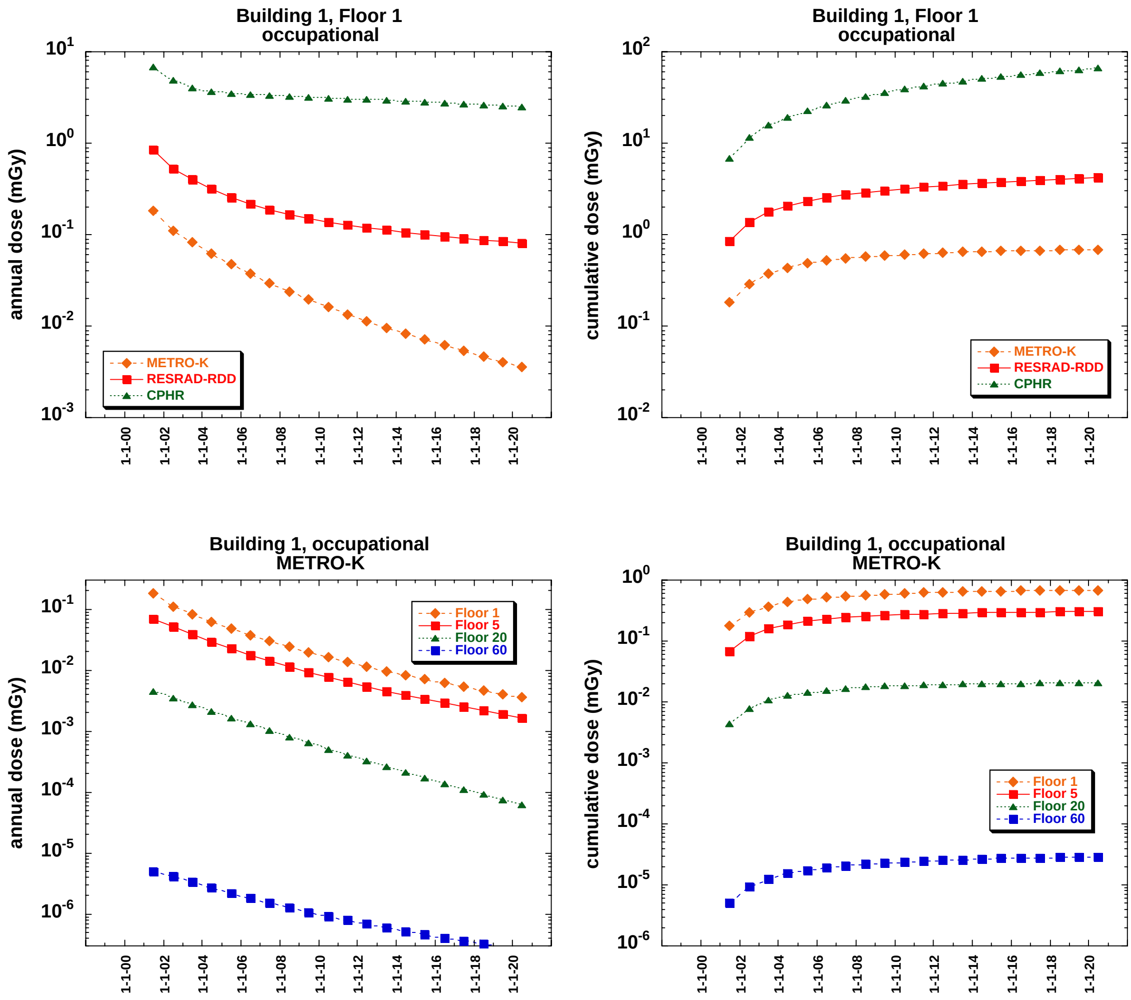

Fig. 4.11. Predicted annual (left) and corresponding cumulative (right) doses (mGy) for occupational exposures at specified locations in Building 1, assuming no countermeasures (no action situation).

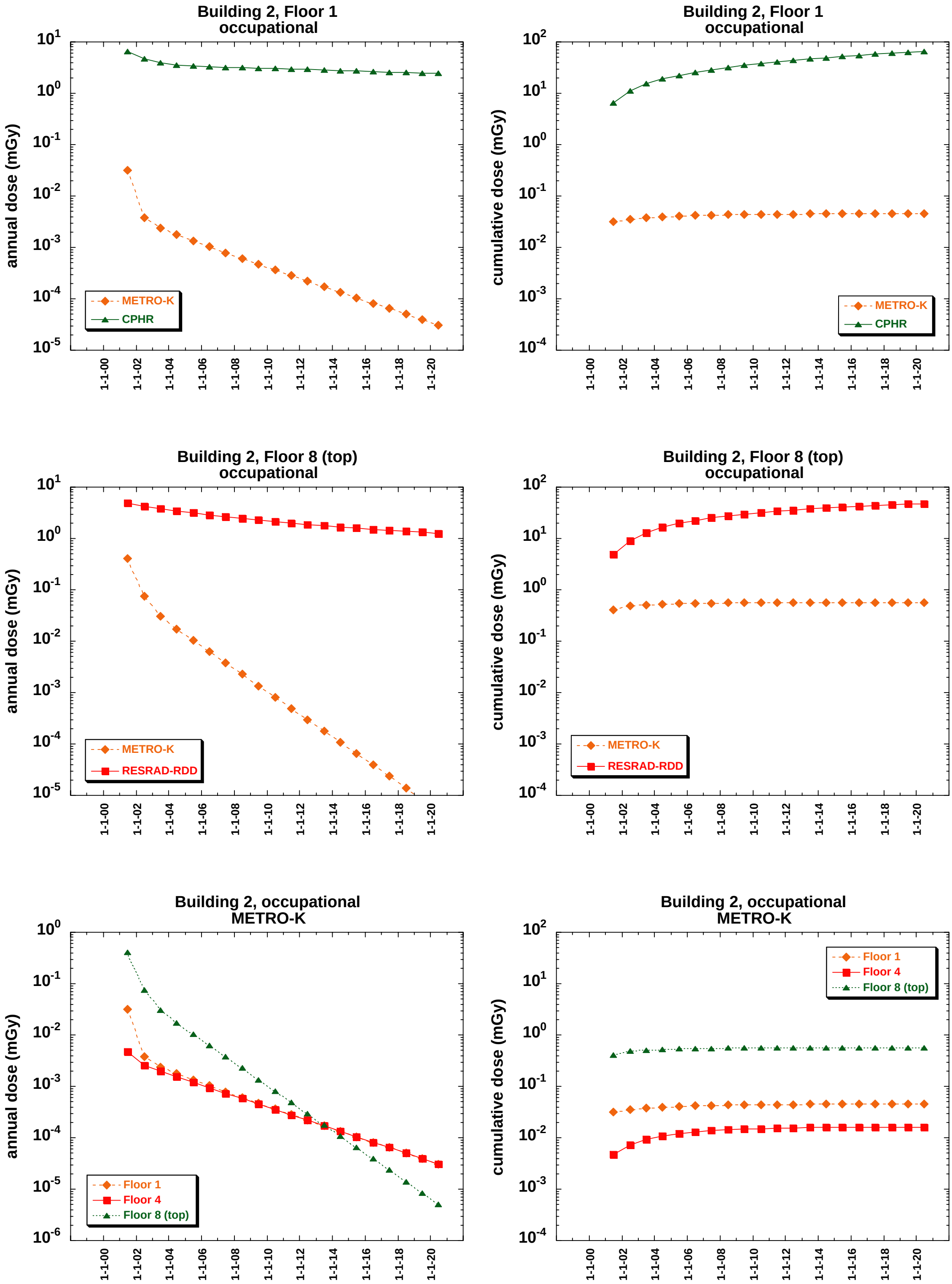

Fig. 4.12. Predicted annual (left) and corresponding cumulative (right) doses (mGy) for occupational exposures at specified locations in Building 2, assuming no countermeasures (no action situation).

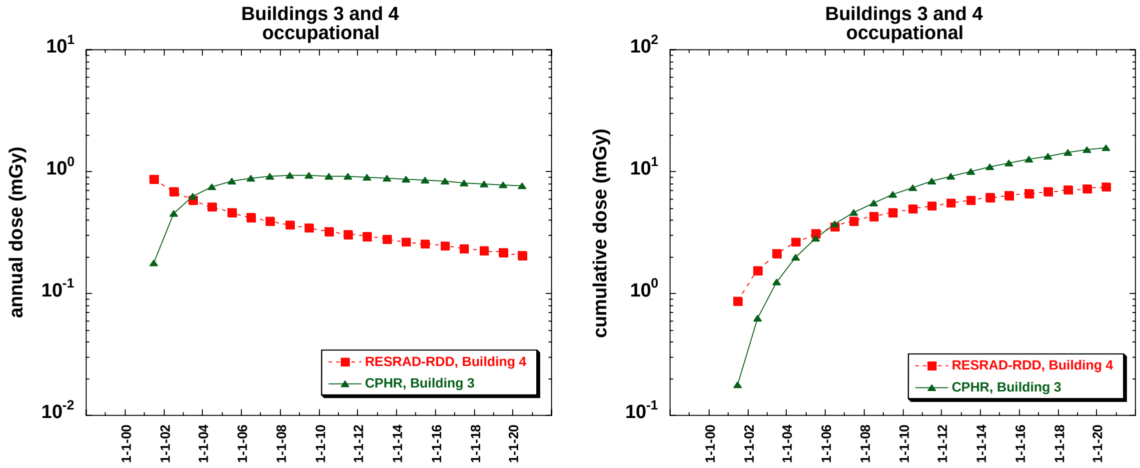

Fig. 4.13. Predicted annual (left) and corresponding cumulative (right) doses (mGy) for occupational exposures in Buildings 3 and 4, assuming no countermeasures (no action situation).

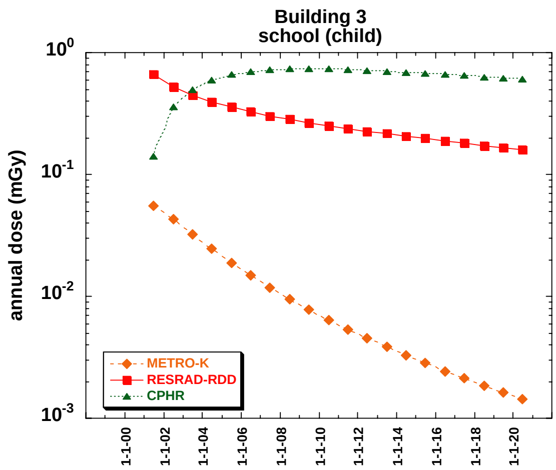

Fig. 4.14. Predicted annual doses (mGy) for a schoolchild's exposure in Building 3, assuming no countermeasures (no action situation).

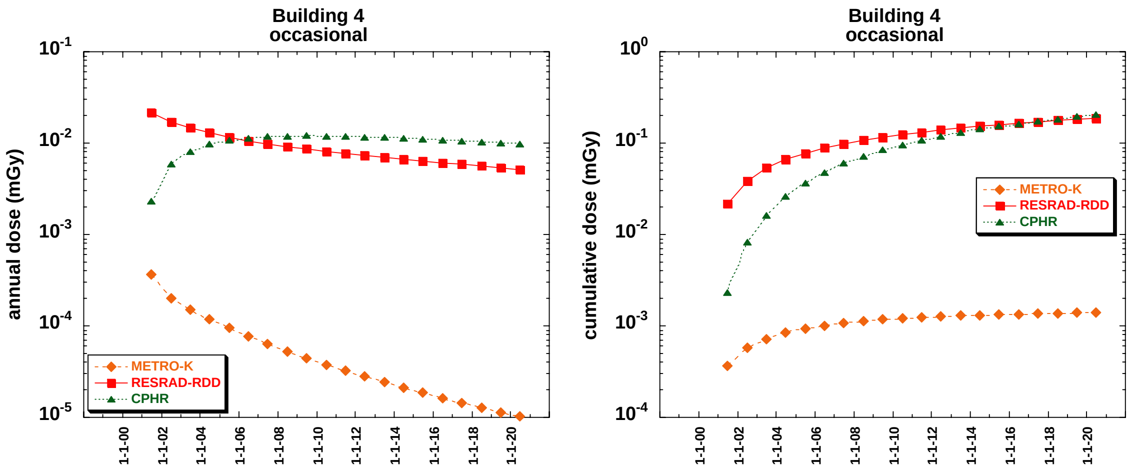

Fig. 4.15. Predicted annual (left) and corresponding cumulative (right) doses (mGy) for occasional exposure in Building 4, assuming no countermeasures (no action situation).

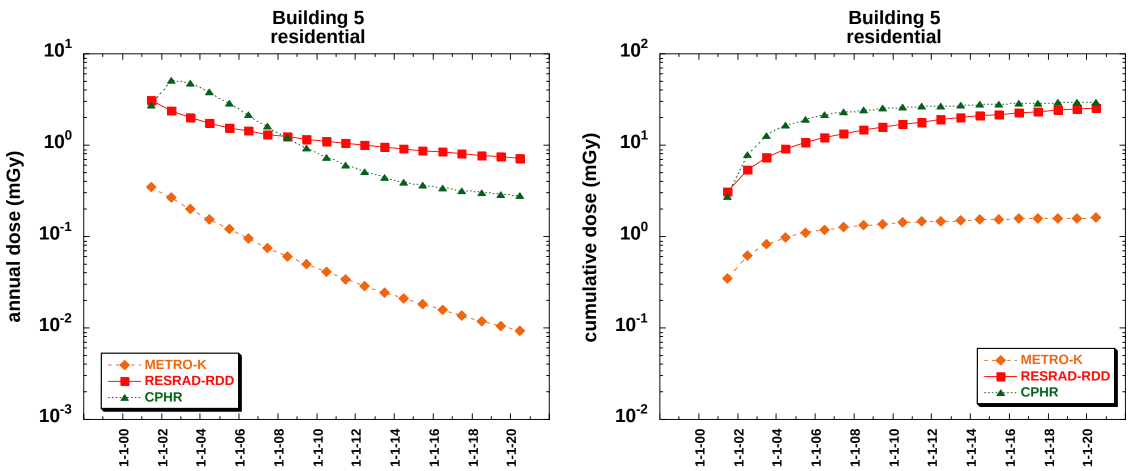

Fig. 4.16. Predicted annual (left) and corresponding cumulative (right) doses (mGy) for residential exposure in Building 5, assuming no countermeasures (no action situation).

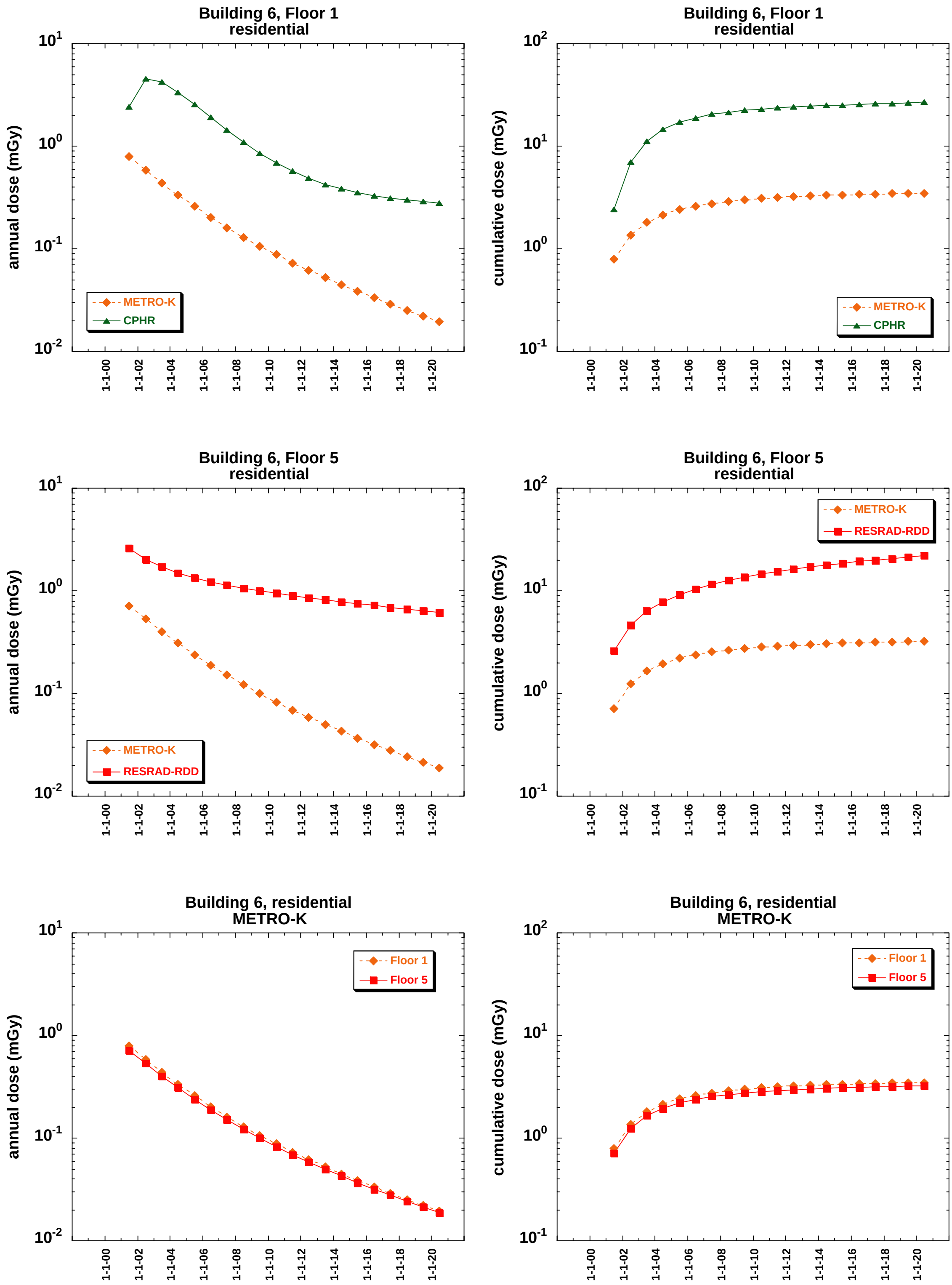

Fig. 4.17. Predicted annual (left) and corresponding cumulative (right) doses (mGy) for residential exposure in Building 6, assuming no countermeasures (no action situation).

4.4.4. Effects of countermeasures

4.4.4.1. Effects of countermeasures on contamination densities

Figure 4.18 shows CPHR model predictions of the contamination densities at each of the six outdoor locations, with no countermeasures and with the effects of each modelled countermeasure. Obviously, it is assumed here that the contamination levels on these surfaces build up dramatically, due to natural transfer from other surfaces, as discussed above (Section 4.4.1.1). Therefore, for instance, washing of roofs and walls is rather effective in reducing the natural transfer of contamination to the considered outdoor surfaces. Removal of contamination entirely (removal of soil or grass) is even more effective. It may be surprising that the effect of countermeasures is overall very modest (Table 2.7). Also the effects of other countermeasures are shown in this figure, as well as the effect of radioactive decay alone.

Figure 4.19 shows the expected effects of countermeasures as modelled with RESRAD-RDD. This suite of diagrams clearly shows that the area outside Building 2 is here assumed to be paved (high effect of washing roads), whereas the other locations appear to be assumed to have high representation of soil or grassed areas (particularly Buildings 3–6). As expected, at these locations, the greatest reduction in contamination density is obtained with removal of soil or grass. Countermeasure efficiencies used in the modelling are given in the model description (summarized in Table 2.7, Section 2.3), and are to a great extent based on experience from trials with Chernobyl radiocesium. These factors may be directly applicable to this scenario, depending on assumptions regarding characteristics such as particle sizes and solubility. Although phase transition (evaporation) may not be significant in connection with this particular radiological dispersal device blast (this would depend on the actual bomb design), cesium salt particles would be expected to be highly soluble, so that the contamination will also in this case rapidly be in cationic form, and retention thereby rapidly similar to that expected from the Chernobyl accident data.

4.4.4.2. Effects of countermeasures on annual and cumulative doses

The following diagrams (Figures 4.20–4.26) show predicted annual doses (mGy) for the first 5 years, with the predicted effects on the annual dose of several different countermeasures. The overall countermeasure dose reduction in each location varies considerably between models, but this is to be expected, since the different models assume great differences in dose-contributing surfaces in these locations, as demonstrated by Figures 4.8 and 4.10. METRO-K and RESRAD-RDD use DRFs based mainly on the suites of countermeasure data templates made after the Chernobyl accident in the European STRATEGY and EURANOS projects. Here, the factors are often given as ranges, explaining which factors may be influential, and in which direction. Much is thus up to interpretation of the data in the templates in relation to the specific scenario, and some variation is also seen in the model descriptions between DRF values used by these two modellers (Table 2.7, Section 2.3). It is unclear where the DRFs applied by the CPHR modeller originate from. Clearly, the effect of countermeasures in this model is assumed to be much more limited. Since countermeasures are, as written in the scenario description, optimized with respect to timing, the small effect assumed in CPHR of methods like grass cutting, which would according to measured data be expected to be highly efficient shortly after a dry deposition, is surprising.

For almost all exposure scenarios, relocation for 6 months gives the largest reduction in annual dose for the first year; the exceptions are some first-floor locations (Buildings 3, 5 and 6), for which METRO-K predicts a larger reduction from removal of grass than from relocation for 6 months. Relocation for 6 months, by definition does not affect the annual doses after the first year. For those years, removal of soil or grass provide the largest reduction in annual dose for RESRAD-RDD and METRO-K for most situations. Removal of trees is significant for the first floor of Building 2 for the METRO-K predictions. For the higher floors of Building 1 and for all floors of Building 2, washing of roofs and walls is an effective countermeasure. For the top of Building 2, where essentially all of the dose rate comes from the roof surface, washing of roofs is obviously the countermeasure of choice and gives a lasting reduction in the annual dose (Figure 4.21). For CPHR, washing of roofs and walls is a more effective countermeasure for several locations than removal of soil or grass, reflecting the model's predicted importance of the contribution of outside walls or roofs to the indoor dose rates (Figure 4.10).

Figures 4.27–4.32 show the corresponding cumulative doses, with the predicted effects of the same sets of countermeasures. These graphs permit the evaluation of the predicted effect of various countermeasures on the long-term cumulative doses for different locations and models. Relocation has the effect of moving the entire curve downward without affecting the shape of the curve. Countermeasures that have a lasting effect in terms of reducing the annual dose for later years also change the shape of the curve (e.g., removal of soil or grass, washing of roofs and walls). Some countermeasures have little or no effect on the predicted cumulative dose, depending on the situation. In general, depending very much on the specific situation, relocation for 6 months, removal of soil, removal of grass, and washing of roofs and walls had the greatest long-term effects on cumulative dose.

The effectiveness of the various countermeasures in terms of the predicted reduction in annual and cumulative doses is summarized for each model in Table 4.2. The ranges given for many countermeasures depend on the reference individuals; for example, cutting and removal of grass gives little or no reduction in dose for an occupational exposure at the top of Building 2, where grass does not contribute significantly to the dose rate. As shown in the table and described above, relocation produces a substantial reduction in the dose over the first time period, but not to annual doses after the initial relocation period. In contrast to the Pripyat scenario, which included short-lived radionuclides, this scenario involves only one long-lived radionuclide; therefore, relocation even for 6 months has only a modest impact on the cumulative dose over 20 years, with the amount depending on the model. Countermeasures involving removal of grass or soil may reduce the annual doses for years to come, as well as reducing the cumulative doses. For a real-life situation, it would be necessary to evaluate the expected impact of a countermeasure on both the short-term and long-term dose, for different individuals and locations. The impact on a given individual will depend on the individual's occupancy at various locations as well as on the effectiveness of the countermeasure in reducing the contamination density or dose rate.

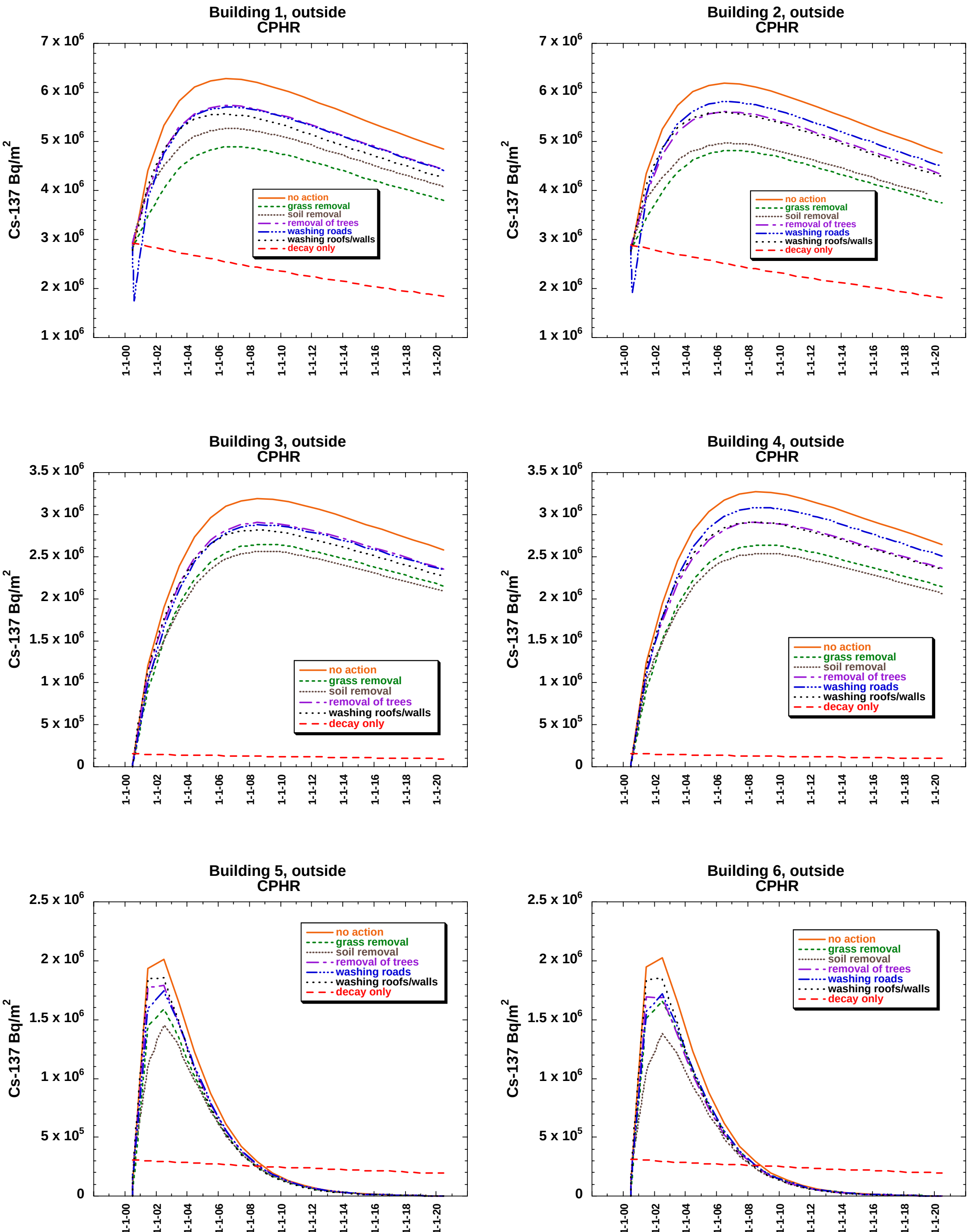

Fig. 4.18. Predicted contamination densities at outdoor locations from CPHR, showing expected effects of countermeasures. The expected change in contamination density due only to radioactive decay of ^{137}Cs is also shown (starting with predicted concentration at 1 month). (Vertical scales are linear and are not necessarily comparable.)

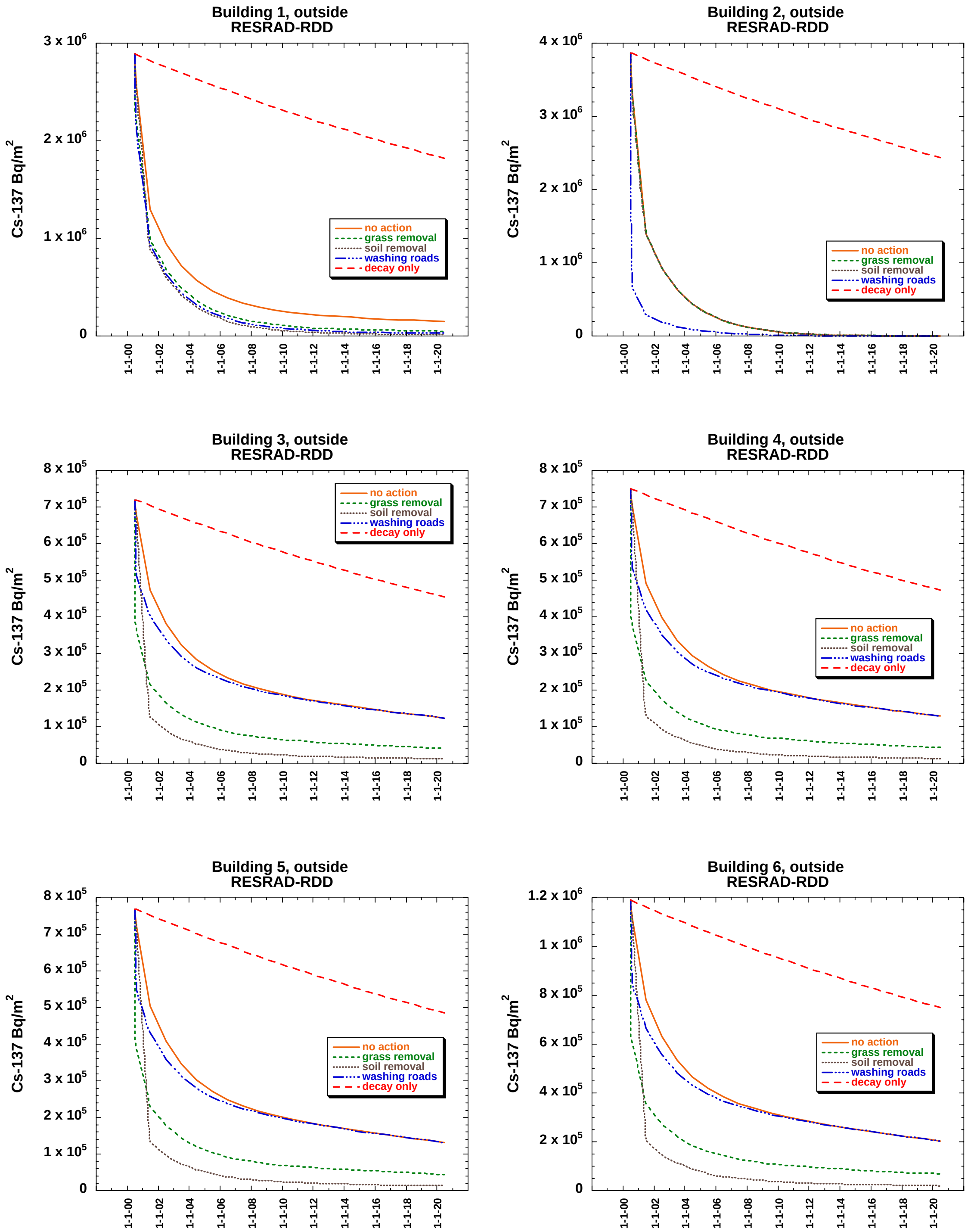

Fig. 4.19. Predicted contamination densities at outdoor locations from RESRAD-RDD, showing expected effects of countermeasures. The expected change in contamination density due only to radioactive decay of ^{137}Cs is also shown. (Vertical scales are linear and are not necessarily comparable.)

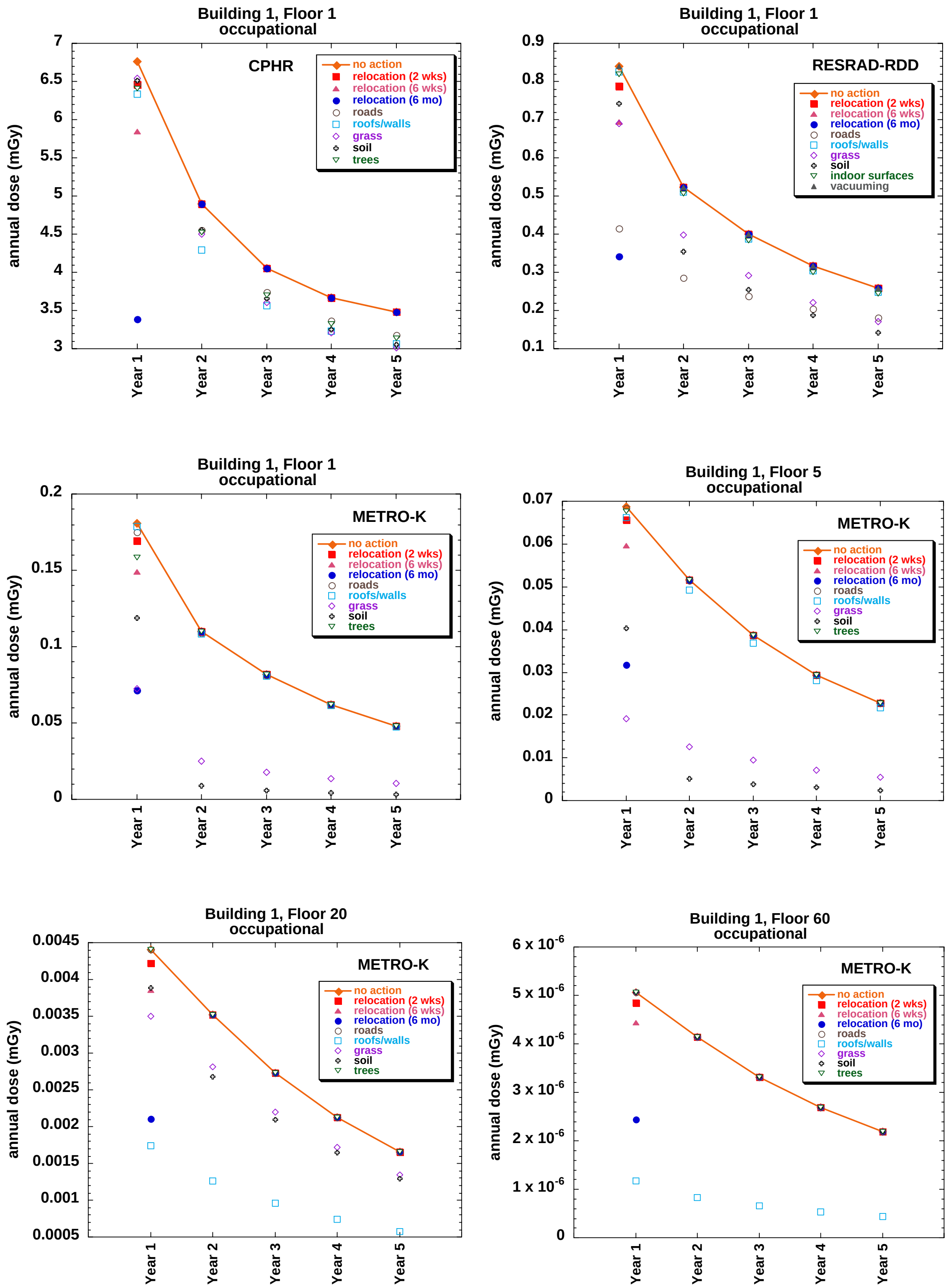

Fig. 4.20. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure in Building 1. (Vertical scales are linear and are different for each graph.)

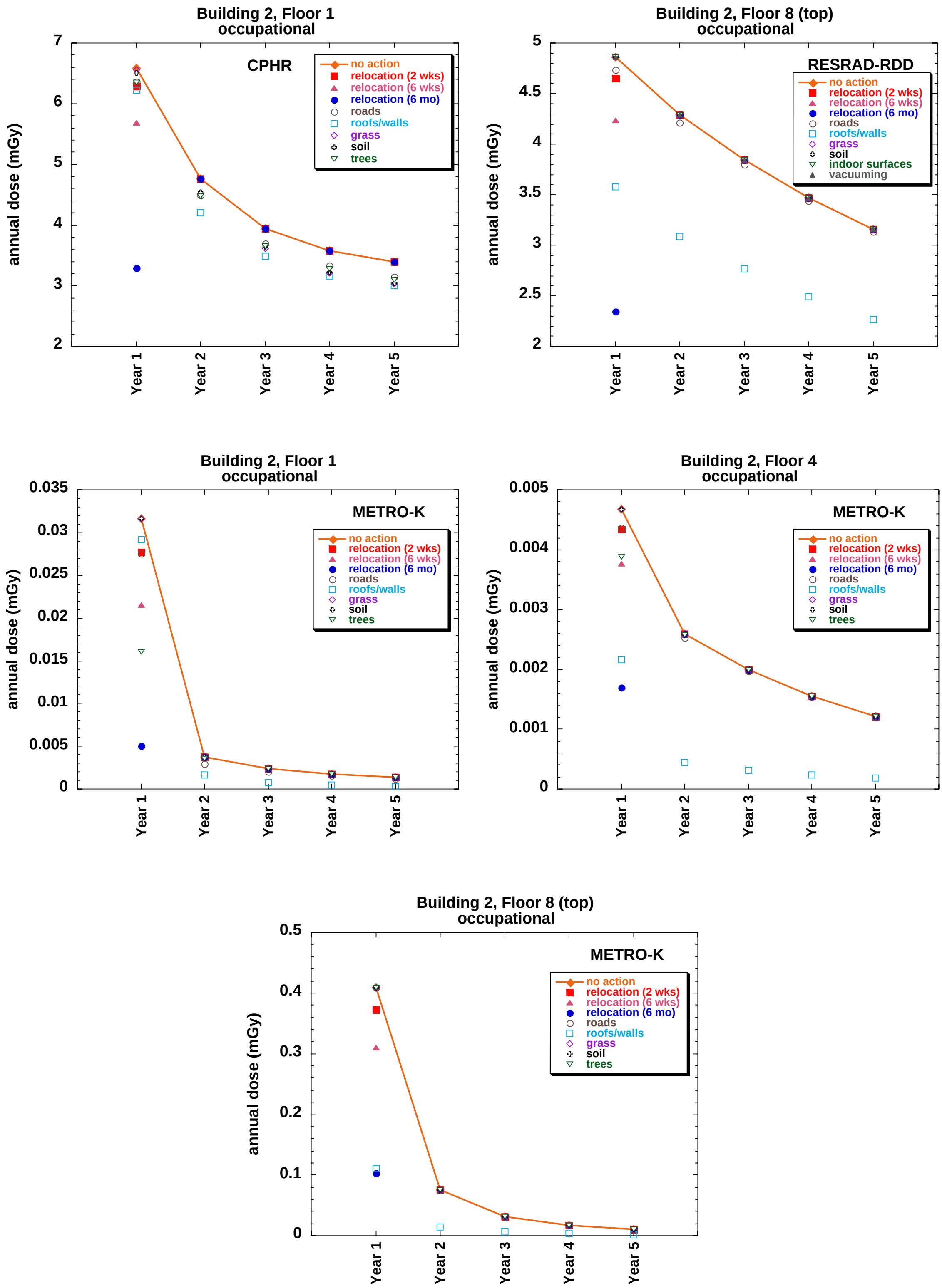

Fig. 4.21. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure in Building 2. (Vertical scales are linear and are different for each graph.)

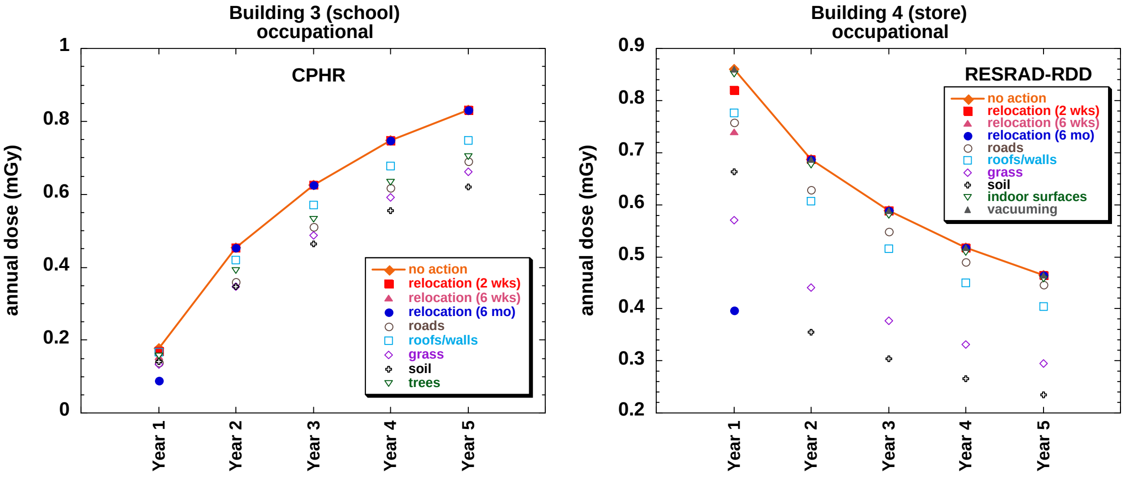

Fig. 4.22. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure (Buildings 3 and 4). (Vertical scales are linear and are different for each graph.)

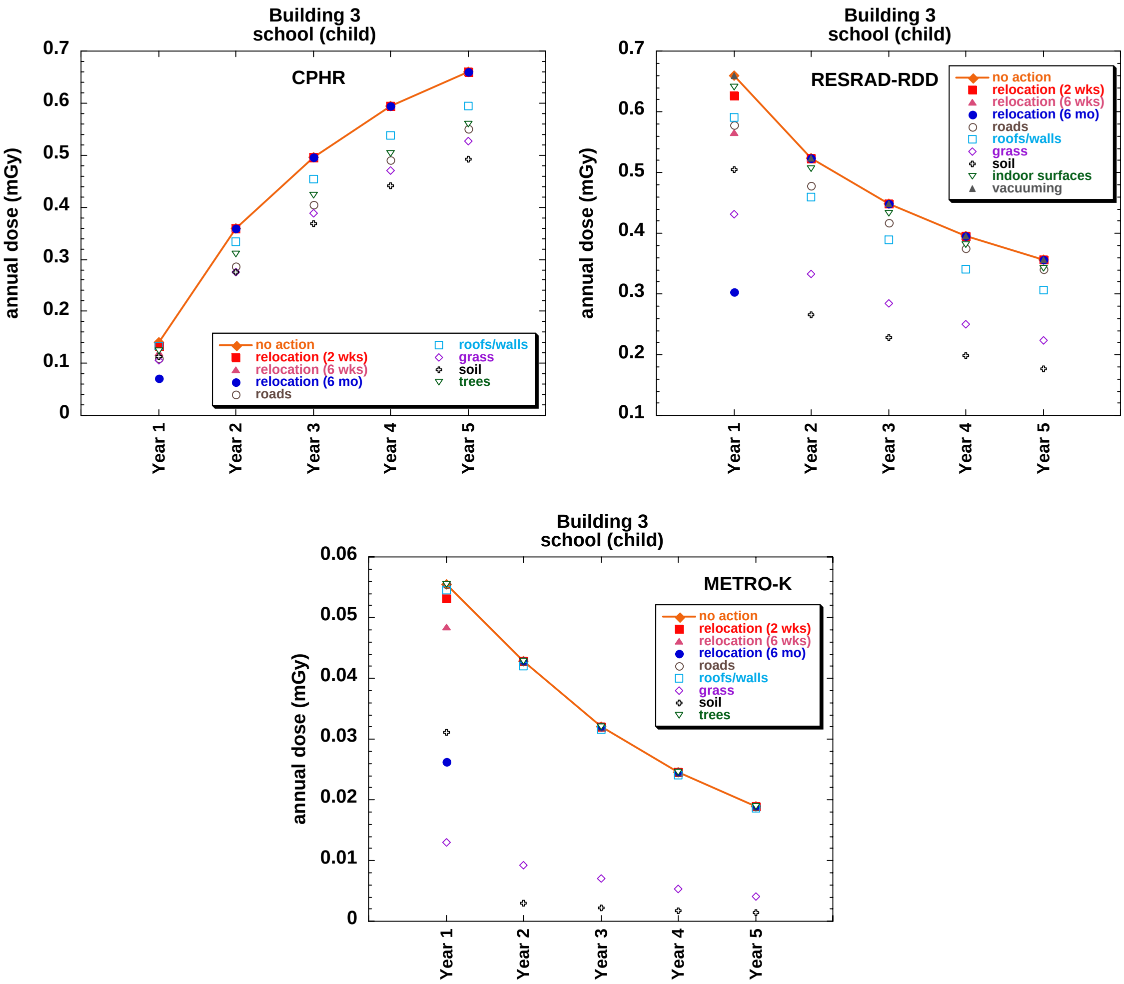

Fig. 4.23. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for exposure of a schoolchild (Building 3). (Vertical scales are linear and are different for each graph.)

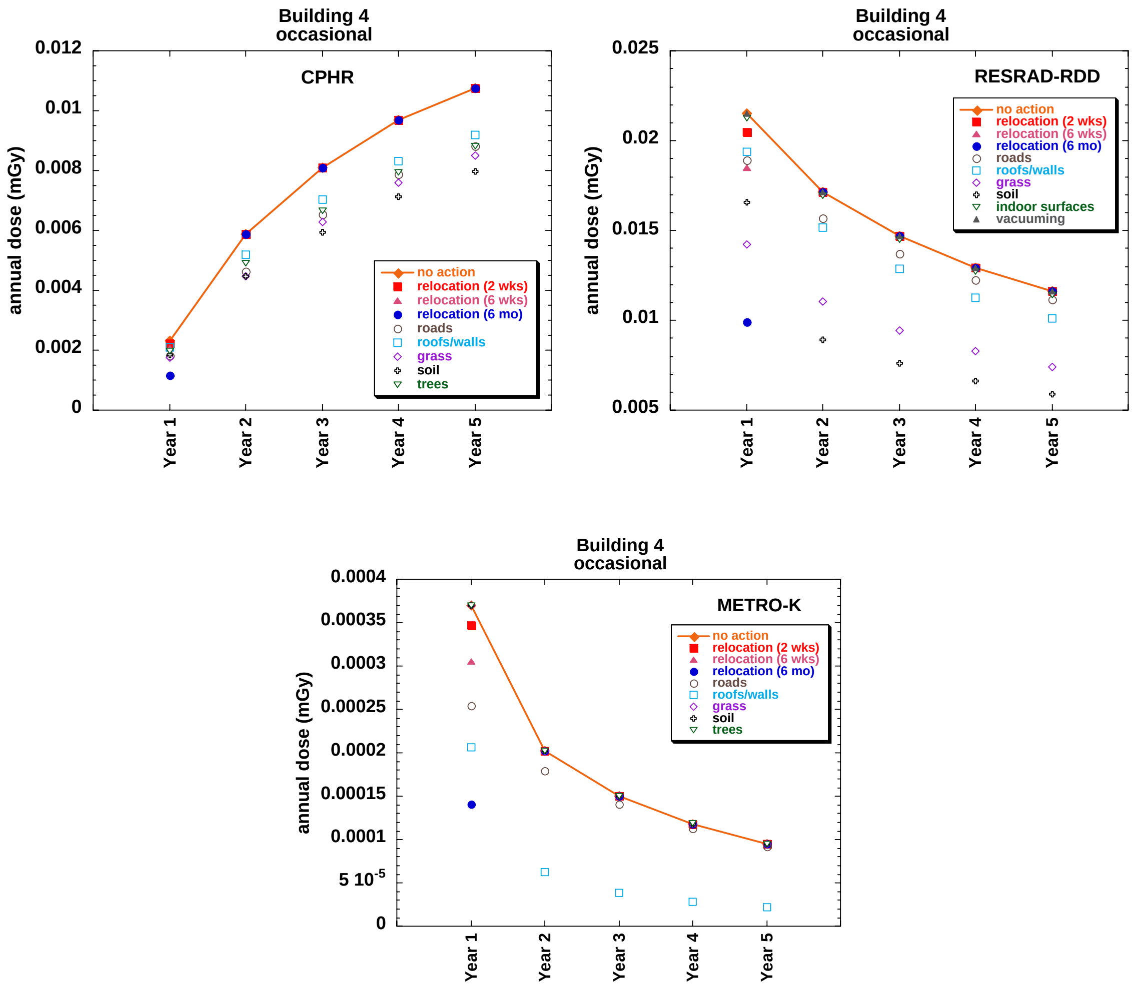

Fig. 4.24. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occasional exposure in Building 4 (a grocery store). (Vertical scales are linear and are different for each graph.)

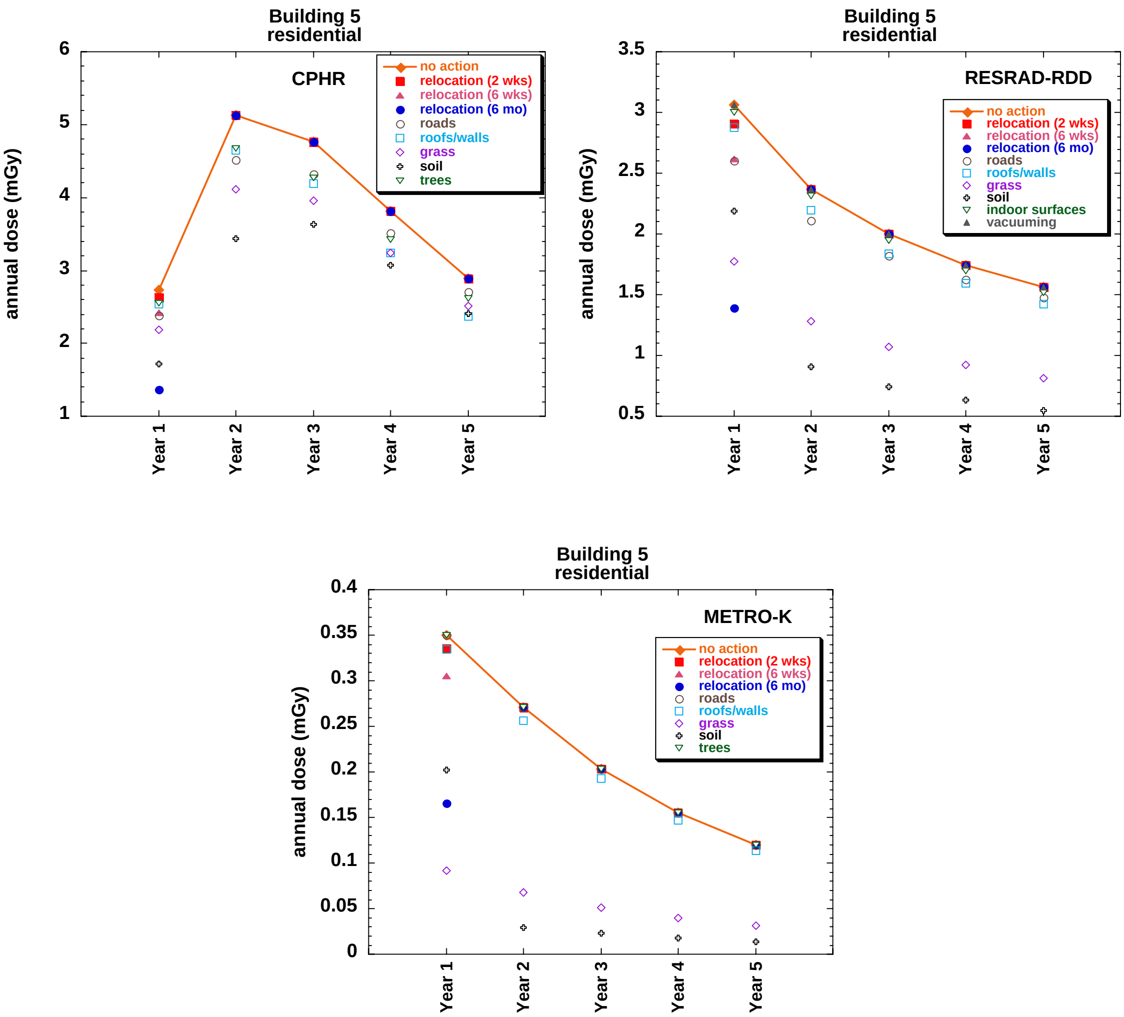

Fig. 4.25. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for residential exposure in Building 5. (Vertical scales are linear and are different for each graph.)

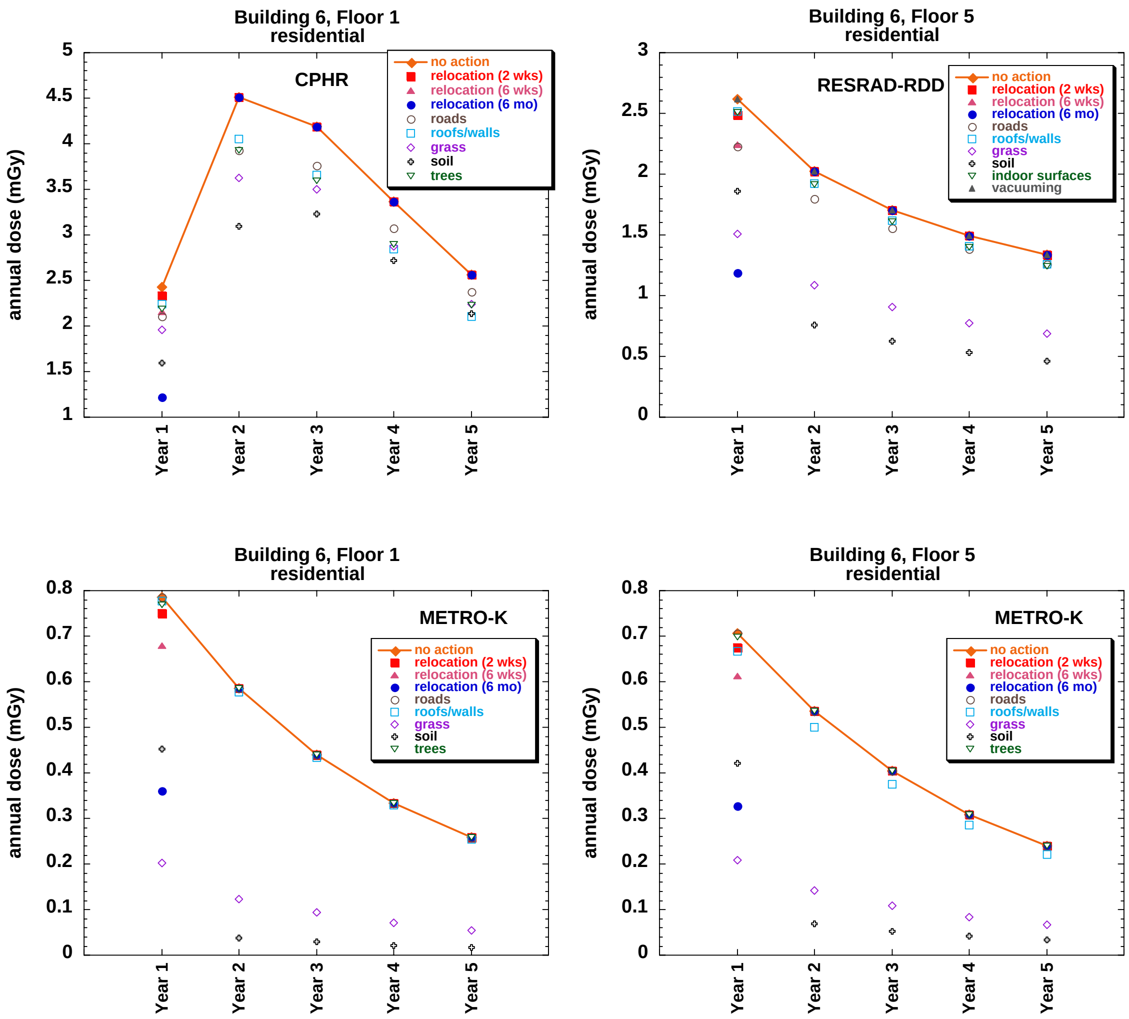

Fig. 4.26. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for residential exposure in Building 6. (Vertical scales are linear and are different for each graph.)

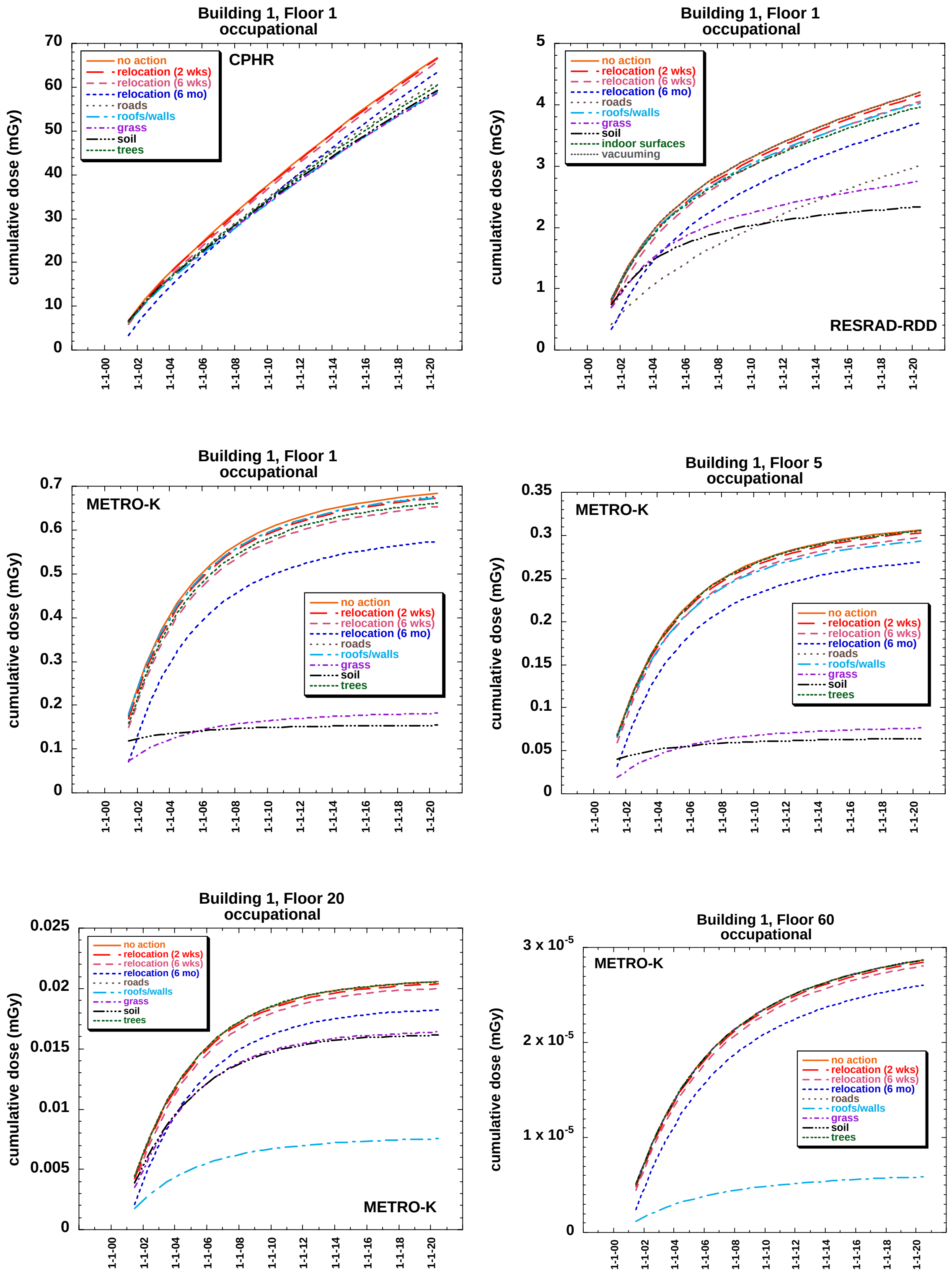

Fig. 4.27. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occupational exposure in Building 1. (Vertical scales are linear and are different for each graph.)

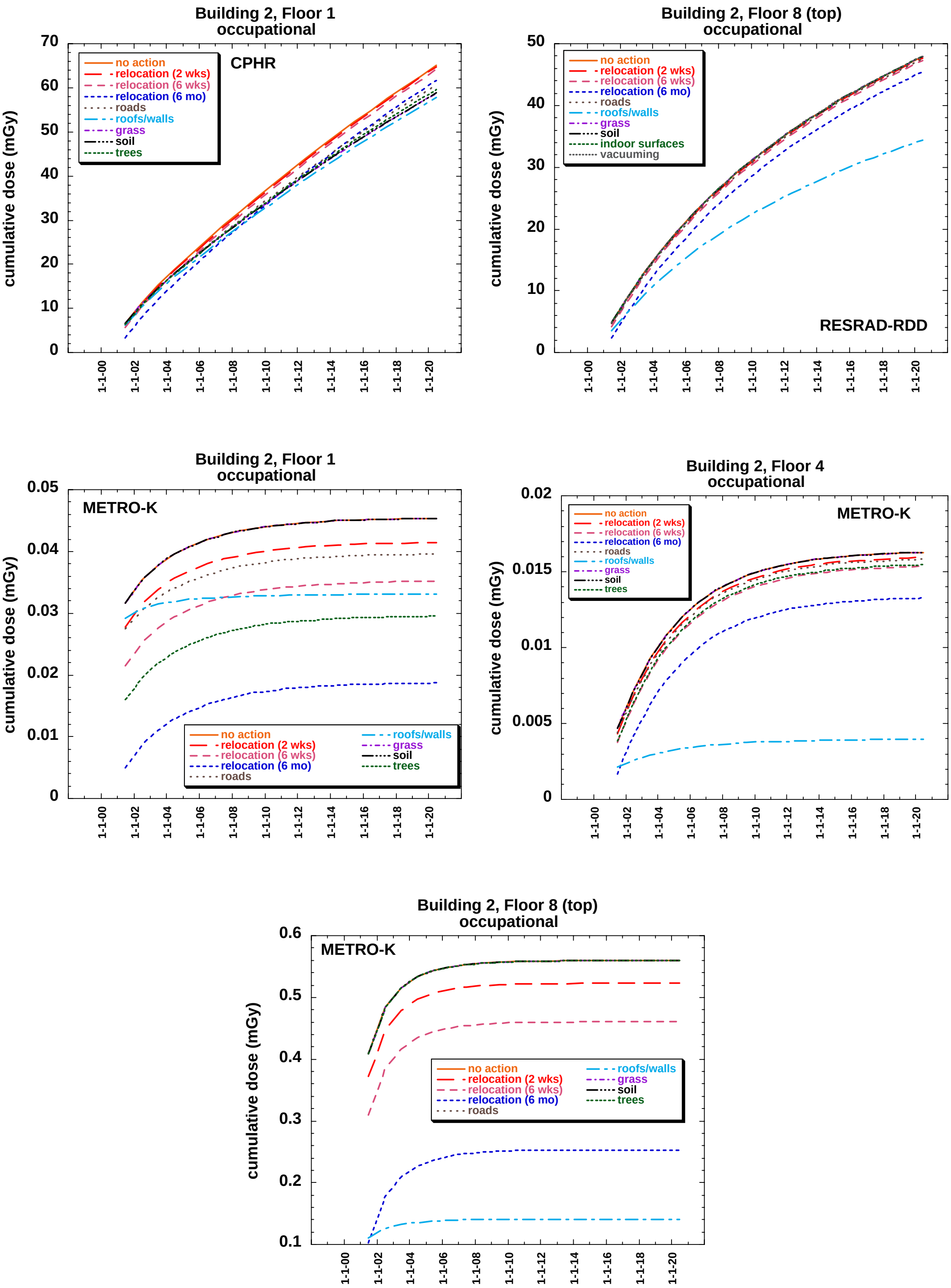

Fig. 4.28. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occupational exposure in Building 2. (Vertical scales are linear and are different for each graph.)

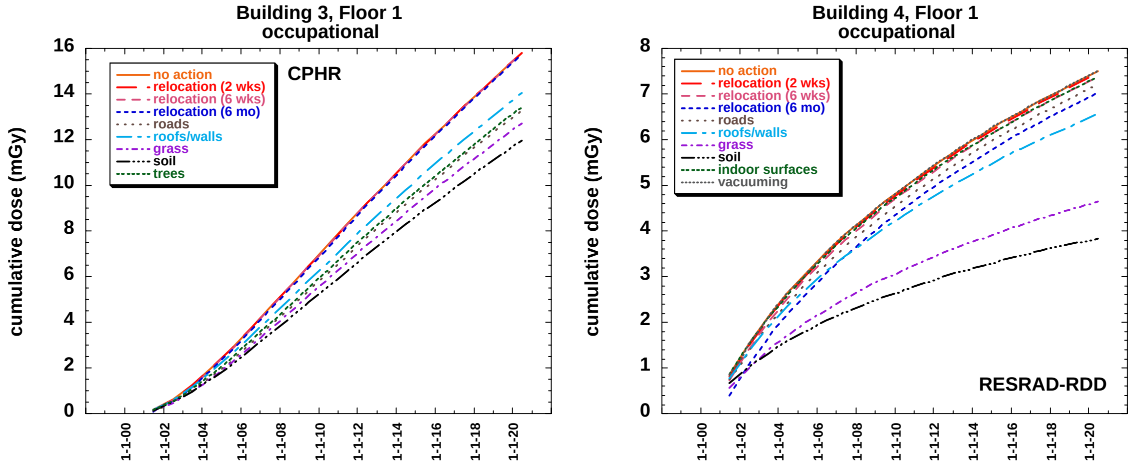

Fig. 4.29. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occupational exposure (Buildings 3 and 4). (Vertical scales are linear and are different for each graph.)

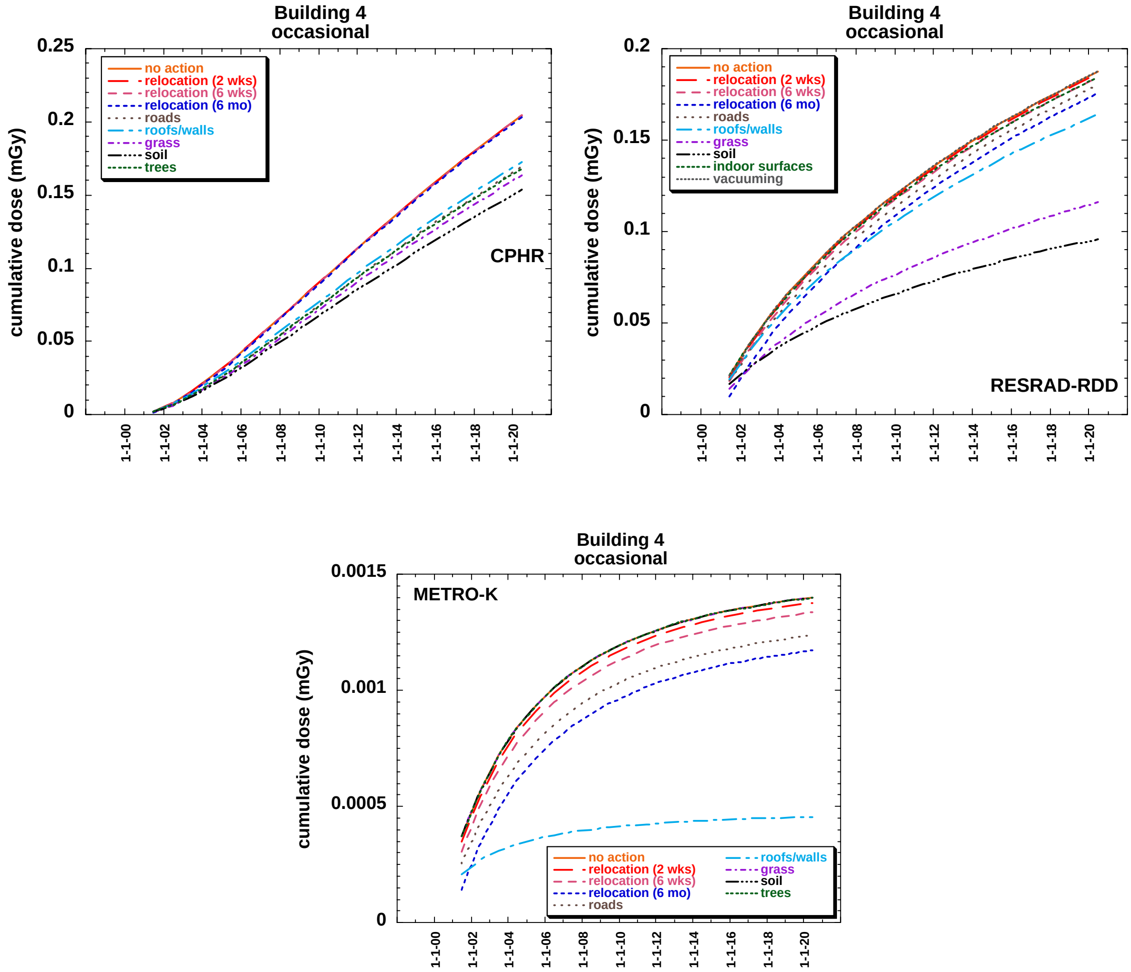

Fig. 4.30. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occasional exposure in Building 4 (a grocery store). (Vertical scales are linear and are different for each graph.)

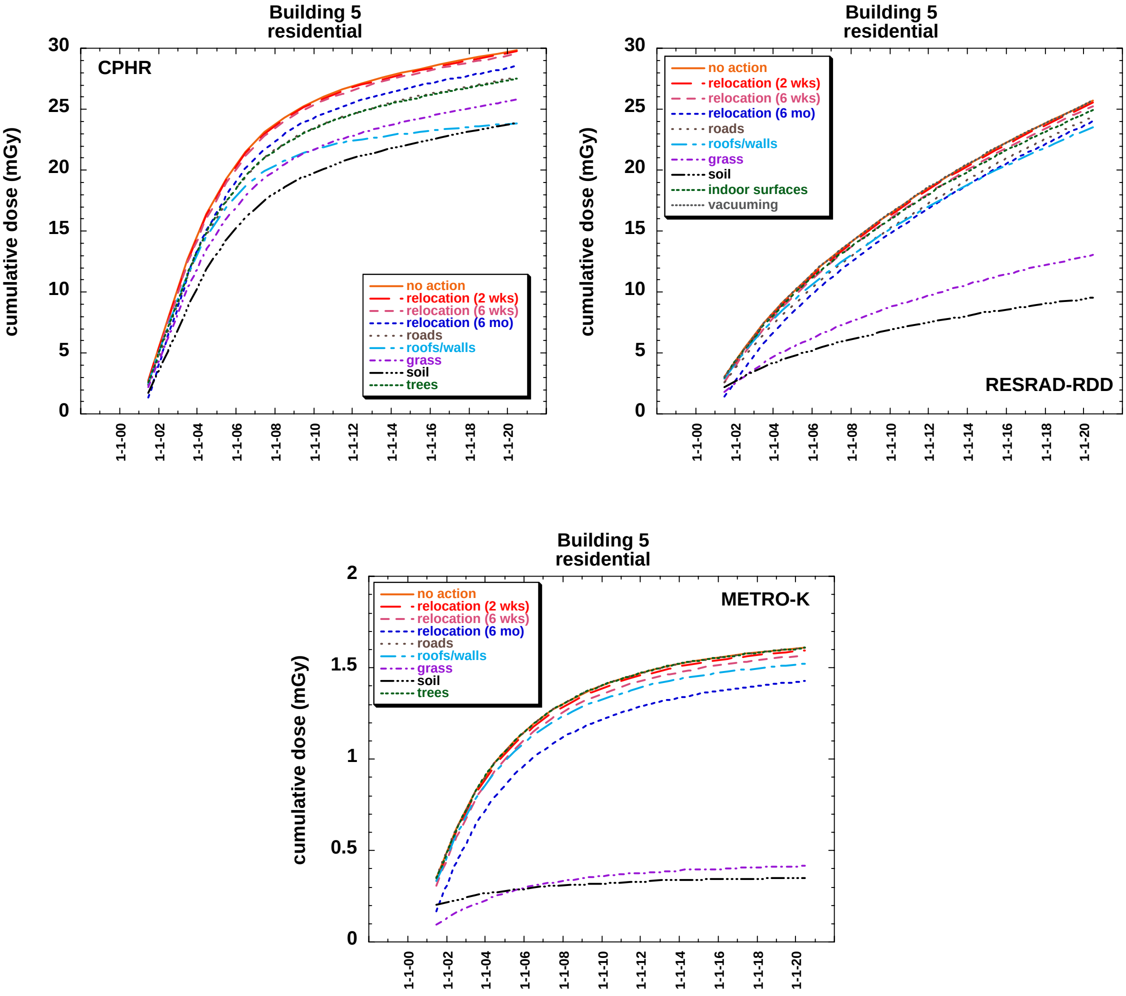

Fig. 4.31. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for residential exposure in Building 5. (Vertical scales are linear and are different for each graph.)

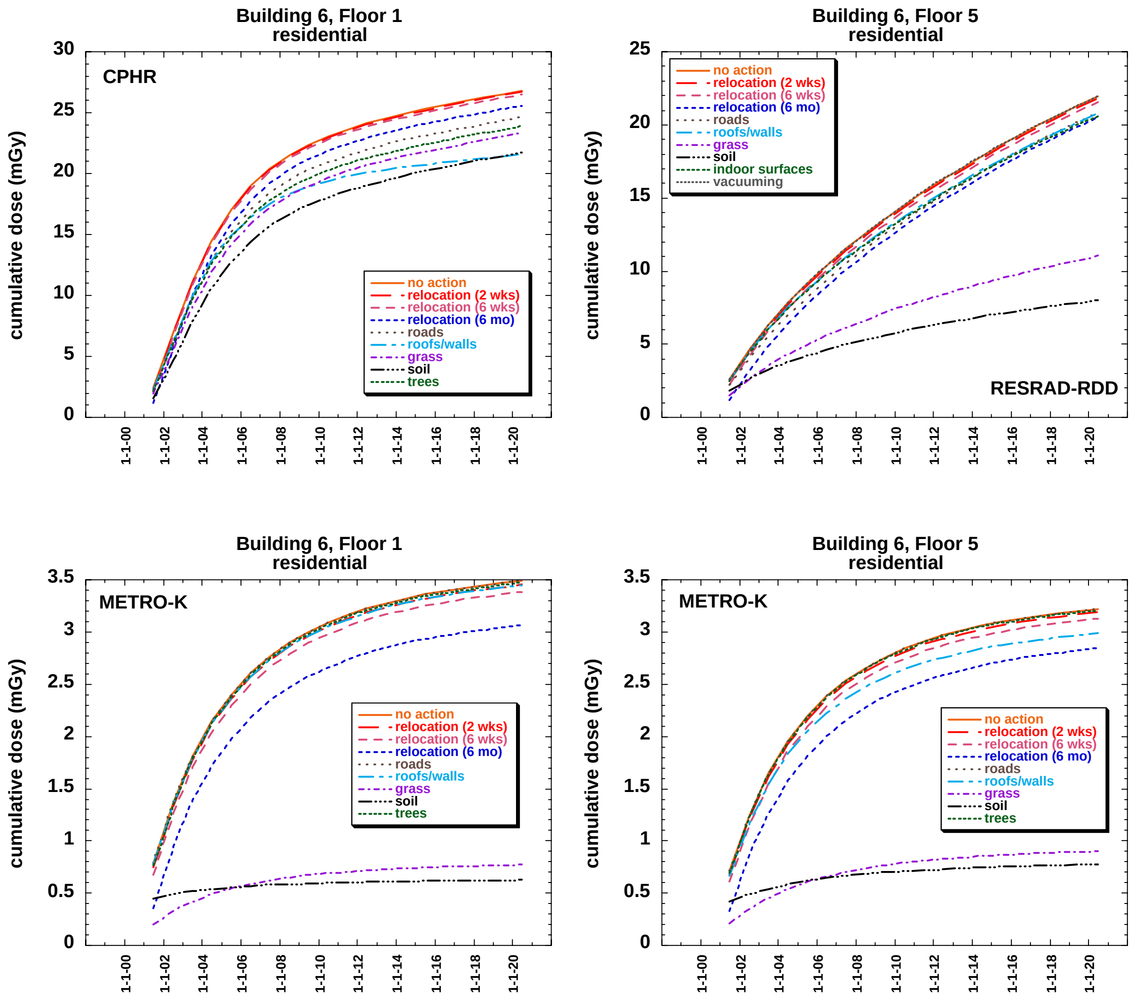

Fig. 4.32. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for residential exposure in Building 6. (Vertical scales are linear and are different for each graph.)

Table 4.2. Comparison of model predictions for the hypothetical scenario, in terms of the percent reduction in annual dose and cumulative dose due to decontamination measures.

Decontamination measure	**Model**								
	METRO-K			**CPHR**			**RESRAD-RDD**		
	Annual		**Cumu-lative**	**Annual**		**Cumu-lative**	**Annual**		**Cumu-lative**
	1st year	**20th year**	**20 years [a]**	**1st year**	**20th year**	**20 years [a]**	**1st year**	**20th year**	**20 years [a]**
Cutting and removal of grass	20–77	38–80	20–78	0–25	0–19	10–20	0–42	0–56	0–50
Washing of roads	1–31	0	1–13	3–22	0–17	7–17	3–50	0	1–28
Washing of roofs and walls	1–77	1–86	1–80	6–10	12–55	11–20	2–26	5–29	4–28
Removal of trees and leaves	2–49	0	0.3–35	3–15	1–18	8–18	–	–	–
Removal of soil (5 cm)	12–44	45–94	21–82	1–37	0–25	9–25	0–29	0–75	0–64
Washing of indoor surfaces	– [b]	–	–	–	–	–	0–4	0–8	0–6
Vacuuming	–	–	–	–	–	–	0	0	0
Relocation (2 weeks)	4–12	0	1–9	4–5	0	0	4–6	0	0–1
Relocation (6 weeks)	12–24	0	2–22	12–15	0	0.1–1.4	13–17	0	1–3
Relocation (6 months)	52–84	0	11–59	50	0	1–5	54–59	0	5–12

[a] Cumulative dose over 20 years (range of predicted reductions for adults).
[b] Countermeasure not used by model.

4.4.5. Differences between initial and revised predictions

By offering the opportunity to compare approaches and results among several modellers, an exercise such as this permits modellers to clarify their initial interpretations of the scenario, rethink parts of their approach, modify parameter values, or identify mistakes that might otherwise go unnoticed. Following the initial comparison of model predictions in April 2007, the modellers in this exercise were provided an opportunity to make revisions if they chose. The results shown in the previous sections were from the November 2007 predictions, including any revisions that were made after the April 2007 meeting. This section highlights some of the major revisions that were made and illustrates the effects of those revisions. Figures 4.33–4.39 illustrate some of the major changes for predicted contamination density, dose rate, contribution to dose rate, annual and cumulative doses, and the effects of countermeasures on the annual and cumulative doses. Additional examples of initial and revised model predictions are included in Appendix IV.

For RESRAD-RDD, the major revision was in the interpretation of the scenario description for the top (8^{th}) floor of Building 2 (Figures 4.34 and 4.37–4.39). This building is a parking garage, with the top floor being open—essentially a flat roof being used as the top floor on which cars are parked. The initial predictions from RESRAD-RDD had assumed that the 8^{th} floor was an indoor location. The other main revision for the RESRAD-RDD predictions was for the top (60^{th}) floor of Building 1. The revised predictions now assume no external contamination at that height (no contamination on exterior walls and roof), although the effect of this revision was not large.

The second set of predictions for CPHR included two major revisions. One involved correction of a situation in which parts of the contamination were counted twice; correction of this scaled down all the curves for CPHR's predictions. The other change was to re-evaluate the dose rates; the first set was based on conversion factors calibrated for the Pripyat exercise, which included a variety of radionuclides. In the second set of predictions, the conversion factors were revised based on a method similar to that described by Zähringer and Sempau ([64]; see Appendix II), and this reduced the dose rates in many cases to something more similar to the values obtained with the other models. The new conversion factor set also seems to have altered the relative importance of the different surfaces contributing to the dose rate. The impact of various countermeasures is also different in the revised predictions, with countermeasures applied directly to the surface (soil removal and grass removal) having a greater effect now than washing of roofs and walls. Examples of the effects of the revisions to CPHR predictions are provided in Figures 4.33–4.39.

A major revision in METRO-K was to change the weathering half-life for trees from 1000 days to 100 days. This greatly reduced the importance of trees to the dose rate after the first year (Figure 4.37), and, as one would expect, also decreased the impact of tree removal on the predicted doses for certain locations (Figures 4.38 and 4.39). In the initial results, the trees continued to give significant contributions to predicted doses even at year 20, although even conifers would be expected to have total replacement of needles long before that time. This revision brings the predicted dose rates and doses more in line with the expected behaviour of the contamination for situations involving trees. Note that revision of the weathering half-life for trees affects a number of endpoints, depending on the initially predicted contribution to dose rate from the tree surface. Examples of the effects of this revision and several minor revisions to METRO-K predictions are provided in Figures 4.33–4.39.

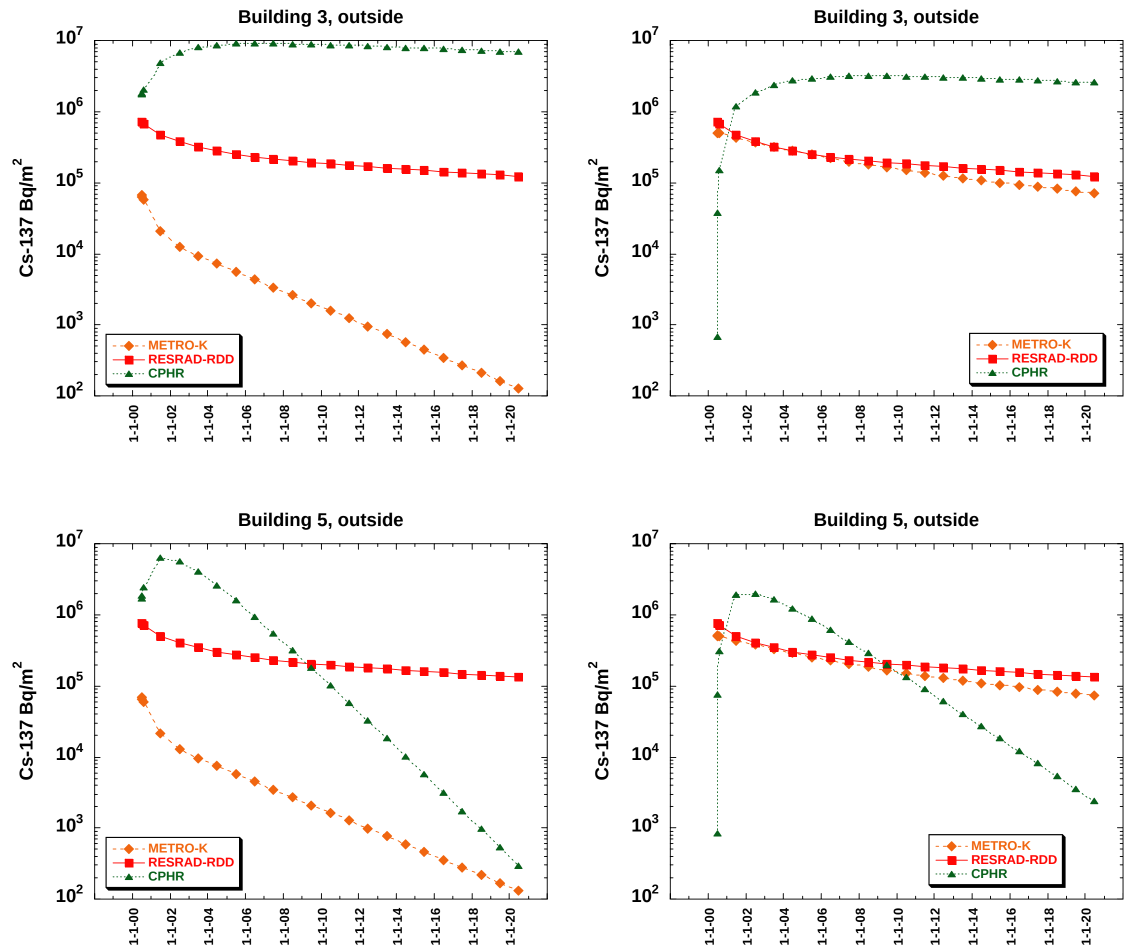

Fig. 4.33. Examples of initial (left) and revised (right) predictions for the contamination density (Bq m^{-2}) at outdoor locations. Revised predictions include changes for METRO-K and CPHR.

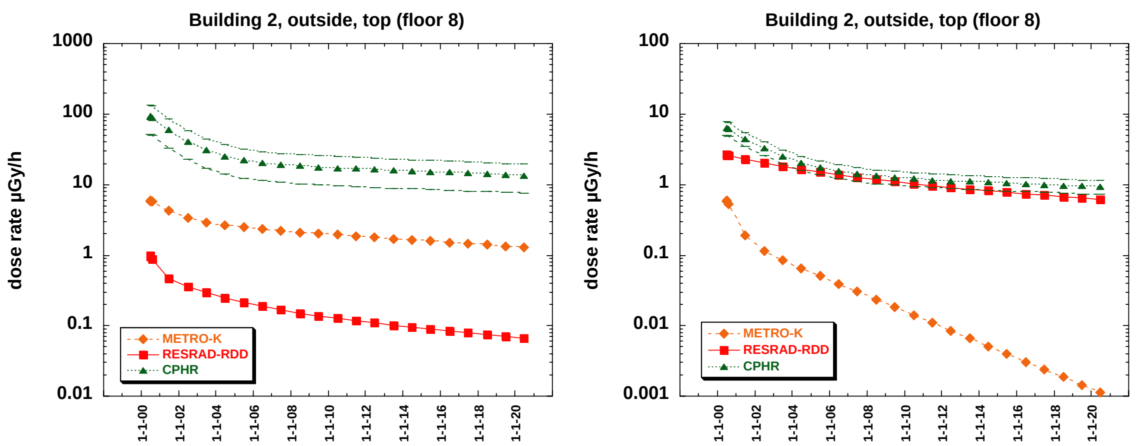

Fig. 4.34. Examples of initial (left) and revised (right) predictions for the dose rate (µGy h^{-1}) at the top of Building 2 and two indoor locations. Revisions include changes for all three models.

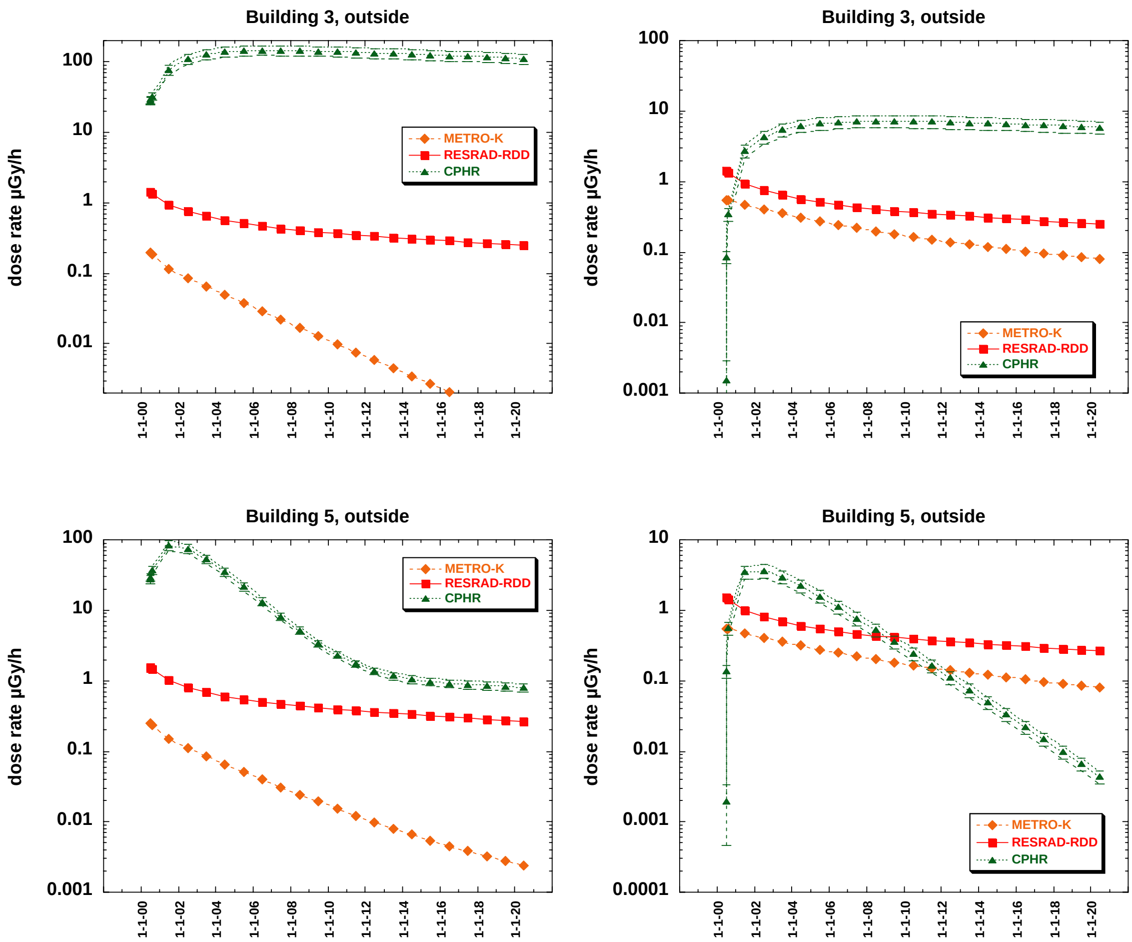

Fig. 4.35. Examples of initial (left) and revised (right) predictions for the dose rate (µGy h^{-1}) at two outdoor locations. Revised predictions include changes for METRO-K and CPHR.

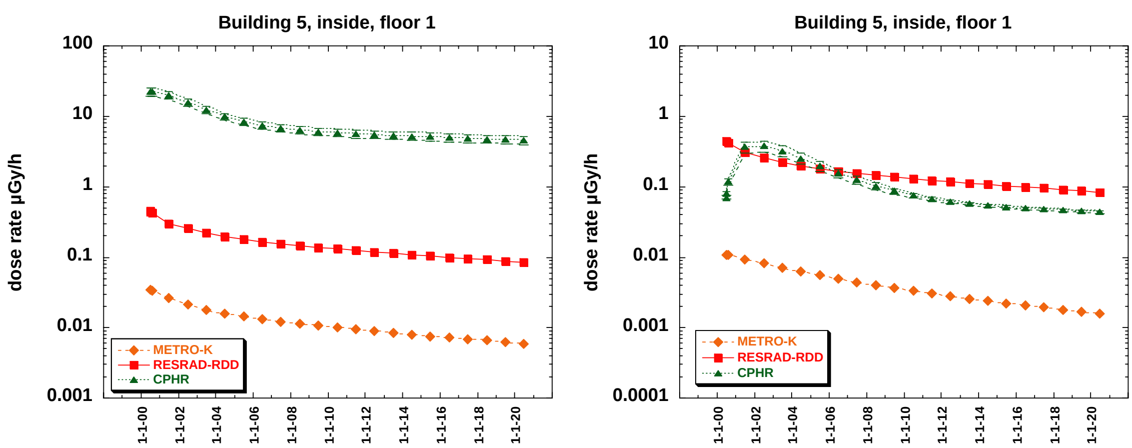

Fig. 4.36. Examples of initial (left) and revised (right) predictions for the dose rate (µGy h^{-1}) at an indoor location. Revised predictions include changes for METRO-K and CPHR.

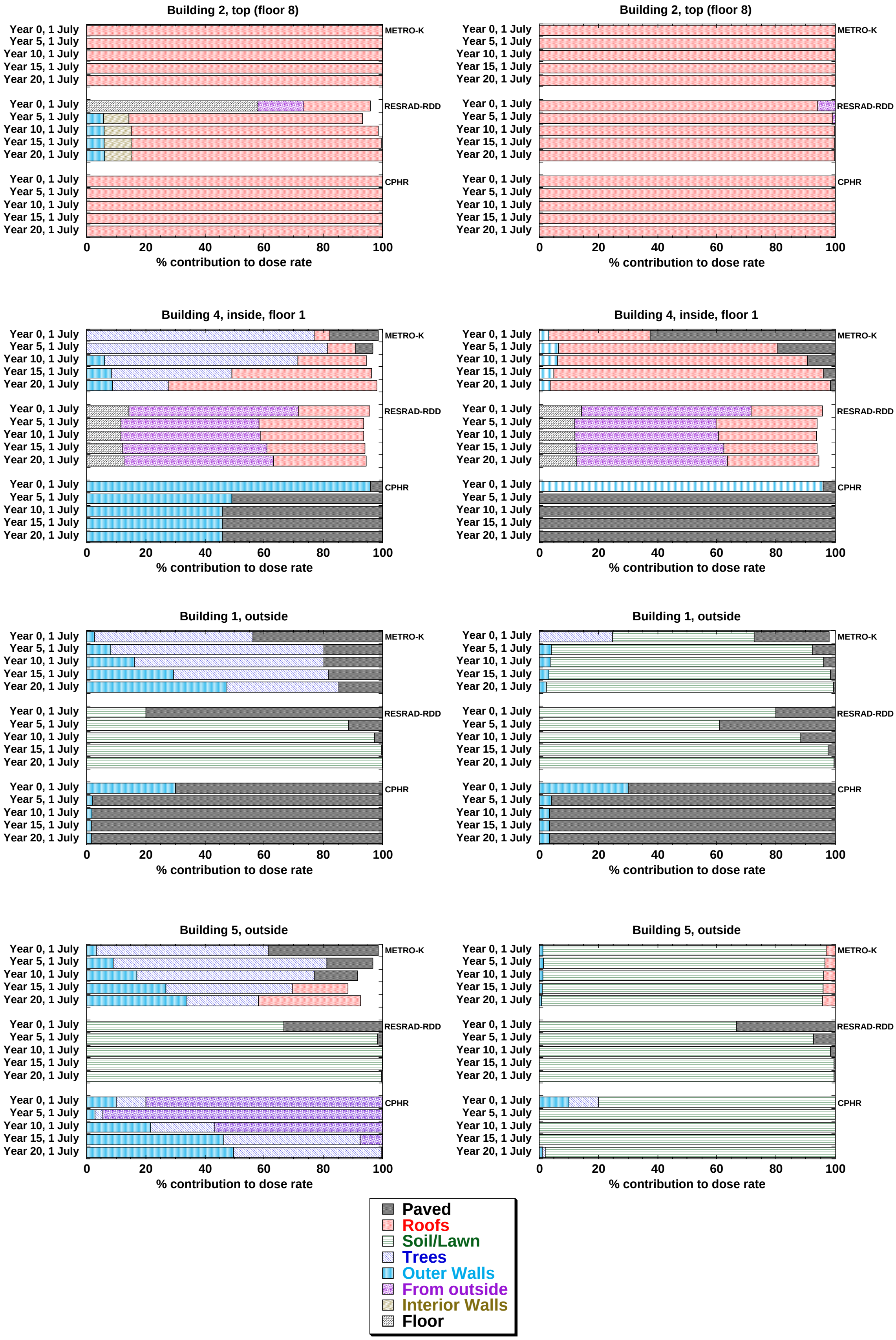

Fig. 4.37. Examples of initial (left) and revised (right) predictions for the contributions to dose rate (%) at selected locations. Revised predictions include changes for all three models.

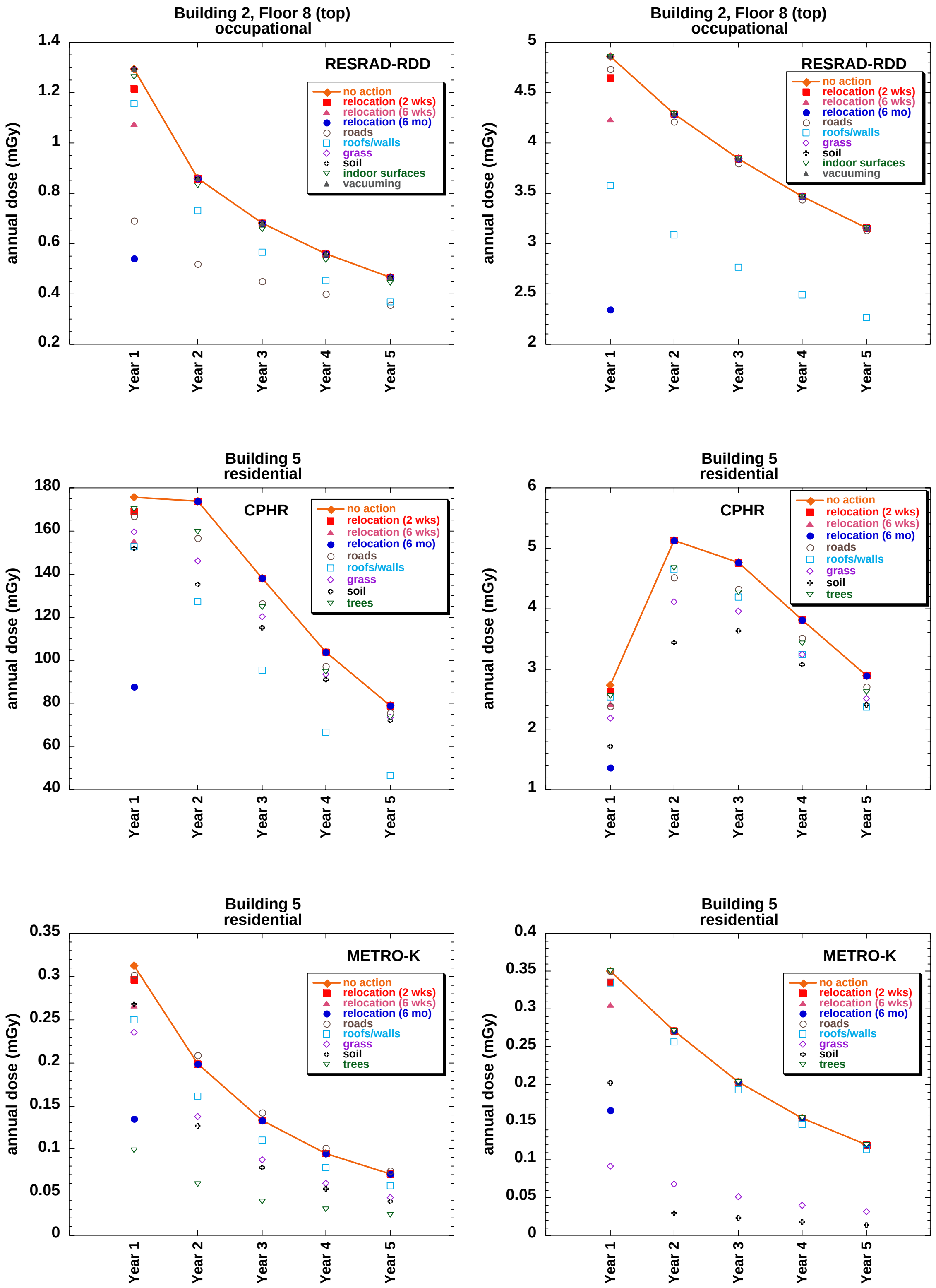

Fig. 4.38. Examples of initial (left) and revised (right) predictions for annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure at the top of Building 2 (RESRAD-RDD) and for residential exposure in Building 5 (CPHR and METRO-K). (Vertical scales are linear and are different for each graph.)

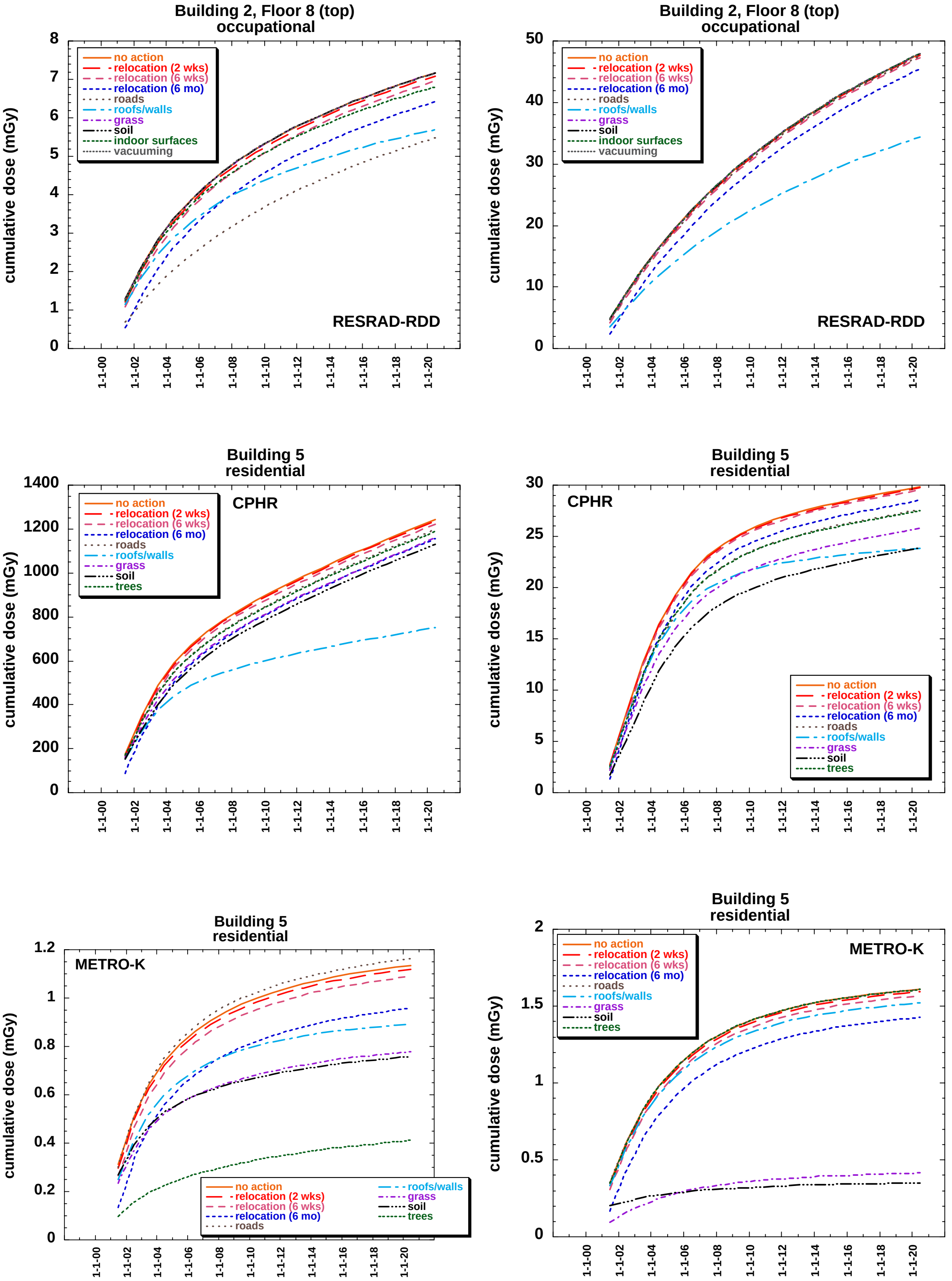

Fig. 4.39. Examples of initial (left) and revised (right) predictions for cumulative doses (mGy), showing the predicted effects on the cumulative dose of several different countermeasures. Results are shown for occupational exposure at the top of Building 2 (RESRAD-RDD) and residential exposure in Building 5 (CPHR and METRO-K). (Vertical scales are linear and are different for each graph.)

4.5. Conclusions from the Hypothetical scenario modelling exercise

The results of the hypothetical radiological dispersal device scenario demonstrate a wide range of important issues in modelling. Differences in generic model assumptions are easiest to identify in the simplest calculations, where the fewest factors influence the picture. For instance, weathering and migration half-lives (Table 2.6 in Section 2.3) and fractioning into fixed, slowly removed and quickly removed parts vary widely between the models. A limited amount of measurement data is available for these parameters, particularly from the Chernobyl accident, and this is used by the RESRAD-RDD and METRO-K modellers. The assumption applied in CPHR of a fraction of the contamination that is so firmly fixed to paved surfaces that it stays there forever is not in line with the generic measurement data. Nor is the considerable fraction that is in CPHR removed with as long a half-life as 18.9 y. Fixation of cesium on paved surfaces is related to the presence (in many construction materials as well as in street dust) of minerals with a characteristic capacity to selectively and very strongly bind cesium (e.g., illite and tobermorite). However, normal weathering processes (e.g., through traffic), particularly in a densely populated city centre, would result in significant reduction in contamination levels, so that very little cesium contamination would be left on paved surfaces after 5 years or so.

The exercise shows that in a complex modelling system there will always be a risk of commonplace model errors; some of these can be caught through intercomparison, providing a more homogeneous (though still not necessarily correct) set of results. This was observed in several cases and is especially important in the absence of measurements. For example, after comparison of initial results, the weathering half-life for trees in METRO-K was changed from 1000 days to 100 days.

It is important to document the models in as much detail as possible, to demonstrate the background data on which the model is based, and to pinpoint where possible misinterpretations of data (if any) may have occurred. There may also be very varying degrees of detail implied in different parts of the model. For instance, in an urban complex with many different surface materials and orientations, it is normally highly advantageous to perform Monte Carlo photon transport calculations to derive dose conversion factors for representative exposure situations. The strength of this type of calculation compared with point kernel/build-up factor approaches has been outlined by Hedemann Jensen [65]. However, libraries for dose conversion factors are available only for a limited set of representative environments that might not correspond to a particular emergency situation.

Already from the first point in the first diagram (Figure 4.4) there are discrepancies between model results, reflecting different assumptions regarding the distribution of the contamination on the various surfaces. However, the uncertainty might be reduced considerably if measurements for various surfaces were available. There is no authorized ‘right’ solution, as assumptions and simplifications are inevitably necessary. The adaptability of an existing code to the particular scenario is not the only problem. If model performances are to be intercompared, it is equally problematic that crucial parameters like overall surface types, surface materials/permeability, particle sizes, grass length/roughness and particle solubility are not explicitly defined in the scenario description. That is a lesson learned from this exercise. Also the frequency and effectiveness of routine cleaning procedures (e.g., removal of leaves in the autumn, street cleaning) need to be defined to facilitate model feature intercomparison. More detailed specification of a modelling scenario would permit identification of actual differences in the construction of individual models, as opposed to differences in interpretation of the modelling scenario.

For instance, not all models take into account exposure contributions from contamination deposited on trees or on indoor surfaces. Deposition on trees may well be more important to consider in cases where the contaminant has a considerably shorter half-life, but indoor deposition has been demonstrated to be potentially important in relation to some dry deposition scenarios [66]. Moreover, it has been shown [66] that deposition to human skin can result in very significant beta and gamma doses (although received over a short time), which also have to be considered (but traditionally rarely are in urban models). Possibly the most important dose contribution in this case could be that received from inhalation during the passage of the cloud, which must also be calculated to put the other dose contributions into context. The quantification of these dose contributions would also require a firmer description of the contaminant characteristics, particularly with respect to aerosol size.

4.6. Additional remarks on radiological dispersal device situations and urban countermeasures

One of the objectives of the Urban Remediation Working Group is to investigate the consequences of a hypothetical event, where a radiological dispersal device detonates in a hypothetical city. The scenario described in this report was designed to allow modelling with and without the effects of various remediation efforts on the changes of the radiological situation over time. Similar to the scenario suggested by Sohier and Hardeman [63], a radiological dispersal device with 5 kg conventional explosives and 50 TBq of ^{137}Cs in powder form is assumed. The choice of 50 TBq is taken because this was the strength of the orphan ^{137}Cs source of the Goiânia accident in Brazil in 1987. Moreover, ^{137}Cs salt in the form of a powder is highly dispersible.

Radiological dispersal devices, however, can be constructed using a variety of other sources with different chemical and physical properties. Sources with high activities are frequently used in industrial and medical applications. Industrial applications include, among others, irradiation facilities (e.g., sterilization, food irradiation), non-destructive material tests (radiography), metrology (e.g., well logging, density gauges) and radioisotope thermoelectric generators (RTG). High activity sealed sources are used in medicine for applications such as teletherapy, blood irradiation and afterloading brachytherapy. The design of these sources usually aims at high activity concentrations and materials that are as difficult to disperse as possible. Manufacturing techniques include, among others,

— Activation of metallic or oxidic targets;
— Production of compounds with low solubility and high melting points; and
— Inclusion of radionuclides in a glass or metal matrix.

Activities may reach 10 000 TBq for ^{90}Sr (RTG), 1000 TBq for ^{60}Co (teletherapy) and even higher ^{60}Co activities for sterilization and food irradiation, 500 TBq for ^{137}Cs (teletherapy), 10 TBq for ^{192}Ir (radiography), and 1 TBq for ^{241}Am/Be (well logging).

The physical and chemical properties of a source are of primary importance for an effective dispersion of the material. Solid material in powder form, as assumed in the hypothetical scenario, can be dispersed easily. Such material could be used for a radiological dispersal device without any treatment. As has been mentioned, sources for industrial applications are usually produced in such a way that dispersion is as difficult as possible during normal operation and in accidental situations. Radionuclides in the form of solid metal or sintered material, for instance, are very difficult to finely disperse and require advanced knowledge about detonation techniques, notably the optimum arrangement of conventional explosives. It is important to acknowledge, however, that solid sources can often be converted to highly active liquids by applying simple chemical treatments, thus becoming highly dispersible.

The physical and chemical properties of a source also strongly influence the magnitude of human radiation exposure, the dominant exposure pathways, the time scale/temporal evolution of exposure and the effectiveness of countermeasures. For gamma-emitting radionuclides, e.g. ^{60}Co, ^{137}Cs and ^{192}Ir, the dominant pathway in the long term usually is external exposure from deposited activity. Inhalation might be relevant only for a rather small area for a short period after detonation. The Urban Remediation Working Group decided to focus on long-term consequences and therefore asked the participants of the model testing exercise to consider only external exposure by gamma emitters, irrespective of the capabilities of their models.

In case of alpha emitters, e.g. ^{241}Am, internal exposure due to inhalation is likely to be the dominant contribution to dose, and knowledge about the activity concentration in air is essential. Resuspension becomes a relevant pathway and the activity concentration in air resulting from resuspended alpha emitters need to be estimated. A common approach to quantify resuspended activity in the terrestrial environment is based on the resuspension factor; other possible approaches include dust loading and resuspension rates. The resuspension factor K, expressed in m^{-1}, is defined to be the activity concentration in air at the breathing height (Bq m^{-3}) divided by the initial deposition per area (Bq m^{-2}). A value of about $K = 10^{-5}\ m^{-1}$ was recently recommended for the first day after deposition under urban conditions with light traffic and light pedestrian activity [67]. In case of heavy traffic a value of about $K = 10^{-4}\ m^{-1}$ needs to be used. These resuspension factors would be expected to decline steeply after the first day. The potential consequences of resuspension are demonstrated for the light traffic scenario, using ^{241}Am of the default lung absorption type M as an example. Assuming a deposition of 1 MBq m^{-2} and an inhalation rate of $2.3 \times 10^{-4}\ m^3\ s^{-1}$ would result in a committed effective dose of about 10 mSv during the first day after deposition for adults [67]. Since resuspension is affected by many natural and anthropogenic factors, including the climatic and meteorological conditions, the chemical and physical properties of the radioactive particles, the properties of the surfaces involved, the mechanical impact on surfaces, and the time since deposition, the uncertainty of this rough estimate is up to three orders of magnitude [67].

For both gamma and alpha emitters, ingestion may be of minor importance in urban environments in many areas of the world, where only small quantities of foodstuffs are produced in private gardens. Such small quantities can easily be replaced by uncontaminated products. However, inadvertent ingestion of radionuclides could be important in some situations [68].

Recovery options for gamma emitters aim mainly at reducing external exposure by removal of contaminated material, decontamination of surfaces, and shielding. In the case of alpha emitters, countermeasures need to focus on reducing the amount of inhaled activity. Staying indoors and preventing ambient air from entering buildings or circulating within them may be very effective. Any further recovery option will be restricted to prevention of resuspension, either by removing or covering contaminated material or fixing radionuclides to surfaces. It is essential to acknowledge that some recovery options work for both alpha and gamma emitters, while other countermeasures and their effectiveness strongly depend on the type of radionuclide.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

As described in Section 1.2, the primary objective of the Urban Remediation Working Group has been to test and improve the prediction of dose rates and cumulative doses to humans for urban areas contaminated with dispersed radionuclides. Specific objectives have included (1) the identification of realistic scenarios for a wide variety of situations, (2) comparison and testing of approaches and models for assessing the significance of a given contamination event and for guiding decisions about countermeasures or remediation measures implemented to reduce doses to humans or to clean up the contaminated area, and (3) improving the understanding of processes and situations that affect the spread of contamination to aid in the development of appropriate models and parameter values for use in assessment of these situations.

Objective 1, the identification of a variety of realistic situations, has been met in two ways. First, two specific scenarios were identified and developed for use in modelling exercises. These scenarios and exercises are described in Chapters 3 and 4 of this report. A wide variety of situations is possible, and the Working Group could not address all of them, but these two scenarios are reasonable examples of the types of situations that could occur and provided the modellers with an opportunity to work through the various aspects of an assessment of urban contamination. Both of these scenarios dealt with external exposure. The Working Group realizes that exposure through inhalation or inadvertent ingestion could also be important in some situations. Both scenarios addressed by the present Working Group required prediction of changes in radionuclide concentrations and dose rates as a function of location and time, as well as prediction of the reduction in radionuclide concentrations, dose rates, or doses expected to result from selected countermeasures or remediation efforts, applied at designated times. Secondly, Section 4.6 of this report discusses other types of deliberate contamination events that could occur and important considerations about them, including the amount and type of radioactivity and the likely importance of individual pathways of exposure.

Objective 2, the comparison and testing of models and modelling approaches for assessing contamination events and guiding decision-makers, has been addressed in several ways. The first is a literature review describing the current state of models and modelling approaches for assessing urban contamination (Chapter 2). The second is the actual modelling exercises carried out for two situations of urban contamination (Chapters 3 and 4). By having three or four sets of model predictions for each exercise, the participants were able: (1) to compare results and approaches for the various endpoints; (2) to identify the differences in the models or modelling approaches and the effects of these differences on the intermediate and final modelling endpoints; (3) to evaluate the effects of various countermeasures in terms of short-term and long-term dose reduction; and (4) to justify selected revisions to the models. From these exercises, the Working Group has been able to prepare some recommendations for improvement of modelling and modelling exercises (Section 5.1). In addition, the Working Group has prepared some practical considerations for decision makers (Section 5.4), both for general preparedness and for dealing with specific situations.

Objective 3, improving the understanding of processes of contaminant spreading, has been addressed by the identification of areas where more information needs to be obtained, either about contaminant behaviour or about the nature of certain surfaces in a given country or type of urban situation (Section 5.2). Lack of knowledge about some of the transport processes and how to represent these processes in a generic fashion are major sources of uncertainty in the modelling exercises described in this report. In some cases, modellers have used very different assumptions about contaminant-transfer processes or behaviour of contaminants on specific surfaces (Chapters 3 and 4). The differences in their results demonstrate the variety of modelling approaches that are currently applied by different modellers in different countries. Where it is not possible to obtain additional data for improvement of the models, this uncertainty must be acknowledged in the use of the model results (Section 5.3).

Based on the experiences of the literature review and the two model testing exercises described in this report, a number of "lessons learned" have been collected by the Urban Remediation Working Group. Conclusions and recommendations from these lessons learned have been grouped into four categories:

(1) Improvement of the modelling of urban contamination and countermeasures, including recommendations for future modelling exercises;
(2) Areas for further study, for which the information base is incomplete or adequate parameter values are not available;
(3) Treatment of uncertainty in urban assessment modelling; and
(4) Practical considerations for persons or organizations with responsibilities for assessing and remediating urban areas in case of an actual contamination event.

Each of these areas is discussed below.

5.1. Improvement of modelling and modelling exercises

The two modelling exercises described in this report are examples of the kinds of possible situations that could be encountered in real life. They are not necessarily the most representative, the most likely, or the most important. Although Pripyat is a real contaminated town, the long-term behaviour of the contamination and the long-term effects of the countermeasures that were carried out there are influenced by the absence of the population—e.g., the lack of traffic, the accumulation of debris and detritus, and the presence of lichens and mosses that retain contamination, all contribute to different results than would be expected in an inhabited town. In addition, due to the close location of Pripyat with respect to the Chernobyl NPP, the contamination, including hot particles, is not necessarily representative of other areas contaminated by the Chernobyl accident. A future modelling scenario could be based on Chernobyl data obtained at a longer distance from the accident, e.g., Gaevle in Sweden. In such a case, the contamination on surfaces would follow a more homogeneous pattern, and the physico-chemical forms of the contamination would be much more relevant to the weathering data currently applied in models.

The hypothetical situation described in the second modelling exercise, again, is a reasonable possibility but not representative of all possible deliberate dispersal events that could occur. The Working Group is aware that other scenarios are possible and would lead to very different situations. An actual radiological dispersal device event or other deliberate dispersal event could involve any of a variety of types of location (e.g., with respect to building density, dimensions, and materials), radionuclide or initial dispersal event (Section 4.6). Non-radiological aspects of radiological dispersal devices including explosions, biological agents, or chemical agents could also be important. It is important for any given situation to consider the reasonableness of the assumptions and parameter choices for that situation.

Nevertheless, these two exercises have provided an important and valuable opportunity to try out some models and modelling approaches in realistic situations and to compare modelling approaches and other considerations. These exercises have also helped to identify areas where further information would be helpful and to consider what sorts of future model testing opportunities could be most helpful for improving models of urban contamination.

Future test exercises need to make use of some very simple, well-characterized locations for representative sets of conditions. For example, these could include the most common types of housing for a region or country, a grassy area (e.g., park), and areas with typical proportions of pavement. Building dimensions, location and height of trees, and other relevant parameters need to be specified in detail. Use of a unit deposition as starting information could be helpful. From these, it could be possible to work up to some more complex situations such as the ones in our test exercises, which are more representative of the wide variety of conditions likely to be found in a real situation. Comparison of parameter values for specific model components (e.g., the unit dose rate from a particular urban surface such as a roof or a wall or a tree; weathering coefficients for specific surfaces; initial deposition on different surfaces) would be helpful, in addition to comparison of model predictions for specific situations.

For a given set of simple situations, it would also be helpful to address specific issues. For example, just the importance of trees in the model: distance from the target location or building, type of tree (coniferous or deciduous), season (i.e., with or without leaves), number of trees (edge of forest vs. group of trees vs. scattered or isolated trees) and type of remediation (defoliation, removal of seasonal leaf fall, removal of the trees). Similarly, how can heavy shrubbery be handled? What is the impact of particle size or of initial weather conditions (wet vs. dry deposition) for the set of specified situations?

Future test exercises need to consider additional radionuclides and pathways of exposure such as inhalation from the plume, inhalation of resuspended material, inadvertent ingestion, or direct contamination of skin, in addition to external exposure. Another issue that requires attention in modelling is the redistribution of contamination (movement between compartments), both with and without countermeasures. Examples include movement of contamination between trees and soil, migration in the soil column, movement from pavement to soil or from building surfaces to pavement, and contamination brought indoors from outdoors.

The general approach currently is to define a specific local “environment” in terms of the amount or proportion of various surfaces, presence or absence of trees, type of construction material, height above ground, and similar considerations. Some models have several different default “environments”, while for others, each situation is characterized by the assessor before the model is used. This type of approach, in combination with the type of exercise (use of well-characterized situations) described above, is valuable in many respects and limited in other respects. Its value lies in having a number of predefined or precalculated situations ready to go, for the specific country or region in question. Its limitations include a lack of flexibility when there is a need to make calculations for a different situation (e.g., for the top floor of a building, just below the roof, as opposed to a location on a middle floor of a building, or when the trees are different from those assumed in the default situation). There will always be a value to having default representative situations. There will also be a value to having models that can define the “outside” adequately and quickly for a variety of specific situations.

The test exercises described in this report have illustrated the importance of looking at contributions to dose rate from individual surfaces, since different assessors may predict similar dose rates using different combinations of surfaces. Outdoor locations with large areas of soil or lawn and limited paved areas are the easiest to model. Such locations tend to have only a few contributing surfaces, with the major contribution to dose rate being from the soil or lawn. More complex outdoor locations (e.g., with paved areas and walls and roofs of buildings being important contributors to the dose rate) and indoor locations are more difficult to model, and modelling results may depend on which surfaces are included in a given model or on how specific surfaces are handled in the model. In addition, many countermeasures involve treatment of a single surface; therefore, modelling of a countermeasure may involve changing how that particular surface is handled in the model.

These test exercises have also demonstrated that scenario interpretation can vary among modellers given the same starting information, a finding in keeping with those of previous exercises involving environmental transport models (e.g., [69, 70]). For example, although the participants in the two test exercises were given the same values for initial deposition on grass, one modeller judged that a different value was more appropriate for one situation. Modellers varied in how they estimated deposition on various surfaces from the initial value for deposition on grass. Artificial surfaces were considered impermeable by some assessors and permeable by others. An assumption about the permeability of a surface has obvious implications for the choice of weathering coefficients or other parameter values. Models also differ in their use of partition factors vs. deposition velocities, selection of weathering coefficients, which surfaces were included, and selection of decontamination factors. In general, the opportunity to compare approaches among several modellers can be extremely useful in helping to ensure adequate description of the situation to be assessed and identifying aspects (e.g., attributes of a surface, amount and heterogeneity of initial deposition) that need more adequate characterization.

Real-life dose calculations will depend greatly on individual locations and habits, which could differ greatly from typical “occupancy factors” such as those used in these exercises. In general, outdoor dose rates will be larger than indoor dose rates, but many people spend more time indoors than outdoors. Exposures involving large amounts of time (e.g., residential and occupational) will be more important than those involving shorter periods (e.g., school, occasional, or incidental). The occupancy factors can be defined for modelling purposes but will not necessarily give accurate dose estimates for individuals.

Much more information was collected for these test exercises than was actually needed or used by the modellers. The major types of data that are needed for a test exercise include: (1) detailed location information (e.g., a suitable map that includes building locations; building information such as dimensions, heights, and roof types; and other information about the local “environment” such as the percentage of various surface types); (2) information about the weather at the time of the contamination event (in particular, whether or not it was raining); (3) long-term average climate information; and (4) appropriate weathering data for the climate (e.g., temperate vs. tropical). Information on particle size and chemistry would be valuable for defining such things as contaminant distribution (dispersion, deposition, partitioning on different surfaces, ingression into buildings), weathering coefficients (movement between surfaces), and countermeasure effectiveness. These are also the most important types of information that relevant authorities need to collect if possible in case of an actual contamination event.

The specification of model endpoints is an important part of conducting a model comparison exercise. The endpoints have to allow the models to be adequately compared. For example, had the endpoints for the Pripyat scenario just included total external dose rate from all surfaces, valuable insights into the differences between models, such as the contributions of surfaces, would have been masked. On the other hand too many endpoints can make the task of model comparison overwhelming. For both scenarios, the percentage contribution to dose rate from the different surfaces was a useful endpoint. Although it synthesizes the effects of deposition, retention and the approach used to calculate dose rates, it still highlights important differences in the internal assumptions and approaches of the models in a reasonably concise set of outputs. In contrast, percentage contribution from different radionuclides for the Pripyat scenario proved to be a much less useful endpoint, as all models gave virtually the same result for each location.

Although it is desirable to specify endpoints, run models, and then compare results and measurements in a single iteration of a modelling exercise, this is probably unrealistic. In reality a number of iterations of the exercise may be required. It is almost impossible to completely specify endpoints so that there is no ambiguity. For example, even after 2–3 iterations of the Pripyat scenario, there were still differences between the modellers' assumptions about integration periods for the dose endpoints. Iteration is particularly necessary where models are under development.

The models used in these exercises were not necessarily developed for the particular types of situations modelled in the exercises, and in some cases they were intended to be specific for a certain country's typical buildings, construction materials, and climate. Therefore, they may have certain limitations when used to model other types of situations or locations. In general, the acceptability of a model will be enhanced if it has an adequate range of application and a good graphical user interface.

5.2. Areas for further study

The type of event (e.g., NPP accident, radiological dispersal device, industrial accident, weapons accident, fire) could affect particle size distribution, chemical form of the contamination, and geographical scale of the contamination. For example, a collection of information on parameters such as dry deposition velocities as a function of particle size would be valuable in assessing various potential contamination situations in advance, as well as ensuring a more useful and comprehensive database with which to make assessments of any real situation that might arise.

More information would be helpful for a variety of model parameters or components. These include the contribution of trees (various types, locations, and densities) to local dose rates, the relationship of particle size distribution to weathering from various surfaces, and how best to model tall buildings. It must be recognized that much of the available information on urban contamination, weathering rates and decontamination factors is based on Chernobyl data, largely for ^{137}Cs; it may not be applicable for other radionuclides, typical building materials in other parts of the world, or other climates. In addition, some decontamination factors may be applicable only for a very early period after contamination, or prior to the first rainfall. In general, additional information on weathering for different surfaces and climates would be valuable.

The modelling exercises described in this report for the most part considered countermeasures one at a time, rather than in combination. The effectiveness of combined countermeasures is not necessarily the sum of their individual effectiveness and may depend on the order in which they are implemented. For example, it is important to wash roads and roofs before it rains. This is another area in which further work would be useful.

Areas in which continued model development would be useful include the ability to handle multiple contamination sources (e.g., from simultaneous explosions) or spatially varying (uneven) deposition, or which can make direct use of GIS data. At the very least, it would be helpful to be able to use GIS data to make initial characterizations of locations of interest (e.g., obtain the percent coverage by various surfaces, building dimensions and materials, etc.), rather than the slower, although definitely useful, methods of manually characterizing the locations from higher-resolution maps, aerial photographs, and resources such as Google Earth. A current difficulty with GIS data is that roads are usually considered as lines; having widths of roads would simplify estimation of the contributions of different surfaces to the total external dose rate.

It could also be helpful to combine model predictions and measurements to improve the maps of contamination. Maps of surface contamination could serve as a starting point for the models. To make full use of the available information, these maps could be prepared by combining measurements and model predictions. This task is effectively completed with models such as IAMM [71] by applying data assimilation techniques. This could be used, for example, to delineate zones of intervention, especially when the source term is not known.

5.3. Uncertainty in urban assessment modelling

A general objective of the EMRAS programme on radioecological modelling is to test the quality of model predictions. The results for both scenarios described in this report demonstrated the importance of many factors that affect the reliability of assessment models. The reasons that the outputs of one model differ from those of other models or from actual measurements have been discussed extensively in Chapters 3 (Pripyat scenario) and 4 (Hypothetical scenario). Only one model in these exercises (CPHR) explicitly considered uncertainty in the calculations, and that was limited to uncertainty in the distribution of the initial contamination and in the dose conversion factors (the latter being relatively small). However, the spread of modelling results for many endpoints gives an idea of the highly uncertain nature of urban contamination modelling at the present time, due mostly to uncertainty in the conceptual model or in interpretation of the modelling scenario.

In general, the types of uncertainty can be broadly grouped into four categories [72]: (1) epistemic uncertainty of the model structure, i.e., the lack of confidence that the conceptual (mathematical/numerical) model is an adequate representation of the assessment problem; (2) epistemic uncertainty induced by the modeller, i.e., the uncertainty of translating a real or hypothetical situation in an available assessment model; (3) epistemic uncertainty of a model parameter, i.e. the uncertainty of a model parameter resulting from a lack of information or knowledge about its true value; and (4) aleatoric uncertainty of a model parameter, i.e. the variability of a model parameter arising from its true heterogeneity over space and time. These sources of uncertainty in predictive modelling are briefly summarized below.

Assessment models are, by their nature, a simplified representation of a complex situation, considering the multifaceted geometry of an urban environment, the large number of different types of surfaces and materials involved, and the wide range of natural and anthropogenic transfer processes. Simplification of a real or hypothetical situation for modelling purposes is a delicate balance between avoiding an excessive number of variable and uncertain input parameters and keeping the model flexible enough to represent relevant surfaces and dynamic processes. In other words, it is a compromise between robustness and oversimplification and depends on the purpose for which the model will be used. There are many possible ways to design a simplified conceptual model. Some of the models explicitly represent several typical urban surfaces as compartments, differing, however, in the number and types of surfaces considered. Interior surfaces, for instance, are sometimes disregarded, and sometimes predicted to be an important and even dominant compartment for a short time span after deposition. EDEM uses a different approach based on empirical functions for time-dependent location factors. Some of the models explicitly take into account transfers between surfaces, whereas other models do not. The developers of the new model ERMIN have chosen to ignore transfers between surfaces other than the major transfer from trees to soil which is too large to be disregarded. The design of a simplified conceptual model proved to be a key factor as to the overall predictive uncertainty.

The model testing exercises demonstrated that even experienced modellers may significantly increase the uncertainty budget. Uncertainties arise from the subjective interpretation of the specific situation to be modelled, i.e., from the way an assessor translates a real or hypothetical situation in a suitable assessment model. It is the experience of the Urban Remediation Working Group that it is almost impossible to completely specify the situation at hand and the endpoints without any ambiguity. For example, even after two or three iterations of the Pripyat scenario, there were still differences between the modellers' assumptions about integration periods for the cumulative dose endpoints. Apart from these individual perceptions, differences in model implementation and in parameter selection may substantially contribute to the overall spread of predictions. The subjective interpretation of a complex assessment problem and its translation in a simplified conceptual model turned out to be the second major contribution to the overall predictive uncertainty.

Individual differences but also common grounds in parameter selection affect the reliability of model outputs. For instance, some of the big differences between EXPURT and CPHR regarding the contributing surfaces in the Pripyat scenario in the long term can, among other factors, be attributed to a different parameterization. Many of the parameter values used for the model testing exercises, however, were of similar origin. The time-dependent location factor functions in EDEM as well as empirical parameter values for deposition and retention, and in some cases dose rate, were largely derived from Chernobyl data at mid and far distant locations from the Chernobyl nuclear power plant. Moreover, the effectiveness of countermeasures and remedial actions was mainly deduced from the experience after the Chernobyl accident. Choosing the same or similar data bases for modelling purposes clearly reduces the aleatoric uncertainties related to model parameters. Applying these parameter values to scenarios which differ from the Chernobyl situation by the radionuclide composition, the physical and chemical properties of the released radioactive material or the urban environment would inevitably introduce an epistemic uncertainty which is hard to quantify.

In summary, the Urban Remediation Working Group came to the conclusion that the uncertainties arising from the simplified structure of assessment models and from the perception and subjective interpretation of the situation to be modelled dominate the overall uncertainty of predictive modelling in urban environments. It is essential to acknowledge the capabilities, limitations and the scientific rationale of an assessment model, including the types and consequences of simplifications and assumptions and the range of applicability of the model. Confidence in model predictions can be improved as the understanding of the processes being modelled is improved or if measurements become available for use in calibrating the model. The purpose of a model and the needs of decision makers must also be considered, in particular whether it is intended to give conservative (protective) vs. realistic predictions or average vs. individual doses. While uncertainties need to be recognized, model predictions are still valuable tools for a variety of assessment types, e.g., retrospective, planning, and emergency response.

5.4. Practical considerations for decision-makers

The Working Group has not attempted to develop a consensus model or an optimization tool for decision-makers. These exercises have attempted to explain and highlight differences in models so that the models can be improved or areas where more research is needed can be identified. The Working Group identified several areas of potential interest to persons or organizations responsible for long-term planning or for remedial activities in case of an actual urban contamination event. For example, having typical pre-calculated situations “urban environments” for one’s own region or country would permit evaluation of various hypothetical events and responses in addition to expediting the planning and remedial responses in case of an actual contamination event. Such “environments” need to be tailored for the relevant region or country, including the building types and construction materials, types of trees, retention factors appropriate for the local climate, etc.

Several types of data that are essential for modelling urban contamination situations were identified by the Working Group. Persons or organizations responsible for cities, facilities such as NPPs, or other significant locations, need to consider assembling much of this information in advance of any actual need. This information includes (but is not limited to) the following:

- Detailed location information or the ability to generate such information as needed, including high-resolution maps (at least 1:10 000), detailed building information (sizes, heights, materials, roof types), land use, and sufficient information (e.g., dimensions of buildings and streets) to calculate percentages of surface types in a designated area;
- Shielding factors and dose conversion factors for representative buildings and a variety of radionuclides;
- Local construction materials and roof types (relevant to shielding factors and to weathering coefficients);
- Good information on surfaces (well-defined surfaces), possibly with a GIS-based classification scheme;
- Appropriate weathering data for the climate and local conditions (e.g., the relevant construction materials or local vegetation types);
- Long-term average climate information;
- Typical living habits of the population (e.g., occupancy factors); and
- Default source terms for different types of events.

In addition, responsible persons need to be prepared to obtain certain additional information immediately upon learning of an actual contamination event. If possible, this information has to include local weather data (conditions of actual deposition, e.g., wet, dry, snow) and visual observations of the plume from people in the vicinity.

The Working Group has considered modelling primarily in terms of radiological endpoints (contamination density, dose rate, and dose). For specific contexts or uses, decision-makers might find other endpoints to be desirable, such as risk estimates for various options (including no action), costs for certain remedial activities, doses to remediation workers, amounts and activities of the waste to be removed, surface activities, disruption to normal activities of residents, public acceptability or legality of proposed remedial activities, and availability of workers or equipment. Some information (e.g., sources of workers or equipment, costs of certain remedial activities, legal requirements) could be prepared or maintained by local authorities. Brown et al. [29] provide a generic handbook for European situations; other countries may wish to develop analogous documents for their own situations.

The countermeasures considered by the Working Group fall into three main types: relocation, or removal of people from the contaminated area; removal of contamination; and reducing the mobility of contamination. Other types of countermeasures include increasing of shielding (e.g., triple digging to put clean soil over contaminated soil) and restriction of access to (or use of) a building or area. For a situation such as the Pripyat exercise, in which a large part of a person's long-term dose was contributed by the shorter-lived radionuclides, relocation during the early period following the release substantially reduces the long-term dose. For a situation such as the hypothetical scenario, involving only the relatively long-lived ^{137}Cs, relocation during the early period reduces the dose during that period but has little impact on the long-term cumulative dose. Permanent removal of contamination, e.g., by removal of soil, grass, or trees, can have a much larger impact on reducing the long-term dose. However, the cost or other impact (e.g., environmental impact of removing trees or soil) may be considerable. These are all factors that need to be considered in planning, either for general preparedness or for a specific situation.

One finding from the model comparison exercises was the importance of looking at the contributions to dose rate from different surfaces. In several cases models gave comparable estimates of the overall dose rates for certain locations, but due to contributions from completely different surfaces. A decision maker who based his decisions on one model might target completely different surfaces than if the decision were based on another model. It is essential that both modellers and decision-makers take care that all potentially relevant surfaces are considered. In some contexts, contributions to dose from other exposure pathways (inhalation, inadvertent ingestion, deposition on skin) could also be important.

A decision-maker who is required to develop a countermeasure strategy must make judgments about how to use the resources available. In particular, it is important to consider the typical exposures of the majority of individuals as well as extreme or atypical cases of other individuals. For example, the dose endpoints requested for the modelling exercises represent typical behaviour and exposures. However, in some communities there will be individuals such as the elderly or infirm who remain in one location for a large proportion of the time and whose primary exposure might therefore correspond to one of the indoor locations. For example, an individual on the top floor of a building would receive a large proportion of the dose from the roof, and treatment of the roof would significantly reduce that individual's exposure. However, for most of the population, treatment of roofs is unlikely to produce a large dose reduction, but treatment of a few selected roofs might be very important in reducing doses to certain individuals.

Another example of a potentially important exposure situation that could occur is the use of a roof as a parking area. Most models consider roofs in terms of exposure from the contaminated surface to persons inside the building, below the roof. However, flat roofs on some buildings are used as parking areas, garden areas, or as locations for ventilation equipment that would require maintenance or servicing, such that humans will spend time on the roofs in ordinary circumstances and therefore would be exposed to any contamination on the roof (which for some situations could be considerable). Balconies or terraces may require similar considerations, both for assessment and for remediation in the case of an actual event.

An additional consideration for decision-makers is the purpose for which a given model was developed: was it developed to give conservative or realistic results. A conservative model is generally intended to demonstrate that a situation does not exceed a level of concern; however, the dose estimates or other endpoints may be an overestimate, even a substantial overestimate, of the actual situation. A realistic model, as its name implies, is intended to give an estimate of the true dose or other endpoint, within some limits of uncertainty. In general, for assessing a situation with respect to need for or feasibility of remediation, a realistic assessment is preferred over a conservative one. The latter could result in substantially higher costs of remediation or disruption of people’s lives, without actually giving an appropriate benefit in terms of dose reduction. Also, conservative models may differ in the conservatism present for different exposure pathways or remediation options, thus making comparison of alternatives less accurate.

In summary, it is essential for modellers and decision-makers to work together, so that the modellers provide the information needed by the decision-makers, and the decision-makers have the best possible information for their needs, provided in a useful form. Both groups need to consider the following issues:

— Selection of the appropriate model for the assessment purpose, including all relevant surfaces and exposure pathways that potentially contribute to individual doses;
— Avilability of relevant data sets and information bases prepared in advance of any contamination events;
— Availability of people prepared to obtain specific information in case of an actual event; and
— Atypical or unusual exposure situations that might be important.

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APPENDIX I. SCENARIO DESCRIPTION AND DOCUMENTATION OF DATA FOR THE PRIPYAT SCENARIO

Scenario for Modelling changes in radiological conditions in contaminated urban environments, Pripyat, Districts 1 and 4

I.1. Introduction

The overall objective of the EMRAS Urban Remediation Working Group is to test and improve the prediction of dose rates and cumulative doses to humans for urban areas contaminated with dispersed radionuclides, including (a) prediction of changes in radionuclide concentrations or dose rates as a function of location and time, (b) identification of the most important pathways for human exposure, and (c) prediction of the reduction in radionuclide concentrations or dose rates expected to result from various countermeasures or remediation efforts. The present scenario is based on Chornobyl (Chernobyl) fallout data for Pripyat, a town in Ukraine which was evacuated soon after the Chornobyl accident and has remained essentially uninhabited.

The scenario is designed to allow modeling of the changes over time of external exposure rates and concentrations of radionuclides in different compartments of an urban environment. Information is provided to support modeling for two districts of Pripyat, District 1 and District 4. For each district, participants are asked to model the effects of no remediation (only natural processes and any human activity) and of various specified remediation efforts on the changes over time of the radiological situation.

A set of input information (measurements of deposition and of radionuclide composition) are provided for use for all phases of the scenario, to provide a common starting point. Some additional data are provided for use in model calibration for participants desiring to do so. Test data (measurements) are available for some modeling endpoints; additional endpoints will also be used for model intercomparison.

This document provides information about the situation to be modeled (input information) and a list of the endpoints to be modeled. Note that all tables are provided in an accompanying Excel workbook. Data in GIS format (MapInfo or ESRI formats) are also available.

I.2. Background

In the context of urban radioecological study, the main interest is what radioactive fallout resulted, and when and where it fell out during the active phase of the Chornobyl accident. According to a number of assessments, the series of heat explosions in the fourth Chornobyl power unit were caused by actions of the operating staff and due to the nuclear-physical conditions that arose and to the constructional peculiarities of the nuclear reactor [I.1]. The safety system of the reactor and its building were destroyed. Products of nuclear fuel processing and of the reactor constructional materials were released to the environment. The largest releases continued for 10 days until May 6, 1986, and their distribution depended on fractional composition, height of elevation in the atmosphere, and meteorological conditions near the reactor and in regions where the radioactive clouds passed [I.1, I.2].

The first radioactive cloud, which had formed during the explosion, under conditions of steady night weather, was elevated to 300–500 m height and went to the west, creating a long (up to 100 km) and almost straight, narrow trace [I.2]. It passed south of Pripyat’s residential buildings by 1.5–2 km. This trace fallout contained many unoxidized fuel particles, some of which were very large (up to 10–100 μm) and were deposited along the first kilometers of the cloud's path [I.3]. Also, at the moment of the explosion, almost all of the reactor's noble gases were released into the atmosphere [I.2]. Further, during natural fuel heat-up and graphite stack burning (up to 1800–2000 °K), a spurt of radioactive releases was elevated to 1000–1200 m height and directed to the northwest [I.1, I.2], bending around Pripyat. They were enriched by highly mobile, volatile radionuclides (I, Te, Cs) and finely dispersed, oxidized fuel particles (1–3 μm). In the surface layer of the atmosphere, the air current was transferred mainly to the west and southwest directions. By noon of April 26, the plume reached the settlement of Polesskoe and crossed it by a narrow trace. The dose rate[1] reached 0.1–0.6 mR h^{-1} there (in some places, 2.0 mR h^{-1}) [I.4].

On April 27, the north and northwest directions of surface air currents prevailed. This caused a quick worsening of the radiation situation in Pripyat. On April 26, the radiation level in the town was 0.014–0.13 R h^{-1}, but by the evening of April 27, this level had reached 0.4–1.0 R h^{-1}, and in some places, 1.5 R h^{-1} [I.1] (by other data, up to 4–7 R h^{-1} [I.5]). During the period of 14:00–16:30, all of the town's residents were evacuated. The strongest radioactive fallout occurred along the eastern outskirts of the town. Although during that time the releases were enriched by small particle aerosols with sublimated radionuclides, there were also some heavy combustion products which precipitated on the closest territories, including Pripyat's surroundings. On April 28–29, the radioactive releases began to lose height (600 m) and activity, and the transfer turned gradually to the northeast [I.2].

Because of a considerable decrease of reactor core temperature, the intensity of the radioactive releases gradually dropped by April 30 (up to 6 times [I.2]). This promoted the intensive oxidizing of fuel [I.3] and determined the character of further releases. As a result of the first countermeasures undertaken, the reactor core was very filled up, which made heat exchange worse and contributed to a new active stage of the accident. Starting May 2–3, 1986, the reactor core warmed up again. Radioactive releases had a large fraction of dispersed oxidized fuel particles. Because the prevailing direction of air currents had changed since the afternoon of April 29, the main plumes of the Chornobyl fallout lay to the south [I.2]. That continued till May 6, 1986, when the intensity of the releases dropped to 1% of the initial amount and less. Further radioactive releases continued to decrease, and had almost ended by May 25, 1986 [I.2].

Thus, the Chornobyl accident and the following spread of radioactive releases caused contamination of broad territories in Europe, including several urban areas. Deposition from the accident contained a wide spectrum of nuclear fission products, activation products, and transuranium elements. Fallout in the town of Pripyat was mainly in the form of finely dispersed fuel. The total level of deposition reached up to 80–24 000 kBq m^{-2} of ^{137}Cs, 50–6660 kBq m^{-2} of ^{90}Sr, and 1.5–200 kBq m^{-2} of $^{239+240}$Pu [I.6][2]. Deposition data for the specific districts of Pripyat considered in this scenario are discussed later.

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1 For purposes of this scenario, assume that "R" refers to Roentgen for measurements made in 1986 and to Rad for measurements made in 1987 or later.

2 Another source [I.7] gives the following information (MBq m^{-2}) for the density of surface soil contamination in Pripyat (4 km from the source of contamination), measured in the summer of 1986: ^{144}Ce, 55.5; ^{141}Ce, 4.4; ^{103}Ru, 4.85; ^{106}Ru, 14.43; ^{137}Cs, 5.22; ^{134}Cs, 1.96; ^{95}Zr, 28.7; ^{95}Nb, 53.7. These values represent at least 3 samples 15 cm in diameter, taken to a depth of 5 cm.

I.2.1. Description of the town of Pripyat

The town of Pripyat was established in 1970 (on the place of a village called Semykhody and close to a village called Novoshepelychy) as a town for the staff and builders of the Chornobyl NPP and related facilities and services. The town of Pripyat occupies nearly 600 ha (including 42 ha of lawns and forest areas). In 5 microdistricts there are 149 multistoried buildings. The total apartment area is about 520 000 m^2 (13 500 flats and up to 30 000 rooms). The total length of underground communications is 135 km, including 52 km of heating main. The area of industrial premises is 30 000 m^2, and of other non-residential buildings, 10 000 m^2 [I.4].

All of the population (up to 49 360 at the time of the accident) was evacuated in 1986 as a result of accidental radioactive contamination, and the town has remained uninhabited since then. Different kinds of decontamination works were fulfilled there during 1986–1990, which allowed for the use of some buildings, communications and areas for temporary placement of research, monitoring, service and industrial enterprises which worked on problems of the Chornobyl zone and NPP until 1994–1998. Later the town became almost totally abandoned. It remains an area of restricted access.

The town of Pripyat is situated 3 km northwest of the Chornobyl NPP (2.7 km from the destroyed fourth unit to the closest residential buildings, 3.5 km to the town center), on the right bank of the river bearing the same name, on the first terrace above the floodplain. The town surface topography is mainly flat, with a small slope towards the floodplain. Within most of the region, the elevation amounts to 112.5 m, with only the southeastern outskirts containing hilly uplands up to 118–120 m above sea level. The altitude differential at the terrace is approximately 5–7 m. From the northeast, the following floodplain water basins directly approach the town area: Pripyat backwater and Semykhody oxbow. Before the accident, these water basins flowed into the Pripyat River. The surroundings of the town include meadows of the river floodplain and the first terrace (some of them were arable lands before the accident); spotted spread of pine tree plantations (mainly 15–30 years old) along the southeast, south and southwest outskirts; and 90 ha of sandy plateaus, up to 5–7 m high, inwashed by the floodplain northeast of Pripyat for future building (at the time of the accident, the sands had no surface fixation). The town had railway, river and developed road communications with other regions.

I.2.2. Structure of the urban area

The town has an area of up to 4.5–5 km^2 (together with the Chornobyl NPP industrial area, forest areas and sand plateau, up to 18–20 km^2). Structurally, there are eight residential microdistricts (1, 1a, 2, 3, 3a, 4, 4a, 5) within the town area (Figure I.1), as well as some adjacent sectors that were used as industrial and recreational zones or were being prepared for further buildup. Microdistricts 1, 1a, 2, and 3 (closest to the NPP) are the oldest (5–15 years by 1986); these areas had developed tree and bush vegetation. The wood vegetation of new microdistricts 4, 4a, and 5 (opposite side of the town from the NPP) was mainly developed after the accident. The buildings occupy approximately 18% of the total residential area; asphalt and concrete coverings, 20%; natural conditions (pine forests), not more than 12%; gardens with cultivated soils, 4%; lawns, public gardens, and other town green areas, 24%; other areas, 23%. There is a public park (up to 10 ha) and sport stadium. The forest plantations occupy approximately 20% of the surrounding lands; the rest is mostly industrial areas. The town has a developed system of industrial and storm sewage, road network, and other communications.

I.2.3. Type of soil and vegetation

There are three variants of soil and hydrological conditions within the town territory. The southeastern part is located in the artificially planned hilly terrace above the floodplain, which consists of well-selected sands more than 2 m thick and the soddy, weakly podzolic soils that have formed above them. Before construction activities started, there had grown white-mossed and green-mossed pine forests of artificial origin. The central main part of the town (up to 50% of its total area) is situated on these same sands, but with clay veins; soils are represented by soddy, weakly podzolic powder-sandy ones.

Before the town was constructed, these plots had been partially ploughed up (or used for pasture) and partially planted with pine-tree plantations, which further became a part of the town’s woodland plantations. The northwestern part of the town is located in powder sands with light loam and loamy-sand interbeds at the depth of 0.3–0.7 m; soil covering is composed of soddy-podzolic powder-sandy soils, which become clayey below a depth of 0.3–0.4 m. These plots had been ploughed up before the town was constructed.

In the course of constructing the town (in the 1970–80s) the local landscape and ecological conditions were considerably changed. The fact that trenches were several meters deep resulted in irreversible changes in lithologic and groundwater conditions. Light, sandy soils were reinforced with gravel mounds that were littered by construction waste. In this way, the site, which differed from the adjacent soil in soil texture and chemical characteristics, was formed. The following post-construction recultivation activities were added to these changes: filling a peat or meadow sod layer, using organic and mineral fertilizer, and artificial irrigation. As a result, a rather complicated pattern of soil-substrate conditions and vegetation cover has emerged.

Vegetation of the town is mainly represented by deciduous woods and bushes of artificial plantation (chestnut, lime, maple, poplar, locust, weeping willow, etc.). Almost all are of comparable age with the age of the corresponding microdistricts. The oldest vegetation was in microdistricts 1, 1a, 2, and 3: up to 15–20 years by the time of the accident. In new microdistricts 4, 4a, and 5, there were mostly young, newly planted trees. Within the residential area there are only two pine-tree plantations (in microdistricts 1a, 3), which were there before the town was built. Many more pine-tree plantations surround the residential area in the southeast, south and southwest outskirts (recreation area). Some southern plantations were 30–50 years old by the time of the accident, the rest, up to 20–30 years. There were many rosebushes and other bushes, and many flowerbeds and lawns. There were a few ploughed plots within the residential area (traditionally, flowerbeds and small plots around the trunks of trees). Fallen foliage and grass were always taken away before the accident (commonly, in April).

It is very important to note that, by the end of April 1986, deciduous trees and bushes had only just begun to open their leaves, while the pine-tree plantations had very developed surfaces for adhesion. However, during the 10 day acute period of the accident, all leaves were opened and were able to capture radioactive fallout [I.2].

After the population was evacuated, natural transformation processes of vegetation cenosis began. Under conditions of the absence of human care, former lawns, flowerbeds, play-yards and other open plots were transformed to meadow-like areas, and wood plantations to semi-forest areas. Forest litter began to form under the canopy of trees and bushes, and juvenile soil on waterproof surfaces of roads and footways [I.8]. Humidity has increased in most of the forest districts.

I.2.4. Building types

In the town there are mainly multistoried residential buildings (5–16 storied). The old microdistricts (1, 1a, 2) have mostly 5-storied buildings, while microdistricts 3, 3a, 4, 4a and 5 have almost all 9-storied ones. Only 7 buildings have 16-storied height. The buildings of 1–3 stories were used for different public purposes (schools, kindergartens, hospital, clinics, theaters, sports, shops, etc.) or for services and facilities (municipal, instrument-making plant, greenhouses, transport parks, laundry, garages, etc.). There are approximately 400 buildings total, located in the town and out on the surrounding area (55% are residential; 13% are schools, kindergartens, hospitals, etc.). Some buildings belong to the surrounding area, outside of the town circle.

Almost all buildings have plane (flat) roofs, waterproof external surfaces, and external balconies. Most of buildings are constructed from large or medium size concrete blocks; some are constructed from bricks and finished by ceramic tiles. The town had a district heating, water and power supply.

Figures I.2 and I.3 show the layout of the buildings in Districts 1 and 4, respectively, of Pripyat and the number of stories in each building. Table P-1[3] contains additional information on the buildings in Districts 1 and 4, including the heights, type of use (e.g., apartment house, school, etc.), and types of materials.

I.2.5. Population and activities

In April 1986 the town had 49 360 people (including approximately 17 000 children), and the population density was approximately 10 000 people per km^2. A considerable part of the adult population was busy in operative, service and management works at the Chornobyl NPP. Many people worked at the building sites of the town and new power-units. There were 5 schools (plus one was being built), 1 technical school, 16 kindergartens, and one large hospital complex. Many people were busy with municipal and transport services and in trade.

I.3. Contamination

As a result of the Chornobyl accident, the Pripyat urban area was contaminated many times, by different sources, and very heavily altogether. Still now the level of contamination of the town remains increased, in comparison with natural background, especially with respect to the content of transuranium elements.

According to the data of a Chornobyl meteorological station, during the first nights after the accident there was almost still weather at the surface layer of the atmosphere, while at upper layers there were west and northwest prevailing winds. In April 26, 1986, radioactive fallout was deposited mainly in the southern district of the town, which was sparsely populated with a railroad station and a market, and the adjoining settlement Yanov and lawn-and-garden plots of Pripyat residents. The heavy constituents of the radioactive releases (explosion products)

[3] All tables are found in the accompanying Excel workbook, details of which are to be found at the end of this Appendix.

were deposited on industrial and forest areas, nearest to the unit. Also, this day and in all subsequent days, radioactive ‘dirt’ was brought into the town by transport and people, creating local irregular contamination. During the day of April 26, radioactive releases continued to be transferred to the west and southwest, passing Pripyat. The radiation level in the town was about 0.014–0.13 R h^{-1} [I.1]. By noon of April 27, the wind had changed and was directed to the eastern outskirts of Pripyat. The exposure dose rate quickly increased up to 0.4–1.0 R h^{-1}, and in some places, 1.5 R h^{-1} (by other data, up to 4–7 R h^{-1} [I.5]). During the period of 14:00–16:30 all of the town’s residents were evacuated. The main radioactive precipitation fell out on the town during April 27–29. All fallout was dry and contained many ‘hot’ particles (finely dispersed fuel and reactor constructional materials). Thus, the most strongly radioactive fallout occurred along the southern and eastern outskirts of the town. A meteorological data set for the first days (26 April–30 June 1986), for the Chornobyl meteorological station, is provided in Table P-2; additional meteorological data are provided in Tables P-3 through P-9.

The first observation point network was established by ChNPP radiation protection service officers. These data included 26 points located in the town of Pripyat (Figure I.4). There are four sets of data: 26.04 12:00, 26.04 24:00, 27.04.12:00, and 27.04 17:00. (On the basis of these data, the Government Committee made the decision about evacuation of the town's population, which was formally accepted about 12:00 27.04.) Isolines of dose rate at each time point, based on these data, are shown for the whole town of Pripyat (Figures I.5–I.8). The data for the observation points are given in Table P-10. For the isolines, values of the dose rates in and near Districts 1 and 4 of Pripyat are provided with coordinates in Tables P-11 through P-14 (information to correlate the map coordinates for the isolines with latitude and longitude is provided with Table P-11).

During the summer of 1986, some dosimetrical surveys were done in the town by a team of students from “Gorkiy Polytechnic Institution”, department of radiation safety. These students were involved in activities directed toward liquidation of the consequences of the Chernobyl catastrophe on the temporal principles. They made measurements in some local areas of the Zone (especially in the town of Pripyat) during the summer of 1986 (probably mid-June to the beginning of July). Some sets of data from this team are available, but the notes from this expedition have not been located. The data obtained by this team for Districts 1 and 4 of Pripyat are given in Figures I.9 and I.10 and Table P-15.

I.4. Decontamination activities

Some decontamination activities in Pripyat were carried out for the whole town, but the most extensive decontamination efforts were applied primarily in District 4. Details of the decontamination efforts are provided below. A summary of the decontamination activities carried out in various areas is provided in Table P-16; the areas are shown in Figure I.11.

Decontamination of the town was done in two stages. During the first stage (May–June 1986), all buildings, roads and trees were washed using a fire-hose and a surface-active additive. Road surfaces (asphalt, concrete, etc.) were treated with clay solutions, which were then washed. Levees were built on the river bank along the northeastern and northern border of the urban area. During periods of intensive decontamination, the industrial and storm sewer systems were plugged to prevent drainage of radioactive materials into the Pripyat River. During the summer of 1986 the streets of the town were regularly treated with dust-suppression techniques.

The first decontamination work in the town of Pripyat was carried out hurriedly (over a few days) in the beginning of May 1986 on a small area opposite the hotel 'Polessje', where the Government Committee was staying during the accident's active phase. The work included washing of areas and buildings, and removing of some lawns (Site 1 in Figure I.11 and Table P-16).

Some days later (11.05.86) a decision was made to conduct test decontamination of some buildings. On 14.05.86 the first three buildings in micro-district 4 were experimentally decontaminated to define a more successful method of decontamination [I.9, I.10]. The best results were given by water-jet methods (fire-hose, with or without additive surface-active substance of trade mark 'SF-2U'). The decontamination coefficient for concrete surfaces was approximately 20 times, for other surfaces, 10–100 times. The flat rubberoid roof remained almost as dirty as before treatment, and needed to be intensively cleaned by brushes. Adjoining asphalt covers were cleaned up to background level. Using this experience, 70% of residential buildings and adjoining areas (roads, vegetation) were washed by the end of June 1986.

The next stage began in September 1986 and included total decontamination of some areas. During September 3–20, the western and central part of micro-district 4 (Sites 2 and 4 in Figure I.11 and Table P-16, including 9 residential buildings, two kindergartens, a school, and 2 dormitories later used for accident staff) were decontaminated [I.10]. The decontamination coefficient of glaze surfaces was approximately 160 times. The brick surfaces and relief wall plaster had the lowest decontamination coefficients (10 and 15, respectively). Intensive treatment of roofs using washing and brushes gave 10–20 fold results. Ground areas were decontaminated by bulldozer removal of the 10–15 cm upper soil layer (9.9 ha total); the radiation level dropped from 20–40 to 3–7 mR h^{-1}, and after additional manual cleaning, to 0.7–2.2 mR h^{-1}. On a plot, when decontaminated ground was covered up by clean sand (5–10 cm layer), radiation reached 0.3–0.7 mR h^{-1}. Damaged ground surfaces were treated with silicate and vinyl compositions. Interior apartments of the buildings were also decontaminated.

Dust-suppression technologies included an application of technical lignosulphates (TLS) for ground areas (land or air spraying), and oil tailings for road surfaces (land spraying) [I.11]. These works were carried out in May–October 1986, on the town's territory and surrounding areas (including sand plateau, 'red forest' and industrial area; includes Sites 8 and 12 in Figure I.11 and Table P-16). Due to the decontamination works, the average exposure dose rate in the town in December 1986 dropped to 2.8 mR h^{-1}, while without their performance it could be about 20–40 mR h^{-1} [I.12]. The same activities were expanded to areas of micro-districts 4a, 3a, and 2a in 1987.

Decontamination of the town of Pripyat was carried out to provide convenient conditions for work and rest for the accident staff. The following buildings and working areas were restored (including Sites 3, 8, 9, and 10 in Figure I.11 and Table P-16): Special Enterprises 'Complex' (former building of city administration and some others), Enterprises 'Specatom' (former instrument-making plant 'Jupiter'), Department of dosimetry control (buildings of former technical school, and Lab of external dosimetry), scientific organizations (former kindergarten, greenhouses and adjoining technical area in district 4a), department of town's communication, water-cleaning plant and transport parks (districts 2a and 3), special laundry (district 1a), telephone office center (town's center), police department (district 2a), and some others. In total, up to 22 buildings were restored. Decontamination works took place on 246 ha; up to 110 000 m^2 of building outdoor surfaces were cleaned, and up to 13 000 m^2 of roofs.

Up to 100 000 m^3 of contaminated upper soil layer were removed, and 144 000 m^3 of clean sand were brought in. All restored buildings and areas were provided with heat and electric power from Chornobyl NPP, and water from deep wells. Water cleaning and sewage constructions were also restored.

Since 1988 decontamination measures in the town have been carried out occasionally and in restricted areas, but dust-suppression washing of the streets was continued regularly in arid seasons for at least 10 years after the accident.

Some areas surrounding Pripyat to the east, south and southwest (Sites 12 and 13 in Figure I.11 and Table P-16) were totally decontaminated in 1987–1989 also, to eliminate sources of secondary contamination of the town and to decrease the dose burden on the accidental staff. These areas were: sand plateau (to east, close to the town), “red forest” and industrial area (to south, 1.5–2 km from town), and former railway station settlement ‘Yanov’. In 1986 only dust-suppression technologies were used, based on land or air spraying of technical lignosulphates (TLS) and oil tailings for road surfaces (land spraying) [I.11]. In the spring of 1987 a new technique of land fixation was tested on a plot of the sand plateau. A mixture was sprayed, including some kind of latex, peat pellets and cereal seeds (including oats) [I.13]. During April–June 1987 almost all areas around the Chernobyl NPP and Pripyat were treated by this method. A new technique included an application of TLS and cereal seeds, together with a thicker peat layer (3–5 cm) on damaged surfaces. The center of the town of Pripyat was treated by this method [I.14]. Use of both methods gave an unstable effect: some areas did not get surface layer fixation.

In September 1987 the next technique was applied. The damaged surfaces were treated by TLS and ground limestone, then the area was ploughed; seeds of wild cereals were sowed together with winter rye, and then the ground was additionally treated by TLS [I.11]. This also gave unstable results. Later the area of the former ‘red’ forest was additionally planted by bushes and trees (1988–1990). The grass cover inside Pripyat districts (damaged by decontamination works) was restored also. However, the sand plateau still remains without grass and wood vegetation, and its surface layer is only partially fixed by poor moss cover.

Due to the countermeasures on soil fixation and dust-suppression, air contamination was decreased by ten times already in the summer of 1987 [I.13]. Since July 1987 air contamination in Pripyat’s district 4 did not exceed 18.5×10^{-2} Bq m^{-3} [I.15]. By other data, air radioactive deposition in the town in the summer of 1987 was 37–74 Bq m^{-2} per month (^{137}Cs), the total concentration of beta-emitting radionuclides in air was approximately 10^{-5} Bq m^{-3}, and of alpha-emitting radionuclides, 10^{-7} Bq m^{-3} [I.12]. In 1987 the main contribution to the value of the exposure dose rate in Pripyat was provided by ^{144}Ce and ^{134,137}Cs, with a gradually increasing fraction of ^{137}Cs (Table P-17). The radionuclide concentrations in air at the two automatic radiation control posts (‘Stadium’ and Lab of external dosimetry) during the 1989–1991 period are given in Table P-18.

As a result of removing the original upper soil layer and without application of fertilizers and new humus soil, the decontaminated areas have a peculiarity of low radionuclide binding. On the decontaminated depletion areas, ^{90}Sr and ^{137}Cs migrate down and transfer to vegetation more intensively [I.6].

I.5. Input information (deposition data)

Deposition information (radionuclide content in the top layer of the soil) for Districts 1 and 4 of Pripyat is provided in Tables I.1 and I.2 (below) and Table P-19 (in the Excel workbook). Vertical distributions of activity in soil for the same samples in District 1 are given in Table I.3 (below) and Table P-20 (in the Excel workbook). These data are to be used as the starting point for calculations for the Pripyat scenario.

I.6. Additional data for use in calibration

Two additional sets of data are provided for use in calibration, if desired. The first of these consists of detailed measurements of activity on several buildings in District 1a of Pripyat (very close to District 1) in October 1986. A description of the situation, including detailed diagrams of the buildings and sampling points, is provided in the Annex to this Appendix, including Table A-1 (in the Excel workbook). Details of the measurements are provided in Table A-2.

The second data set consists of the results of an air gamma survey (^{137}Cs, Bq m^{-2}) performed in 1991. These data are given in Table P-21 and Figures I.12 and I.13 for Districts 1 and 4 of Pripyat. Table P-21 gives the calculated values of ^{137}Cs density of contamination for a grid size of 50 $\times$ 50 m.

I.7. Modeling endpoints

The modeling endpoints for Districts 1 and 4 of Pripyat are as follows:

(1) External exposure rates (dose rates, mGy h^{-1}) at specified locations, from all relevant surfaces (by surface and by radionuclide, and total);
(2) Contributions to the dose rates (%) from each surface and each radionuclide, for the most important surfaces and radionuclides;
(3) Annual and cumulative external doses (mGy) to specified reference (hypothetical) individuals (District 4 only); and
(4) Radionuclide concentrations (Bq m^{-2}) at the outdoor locations.

Model calculations need to start about 3–4 months after the Chornobyl accident and need to be carried forward for at least 10 years, preferably 20 years. Results need to be presented as a time series, with the date specified for each predicted dose rate, dose, or radionuclide concentration. Example formats are provided in the accompanying Excel workbook.

The remedial measures (countermeasures, remediation measures) to be considered in model calculations are listed in Table I.4 (below), together with the time of application to be assumed. Information on effectiveness of various countermeasures is available in documents prepared by B. Zlobenko and S. Golikov (See Appendix V of this report) and in other literature.

For dose calculations (District 4 only), use the following (hypothetical) reference individuals:

(1) An adult, employed in indoor work;
(2) An adult, employed in outdoor work;
(3) A pensioner;
(4) A child, attending school or kindergarten; and
(5) A pre-school child.

For reference children, predictions of annual dose are requested; for reference adults, annual and cumulative doses are requested. Suggested occupancy factors are provided in Table I.5 (below) and Table P-22 (in the Excel workbook). Assume that the individuals lived and worked in District 4, in the following situations and locations:

- "inside homes", Location 17 (first floor of apartment building);
- "inside at work" (indoor workers and outdoor workers), Location 16 (kitchen/canteen at apartment buildings);
- "inside at school" (school children and pre-school children), Location 23 (first floor of school);
- "outside, asphalt surfaces" (all adults), Location 21 (road);
- "outside, asphalt surfaces" (children), Location 22 (schoolyard);
- "dirt surfaces" (all persons except outdoor workers), Location 15 (yard outside apartment buildings);
- "dirt surfaces" (outdoor workers), Location 20 (yard between apartments and school);
- "kitchen gardens", Location 15; and
- "virgin land" (inside city) and "forests and meadows" (outside city), assume initial deposition for District 4 for undeveloped (natural surface) land and forest/grass, respectively, and no remediation.

All endpoints will be used for model intercomparison. Test data (measurements) are available for a few locations and time points (described above), which will permit comparison of model predictions and measurements for selected situations.

I.7.1. District 1

In District 1, the changes over time of actual external exposure rates and radionuclide concentrations are due primarily to natural processes (no human activity, no remedial measures). However, for the purposes of the modeling exercise, the effects of various countermeasures will also be considered, i.e., if the countermeasure had been applied, what would have been the effect on dose rates and radionuclide concentrations.

For each test location in District 1 and for each applicable countermeasure, calculate the external exposure rates (mGy h^{-1}) and radionuclide concentrations (Bq m^{-2}) at nine specified locations (Figure I.14; map positions are given in Table P-23). Locations 1, 2, 5, and 6 are outdoors, two of them next to a road, one on a natural surface, and one on an artificial surface. Locations 3 and 4 are indoors in schools. Locations 7, 8, and 9 are on the 1st, 3rd, and 5th floors of a 5-story apartment building.

I.7.2. District 4

In District 4, the changes over time of actual external exposure rates and radionuclide concentrations are due to both natural processes and human activity, including various remedial measures. The effects of various countermeasures will be considered for the purposes of the modeling exercise, although not all countermeasures were applied in all locations.

For this phase, calculate the external exposure rates (mGy h^{-1}) and radionuclide concentrations (Bq m^{-2}) at fifteen specified locations in District 4 (Figure I.15; map positions are given in Table P-23). Also calculate the doses to reference individuals, assuming that people had lived in District 4 for the entire period covered by the model calculations.

Five of the locations (Locations 10–14) are outside the areas where remedial activities were implemented; the other ten locations (Locations 15–24) are within the areas where remedial activities were implemented (Sites 2 and 4, Figure I.11) and where people lived for several years after the accident. Locations 10, 11, and 12 are indoors on the 1^{st}, 5^{th}, and 7^{th} floors of the unfinished end of an apartment building. Locations 13 and 14 are outdoors, one on a natural surface and one on an artificial surface. Locations 15, 20, 21, and 22 are outdoors; two of these are on natural surfaces, one on a road, and one on an artificial surface outside a kindergarten. Location 16 is indoors in a 1-floor kitchen. Locations 17, 18, and 19 are on the 1^{st}, 5^{th}, and 9^{th} floors of a 9-story apartment building adjacent to the kitchen. Locations 23 and 24 are on the 1^{st} and 2^{nd} floors of a 2-story kindergarten building.

I.7.3. Documentation of model predictions

For each phase of model predictions, appropriate documentation was requested, including key assumptions and specific parameter values used. Model documentation is provided in Appendix III of this report. For each countermeasure (or combination of countermeasures, if appropriate), requested documentation includes a description of how the countermeasure was modeled and the parameter value(s) used.

I.8. Test data (measurements)

Some test data are available for the period 1996–1998, for 1999, and for 2006. The 1996–1998 data are from a dosimetric survey done in 1996–1998. These data were presented in a report of the Chornobyl Scientific and Industrial Center for International Research in 1999. Measured dose rates at locations in Districts 1 and 4 (in the vicinity of the test locations) are provided in Table T-1 (in the Excel workbook). The sampling locations are shown in Figures I.16 and I.17. Sampling dates for specific measurements are not available.

The 1999 data are from a sampling and dosimetric survey of Pripyat based on a permanent observation network. Data include dose rates (surface and 1 m height) and surface contamination of various radionuclides (kBq m^{-2}, 0–5 cm). Data for locations in Districts 1 and 4 (in the vicinity of the test locations) are provided in Table T-2. The sampling locations are shown in Figures I.16 and I.17. Sampling dates for specific measurements are not available.

Additional measurements of dose rate were made by S. Gaschak and A. Arkhipov on 25 July 2006, as close as possible to the test locations (Figures I.14 and I.15). Measurements were made with a DBG-06T dose meter (trade mark, Russia) at a height of 1 m above the ground or floor. Six measurements of 30 seconds each were made. Results of the measurements (individual results, mean, and standard error) are provided in Table T-3, together with a description of the location where each measurement was made. Aerial photographs of the test areas showing the measurement locations are provided in Figures I.18 and I.19. One interesting feature noted when the 2006 measurements were made was the accumulation of detritus in the uninhabited city, something that would be less likely in an inhabited location but which could contribute to higher than expected levels of contamination remaining over time.

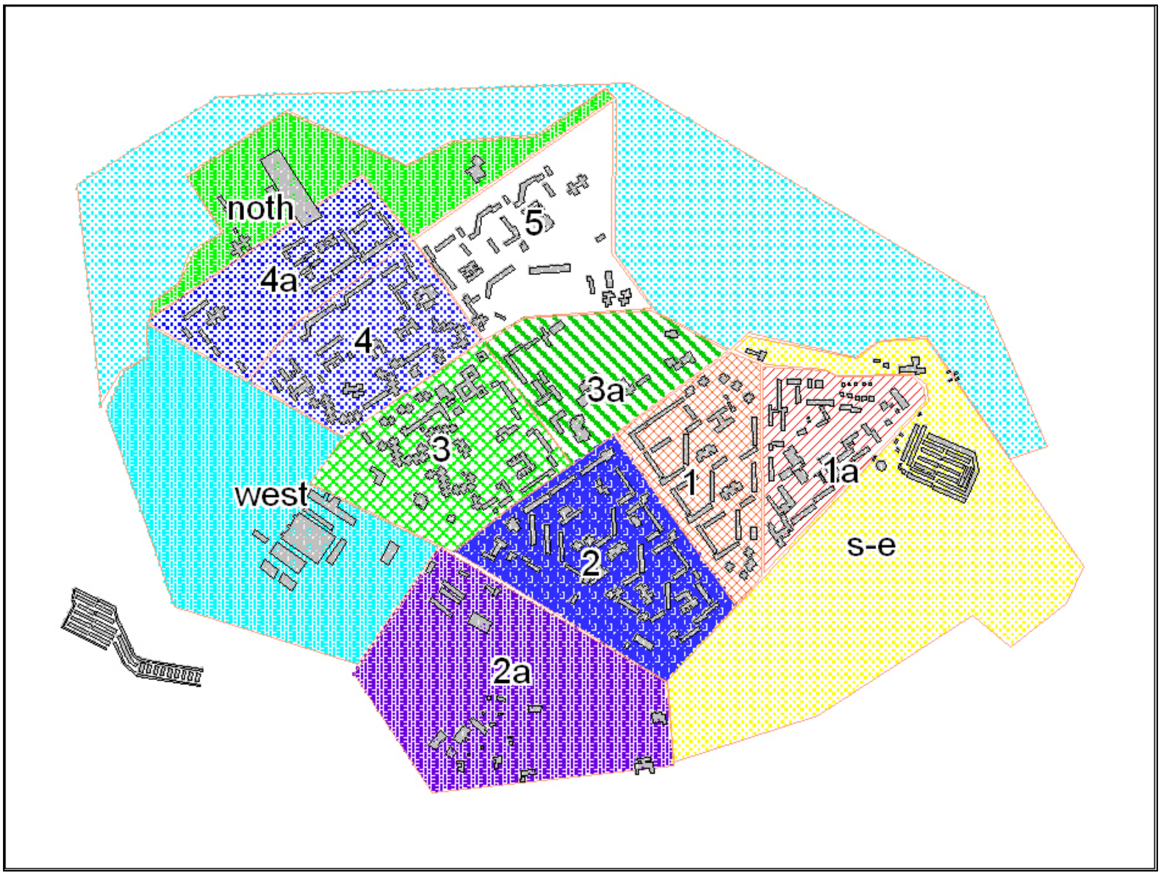

Fig. I.1. Map of microdistrict locations in the town of Pripyat.

Fig. I.2. Map of District 1 of Pripyat, showing building locations and heights. Buildings are listed by number in Table P-1.

Fig. I.3. Map of District 4 of Pripyat, showing building locations and heights. Buildings are listed by number in Table P-1.

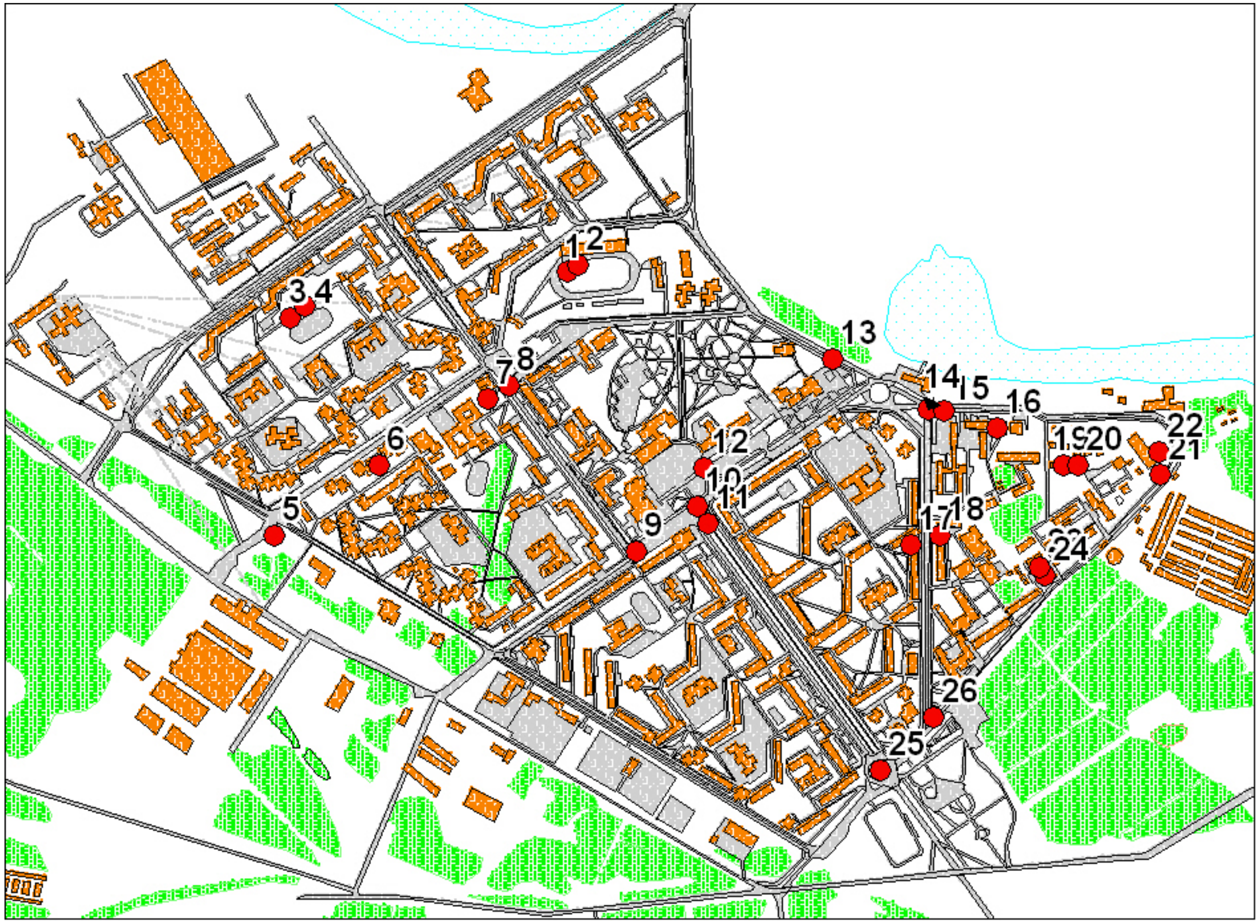

Fig. I.4. Locations of the observation points in Pripyat for measurements made during 26–27 April 1986. Data obtained at these points are provided in Table P-10. Isolines derived from these measurements are shown in Figures I.5–I.8, and the are data provided in Tables P-11 through P-14.

Fig. I.5. Isolines of dose rate (mR h^{-1}) in Pripyat at 12:00 (noon) on 26 April 1986 (see also Table P-11).

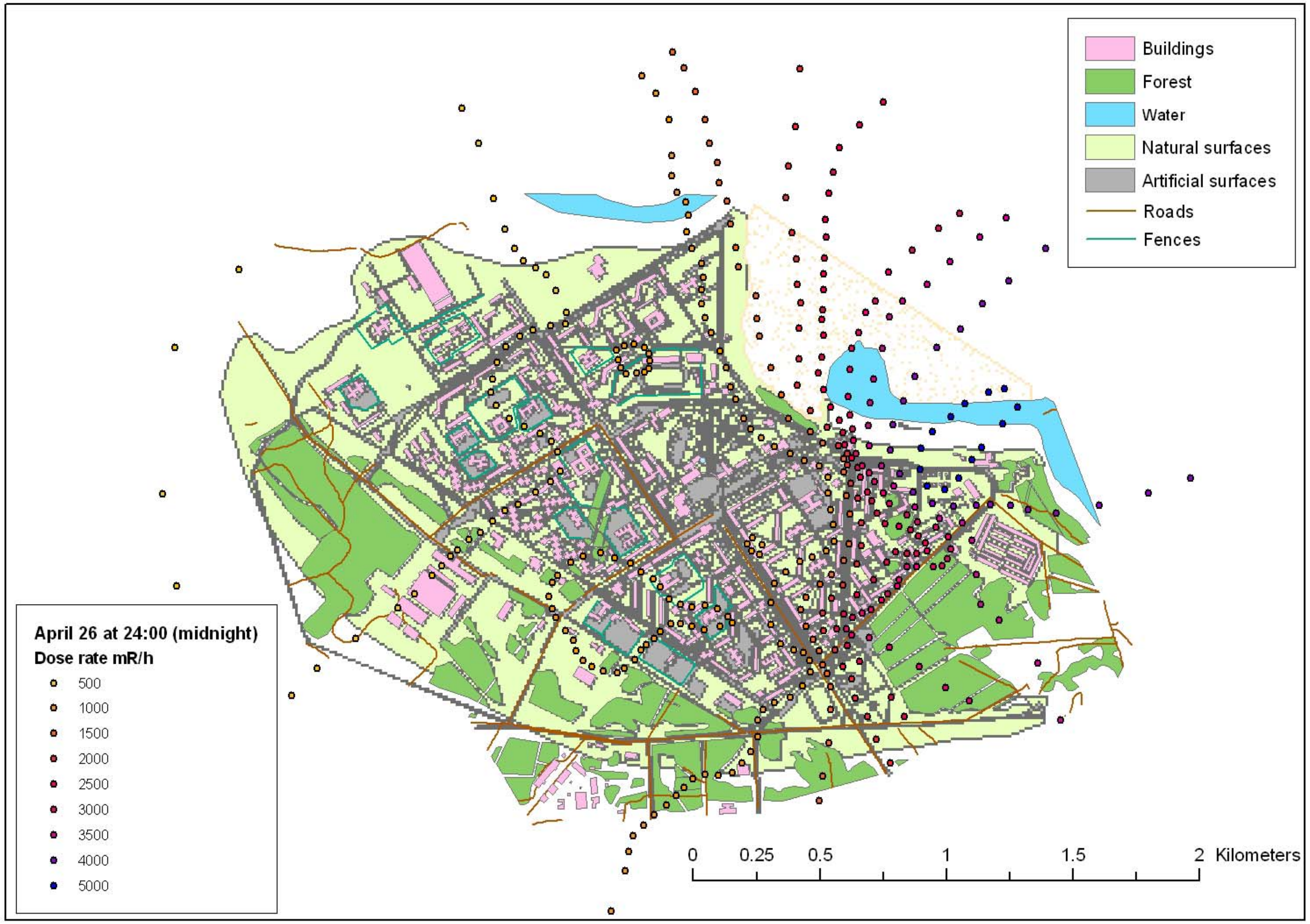

Fig. I.6. Isolines of dose rate (mR h^{-1}) in Pripyat at 24:00 (midnight) on 26 April 1986 (see also Table P-12).

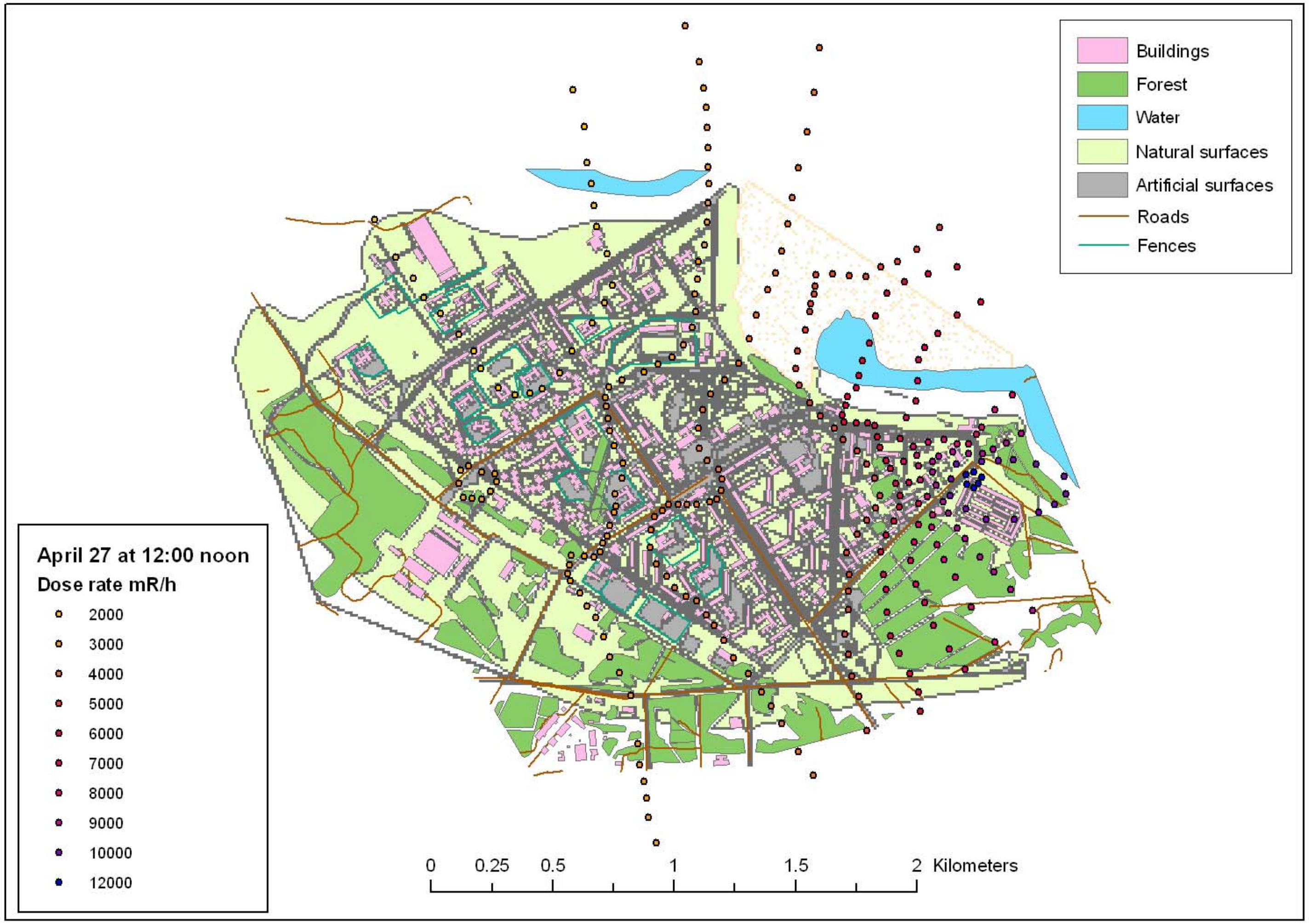

Fig. I.7. Isolines of dose rate (mR h^{-1}) in Pripyat at 12:00 (noon) on 27 April 1986 (see also Table P-13).

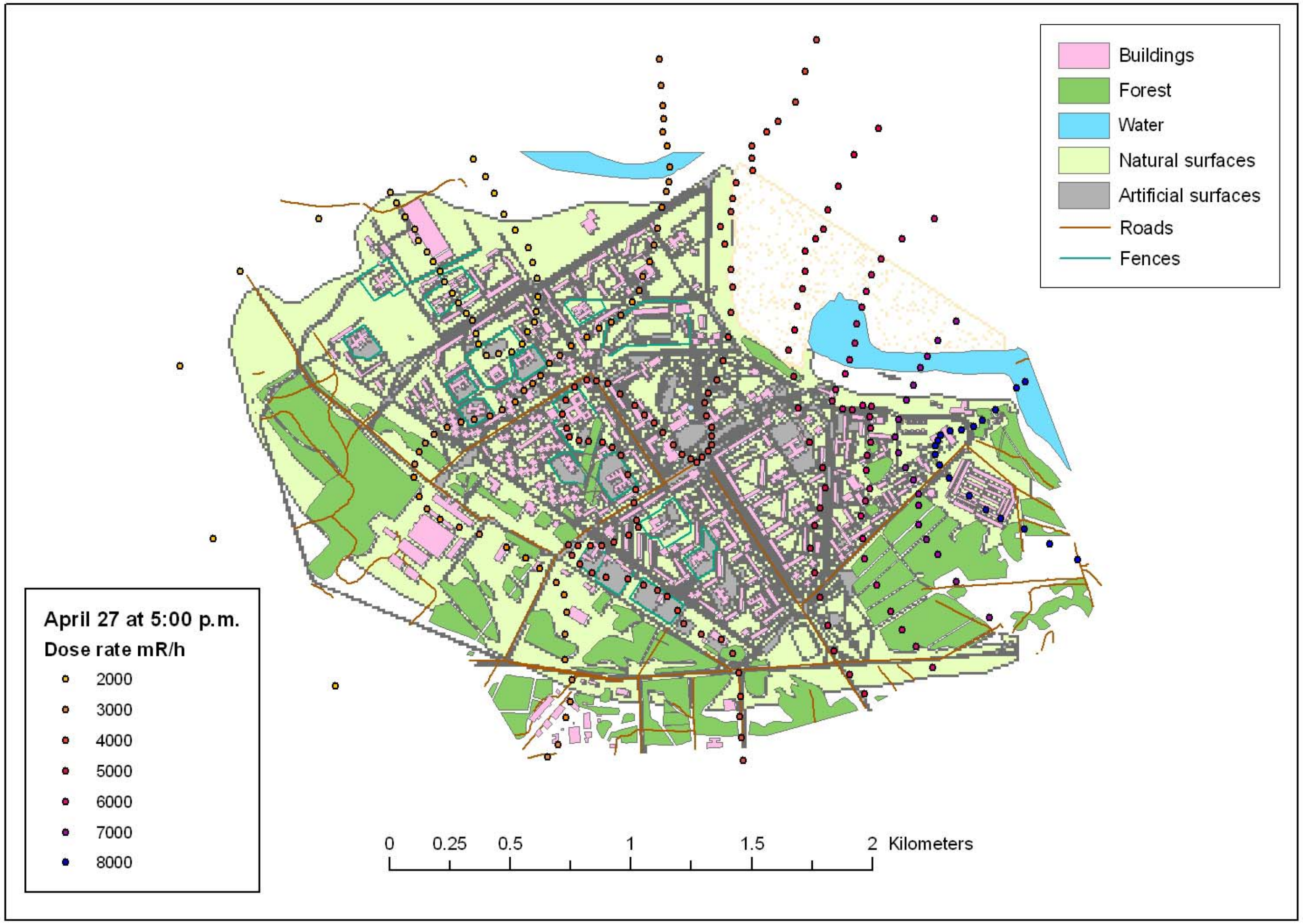

Fig. I.8. Isolines of dose rate (mR h^{-1}) in Pripyat at 17:00 (5:00 p.m.) on 27 April 1986 (see also Table P-14).

Fig. I.9. Dose rates (mR h^{-1}) measured in District 1 of Pripyat during the summer of 1986. Measured values are given in Table P-15.

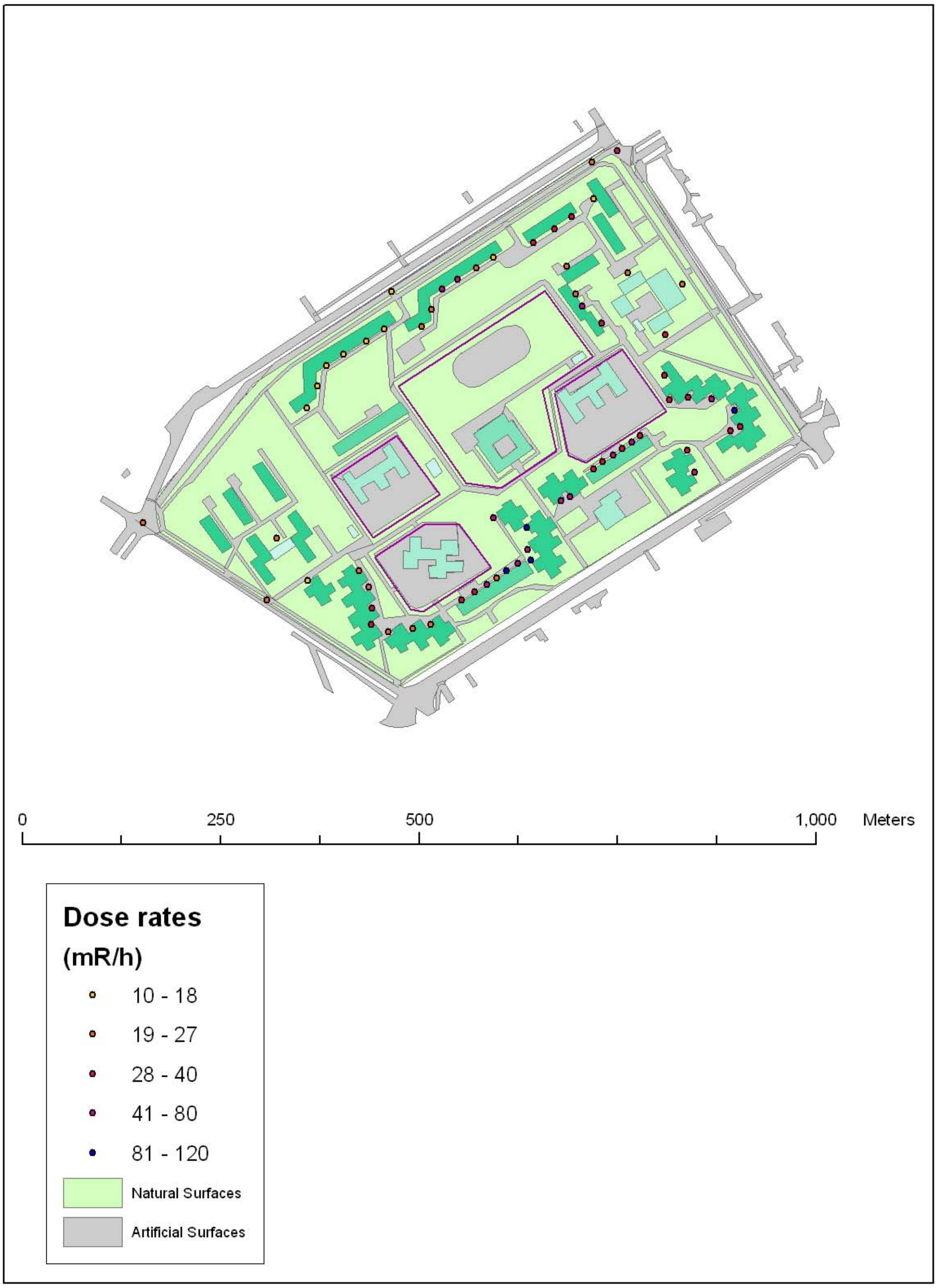

Fig. I.10. Dose rates (mR h^{-1}) measured in District 4 of Pripyat during the summer of 1986. Measured values are given in Table P-15.

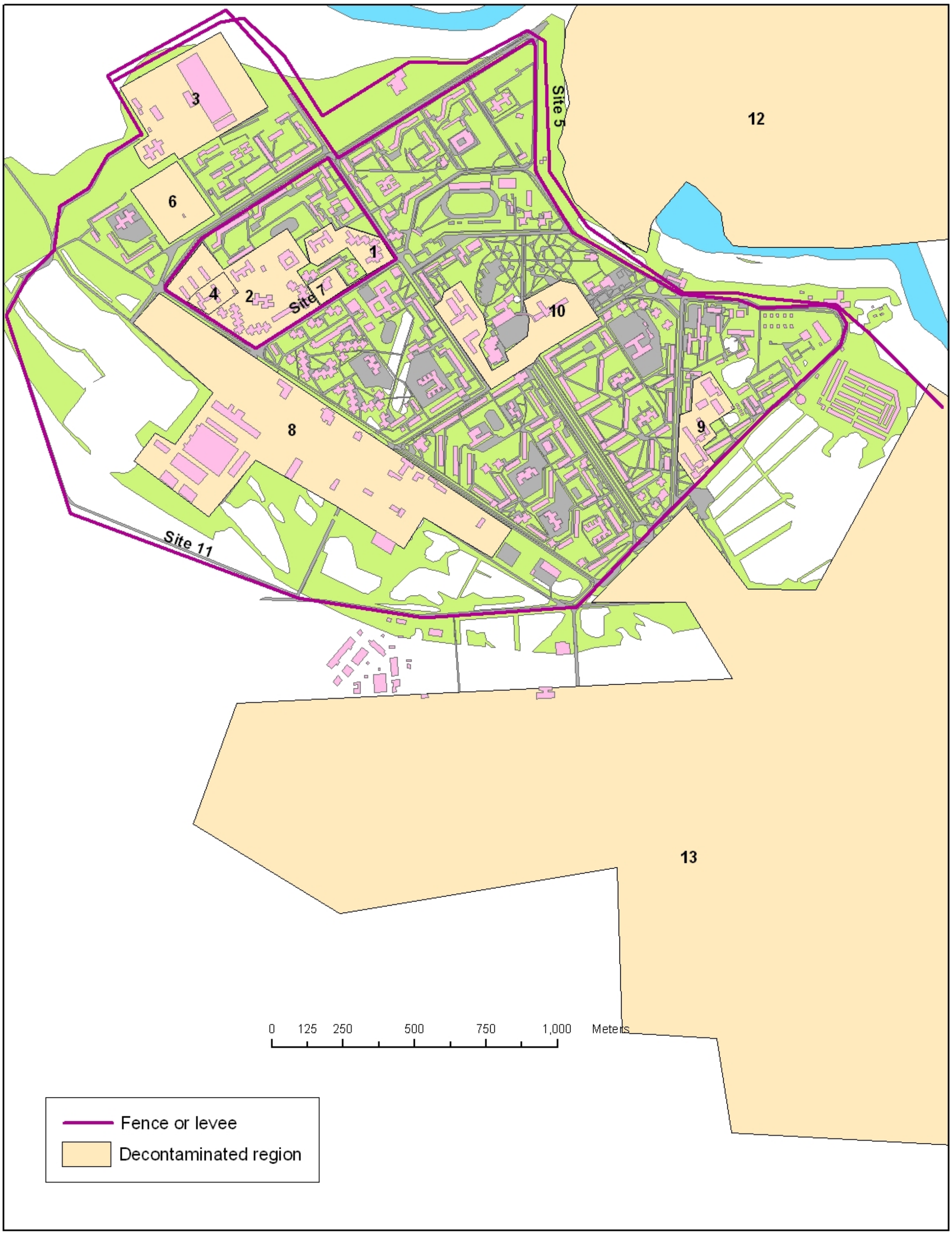

Fig. I.11. Map of Pripyat showing the sites where major decontamination activities were carried out. For details of the activities in each area, by number, see Table P-16 and the main text. Note that sites 5, 7, and 11 correspond to fences or levees, rather than areas.

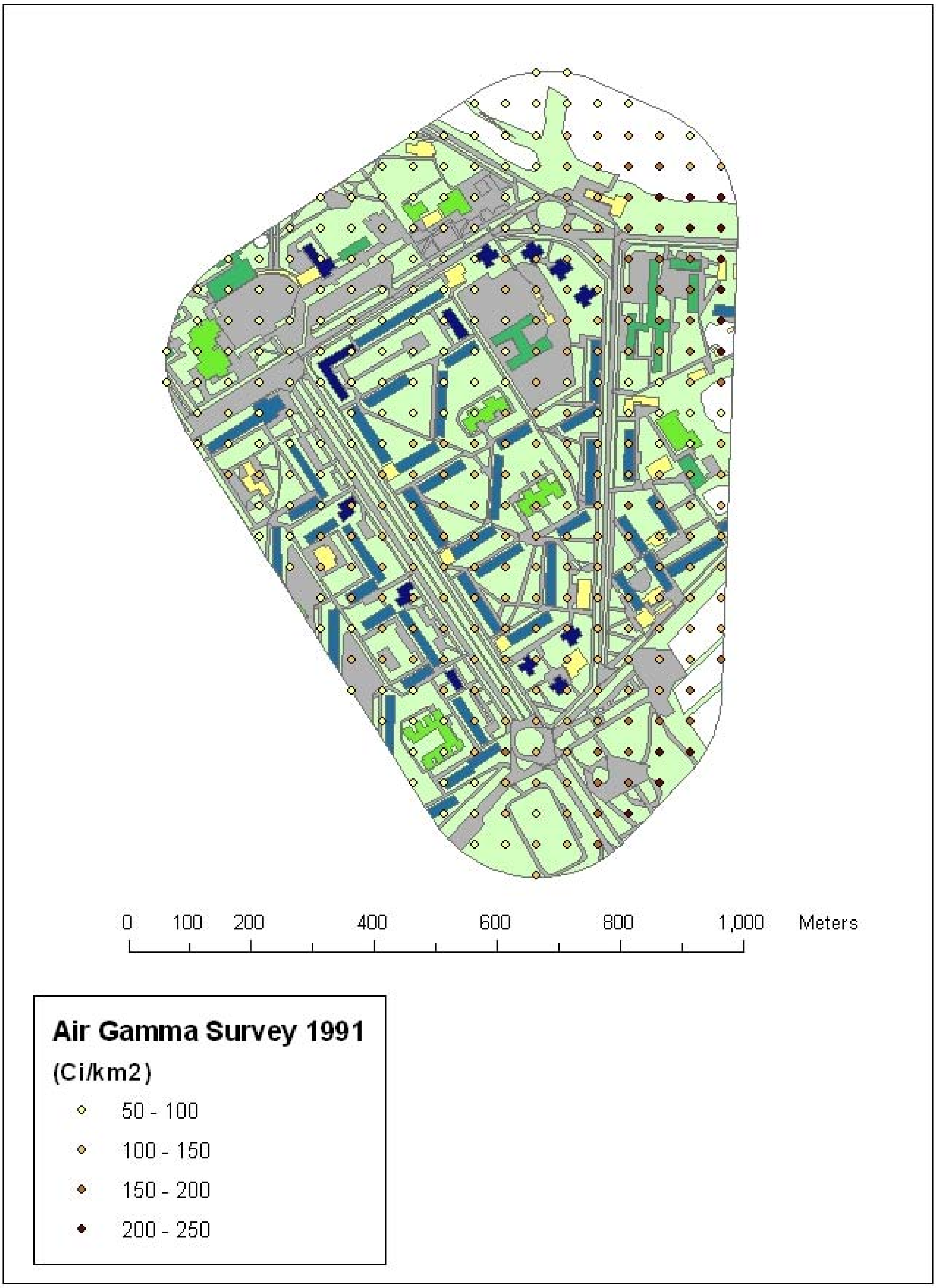

Fig. I.12. Results of an air gamma survey performed in 1991, shown for District 1 as calculated values of ^{137}Cs contamination density (Ci km^{-2}) for a 50 × 50 m grid. Values are provided in Table P-21.

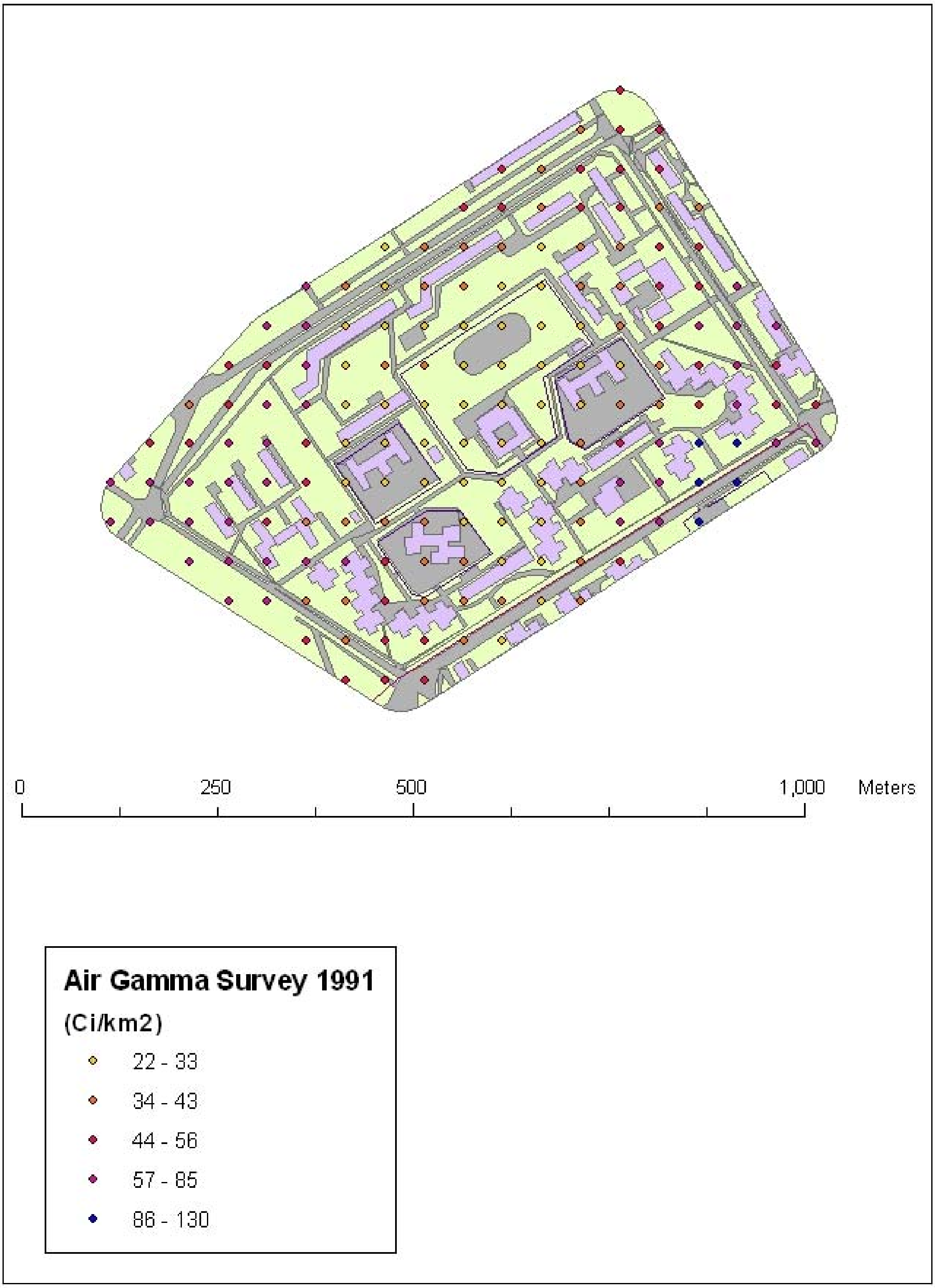

Fig. I.13. Results of an air gamma survey performed in 1991, shown for District 4 as calculated values of ^{137}Cs contamination density (Ci km^{-2}) for a 50 × 50 m grid. Values are provided in Table P-21.

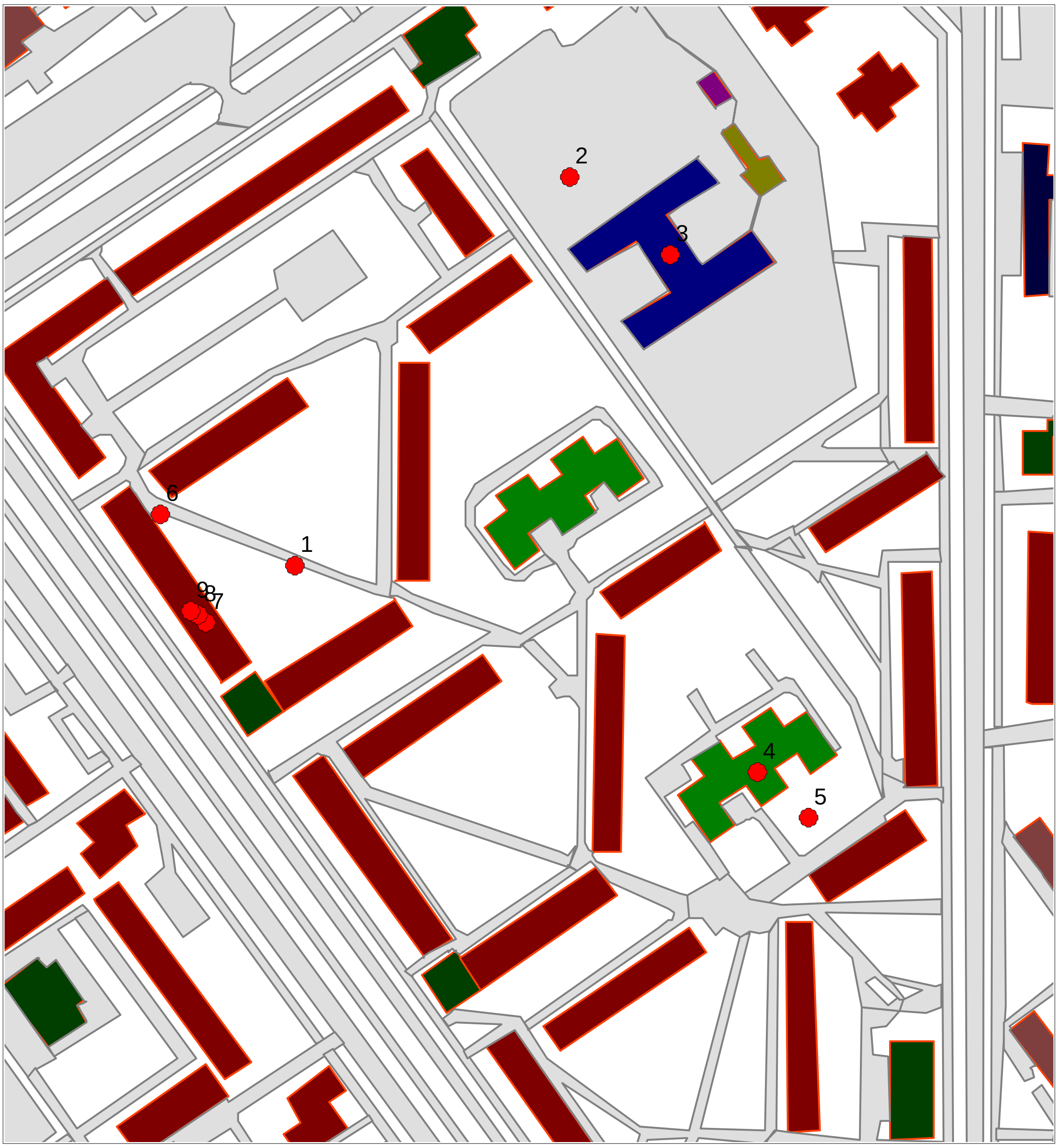

Fig. I.14. Locations for model calculations in District 1 of Pripyat. Map positions of the locations are given in Table P-23. Locations 1, 2, 5, and 6 are outdoors. Locations 3 and 4 are indoors in schools. Locations 7, 8, and 9 are on the 1st, 3rd, and 5th floors of a 5-story apartment building.

Fig. I.15. Locations for model calculations in District 4 of Pripyat. Map positions of the locations are given in Table P-23. Locations 13, 14, 15, 20, 21, and 22 are outdoors. Locations 10, 11, and 12 are indoors on the 1st, 5th, and 7th floors of the unfinished end of an apartment building, and locations 17, 18, and 19 are indoors on the 1st, 5th, and 9th floors of a 9-story apartment building. Location 16 is indoors in a 1-floor kitchen. Locations 23 and 24 are on the 1st and 2nd floors of a 2-story kindergarten building.

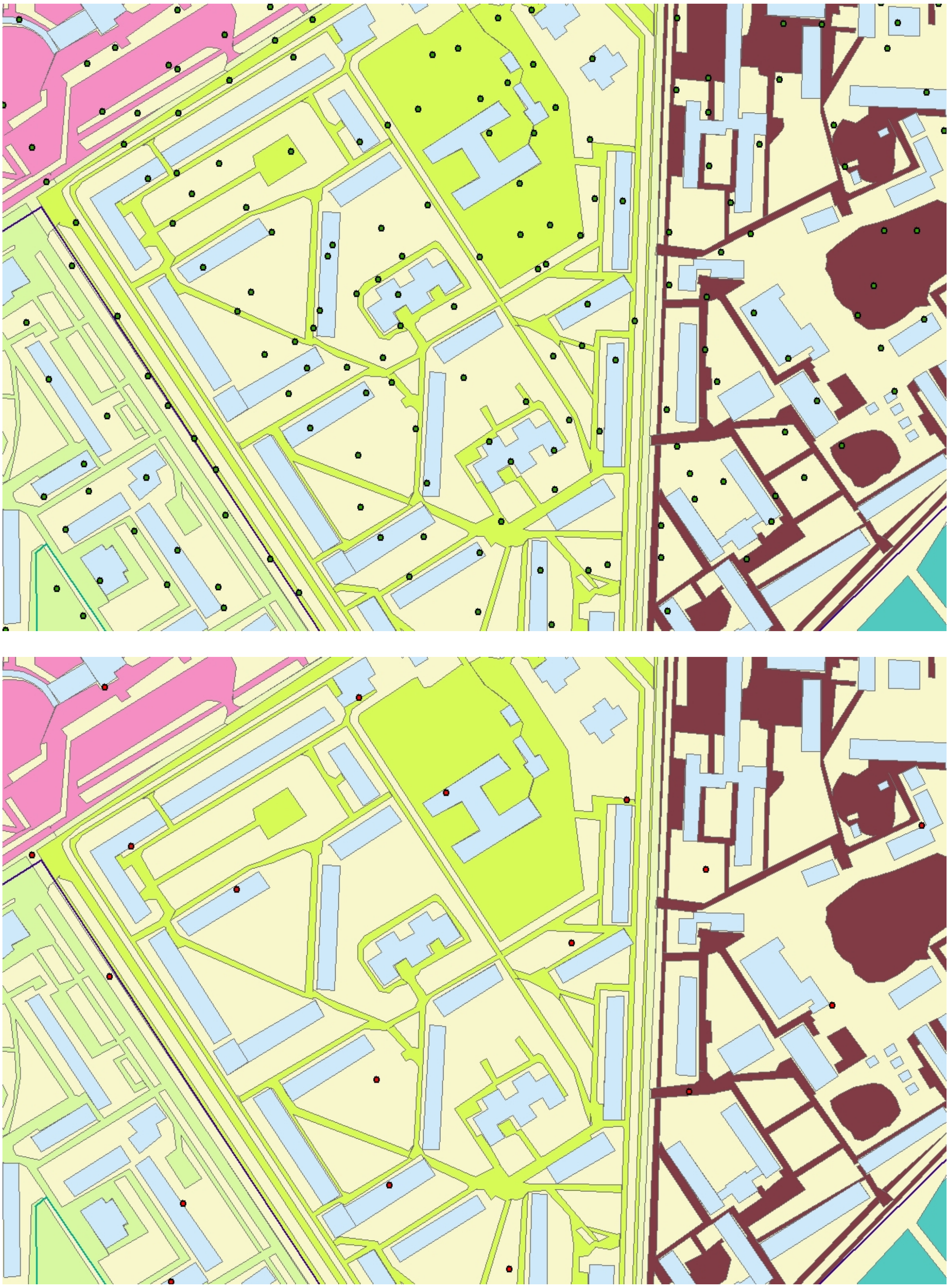

Fig. I.16. Locations of measurements made in 1996–1998 (top) and 1999 (bottom) near the test locations in District 1 of Pripyat. Values and map positions are provided in Tables T-1 and T-2.

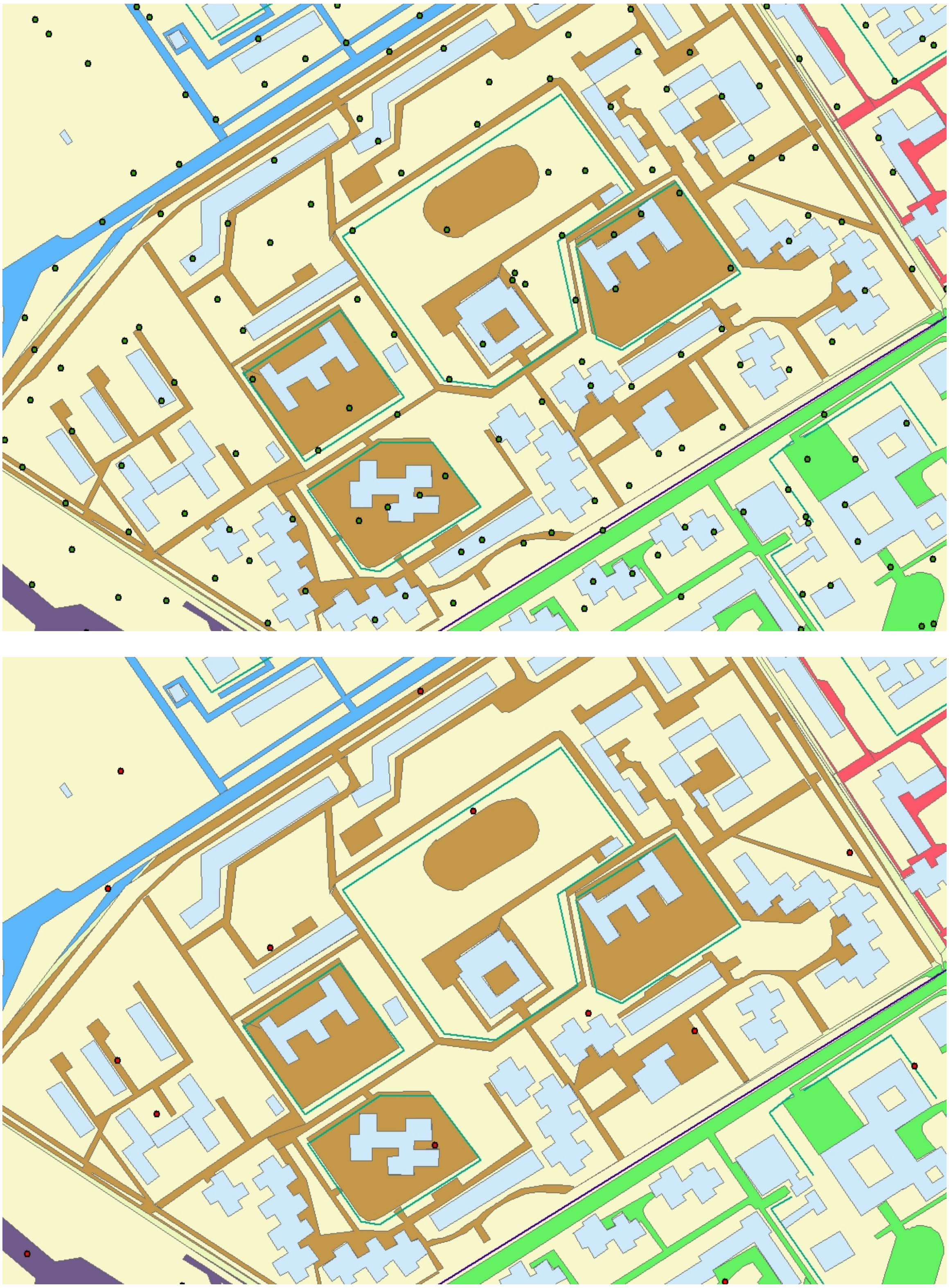

Fig. I.17. Locations of measurements made in 1996–1998 (top) and 1999 (bottom) near the test locations in District 4 of Pripyat. Values and map positions are provided in Tables T-1 and T-2.

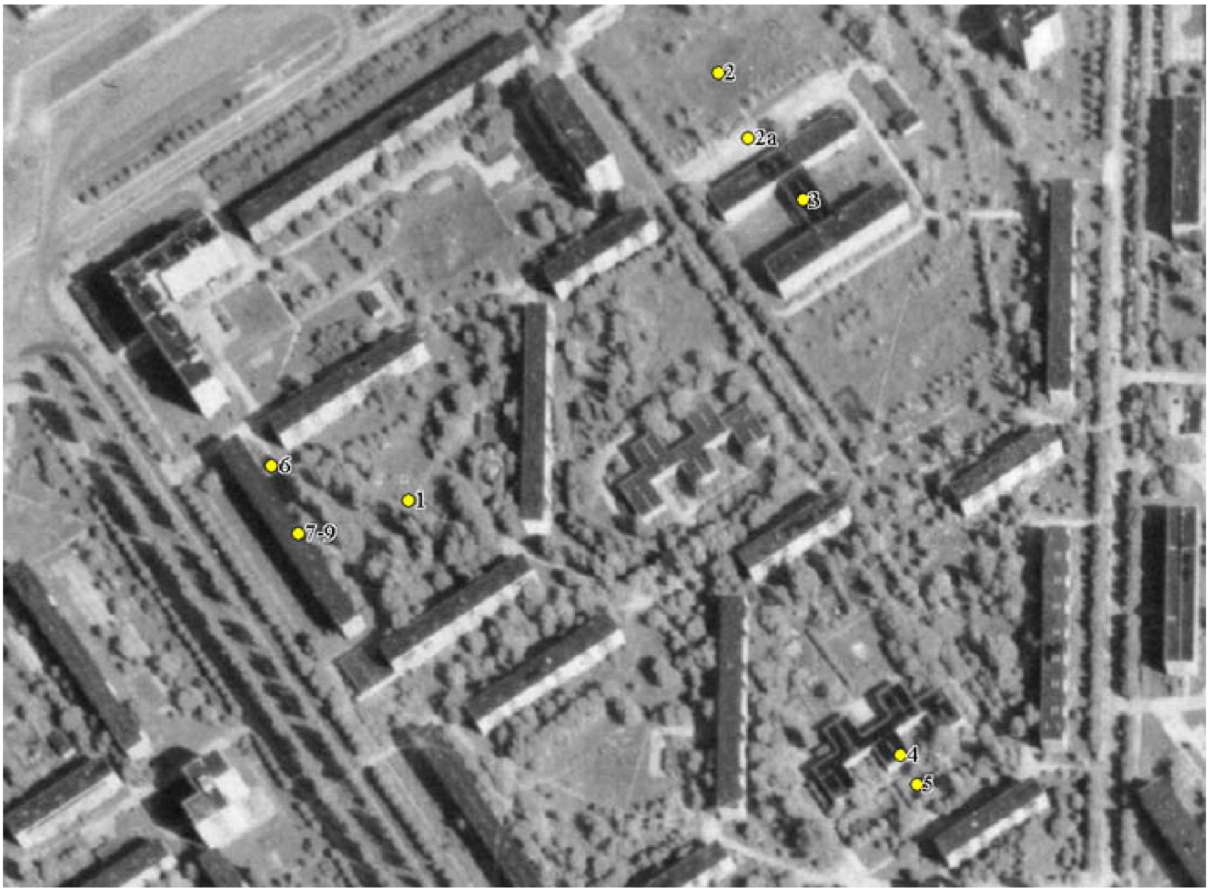

Fig. I.18. Locations of measurements made in 2006 at the test locations in District 1 of Pripyat. Values are provided in Table T-3.

Fig. I.19. Locations of measurements made in 2006 at the test locations in District 4 of Pripyat. Values are provided in Table T-3.

Table I.1. Measured deposition in District 1 of Pripyat.

Radionuclide	MBq m^{-2} Nearest sample[a]	% of radionuclide Nearest sample[a]	Three samples[b] Mean	Std. Dev.
^{95}Nb	12.811	28.91	29.95	1.241
^{95}Zr	7.816	17.64	16.51	1.367
^{103}Ru	1.647	3.72	3.79	0.085
^{106}Ru	4.079	9.21	10.89	1.959
^{134}Cs	0.703	1.59	1.40	0.189
^{137}Cs	1.397	3.15	3.03	0.373
^{141}Ce	1.036	2.34	2.26	0.087
^{144}Ce	14.800	33.40	32.11	1.125
Total gamma	**44.308**			

[a] Based on 1 sample, obtained 26 September 1986.
[b] Including the nearest sample, obtained 9 September, 26 September, and 4 October 1986.

Table I.2. Measured deposition in District 4 of Pripyat[a].

Radionuclide	MBq m^{-2}	% of radionuclide
^{95}Nb	4.995	30.00
^{95}Zr	2.835	17.03
^{103}Ru	0.578	3.47
^{106}Ru	1.438	8.64
^{134}Cs	0.296	1.78
^{137}Cs	0.523	3.14
^{141}Ce	0.574	3.44
^{144}Ce	5.365	32.22
Total gamma	**16.65**	

[a] Based on 1 sample, obtained 24 September 1986.

Table I.3. Vertical distributions of activity in soil in District 1 (Bq kg^{-1} dry weight of soil)[a].

Area of sample (cm)	Depth (cm)	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{134}Cs	^{137}Cs	^{141}Ce	^{144}Ce
Sample date 26 September 1986									
20 × 20	0–1	1.02E+06	6.25E+05	1.32E+05	3.26E+05	5.62E+04	1.12E+05	8.29E+04	1.18E+06
	1–2	2.46E+04	1.37E+04	3.21E+03	7.84E+03	1.57E+03	3.44E+03	1.73E+03	2.14E+04
	2–3	2.68E+04	1.68E+04	3.36E+03	7.81E+03	3.00E+03	7.96E+03	2.82E+03	2.64E+04
	3–5	4.37E+03	2.56E+03	3.81E+02	5.66E+02	2.87E+02	6.07E+02	4.48E+02	4.00E+03
20 × 10	5–10	7.22E+02	2.96E+02	1.26E+02	2.98E+02	<5.77E+01	1.08E+02	6.88E+01	3.29E+02
	10–15	5.11E+02	<1.17e+02	<5.74E+01	<2.68E+02	<4.66E+01	<5.74E+01	<4.44E+01	<1.99E+02
	Bulk	1.29E+05	7.88E+04	1.57E+04	3.96E+03	6.73E+03	1.39E+04	1.20E+04	1.52E+05
Sample date 4 October 1986									
20 × 20	0–2	4.63E+05	2.49E+05	5.74E+04	1.54E+05	1.78E+04	3.85E+04	3.36E+04	4.63E+05
	2–4	1.16E+03	6.03E+02	2.79E+02	9.95E+02	8.25E+01	1.65E+02	9.47E+01	1.43E+03
	4–6	4.26E+02	2.10E+02	<3.53E+01	<1.72E+02	<3.89E+01	7.81E+01	4.92E+01	2.56E+02
	6–8	4.00E+02	1.60E+02	8.62E+01	<1.80E+02	4.22E+01	1.04E+02	<3.01E+01	4.11E+02
	10–15	2.58E+03	1.46E+03	6.73E+01	<2.36E+02	1.53E+02	2.86E+02	2.96E+02	3.25E+03
	15–20	<1.72E+01	<4.55E+01	<1.82E+01	<9.69E+01	<3.18E+01	<6.33E+01	<1.78E+01	<7.77E+01
	Bulk	1.01E+05	5.55E+04	1.05E+04	2.57E+04	4.74E+03	1.13E+04	7.81E+03	1.03E+05
Sample date 9 September 1986									
20 × 20	0–2	5.51E+05	2.79E+05	7.03E+04	2.43E+05	2.62E+04	6.18E+04	4.03E+04	5.88E+05
	2–4	2.36E+02	7.88E+01	8.18E+01	<1.86E+02	<4.40E+01	1.78E+02	<3.07E+01	2.25E+02
	4–6	8.99E+02	2.46E+02	1.67E+02	4.59E+02	<3.92E+01	7.88E+01	7.18E+01	1.37E+03
	6–8	<2.99E+01	8.81E+01	<3.11E+01	1.76E+02	<3.05E+01	1.27E+02	<2.49E+01	<1.10E+02
	8–10	4.70E+01	<4.18E+01	<2.29E+01	<9.44E+01	<2.21E+01	7.59E+01	<1.72E+01	<7.81E+01
	10–13	2.17E+01	<5.14E+01	<1.82E+01	<9.51E+01	<2.52E+01	<2.04E+01	3.11E+01	<7.99E+01
	Bulk	3.40E+04	1.83E+04	3.65E+03	1.24E+04	1.34E+03	2.68E+03	2.70E+03	3.89E+04

[a] Same samples as in Table I.1.

Table I.4. Countermeasures and times of application for use in model calculations.

Number	Countermeasure	Time of application (after the accident)
1	No remediation	–
2	Cutting and removal of grass	Day 7
3	Washing of roads	Day 14 (no rain)
4	Washing of roofs and walls	Day 14 (no rain)
5	Removal of trees (or leaves)	Day 30
6	Removal of soil (5 cm)	Day 180
7	Vacuuming indoors	Day 14
8	Washing indoor surfaces	Day 14
9(a)	Relocation of population (temporary):	For the first 2 weeks
9(b)		For the first 6 weeks
9(c)		For the first 6 months

Table I.5. Occupancy factors (% of time) for urban populations [I.16].

Location	Indoor workers	Outdoor workers	Pensioners	School children	Pre-school children
Inside homes	0.51	0.51	0.75	0.58	0.51
Inside at work or school	0.31	0.10	0	0.15	0.25
Outside:					
Asphalt surfaces	0.07	0.08	0.07	0.08	0.04
Dirt surfaces	0.03	0.23	0.07	0.10	0.12
Kitchen gardens	0.05	0.05	0.08	0.04	0.03
Virgin land (inside city)	0.01	0.01	0.01	0.04	0.04
Forests, meadows	0.02	0.02	0.02	0.01	0.01

ANNEX I. RADIOMETRIC SURVEY, OCTOBER 1986

Summary of the results of a radiometric survey in microdistrict 1a, Pripyat town, 2–3 October 1986. Figure I-1 in this Annex shows the entire layout of District 1a. The buildings surveyed are at the lower corner of the district, next to the boundary with District 1 (see Figures I.1 and I.2 in Appendix I), and correspond to buildings 369 (Dormitory 3), 2 (Dormitory 7), 360 (Canteen), 370 (Dormitory 4), and 371 ("Svetlyachok" and an accompanying parking area). Information on the buildings (area, height, locations, etc.) is provided in Table A-1 (in the Excel workbook).

Figures I-2 to I-31 (below) show the locations of sampling points on and between the buildings; the diagrams are not necessarily drawn to scale. The measurements are provided in Table A-2. For gamma radiation, the measurements are reported in mR h^{-1}; for beta and alpha radiation, the measurements are in counts per minute. The data in the Excel worksheet (Table A-2) are correlated with the diagrams as follows:

Column	Title of column	Explanation
A	Layout	This number refers to the number of the diagram below. (The general layout diagram is not included in the numbers.)
B	Location 1	Name of building as indicated in the general layout diagram
C	Location 2	Part of the building (e.g., which wall)
D	Location 3	Additional description of the sampling point (e.g., roof surface or wall surface)
E	Substrate	Type of surface where the sampling was done
F	Height over land, m	Distance above ground level
G	Remoteness from wall, m	Distance of the sampling point from the wall, when relevant
H	Point #	Corresponds to the number of the sampling point from the diagram indicated in column A
I	Alpha, counts	Measurement of alpha radiation (counts per minute)
J	Beta, counts	Measurement of beta radiation (counts per minute)
K	Gamma0, mR h^{-1}	Measurement of gamma radiation near the surface
L	Gamma1, mR h^{-1}	Measurement of gamma radiation at height of 1 m

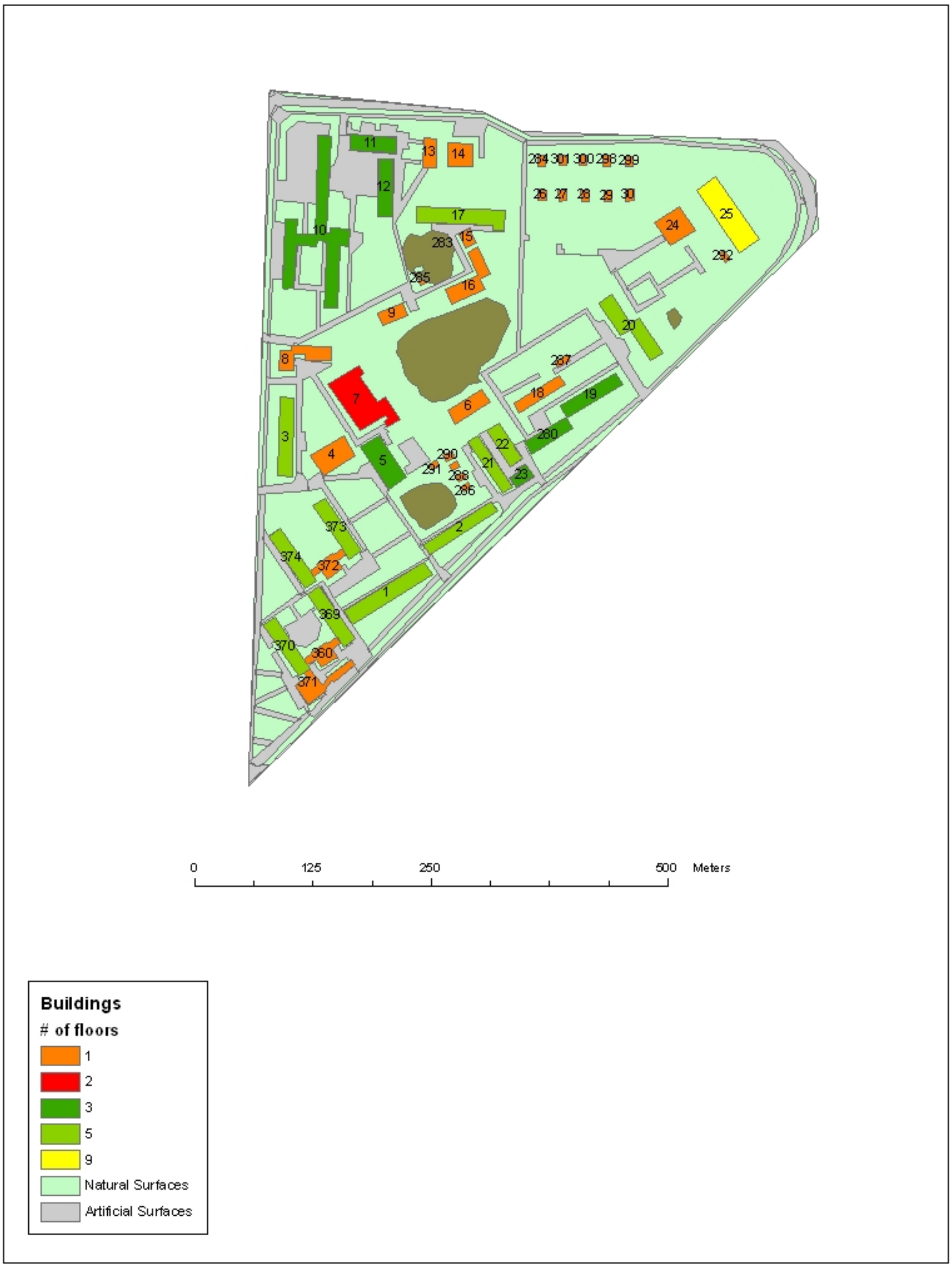

Fig. I-1. Map of District 1a of Pripyat, showing building locations and heights. Buildings are listed by number in Table A-1.

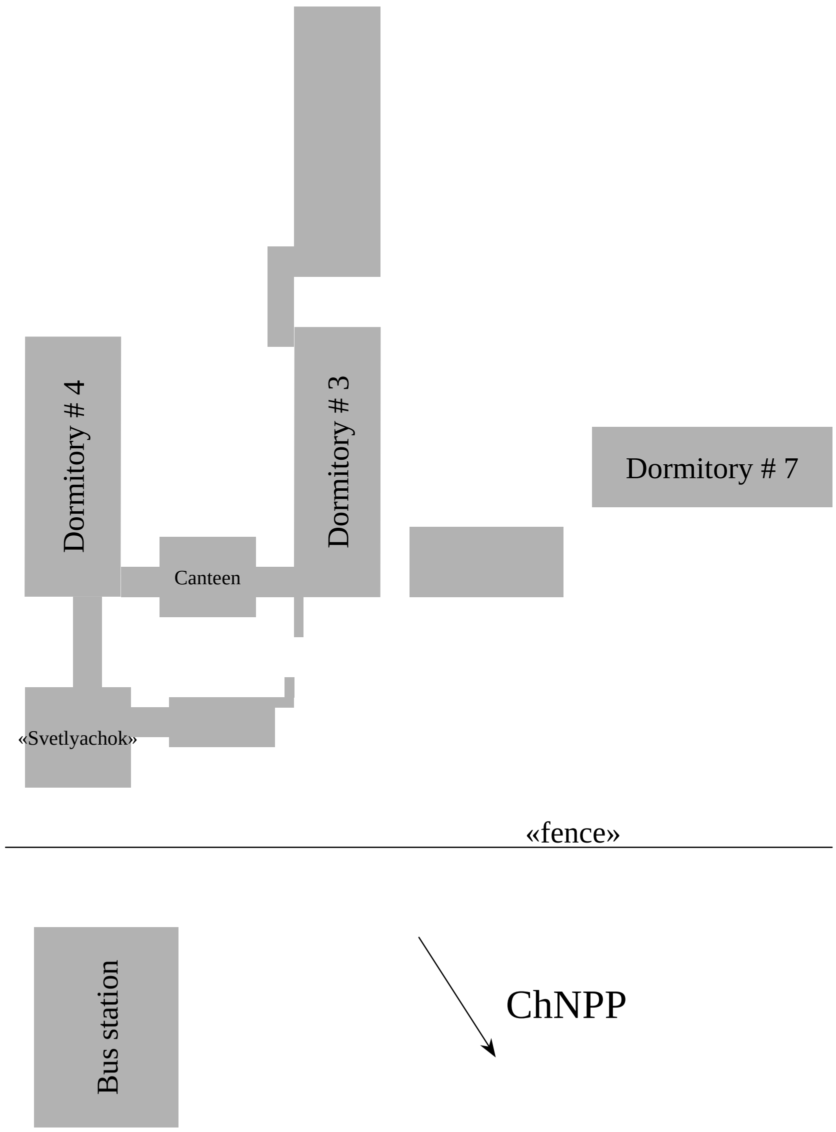

Fig. I-2. General layout of the Pripyat district, studied.

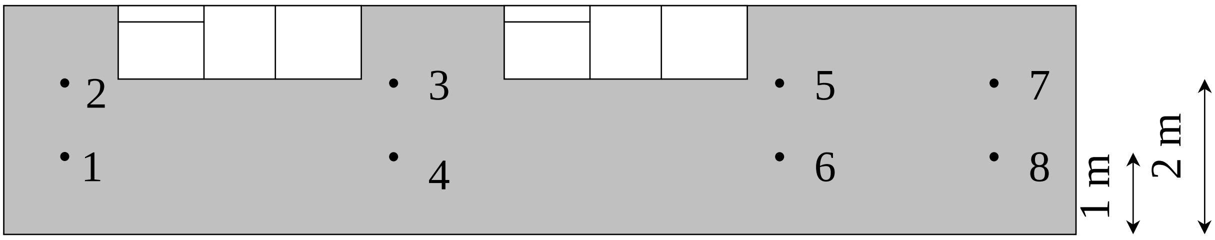

Fig. I-3. Sampling points on the southern wall of dormitory 3.

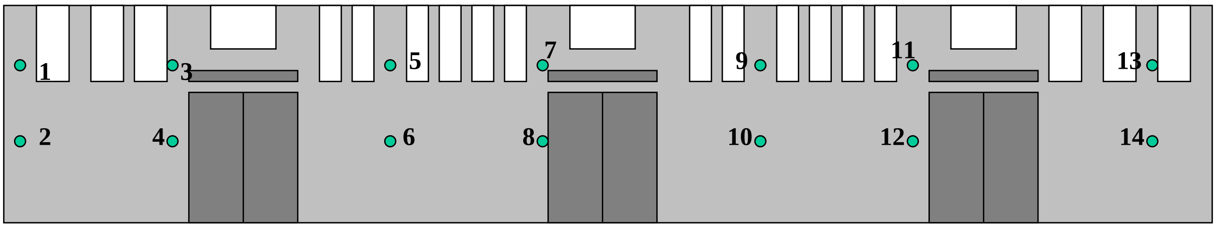

Fig. I-4. Sampling points on the eastern wall of dormitory 3.

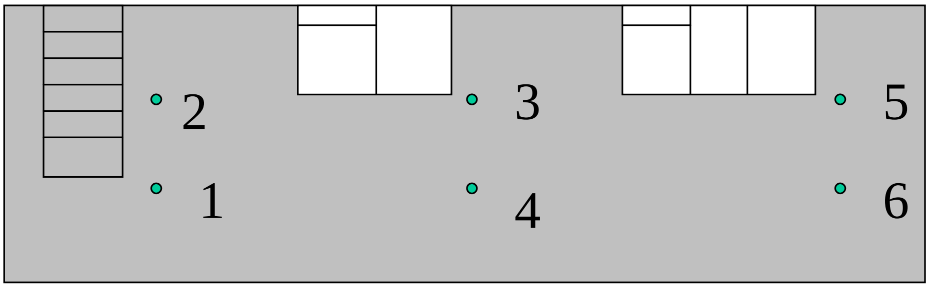

Fig. I-5. Sampling points on the northern wall of dormitory 3.

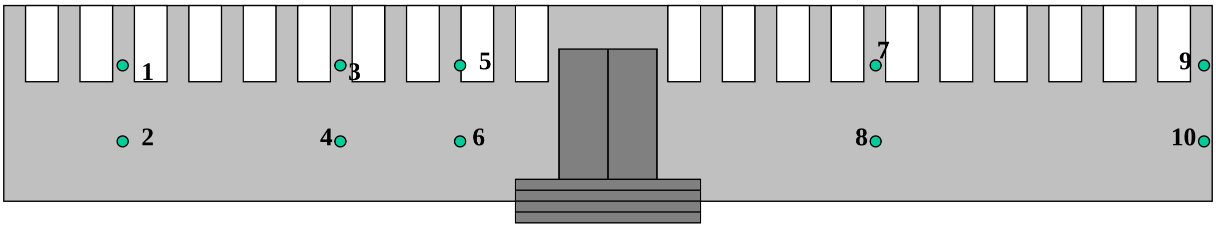

Fig. I-6. Sampling points on the western wall of dormitory 3.

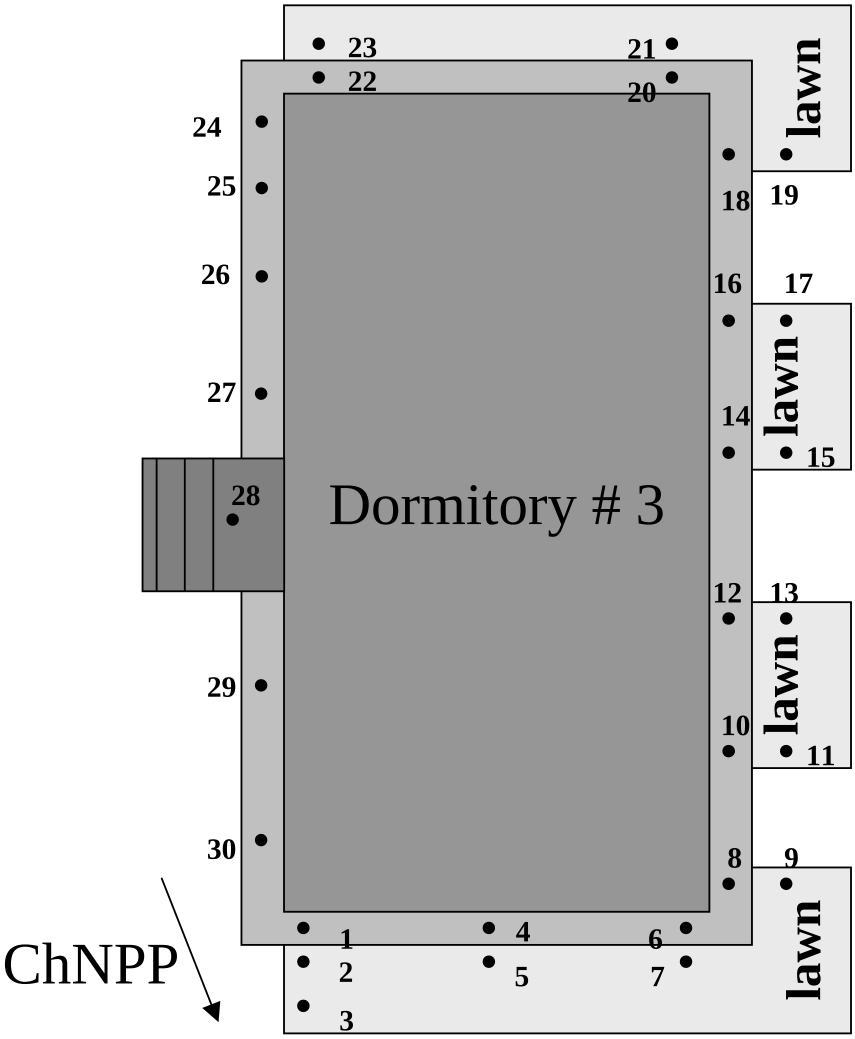

Fig. I-7. Sampling points in the area around dormitory 3.

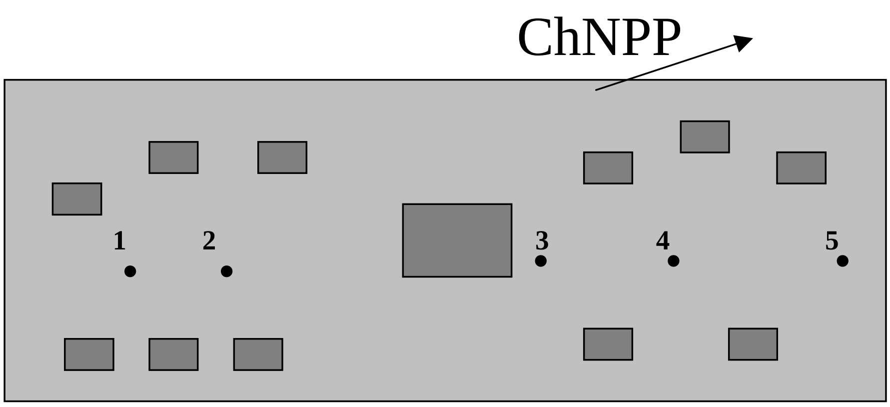

Fig. I-8. Sampling points on the roof of dormitory 3.

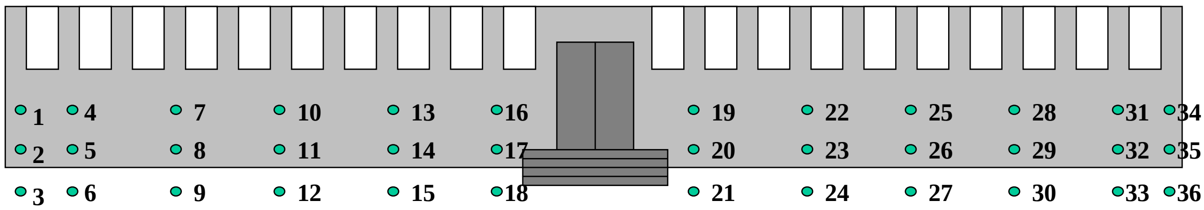

Fig. I-9. Sampling points on the southern wall of dormitory 7.

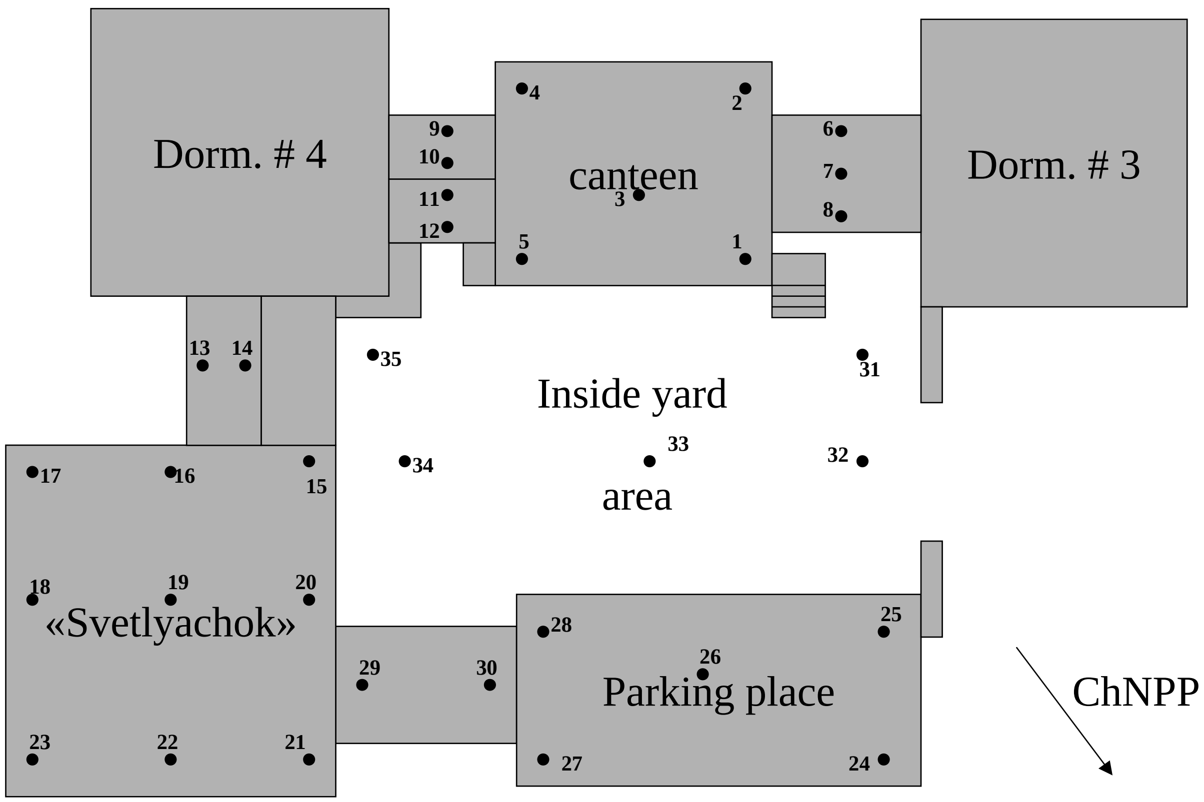

Fig. I-10. Sampling points on the roofs of the canteen and adjoining outbuildings.

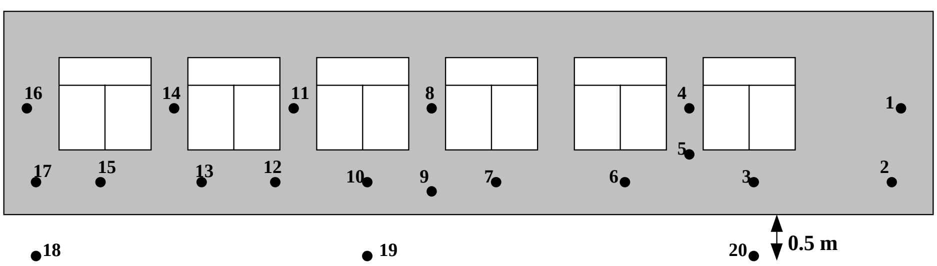

Fig. I-11. Sampling points on the southern wall of canteen.

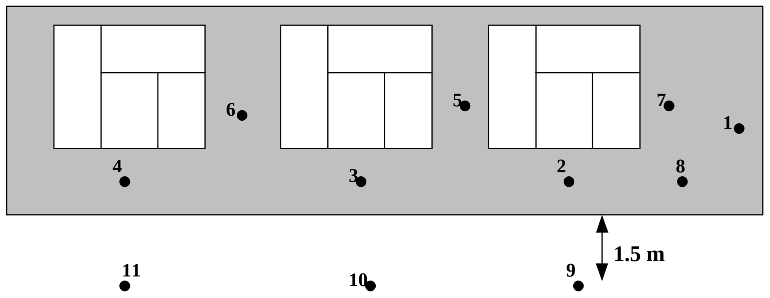

Fig. I-12. Sampling points on the wall of the eastern canteen passage.

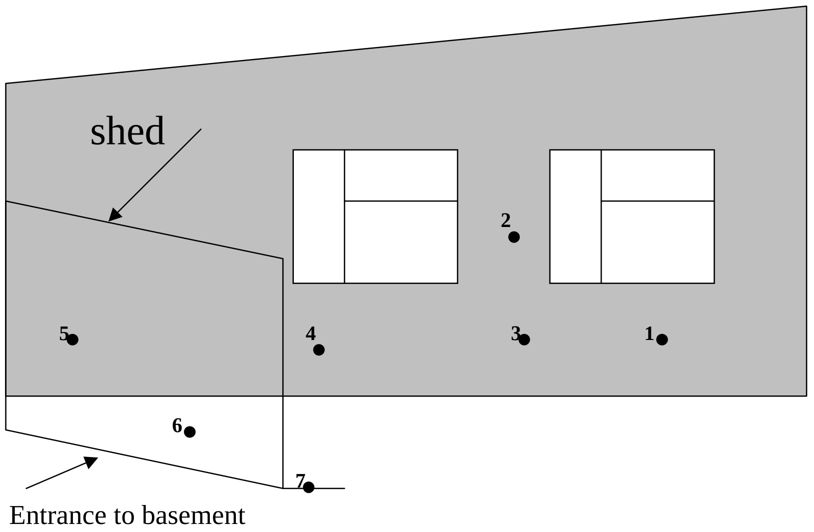

Fig. I-13. Sampling points on the eastern wall of the canteen.

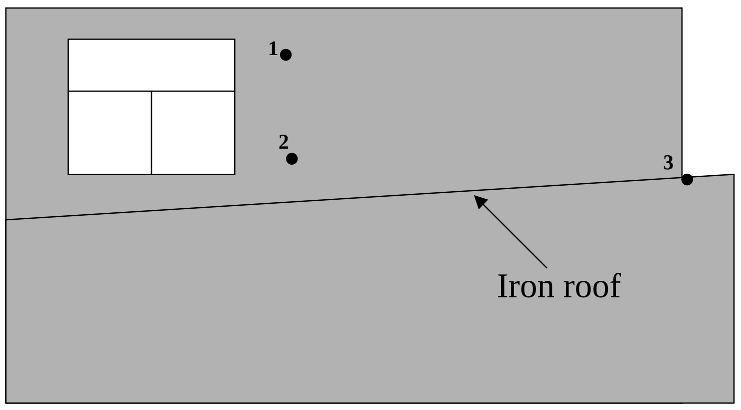

Fig. I-14. Sampling points on the western wall of the canteen.

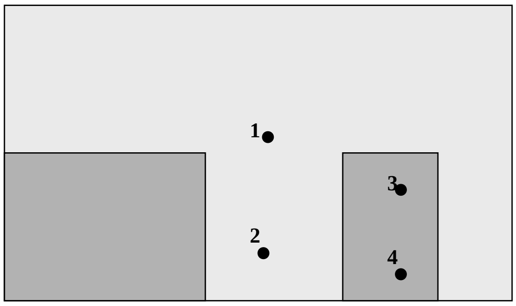

Fig. I-15. Sampling points on the southern wall of the passage.

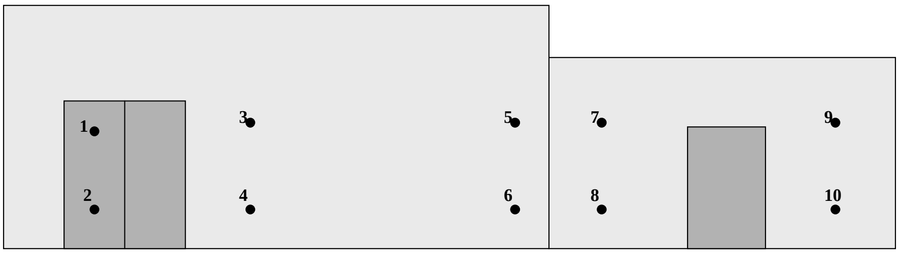

Fig. I-16. Sampling points on the eastern wall of “Svetlyachok”.

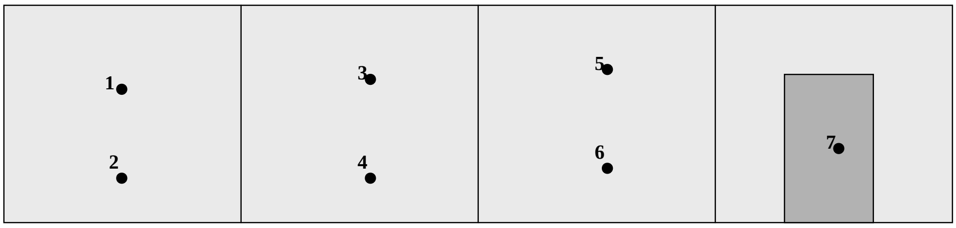

Fig. I-17. Sampling points on the northern wall of the “Svetlyachok’s” outhouse.

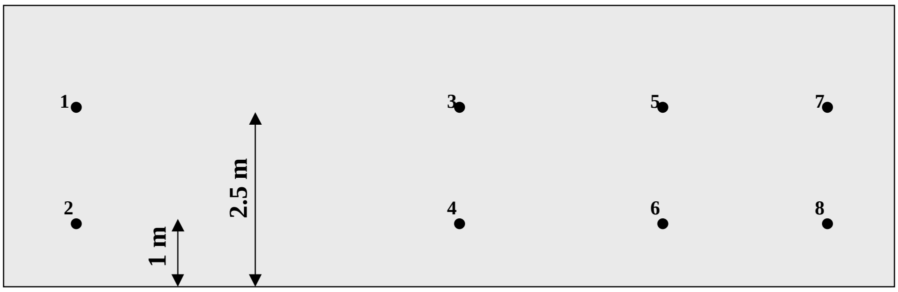

Fig. I-18. Sampling points on the northern wall of parking place.

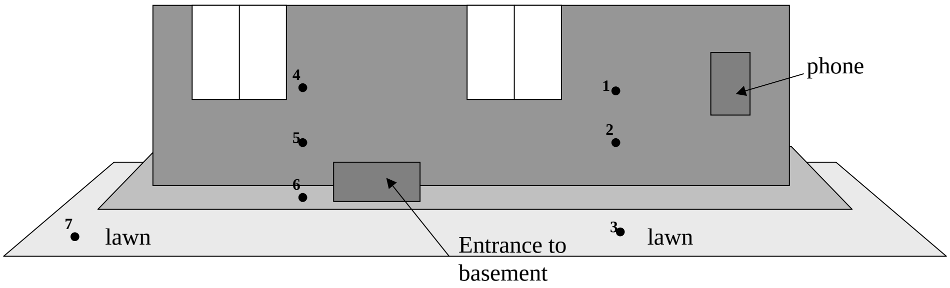

Fig. I-19. Sampling points on the northern wall of dormitory 4.

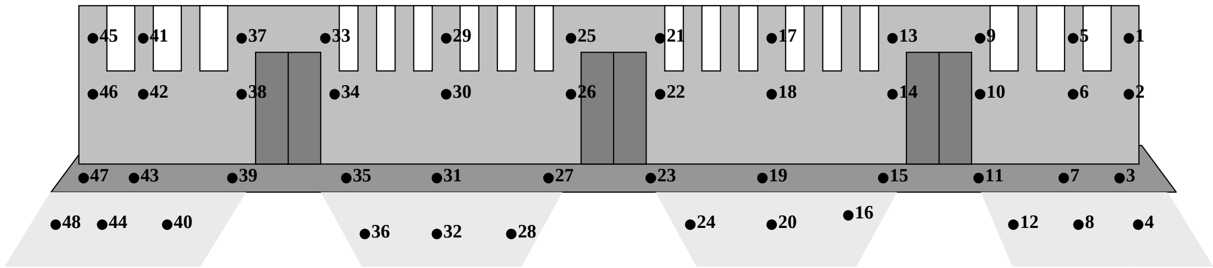

Fig. I-20. Sampling points on the eastern wall of dormitory 4.

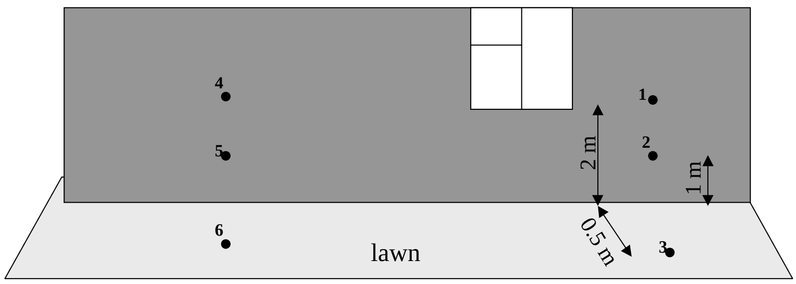

Fig. I-21. Sampling points on the southern wall of the dormitory 4.

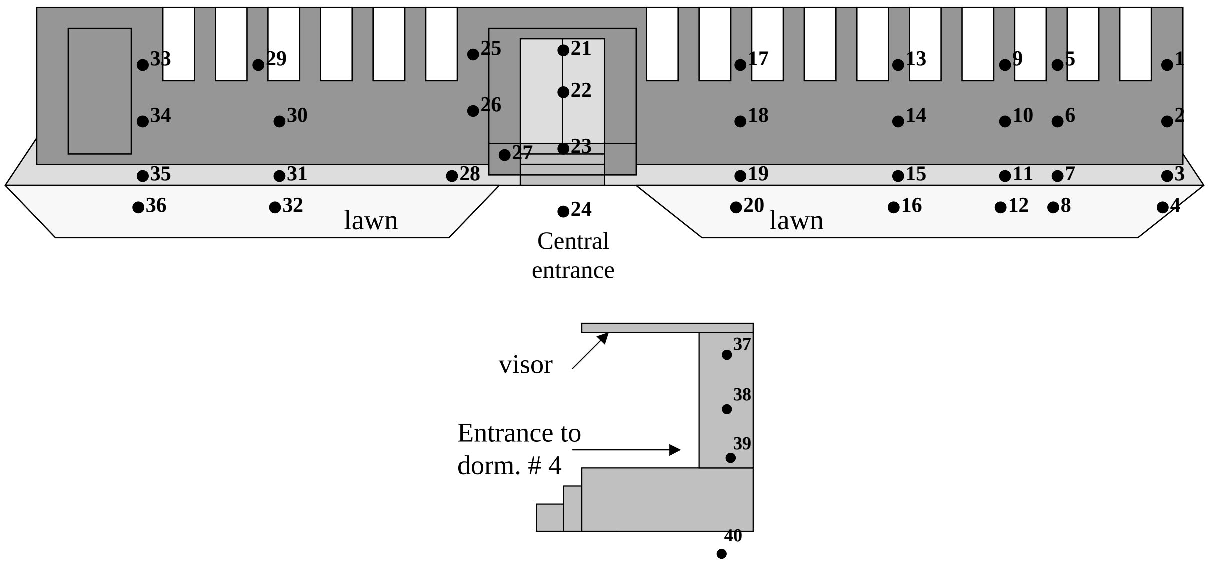

Fig. I-22. Sampling points on the eastern wall of dormitory 4.

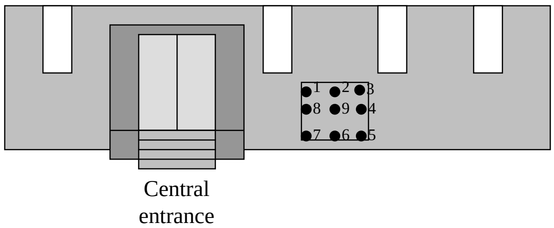

Fig. I-23. Sampling points on the eastern wall of the dormitory 4, plot 1×1 m.

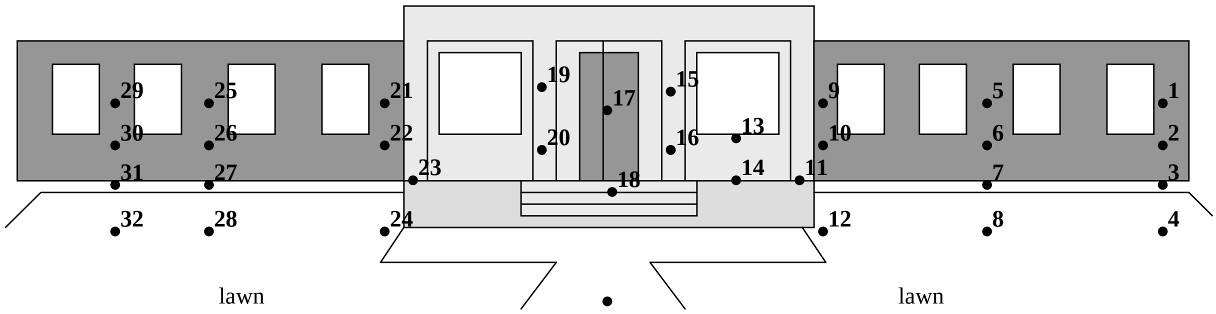

Fig. I-24. Sampling points on the northern wall of the canteen.

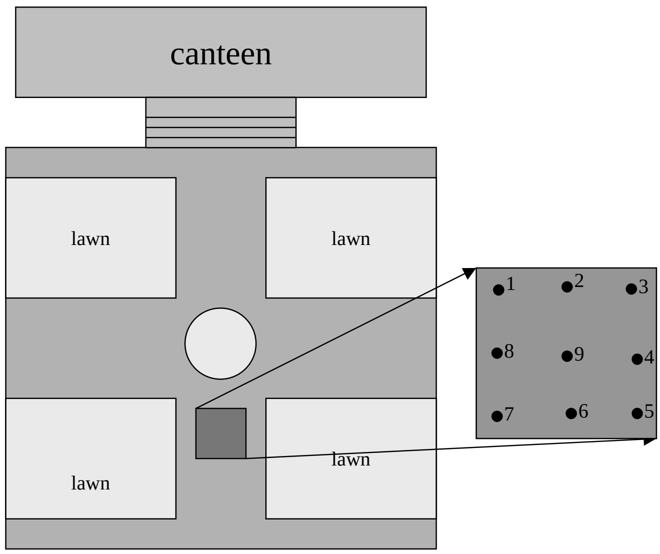

Fig. I-25. Sampling points on the foot-path in the yard between canteen and two dormitories, plot 1×1 m.

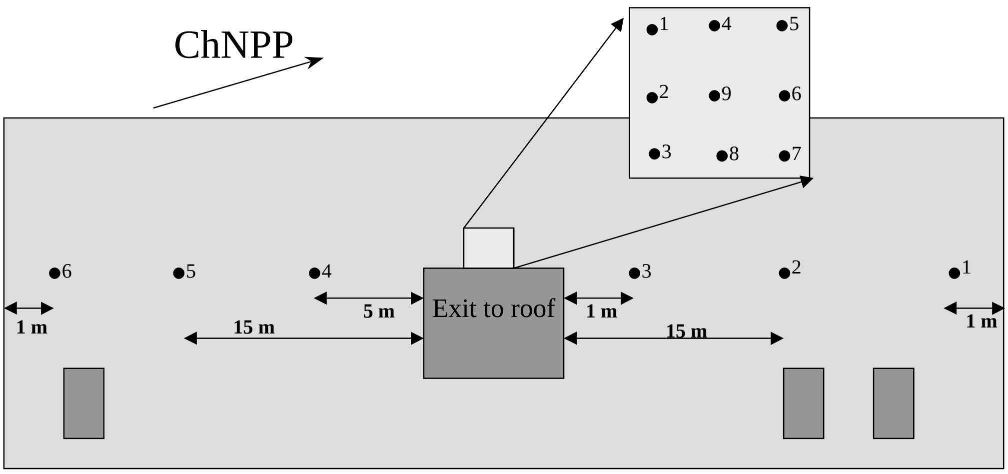

Fig. I-26. Sampling points on the roof of the dormitory 4, and 1×1 m plot of the roof.

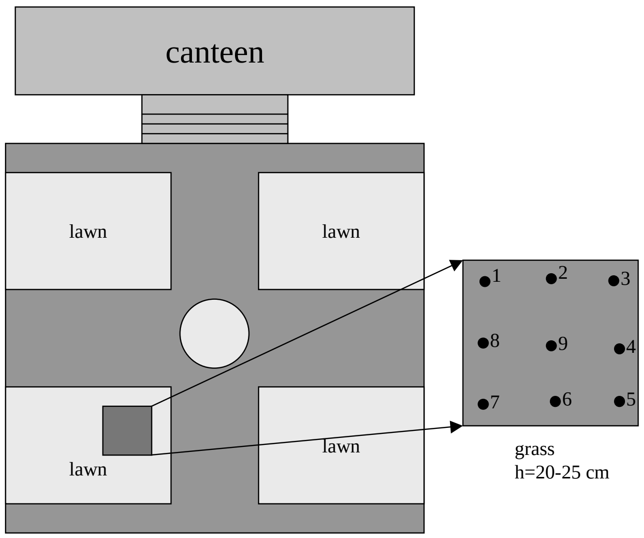

Fig. I-27. Sampling points on the lawn in the yard between canteen and two dormitories, plot 1×1 m.

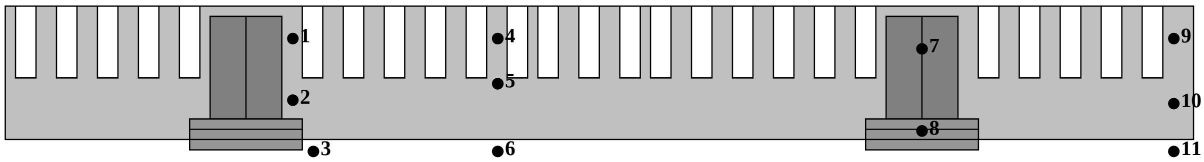

Fig. I-28. Sampling points on the northern wall of the dormitory 7.

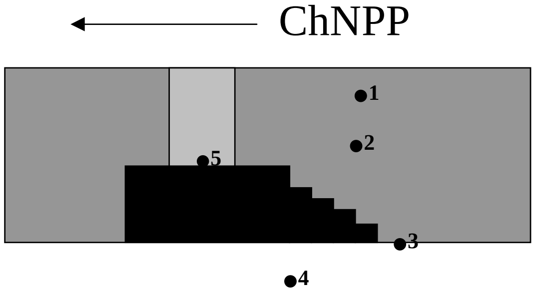

Fig. I-29. Sampling points on the eastern wall of the dormitory 7.

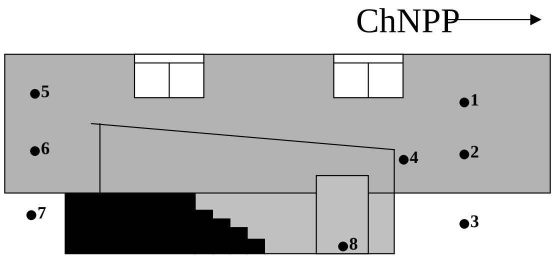

Fig. I-30. Sampling points on the western wall of the dormitory 7.

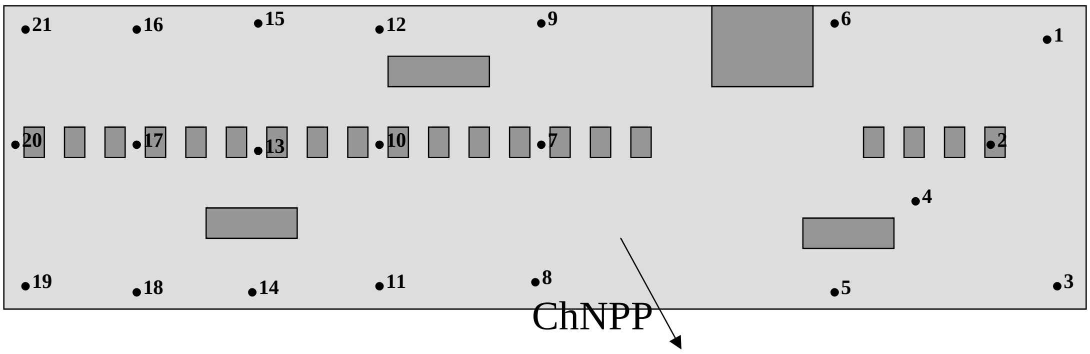

Fig. I-31. Sampling points on the roof of the dormitory 7.

DETAILS OF SUPPORTING FILES FOR THE PRIPYAT SCENARIO

Additional information (Excel workbook)	
Table P-1	Information about the buildings in Districts 1 and 4 of Pripyat.
Table P-2	Meteorological data for the Chornobyl station, 26 April–30 June 1986.
Table P-3	Meteorological data for the Chornobyl station, July 1986–July 1998.
Tables P-4 to P-9	Additional meteorological data.
Table P-10	Dose rate measurements made in Pripyat during 26–27 April 1986.
Table P-11	Isolines of dose rate for 26 April 1986, 12:00 (noon), in or near Districts 1 and 4 of Pripyat.
Table P-12	Isolines of dose rate for 26 April 1986, 24:00 (midnight), in or near Districts 1 and 4 of Pripyat.
Table P-13	Isolines of dose rate for 27 April 1986, 12:00 (noon), in or near Districts 1 and 4 of Pripyat.
Table P-14	Isolines of dose rate for 27 April 1986, 17:00 (5:00 pm), in or near Districts 1 and 4 of Pripyat.
Table P-15	Dose rate measurements made in or near Districts 1 and 4 of Pripyat during the summer of 1986.
Table P-16	Summary of major decontamination activities carried out in the town of Pripyat.
Table P-17	Contribution of different radionuclides to the value of the exposure dose rate in Pripyat.
Table P-18	Air contamination in the town of Pripyat in 1989–1991.
Table P-19	Measured deposition in Pripyat (Districts 1 and 4).
Table P-20	Vertical distributions of activity in soil (District 1).
Table P-21	Air gamma measurements made in or near Districts 1 and 4 of Pripyat in 1991 (^{137}Cs).
Table P-22	Occupancy factors for urban populations.
Table P-23	Map locations of test points in Districts 1 and 4 of Pripyat (Figures I.14 and I.15 in Appendix I).
Table A-1	Information about the buildings in District 1a of Pripyat.
Table A-2	Results of radiometric survey in District 1a in October 1986.
Formats for model predictions (Excel workbook)	
District 1	
District 4	
Dose summary	
Test data (Excel workbook)	
Table T-1	Measurements of dose rates in 1996–1998, near the test locations in Districts 1 and 4.
Table T-2	Measurements of dose rates and surface radionuclide contamination in 1999, near the test locations in Districts 1 and 4.
Table T-3	Measurements of dose rates in 2006, at the test locations in Districts 1 and 4.

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APPENDIX II. SCENARIO DESCRIPTION FOR THE HYPOTHETICAL SCENARIO, POINT RELEASE OF CONTAMINATION

Scenario for modeling changes in radiological conditions in contaminated urban environments
Hypothetical scenario

II.1. Introduction

The overall objective of the EMRAS Urban Remediation Working Group is to test and improve the prediction of dose rates and cumulative doses to humans for urban areas contaminated with dispersed radionuclides, including (a) prediction of changes in radionuclide concentrations or dose rates as a function of location and time, (b) identification of the most important pathways for human exposure, and (c) prediction of the reduction in radionuclide concentrations or dose rates expected to result from various countermeasures or remediation efforts. The present scenario is based on a hypothetical event in a hypothetical city, intended to represent the long-term consequences of a radiological dispersal device situation.

The scenario is designed to allow modeling with and without the effects of various remediation efforts on the changes over time of the radiological situation.

The primary input information for the modeling exercise is the reference surface contamination at six selected buildings. Concentrations of ^{137}Cs in air as a function of height at the building locations are also provided. A contour plot of the ground deposition and a plot of the plume centerline deposition are also included. A selected set of endpoints was used for model intercomparison.

This document and an accompanying Excel workbook provide information about the situation to be modeled (input information) and a list of the endpoints to be modeled.

II.2. Background

The EMRAS Urban Remediation Working Group has discussed a number of types of hypothetical situations that could result in the accidental or deliberate dispersal of radioactive material in urban settings. Such situations include a nuclear power plant accident, a radiological dispersal device using conventional explosives, deliberate or accidental dispersal of radioactive material without use of explosives, transport accidents, and accidents at facilities for waste storage or spent fuel storage. The Working Group's Pripyat scenario (Appendix I of this report) provides an opportunity to model urban situations—initial contamination and the effects of various remedial activities—after a nuclear power plant accident (the Chernobyl accident); data are available for testing some of the model calculations.

The following hypothetical scenario is designed to provide an opportunity to model a radiological dispersal device situation. Participants are asked to model the effectiveness of various countermeasures in decreasing long-term radiation exposures and doses of persons living or working in the test area. The scenario uses a hypothetical city based partly on a real, but unidentified, city. A description of the city is provided below. Additional data for the city are provided in the accompanying Excel workbook.

For purposes of this scenario, the decision was made to select a section of an existing city that would provide a representative set of features, rather than to design a model city that was entirely hypothetical. In addition to providing a realistic geographical layout, this approach also permitted the collection of an internally consistent set of meteorological data and other physical data that correspond to that city. However, the Working Group has not attempted to develop complete site-specific information about the test site. In particular, building sizes, heights, and areas are approximated in many or most cases, and building uses and occupancy factors assumed for this scenario do not necessarily correspond to the real situation. Nothing in this scenario or any subsequent report should be taken to mean that this city or any feature of this test site is considered to be a possible target for destructive activity. Rather, it has been selected simply to provide modelers with useful practice in modeling the long-term effects of a situation that we all hope never occurs.

II.3. Description of the hypothetical city and test site

The test site was selected to provide a representative section of a major city; it includes large buildings (in terms of ground surface area covered, building height, or both), residential areas, a major highway, other roads, car parking areas, grassy park areas, and trees. An open area was selected as the origin of the event. An explosive event too close to major buildings would not be expected to disperse widely, due to the effects of the buildings; therefore, in the interest of a more useful situation for modeling purposes, the origin of the event has been placed in an open area, so that there would be dispersion past the nearest buildings. Again in the interest of a useful modeling situation, the receptor locations have been placed in the primary downwind direction, within a 2 km radius, so as to be in an area where the assumed contamination would clearly justify consideration of remedial measures.

The test site is shown in aerial photographs at different scales in Figures II.1–II.3. The assumed origin of the event is at the fountain in the park in the center of Figure II.1. For purposes of this scenario, the fountain is considered to be at coordinates (0,0), measured in meters. The park is 230 m in length; the width of the park is 66 m. The road on the west side of the park is 13 m wide; the road on the east side is 11 m wide. The total width of the park and the two roads is 90 m. The fountain area (circular area) is 22 m in diameter. A close-up photograph of the park is provided in Figure II.4.

The entire city covers 340 km^2; the resident population is 420 000, of whom approximately 100 000 are children. The major highway that runs approximately north-south in Figure II.3 is 75 meters wide (12 lanes, not including exit and entrance ramps) and carries 300 000 vehicles per day. The other roads are 10–15 meters wide (2 to 4 lanes).

In the immediate area of the event's origin (Figure II.1), 50% of the ground surface is covered by buildings and 40% by pavement (roads, parking areas, sidewalks); the rest is lawn (grass) or trees. In some of the receptor areas (east of the highway), the fraction of surface covered by buildings and roads is substantially lower (25% buildings, 25% pavement, 50% vegetation).

The area has extensive commuter traffic from 6:00 to 9:00 am and 4:00 to 7:00 pm. Traffic during the rest of the daylight hours is moderate to heavy, with substantially less traffic at night. Areas close to schools can have heavy traffic in the mid-afternoon, when classes end. Occasional big events in the city (e.g., sports events) produce heavy traffic at other times, for example, weekend afternoons or evenings. Two subway lines go underneath the area (an east-west line and a north-south line).

Fig. II.1. Aerial photograph of the center of the test area. The hypothetical event is assumed to originate at the fountain in the park area in the center of the photograph.

Fig. II.2. Aerial photograph of the center of the test area (smaller scale than in Figure II.1). The park area is in the center of the photograph.

Fig. II.3. Aerial photograph of the test area (smaller scale than in Figure II.2). The park area is in the center of the photograph. The major north-south highway is visible to the right of the center area.

In general, the largest buildings have concrete exteriors and roofs; the roofs are flat. The smaller buildings (houses, schools, apartment buildings, stores) are constructed of brick, concrete block, or wood frame covered with vinyl siding. Flat roofs are concrete. Sloped roofs are covered with asbestos shingles or clay tiles. Assumed size and use are listed in the Excel workbook for the six receptor buildings (buildings for which calculations will be made).

Buildings have their own heating and cooling systems; buildings with more than one residential or commercial (e.g., office) unit may have central systems for the building or may have separate systems for each unit. For this scenario, assume that each floor of a building has its own ventilation (heating and cooling) system. Water, electrical power, and natural gas supplies are central for the entire city. There are extensive sanitary and storm sewer systems. Many commercial buildings have extensive paved parking areas or parking garages.

Tree cover for the whole city is about 30%. The predominant soil types in the area are heavy red and yellow clays. Most non-paved areas are vegetated, either with grass (lawns around most residential buildings and some commercial buildings) or with shrubs and trees. Grass is present year-round, with mowing necessary most of the year (weekly or bi-weekly, depending on rainfall). Deciduous trees leaf out in March, and leaf fall is complete by the end of November. Approximately one-fourth of the trees are pines or other conifers. Typical tree height in the test area is 10 m (ornamental trees around commercial areas) to 30 m in the wooded areas.

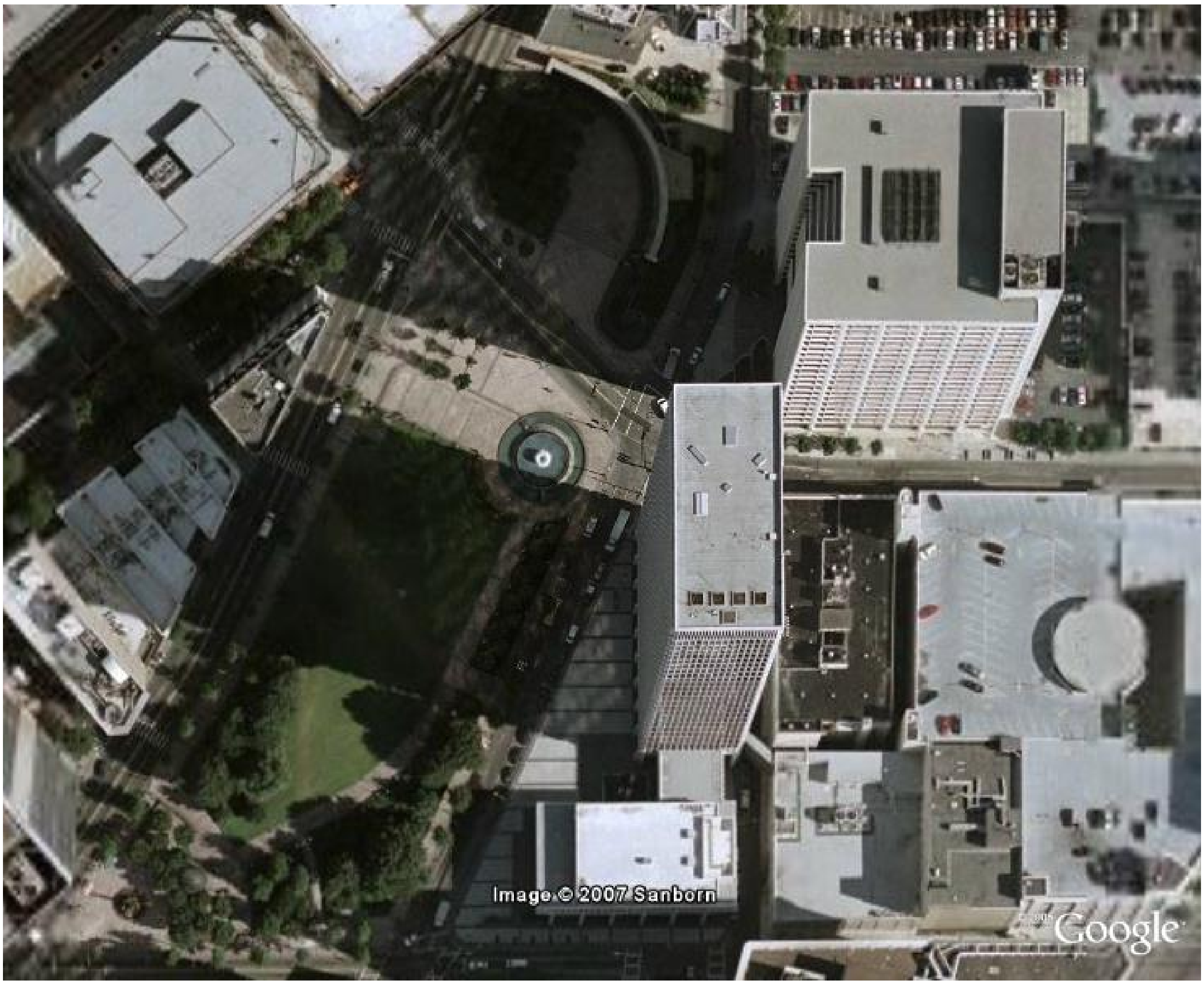

Fig. II.4. Close-up photograph of the park.

Average meteorological data for the town are provided in the Excel workbook. The predominant wind direction depends on the time of year. The hypothetical event is set in July, when the predominant wind direction is from west to east. Average wind speeds are between 3 and 5 m s^{-1}, with peak gusts up to 20–25 m s^{-1}. A wind rose is provided in Figure II.5; detailed information is in the Excel workbook. Average annual rainfall is about 1275 mm. The meteorological station is 13 km south of the test site; the elevation is about 300 m.

II.4. Contamination (hypothetical situation)

For this scenario, we have assumed a scenario similar to that suggested by Sohier and Hardeman [II.1]: a 5 kg conventional explosion of a radiological dispersal device containing 50 TBq of ^{137}Cs in powder form. The event is assumed to happen on 1 July of Year 0. The weather at the time of the event is assumed to be dry, with a wind speed of 5 m s^{-1} in the prevailing direction (from west to east; 5 m s^{-1} is a little higher than average for July, but not unreasonable). Release height is assumed to be ground level. Based on these assumptions, a simulation of the explosion event was carried out with the Hotspot code [II.2, II.3]. Deposition velocities were assumed to be 0.3 cm s^{-1} for the respirable fraction and 8 cm s^{-1} for the non-respirable fraction (recommended in the Hotspot code for unknown source term characteristics). The respirable fraction is assumed to be 0.5, and the airborne fraction (aerosolization fraction) is assumed to be 0.3. The hypothetical release is located in a park area surrounded by buildings. Hotspot was run using the setting for city terrain, which accounts generally for the presence of buildings but not specifically for a given location.

The Hotspot model is based on a time-integrated Gaussian equation which determines the atmospheric concentration of a gas or an aerosol:

$$C(x, y, z, H) = \frac{Q}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot u} \cdot e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} \cdot \left\{ e^{-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2} + e^{-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2} \right\} \cdot e^{-\frac{\lambda}{u} \cdot x} \qquad \text{(II.1)}$$

where:

C = Time-integrated atmospheric concentration (Bq s m^{-3});
Q = Source term (Bq);
H = Effective release height (m);
λ = Radioactive decay constant (s^{-1});
x = Downwind distance (m);
y = Crosswind distance (m);
z = Vertical axis distance (m);
σ_y = Standard deviation of the integrated concentration distribution in the crosswind direction (m);
σ_z = Standard deviation of the integrated concentration distribution in the vertical direction (m); and
u = Average windspeed at the effective release height (H), (m s^{-1}).

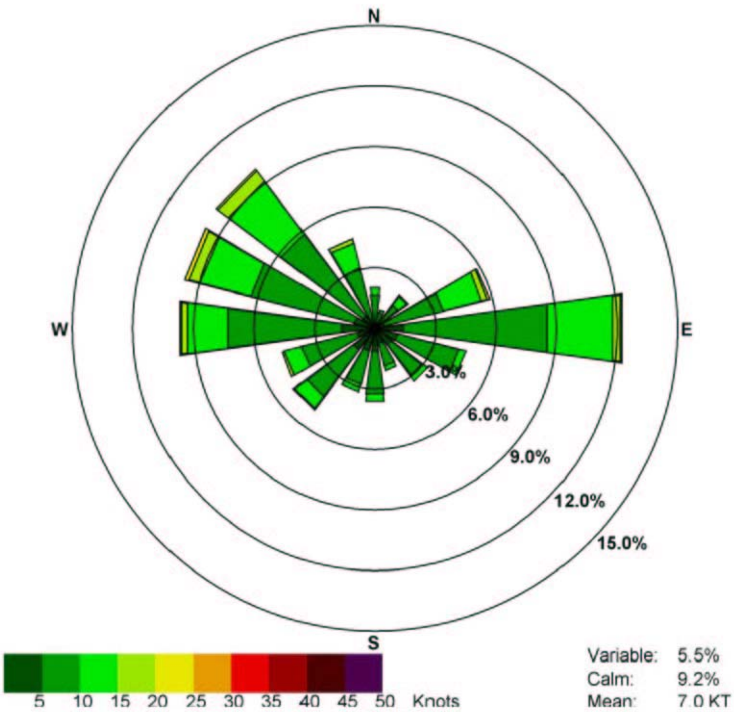

Fig. II.5. Wind rose for a meteorological station 13 km south of the test site. Detailed information on wind speed and direction, along with other meteorological information, is provided in the Excel workbook.

The first factor in Equation II.1 provides scaling. The second factor describes propagation of the plume along the y-axis. The third factor incorporates propagation along the z-axis and resuspension. The fourth factor describes radioactive decay of the source term.

Ground surface concentrations (Bq m^{-2}) are found by multiplying the result from Equation II.1 by the deposition velocities of the source term partitions of interest. Deposition is highly dependent on source term partitions, particle size, chemistry, dry or wet type of deposition, and plume depletion [II.4]. For the purpose of this exercise, it was assumed that particle size distribution follows a log-normal distribution for cumulative activity percentage of the source term after explosion. Therefore, no phase transition was assumed to be induced by explosion of the source term. Deposition was assumed to be dry.

The Gaussian model is a straight-line model. It cannot compensate for changes in weather conditions; therefore the domain of propagation must be represented with one set of meteorological data, representative of the whole domain of propagation. Such a statement implies homogeneous turbulent flow within the domain of propagation. Statistical properties within the domain are assumed to be independent of position, and stationary turbulence is stationary in time. The Gaussian plume model does not require complex meteorological data, but it is of crucial importance to have good quality data for the desired results. Meteorological data consist of wind rose data and insulation, and these data define the dependence of the standard deviation on downwind distance [II.5].

The Hotspot results for plume centerline ground deposition are shown in Figure II.6. Using the Hotspot results as a starting place, further simulation was carried out (described in Section II.5) to generate realistic values for the surface contamination at selected building locations.

II.5. Mapping the radioactive contamination in an urban environment

After the detonation of a radiological dispersal device measurements of the gamma dose rate (GDR) would be carried out by mobile teams around the radiological dispersal device location. The GDR signal will fluctuate markedly depending on the environment of the measurement location. To improve the comparability of the GDR signals from different locations they must be corrected for the influence of the measurement environment. To this aim location factors f_{loc} are introduced which connect the GDR_{real} in a ‘real’ urban environment to the (hypothetical) GDR_{ref} over the reference surface of an infinite lawn [II.6]. If, as in the present scenario, the radioactive contamination is caused by a single radionuclide, this is done by the simple relation

$$GDR_{real} = f_{loc} \cdot GDR_{ref} \qquad \text{(II.2)}$$

The reference GDR_{ref} is caused by deposited radio-aerosols. Assuming a homogeneous deposition pattern on the lawn, the corresponding surface contamination A_{ref} is related to GDR_{ref} via

$$GDR_{ref} = c_{ref} \cdot A_{ref} \qquad \text{(II.3)}$$

with a dose conversion factor c_{ref}, which depends on the deposition mode, the time after deposition and the nuclide energy. For dry deposition of ^{137}Cs immediately after deposition, c_{ref} = 2.28 (2.03; 2.52) nGy h^{-1} per kBq m^{-2} (dose rate in air at 1 m above ground per unit activity of ^{137}Cs per unit area for an ideal site, i.e., infinitely extended lawn) has been calculated by Zähringer and Sempau [II.7] with the Monte-Carlo method. The probability distribution of the conversion factor is assumed to be triangular. The most probable value is given here with its minimum and maximum in brackets.

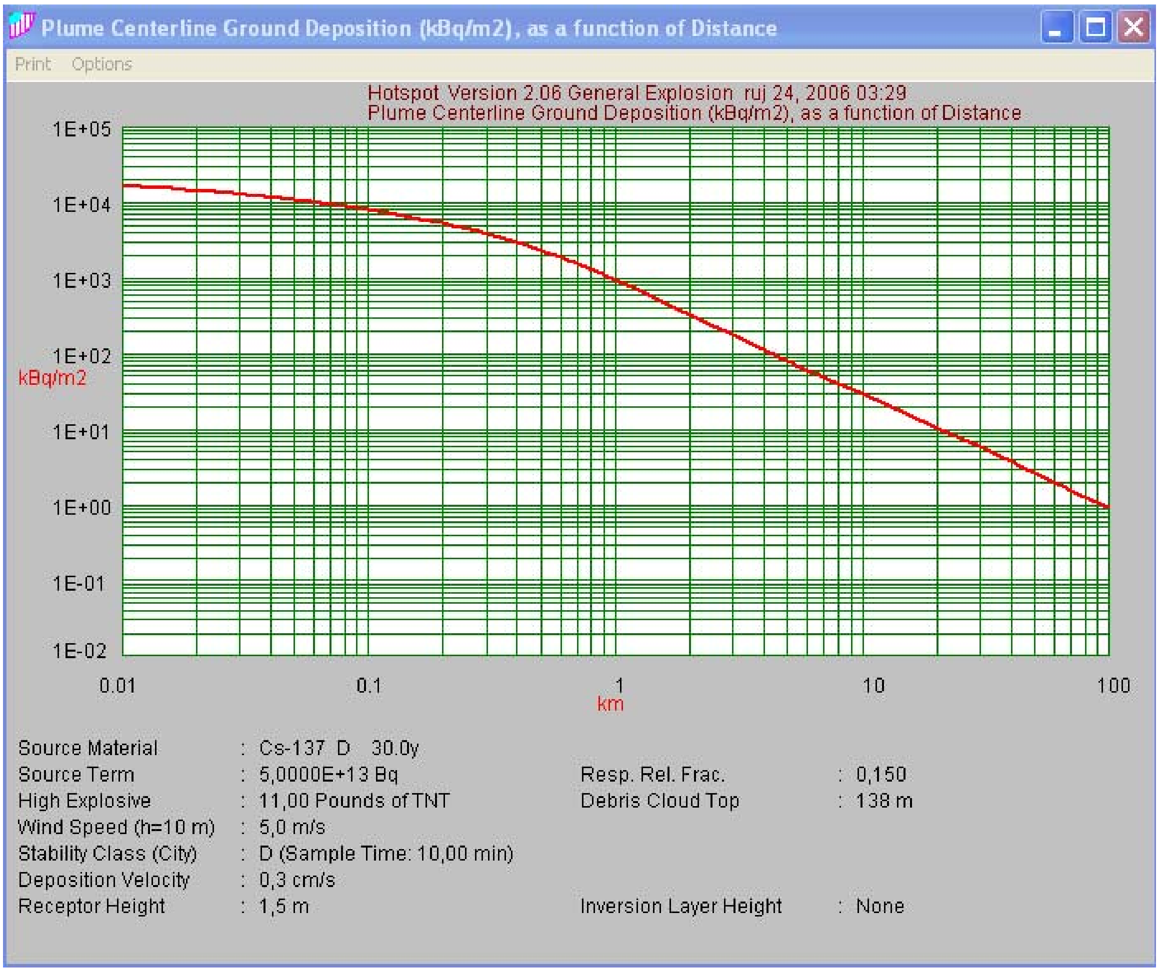

Fig. II.6. Plot of the plume centerline ground deposition as calculated with Hotspot, showing deposition (kBq m^{-2}) as a function of downwind distance (km).

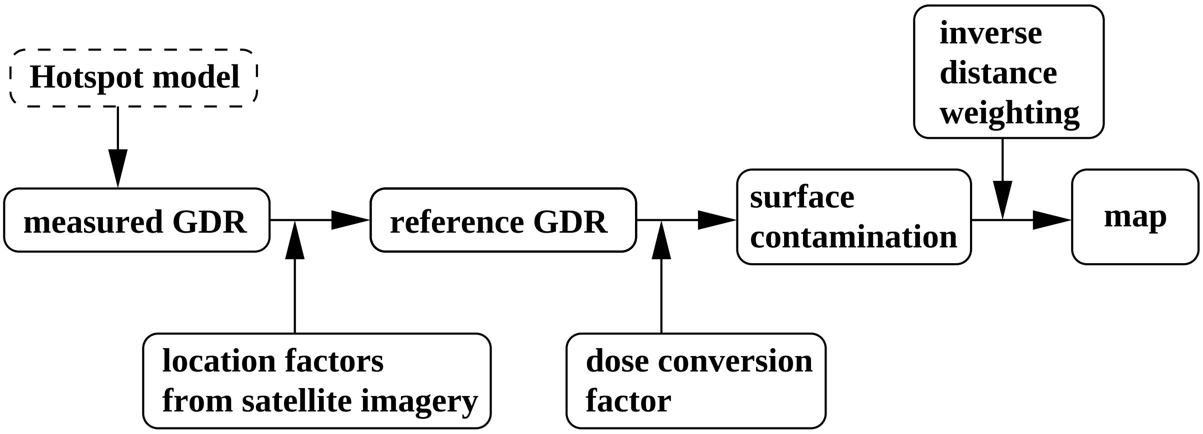

Fig. II.7. IAMM workflow scheme to produce maps of surface contamination in urban environments.

In this scenario the Hotspot results for the deposition are taken to be the 'true' contamination A_{ref} of the reference surface. In a realistic situation the reference surface contamination would be calculated from GDR_{real} based on the conversion relations (1) and (2). Direct measurements of A_{ref} by in-situ gamma spectroscopy are costly and laborious up to now and may not be possible at all locations. To produce maps of the surface contamination from GDR measurements after nuclear emergencies, the Inhabited Areas Monitoring Module (IAMM) is being developed as a component of the RODOS decision support system [II.8].

IAMM converts dated gamma dose rate measurements from geo-referenced locations into maps of surface contamination with an enhanced spatial resolution. For this scenario a preliminary version of IAMM was used. Depending on the availability of monitoring data, the full version operates in two different modes. If there are only a few measurements, these are taken to improve the predictions of a deposition model using data assimilation. If the number of measurements is sufficient to apply spatial interpolation, IAMM will rely entirely on monitoring data. In both modes geo-referenced measurement points will be interpreted with respect to their detector environment using the concept of location factors. The endpoints of IAMM can be used directly for decision making or as input to assessment models such as those applied here. For this exercise the mode of spatial interpolation is used. The following sections explain this mode step by step. Figure II.7 gives an overview of the stages of processing of GDR measurements in urban environments that IAMM applies to produce maps of surface contamination.

II.5.1. Determination of location factors

The input for the IAMM tool are geo-referenced and dated GDR measurements. These measurements are converted to reference GDR_{ref} with location factors f_{loc}, which are derived at the corresponding measurement points using satellite imagery. For many regions in the world suitable images with sufficient spatial resolution are available from the GoogleEarth (GE) data base (http://www.googleearth.com).

Here we show two satellite images which have been used to determine location factors. The assignment of these values is guided by the recommendations of Zähringer and Sempau [II.7] and Gering [II.9]. Figure II.8 shows a city park (measuring point no. 38), where the point of measurement is surrounded by some trees which enhance the GDR considerably. The location factor with a triangular probability density distribution of the uncertainty is assumed to be 3.5 (1.5; 4.0).

Figure II.9 shows a parking lot (measuring point no. 1) within a mainly paved environment. The location factor here is less than one since the pavement reduces the GDR due to its lower surface roughness. We assume a value of 0.3 (0.1, 0.7).

More examples for the determination of location factors in urban environments from satellite images are given by Kaiser and Pröhl [II.8]. The estimates for the location factors of all 32 measuring points are given in the accompanying Excel workbook. The possible values range from 0.1 to 6.0.

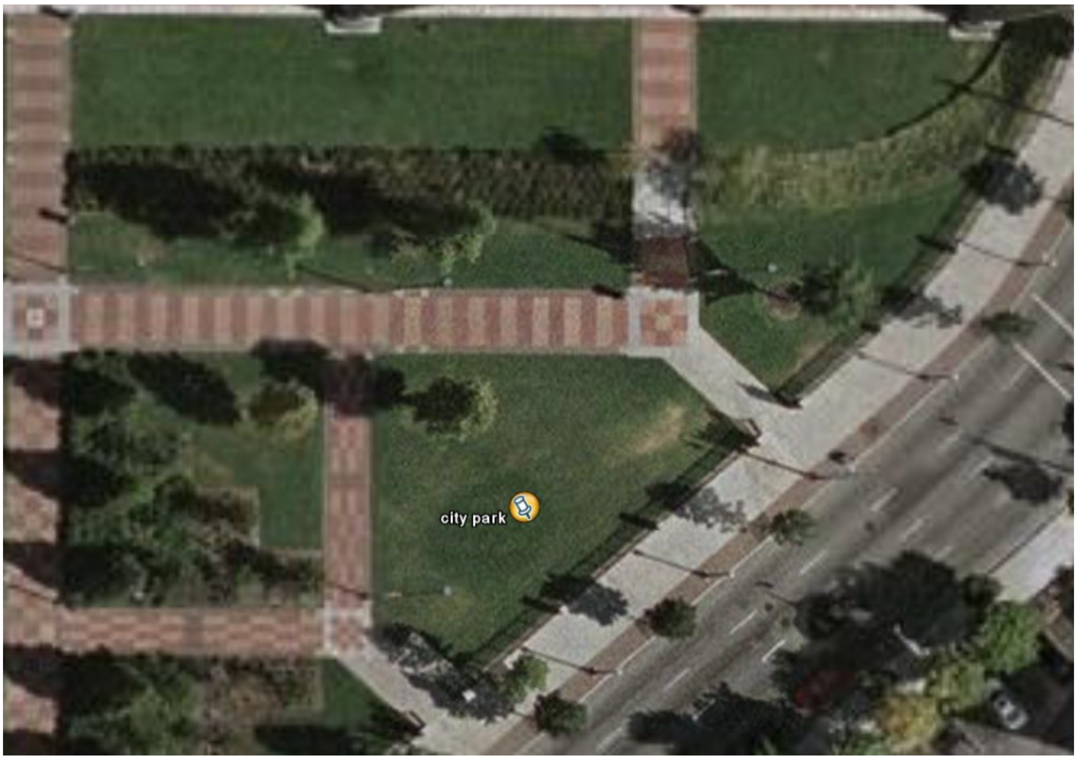

Fig. II.8. Measurement point no. 38 in a city park surrounded by small trees.

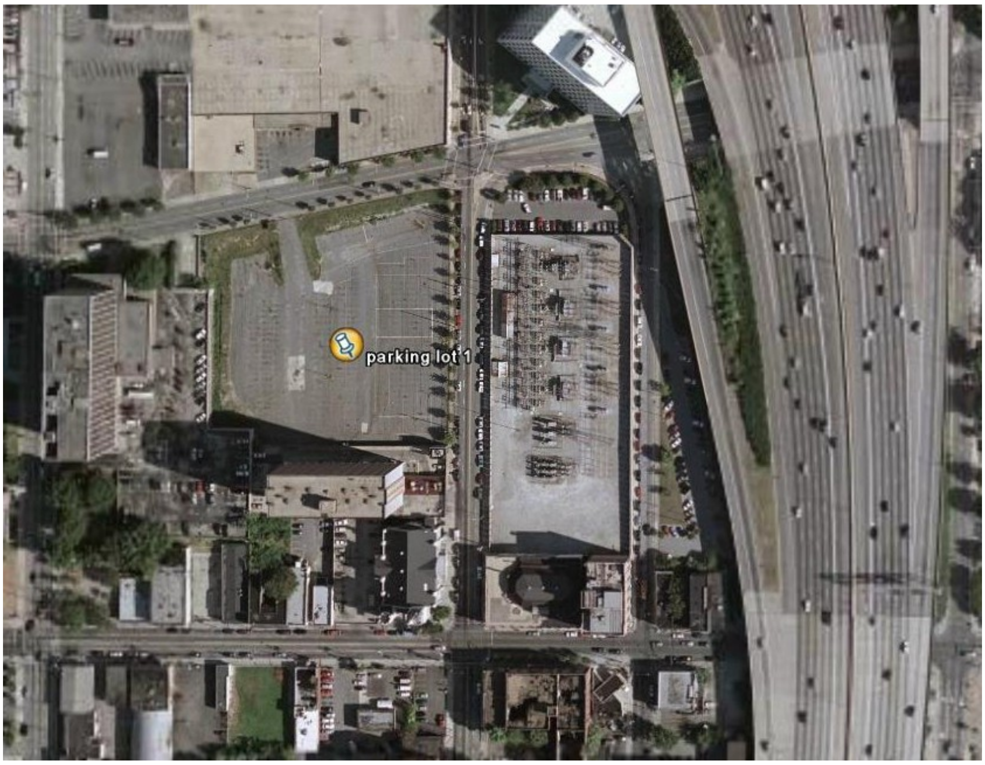

Fig. II.9. Parking lot (measuring point no. 1) in a mainly paved environment.

II.5.2. Interpolation of reference GDR measurements

The location of the measuring points is depicted in Figure II.10. Figure II.11 shows the same points with the Hotspot deposition results (predicted deposition on a reference ground surface, i.e., lawn) superimposed. A more detailed characterization of the locations including the corresponding coordinates is given in the accompanying Excel workbook. The radiological dispersal device location defines the origin of the coordinate system. The west-east extent ranges from –500 m to 2000 m, the north-south extent from –500 m to 1000 m. The satellite image from GE has been geo-referenced with the measurement locations using the GRASS geographical information system (GIS).

The majority of the measuring points are placed downwind of the radiological dispersal device location. The inner city area is located to the west of the highway. East of the highway are mostly residential areas and shopping areas. The GDR_{real} has been 'back-calculated' from the Hotspot result for the surface contamination using relations (1) and (2). It ranges from 4 nGy h^{-1} at point no. 38 to 50 µGy h^{-1} at point no. 7. After correction with location factors the GDR_{ref} ranges from 12 nGy h^{-1} at point no. 38 to 11 µGy h^{-1} at point no. 2. This smaller range causes less variation of the interpolated maps. Explicit values are given in the Excel workbook. For the uncertainty analysis a lognormal distribution of the GDR has been assumed with a relative measurement error of 20 percent.

For the interpolation of the GDR_{ref} and the surface deposition A_{ref}, IAMM applies the method of inverse distance weighting. This method was chosen because of its robustness. One can obtain valid results even if the number of measurements is scarce. It has of course, like any interpolation method, inherent drawbacks. For example, in outer regions without measurements the arithmetic mean of all measured values is approximately assigned since all values possess the same weight. The property tends to overestimate the radioactive contamination where in fact a decreasing trend is expected.

Figure II.12 shows a map of the reference surface contamination with contours at 1, 2, 3 and 4 MBq m^{-2}. The contours have been calculated with the GRASS GIS from a raster map of 50 m resolution. The highly contaminated inner city areas east of the radiological dispersal device location are clearly identified. However, the contour lines do not reproduce the stretched shape of contours from the Hotspot model. The interpolated contours are determined by the interpolation algorithm and by number and location of the measuring points rather than by a physical model. West of the radiological dispersal device location there are only four measurement points. The Hotspot model predicts no surface contamination there, but we assumed values some two orders of magnitude lower than in the vicinity of the radiological dispersal device location. The interpolation result does not suggest that there is negligible contamination west of the radiological dispersal device location since not enough measurements have been taken in that region. In the residential areas east of the highway, enough measurements have been taken so that the interpolated and modeled values are in sufficient agreement (see Table II.2 in a later section).

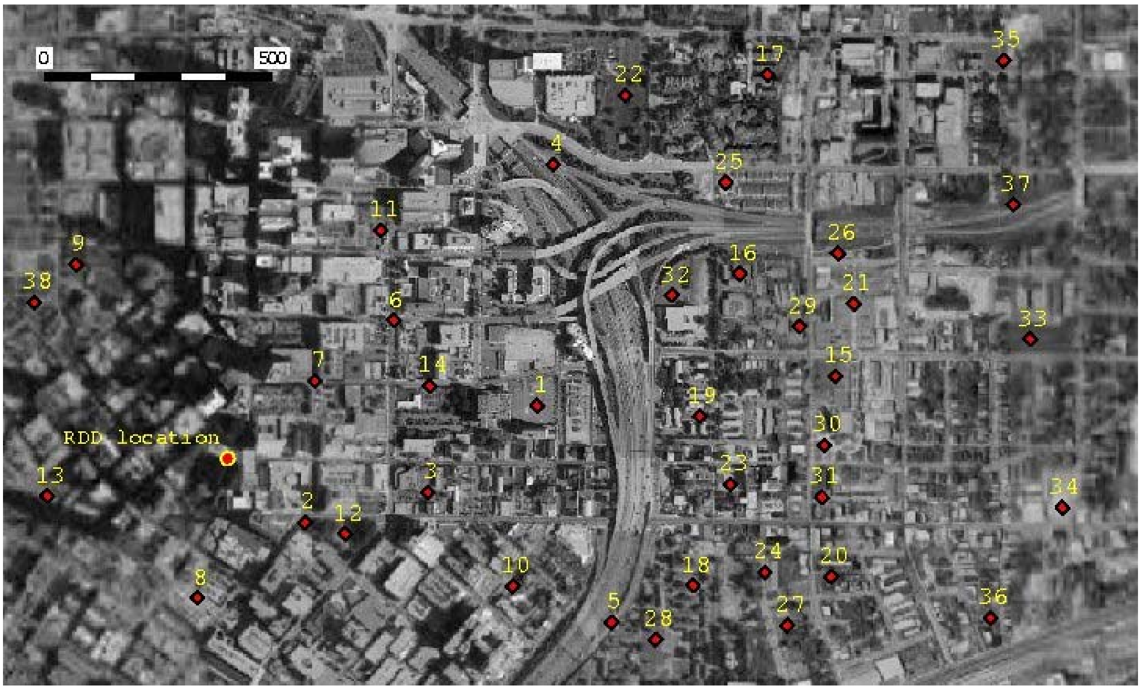

Fig. II.10. Location of the radiological dispersal device and 38 points of GDR measurements.

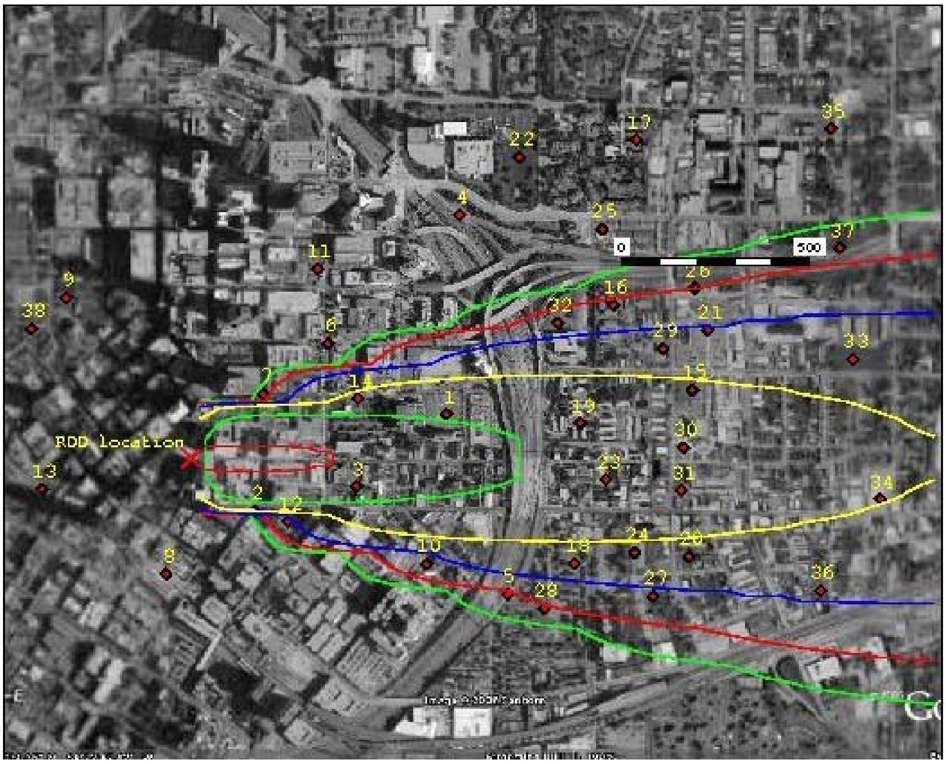

Fig. II.11. Hotspot results for the deposition on a reference ground surface (lawn), superimposed on the test area. From inside to outside, the contour levels (kBq m^{-2}) are 10$^{3.5}$ (red), 10^{3} (green), 10$^{2.5}$ (yellow), 10^{2} (blue), 10$^{1.5}$ (red), and 10^{1} (green). The contours were generated from a raster map of resolution 50 m (coordinates: north, 1025 m; south, -725 m; east, 2025 m; west, 25 m).

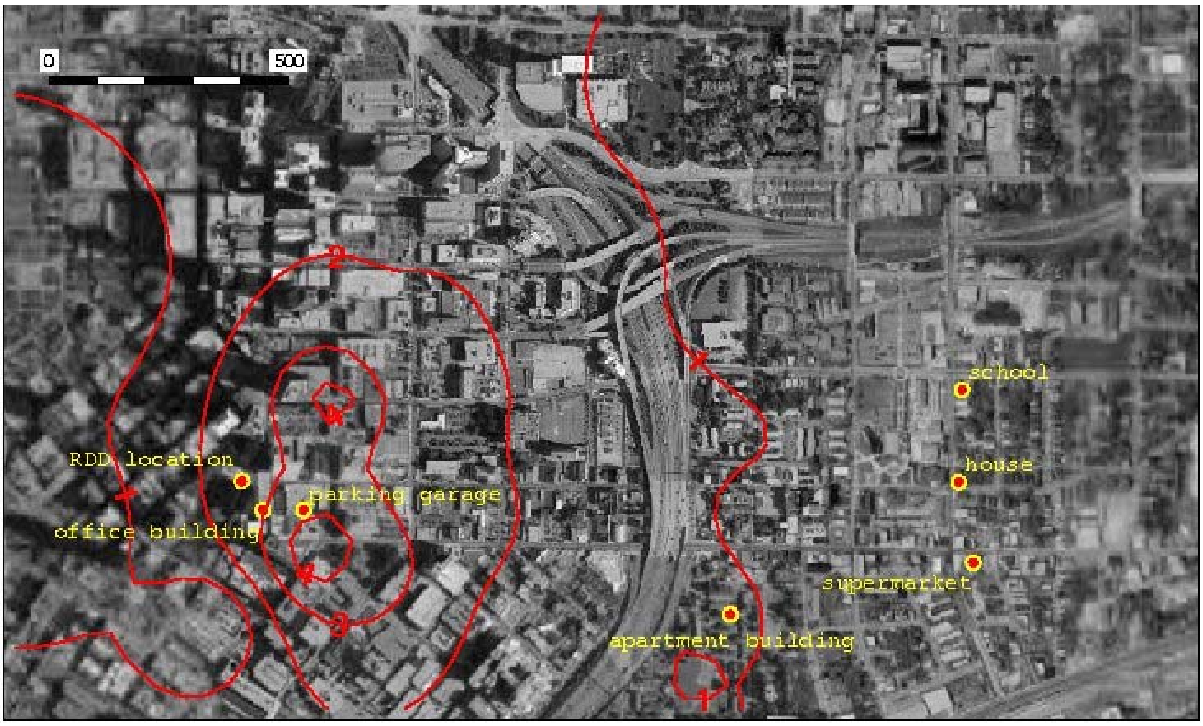

Fig. II.12. Reference surface contamination with contour levels at 1, 2, 3 and 4 MBq m^{-2}.

II.5.3. Treatment of uncertainties

IAMM can produce results either deterministically or stochastically. In the deterministic mode *nominal* values with no uncertainties are assumed for the physical quantities. In the stochastic mode a probability density function (PDF) for the uncertainty is assigned to each measured quantity (Table II.1). Shape parameters for the PDF are also given.

When the reference surface contamination A_{ref} is calculated with relations (1) and (2) from the actual GDR_{real}, three parameters are taken to be uncertain. They are listed in Table II.1. For each of these parameters a PDF is simulated with N_{ens} = 100 realisations. For the GDR_{real} a relative measurement error of 0.2 is assumed. The shape parameters for the location factors are given in the Excel workbook individually. Then the IDW interpolation has been performed N_{ens} times for the reference surface contamination A_{ref}, so that for each raster cell a PDF is generated. The desired uncertainty intervals can be easily derived from this PDF. In IAMM it is possible to produce raster maps for the extrema, the $\pm 2\sigma$ and $\pm\sigma$ uncertainty intervals, the median, the arithmetic mean and the arithmetic standard deviation, respectively.

For emergency planning the upper limits of a radiological quantity are of special interest. Therefore, Figure II.13 shows the contour levels for the $+2\sigma$ (97%) uncertainty interval of the reference surface contamination. Compared to the deterministic values of Figure II.11, they are enhanced by some factor of 2.

II.5.4. Surface contamination at selected building sites

Table II.2 contains the deterministic and stochastic results of the IDW interpolation by IAMM for the reference surface contamination of selected buildings. The sites correspond to those of the map in Figure II.11. The values are given for the ground surface, i.e. at height 0 m. These results can be compared with the ‘real’ values from the Hotspot model, which formed the basis of the interpolation. In the immediate vicinity of the radiological dispersal device location at the office building the IAMM result underestimates the Hotspot result by some factor of three. At the parking garage the IAMM is still lower by a factor of 1.7. At the four building sites, which are more than 1000 m away from the radiological dispersal device location, the values of IAMM begin to overestimate the Hotspot results. Only for the apartment building (no. 6) the Hotspot value lies inside the 2σ-confidence interval given by the stochastic analysis of IAMM.

In general, the interpolated surface of the radioactive contamination appears ‘stiff’. It cannot follow large spatial gradients in the contamination pattern. The IDW algorithm tends to smooth gradients because it computes weighted means of measured values. Therefore, the implementation of a second mode of operation is planned for the IAMM tool. In this mode a map of the surface contamination from another independent source is merged with the IAMM map from interpolation using data assimilation algorithms like ensemble Kalman filtering. If this independent source contains information from a physical prediction model, it is hoped that the maps resulting from data assimilation improve the presentation of the true situation of radioactive contamination.

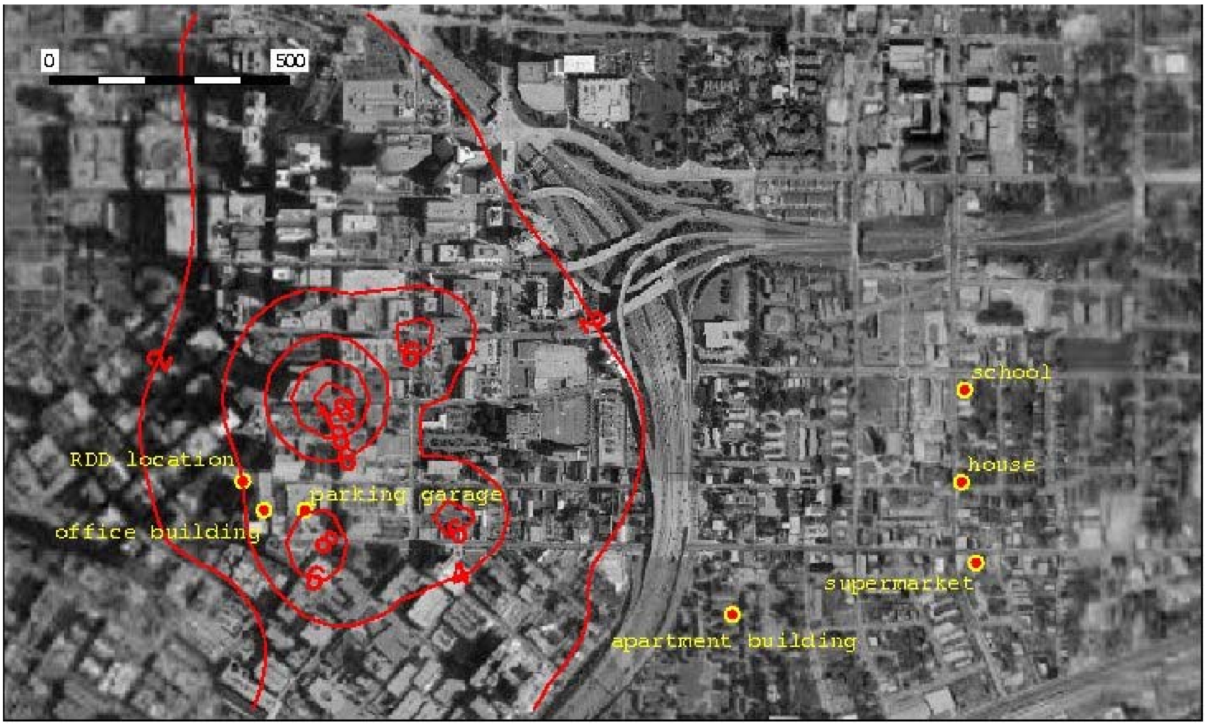

Fig. II.13. Contour levels at 2, 4, 6, 8 and 10 MBq m^{-2} for the +2σ (97%) uncertainty interval of the reference surface contamination.

Table II.1. Usage of physical quantities within IAMM in the stochastic and the deterministic mode.

Parameter Name	Symbol	Stochastic mode PDF	Shape parameter	Deterministic mode Nominal parameter
Measured GDR	GDR_{real}	lognormal	Arithmetic mean, standard deviation	Arithmetic mean
Location factor	f_{loc}	triangular	Minimum, Mode, Maximum	Mode
Dose conversion factor	c_{ref}	triangular	Minimum, Mode, Maximum	Mode

Table II.2. Reference surface contamination at 6 selected building sites from the Hotspot model and from IDW interpolation by IAMM either deterministically with nominal values or stochastically with uncertainties (median and 2σ-confidence intervals).

Building		Coordinates		Distance	Reference surface contamination (MBq m^{-2})				
					Hotspot	IAMM with IDW			
No.	Name	x (m)	y (m)	(m)	model	nominal	median	-2σ	+2σ
1	office	44	-60	74	9.10	2.81	2.89	2.08	4.29
2	parking garage	129	-60	142	6.60	3.89	3.87	2.51	6.15
3	school	1504	191	1516	0.50	0.69	0.72	0.58	0.88
4	supermarket	1528	-170	1537	0.49	0.72	0.75	0.55	0.97
5	one family house	1498	-2	1498	0.51	0.72	0.77	0.55	1.01
6	apartment building	1020	-278	1057	0.87	1.30	1.19	0.64	1.96

II.6. Input information (surface concentrations and air concentrations)

The primary input information for the modeling exercise is the reference surface contamination at six selected buildings, given in Table II.2. Close-up photographs of the six buildings are provided in Figures II.14–II.19. Map locations (coordinates) and information about the buildings are provided in the Excel workbook. Concentrations of ^{137}Cs in air at the building locations are shown in Figure II.20; numeric values are provided in Table II.3 and in the Excel workbook.

II.7. Modeling endpoints

For each test location and each applicable countermeasure listed below, calculate the dose rates and radionuclide concentrations first without any countermeasures and then with each indicated countermeasure. For dose calculations, predict the annual doses for each reference exposure scenario (listed below) without countermeasures and then with each indicated countermeasure. All endpoints will be used for model intercomparison.

The modeling endpoints for this scenario are as follows:

(1) External exposure rates (dose rates, mGy h^{-1}) at specified locations, from all relevant surfaces (by surface and total);
(2) Contributions to the dose rates (%) from each surface, for the most important surfaces;
(3) Annual and cumulative external doses (mGy) for specified reference (hypothetical) exposure scenarios; and
(4) Radionuclide surface concentrations (Bq m^{-2}) at each location (outdoors).

Model calculations need to start following the initial deposition from the radiological dispersal device event and need to be carried forward for 20 years. Results need to be presented as a time series, with the date specified for each predicted dose rate, dose, or radionuclide concentration. Example formats are provided in the accompanying Excel workbook. Where possible, uncertainties on the predictions must be included.

For dose calculations, use the following (hypothetical) exposure scenarios:

(1) Occupational exposure (adult), Building 1, floor 1 (40 h wk^{-1}, residential and other exposures not included);
(2) Occupational exposure (adult), Building 1, floor 5 (40 h wk^{-1}, residential and other exposures not included);
(3) Residential exposure (adult, e.g., pensioner or housewife), Building 5, floor 1 (120 h wk^{-1} indoors and 15 h wk^{-1} outdoors, other exposures not included);
(4) School exposure (child), Building 3, floor 1 (35 h wk^{-1} indoors); and
(5) Occasional exposure (adult), Building 4 (store), floor 1 (1 h wk^{-1} indoors).

For reference children (school scenario), predictions of annual dose are requested; for reference adults (all other scenarios), annual and cumulative doses are requested.

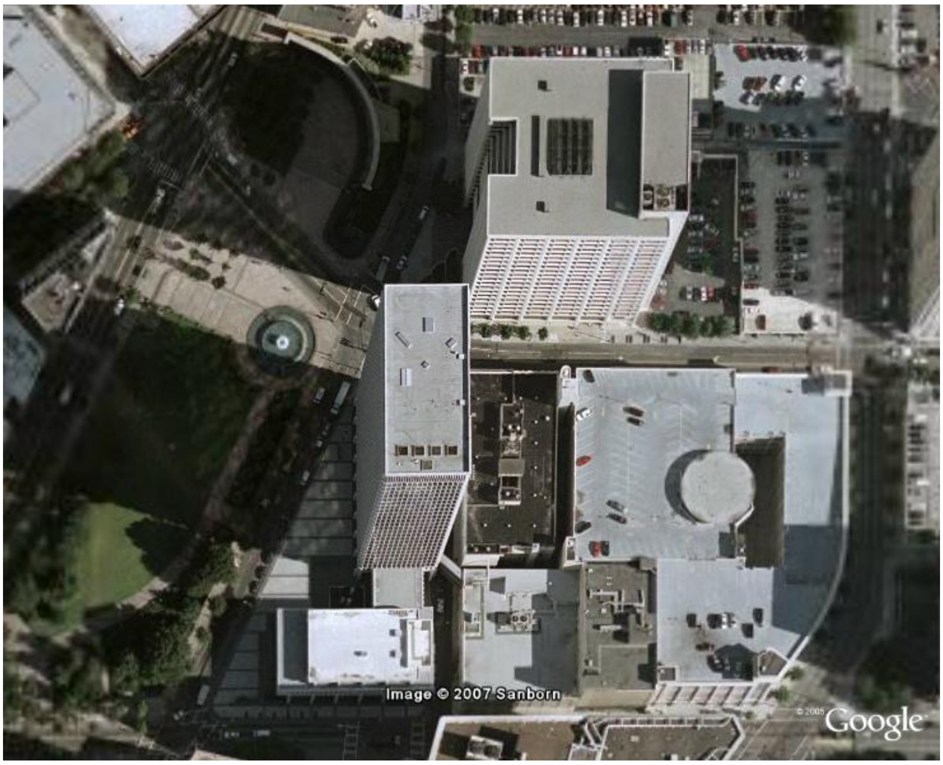

Fig. II.14. Close-up photograph of Building 1, the tall, narrow office building in the center of the photograph, just east of the park.

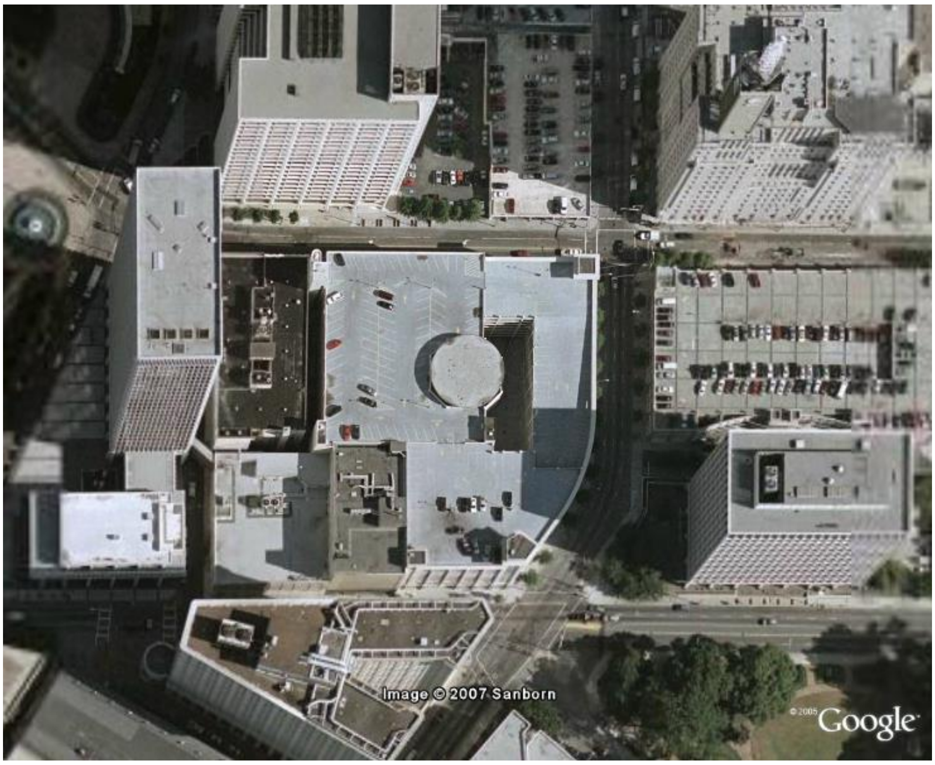

Fig. II.15. Close-up photograph of Building 2, the parking garage in the center of the picture.

Fig. II.16. Close-up photograph of Building 3, the school (in the center of the photograph, on the southeast corner of the intersection. Building 3 refers to the first of the two buildings, the long narrow one.

Fig. II.17. Close-up photograph of Building 4, the supermarket in the center of the photograph (on the southeast corner of the intersection).

Fig. II.18. Close-up photograph of Building 5, a single-family house (on the northeast corner of the intersection near the center of the photograph, the one closest to the corner).

Fig. II.19. Close-up photograph of Building 6, the apartment complex (the third building down in the column of six).

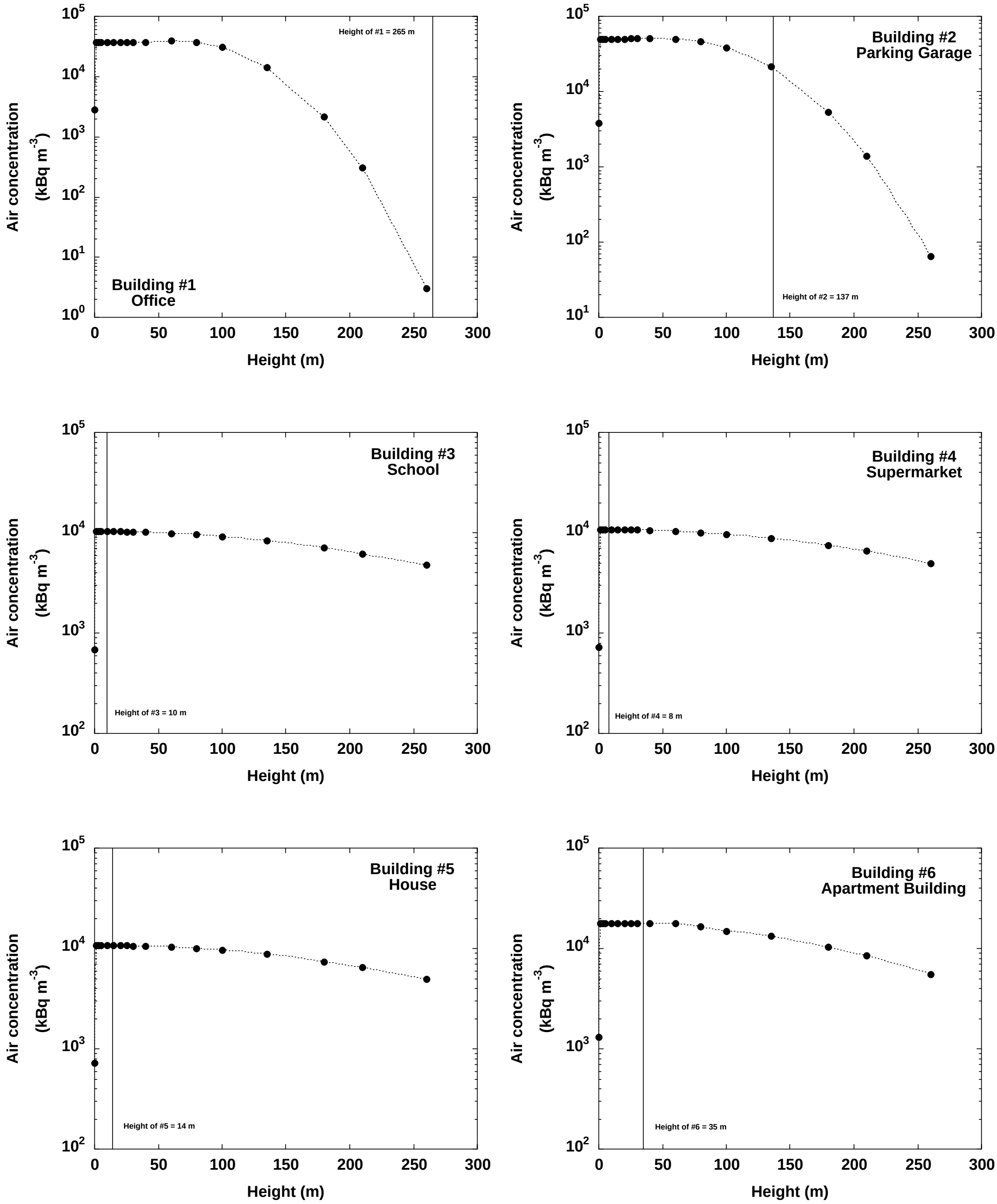

Fig. II.20. Concentration of ^{137}Cs in air as a function of height above ground, at the locations of the indicated buildings. Building heights are indicated on each graph. The locations of the buildings are shown in Figure II.11 of the scenario description. Coordinates of the buildings, building heights, and numeric values of the air concentrations are given in Tables 2 and 3 and in the "Air concentrations" sheet in the Excel Workbook.

Table II.3. Initial air concentrations (MBq m^{-3}) at specified building locations, as a function above ground[a].

Bldg. No.	**Height (m)**	**Height above ground (m)**															
		1.5	**3**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**60**	**80**	**100**	**135**	**180**	**210**	**260**
1	265	37.02	37.02	37.02	37.02	37.02	37.02	37.02	37.02	37.02	40.10	37.02	30.85	14.50	2.16	0.31	0.003
2	137	50.05	50.05	50.05	50.05	50.05	50.05	50.64	50.64	51.23	50.05	46.52	38.86	21.79	5.42	1.41	0.065
3	10	10.31	10.31	10.31	10.31	10.31	10.31	10.17	10.17	10.17	9.90	9.62	9.21	8.39	7.15	6.19	4.81
4	8	10.86	10.86	10.86	10.72	10.72	10.72	10.72	10.72	10.57	10.42	9.98	9.69	8.81	7.49	6.60	4.99
5	14	10.77	10.77	10.77	10.77	10.77	10.77	10.77	10.63	10.63	10.35	10.06	9.64	8.79	7.37	6.52	4.96
6	35	17.96	17.96	17.96	17.96	17.96	17.96	17.96	17.96	17.96	17.96	16.46	14.97	13.47	10.48	8.53	5.54

[a] Based on the IAMM/IDW interpolation from the Hotspot results.

Table II.4. List of countermeasures and the corresponding time of application for use in the modeling exercise.

Number	Countermeasure	Time of application (after the accident)
1	No remediation	–
2	Cutting and removal of grass	Day 7
3	Washing of roads	Day 14 (no rain)
4	Washing of roofs and walls	Day 14 (no rain)
5	Removal of trees (or leaves)	Day 30
6	Removal of soil (5 cm)	Day 180
7	Vacuuming indoors	Day 14
8	Washing indoor surfaces	Day 14
9(a)	Relocation of population (temporary):	For the first 2 weeks
9(b)		For the first 6 weeks
9(c)		For the first 6 months

Information about the six buildings is given in the Excel workbook; photographs are provided in Figures II.14–II.19. For Building 1 (office), test locations include floors 1, 5, 20, and 60. For Building 2 (parking garage), test locations include floors 1, 4, and 8 (8 is the parking level on top of the building). For Building 3 (school), the test location is the first (ground) floor. For Building 4 (supermarket), the test location is the first (ground) floor). For Building 5 (single-family house), the test location is the first (ground) floor. For Building 6 (apartment building), test locations include the first (ground) and 5^{th} (top) floors. For each building, calculate the endpoints both inside and outside the building (outside at ground level; near the entrance if that is known, otherwise the west side).

The remedial measures (countermeasures, remediation measures) to be considered are listed in Table II.4, together with the time of application to be assumed.

II.8. Documentation of model predictions

Appropriate documentation of all model predictions was requested, including key assumptions and specific parameter values used. Model documentation is provided in Appendix III of this report. For each countermeasure (or combination of countermeasures, if appropriate), requested documentation includes a description of how the countermeasure was modeled and provide the parameter value(s) used.

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[II.8] KAISER, J.C., PRÖHL, G., Harnessing Monitoring Measurements in Urban Environments for Decision Making After Nuclear Accidents, Kerntechnik 72:218–221 (2007).

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APPENDIX III. DESCRIPTION OF MODELS AND INDIVIDUAL EVALUATIONS OF MODEL PERFORMANCE

This Appendix contains descriptions of each model used in the exercises described in the report, together with evaluations of the model performance in the exercises. The descriptions and evaluations were prepared by the participants who used the models. In general, the model descriptions include the following information:

- Purpose of the model (research, assessment or scoping; conservative or realistic);
- Type of model (steady-state or dynamic; analytical or numerical; compartment or process-oriented);
- Biological/environmental compartments considered;
- Transport processes considered;
- Endpoints considered;
- Key assumptions;
- Modelling approaches (conceptual and mathematical):
  - how transfers between compartments are modelled,
  - how concentrations in compartments are calculated,
  - temporal and spatial discretization of the model,
  - input data required;
- Parameter values:
  - values of the parameters used in the model,
  - spatial and temporal averaging;
- Uncertainties (approach to estimating uncertainties in the model predictions);
- Application of the model to each scenario (test exercise):
  - how the data given in the scenario description were used to drive the model,
  - what assumptions were made to match the model to the conditions of the scenario; and
- References.

Appendix III includes the following sections:

III.1 EXPURT

III.2 METRO-K

III.3 EDEM

III.4 CPHR

III.5 RESRAD-RDD

A full set of model predictions for each scenario and each model is provided in Appendix IV, in both tabular and graphical format.

III.1. Description of EXPURT
(Tom Charnock, Kamaljit Sihra)

III.1.1. Introduction

III.1.1.1. Model name

EXPURT is a compartment model that calculates surface activity densities and external gamma doses and dose rates as a function of time in built environments with a mixture of urban surfaces including roads, trees, walls, roofs, grass, etc. The current version 3.02 is largely unchanged from version 3.0 described by Jones et al. [III.1.1].

CONDO (CONsequences of Decontamination Options) is a software tool developed to assist decision-makers in the event of a radiation emergency. The current version of CONDO is 3.1; version 2.1 is described in detail by Charnock et al. [III.1.2]. CONDO uses the EXPURT 3.02 model, as well as a database of recovery options (mainly extracted from Brown et al. [III.1.3] and Brown and Jones [III.1.4]), summary calculations and default values to present the decision maker with a number of specific results.

III.1.1.2. Purpose of the model

EXPURT is used to assess average doses and dose rates from external exposure to gamma radiation to a population inhabiting various idealised urban environments contaminated by air-borne radioactive material that has travelled from outside the environment. It can represent the implementation of several clean-up options. It is used for research purposes and for the purposes of generating advice. In addition it has been used to produce data libraries for the probabilistic risk assessment prgramme COSYMA [III.1.5] and a data library of dose reduction factors for use in the Late Countermeasures Module –Terrestrial of the Emergency Response Decision Support system RODOS [III.1.6].

CONDO has been used successfully in several UK national exercises. It has also been used for emergency preparedness to develop scenarios for exploring wider considerations and practical issues with potential stakeholders in the event of a real incident [III.1.7]. It has been used in the production of a handbook for use in the recovery phase of an emergency [III.1.8, III.1.9].

III.1.1.3. Type of model

EXPURT is a dynamic compartment model that simulates the movement of radionuclides between surfaces in inhabited areas as first order differential equations. EXPURT uses a library of unit dose rates for different energies and different urban surfaces calculated by a Monte Carlo code.

CONDO uses EXPURT and augments the EXPURT output with other calculations; in particular it uses a resuspension factor approach to estimate activity concentration in air and to calculate doses to workers and members of the public from the inhalation of resuspended material.

III.1.1.4. Biological/environmental compartments considered

EXPURT considers roofs, exterior walls, paved surfaces, interior surfaces, trees and drains. Grass and the top layer of soil are considered as one compartment, and there are a further four soil layers.

III.1.1.5. Transport processes considered

EXPURT considers the initial deposition of radioactive material onto urban surfaces and the subsequent transfer of that material between surfaces and migration down the soil column due to weathering processes. EXPURT considers the translocation of material between surfaces and out of the system by decontamination. EXPURT also includes the rearrangement of material in the soil column by soil mixing countermeasures. CONDO considers the resuspension of material, from surfaces where it was deposited.

III.1.1.6. Endpoints

The endpoints of EXPURT are:

- Effective dose and dose rate from external exposure to gamma radiation emitted by material deposited on each urban surface to representative locations indoors and outdoors as a function of time, with and without countermeasures (Sv and Sv h^{-1}), and
- Radioactive contamination of each urban surface as a function of time (Bq m^{-2}).

The endpoints of CONDO are:

- Average individual effective dose to members of the public from external exposure to gamma radiation emitted by deposited material, integrated over a number of user specified integration times with and without a countermeasure (Sv);
- Average committed effective dose to members of the public from inhalation of resuspended material over a number of times with and without a countermeasure over a period of 50 years (Sv);
- Individual effective dose to workers from external exposure to gamma radiation (Sv),
- Individual committed effective dose over a period of 50 years to workers from inhalation of resuspended material (Sv);
- Monetary cost of applying a countermeasure (£);
- Effort of applying a countermeasure (person days); and
- Quantity of waste produced (kg) and activity concentration in the waste (Bq kg^{-1}).

III.1.2. Key assumptions

The key assumptions of EXPURT are homogeneous deposition on each type of surface in the environment and, following a user specified period without rain, average weathering from a continuous slow rainfall.

III.1.3. Modelling approaches

III.1.3.1. Transfers between compartments

Figure III.1.1 is a diagram of the EXPURT model; each surface is represented by one or more compartments. EXPURT uses ratios of dry deposition on a surface to dry deposition on a reference surface and interception factors in order to calculate the total deposition in each of the shaded compartments in Figure III.1.1. The required input is an estimate of initial dry deposition of each radionuclide to a reference lawn surface (Bq m^{-2}) and an estimate of the dry to wet deposition ratio on that reference surface provided by the user.

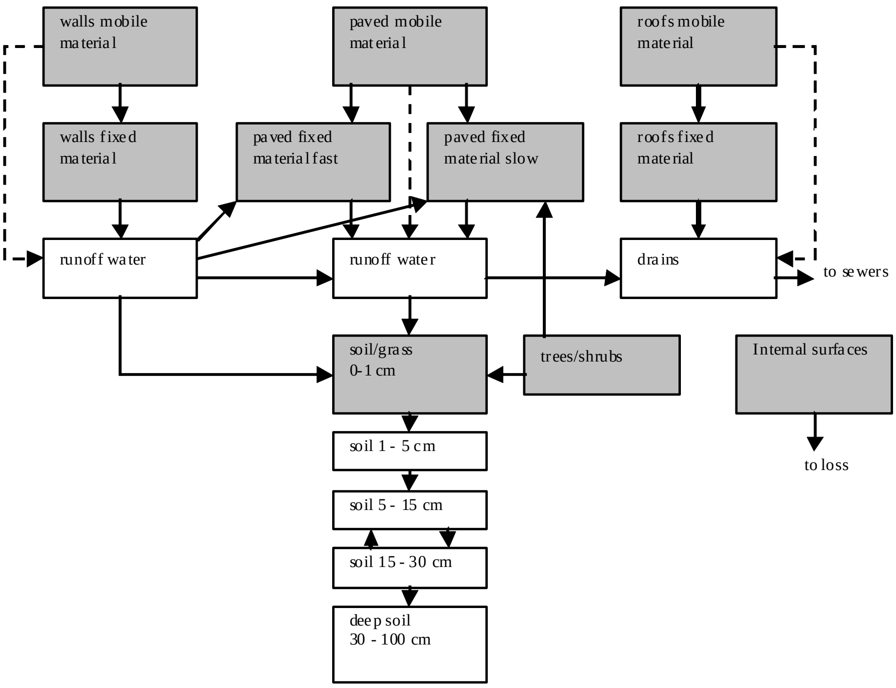


Fig. III.1.1. EXPURT model for transfer of deposited material between buildings, grass, soil and trees. Transfers marked with a dotted line occur only at the time of first rain.

EXPURT simulates the movement of radionuclides between urban surfaces as first order differential equations. For surfaces such as roofs, walls and paved more than one compartment is used to represent mobile and fixed components of the material.

EXPURT calculates the surface radioactivity density (Bq m^{-2}) and time integrated surface radioactivity density (Bq s m^{-2}) of each radionuclide deposited in each compartment in the model at various times. Figure III.1.2 shows the predicted surface contamination of ^{137}Cs calculated for the Pripyat scenario. In the first year the most contaminated surface is that of trees; however this contamination is largely gone by the second year. From then on the soil is the most contaminated surface and the predicted migration through the soil column over the years is clearly discernable. The next most contaminated surface is roof; the remaining surfaces are relatively lightly contaminated and they do not show well on the graph.

EXPURT has access to a library of environments that includes the proportions of different surfaces in each environment and the representative unit indoor and outdoor external gamma dose rates from different gamma energies on different surfaces in each environment. EXPURT combines the data in the library with the calculated radioactivity densities on each surface and time integrated densities on the surfaces in order to calculate external gamma doses and dose rates in different built environments. EXPURT currently contains the energy distributions of 13 significant radionuclides. EXPURT models those radionuclides with significant daughters, such as ^{95}Zr and its daughter ^{95}Nb, by creating a 'composite' radionuclide. A composite radionuclide has a dose rate that includes the both dose rate from the parent and the daughter that has in-grown since the time of deposition. An equilibrium between the parent and the daughter is assumed from time zero although in reality this equilibrium state will take some time to develop depending on the half-lives of the parent and the daughter.

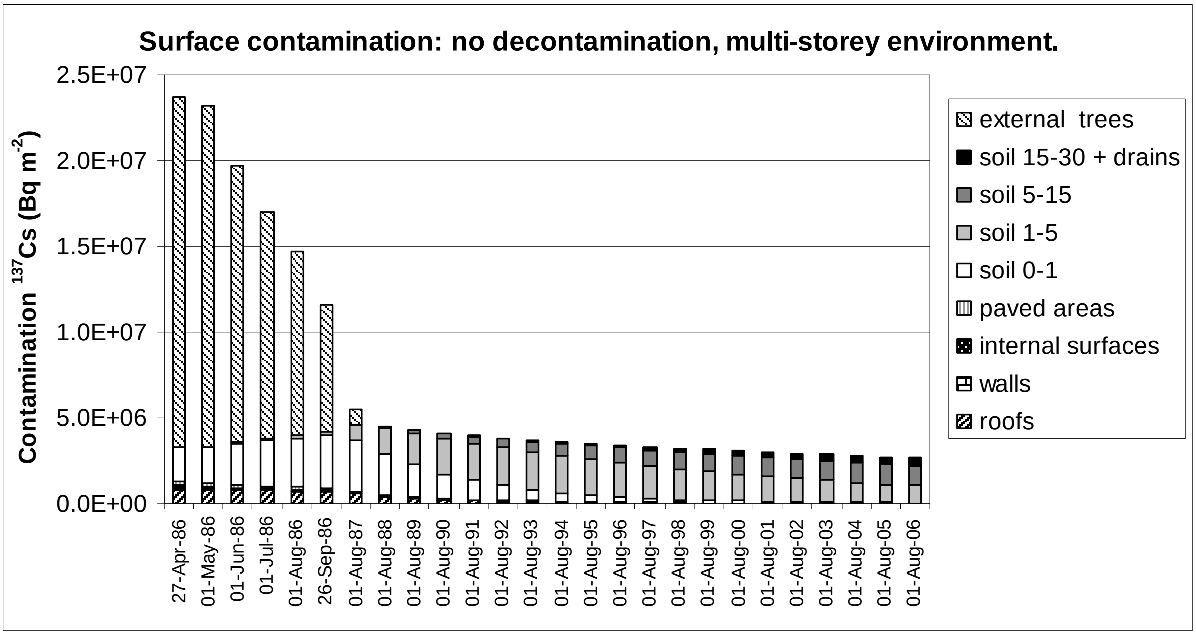


Fig. III.1.2. Predicted surface contamination of ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1.

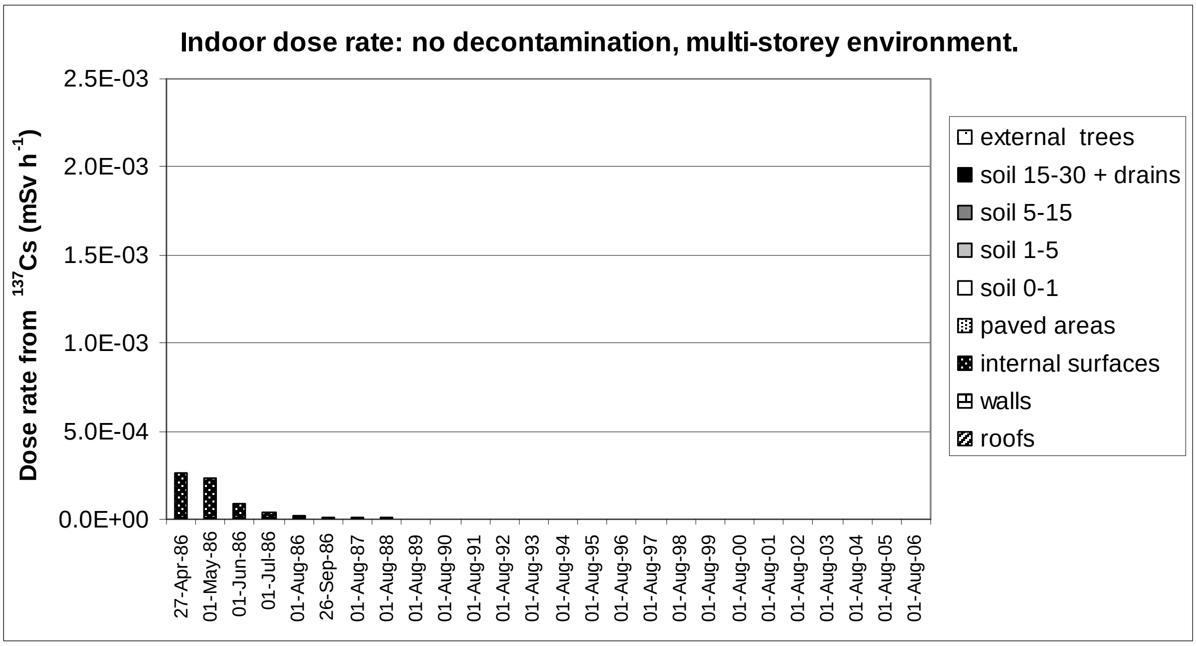


Fig. III.1.3. Predicted indoor dose rate from ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1.

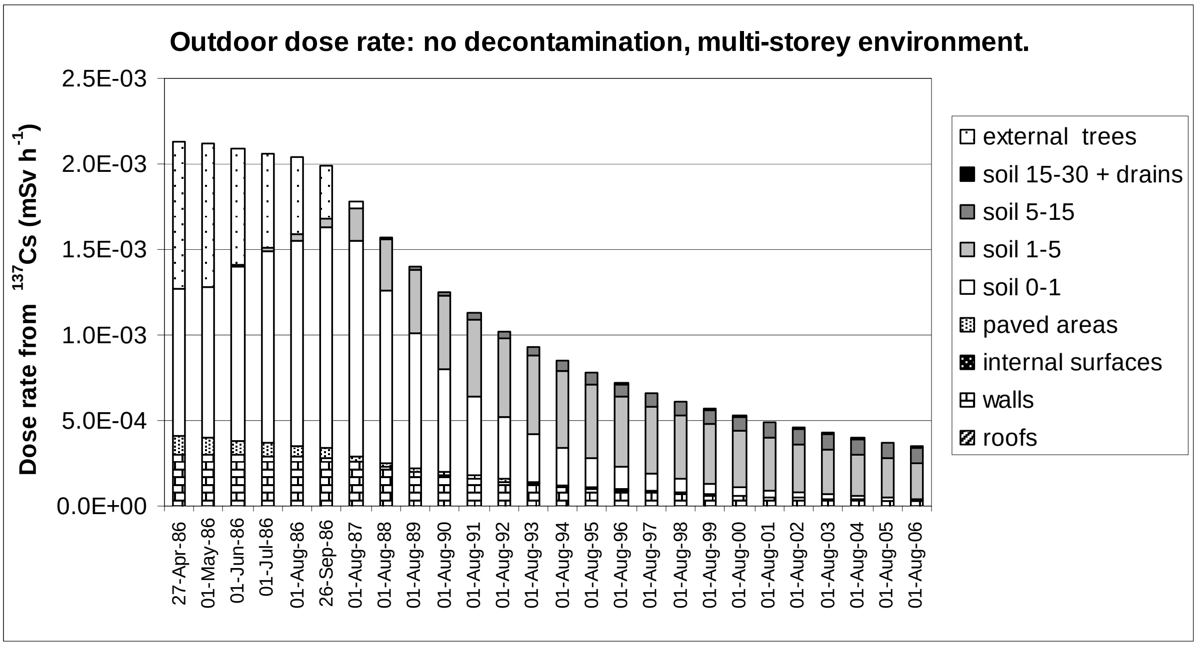


Fig. III.1.4. Predicted outdoor dose rate from ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1.

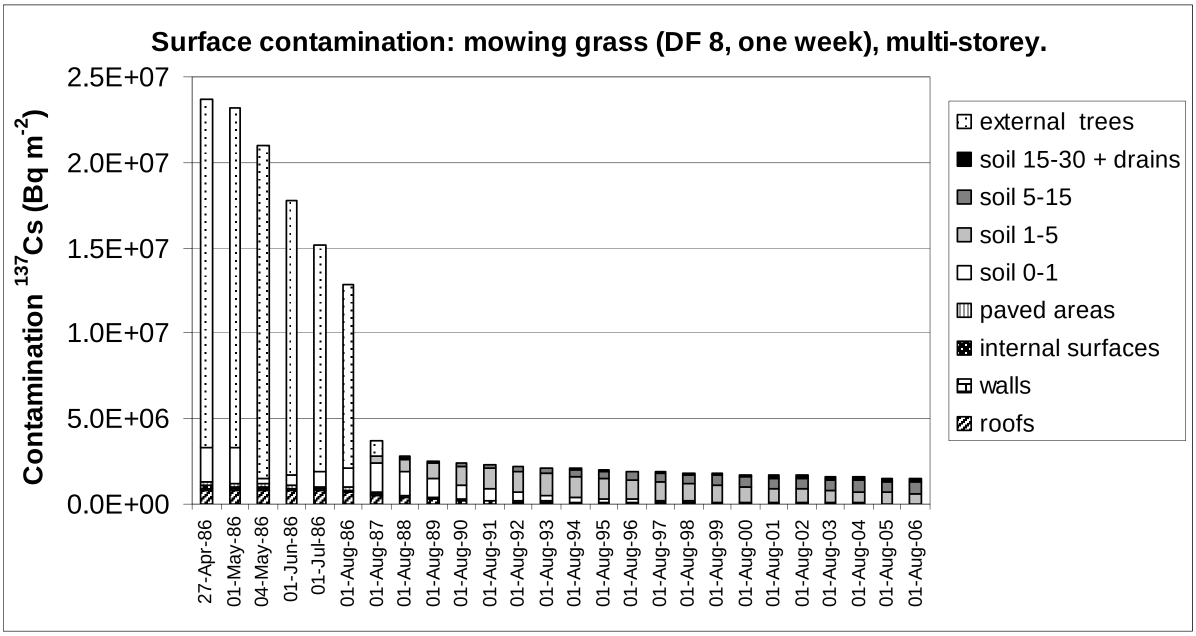


Fig. III.1.5. Predicted surface contamination of ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1; applying a decontamination factor of 8 to the grass compartment at one week to simulate grass cutting and collection.

Figures III.1.3 and III.1.4 show indoor and outdoor dose rates calculated from the predicted contamination in Figure III.1.2. In Figure III.1.3 indoor doses are dominated by the material deposited indoors; there is also a small component from external walls although this does not show well on the graph which has been deliberately drawn to the same scale as the outdoor dose rates. In Figure III.1.4 outdoor dose rates come from a mix of surfaces although the contribution from soil dominates at later times. In EXPURT the deposition on trees is given per unit projected unit of the tree on the ground rather than per unit leaf area. So although the surface deposition appears highest on trees in Figure III.1.2, the soil gives the largest dose rates because the soil covers a much larger fraction of this environment than the total project area of the trees.

Various countermeasures can be represented in EXPURT by manipulating the contents of the compartments. Decontamination techniques are represented by removing contamination from a compartment; cross-contamination during this process is represented by moving a proportion of the removed material to a different compartment. Figure III.1.5 shows the effect of cutting and collecting grass carried out one week after the accident on the predicted surface contamination of ^{137}Cs calculated for the Pripyat scenario. This decontamination technique is represented by applying a decontamination factor (DF) of 8 to the top soil compartment at one week after the initial deposition. There is a small but noticeable reduction in the grass radioactivity compared to Figure III.1.2 and this reduction is seen down the soil profile at later times.

The apparently small surface contamination reduction in Figure III.1.5 is translated into a much more noticeable change in outdoor dose rate in Figure III.1.6. As expected this countermeasure has no effect on indoor dose rates, given the insignificant contribution of the soil/grass surface to the total indoor dose rates (Figure III.1.3).

Soil mixing techniques such as ploughing are represented by moving contamination between the soil column compartments. Figure III.1.7 shows the predicted surface contamination following the redistribution of contamination in the soil profile at 6 months to represent the uniform distribution expected following a ploughing and Figure III.1.8 shows the predicted effect on outdoor dose rates.

EXPURT calculates average individual doses from external exposure to gamma radiation both indoors and outdoors and with or without countermeasures integrated over a number of user defined times. That is the average individual dose a person would receive if they stayed either indoors or outdoors within a given environment 100% the time. CONDO combines this information to estimate the normal-living dose; an estimate of the average dose that a person would receive living in the area which takes account of the time spent indoor and outdoors within the various environments that make up a region. In Figure III.1.3 the total predicted indoor dose rates are an order of magnitude lower than the total predicted outdoor dose rate in Figure III.1.4. However, if the population spends a large proportion of time indoors then the indoor dose may dominate the overall dose received and so countermeasures that target indoor deposition may also be considered.

CONDO uses the doses from EXPURT to calculate the doses to workers who may only be in the area for a short period and whose occupancy of the area will be different from the general public.

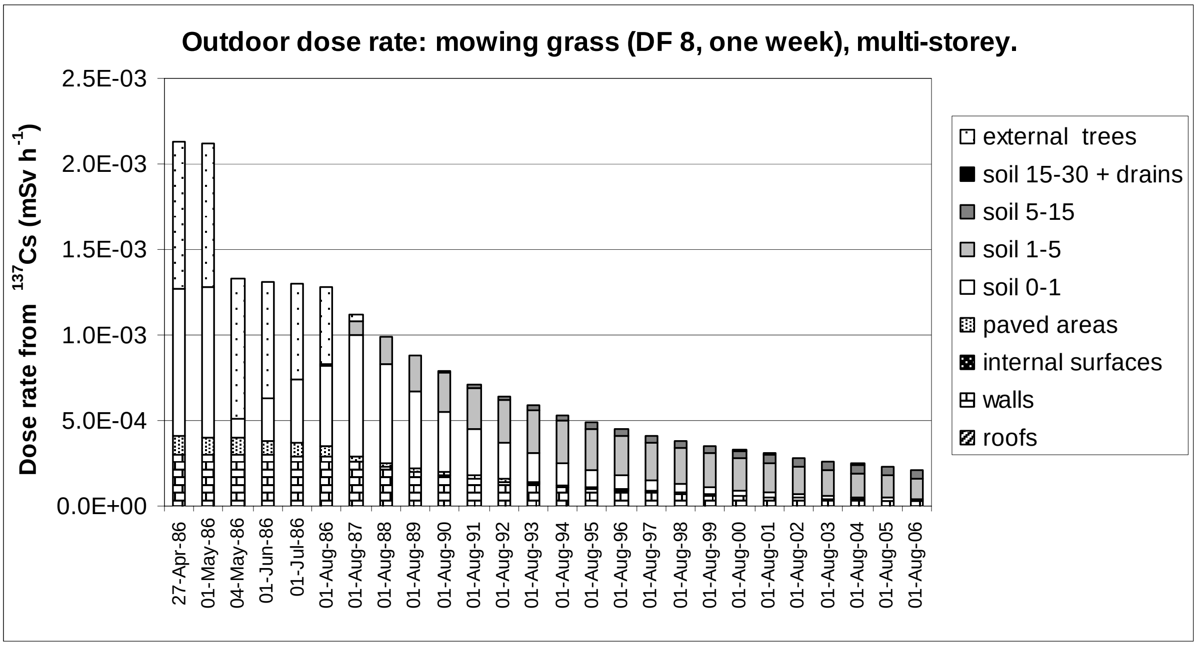


Fig. III.1.6. Predicted outdoor dose rate from ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1; applying a decontamination factor of 8 to the grass compartment to simulate grass cutting and collection.

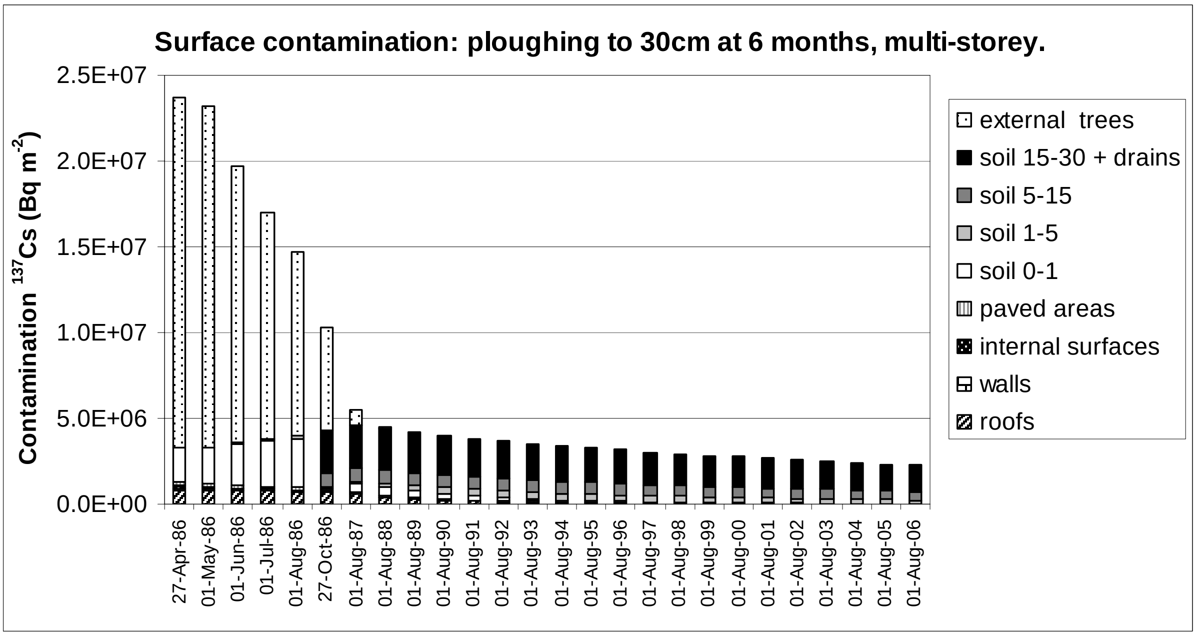


Fig. III.1.7. Predicted surface contamination of ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1; enforcing uniform contamination in the soil profile to simulate ploughing to 30 cm.

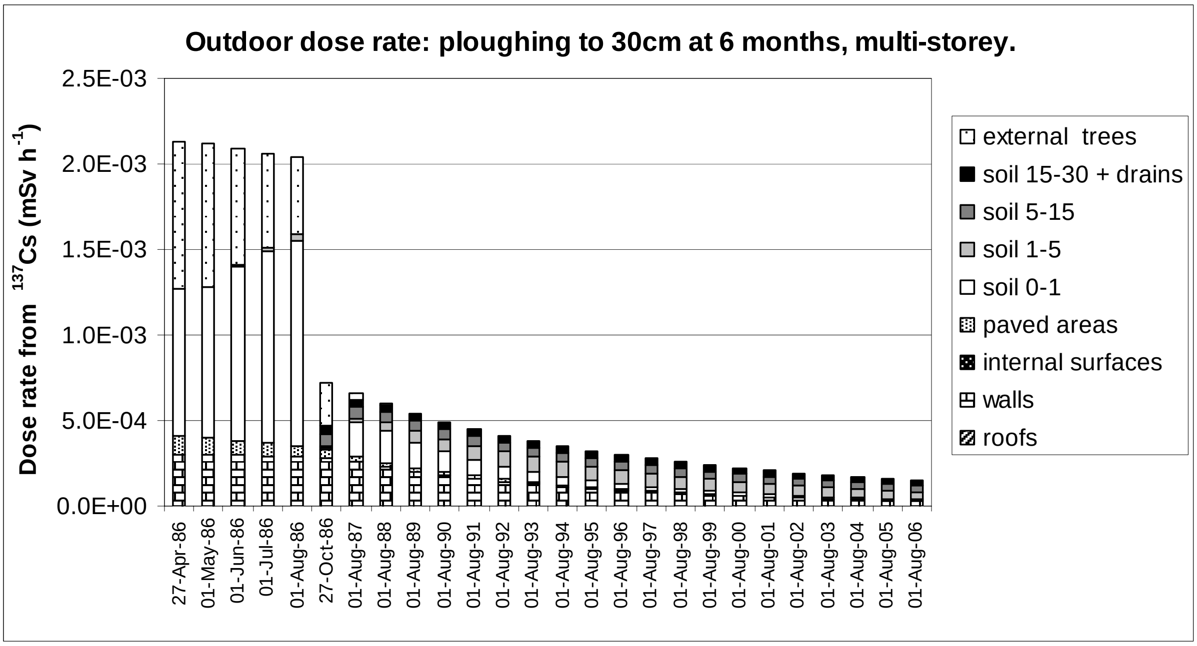


Fig. III.1.8. Predicted outdoor dose rate from ^{137}Cs for the multi-storey environment, low paved and medium trees, for Pripyat scenario Zone 1; applying enforcing uniform contamination in the soil profile to simulate ploughing to 30 cm.

CONDO uses the initial deposition data to estimate the long-term resuspension using a resuspension factor approach [III.1.10]. CONDO uses the difference in overall activity with and without a recovery option to estimate a resuspension dose reduction factor to calculate the resuspension dose with a countermeasure. This is a very rough estimate as it assumes that different external surfaces contribute to the overall resuspension in proportion to the amount of activity on those surfaces.

Within the CONDO recovery option database there are data giving work rates (m^2 team $hour^{-1}$), the number of people on a team and cost rates (£ m^{-2}). This information is combined with the environment mix entered by the user and the proportion of surfaces in the EXPURT environment library to calculate resource endpoints.

CONDO uses waste generation rates (kg m^{-3}) from the recovery option data, along with the proportions of surface from the environment database to calculate the amount of waste produced. EXPURT calculates the amount of activity removed from a surface and so the waste activity concentration (Bq kg^{-1}) can be calculated for each radionuclide. CONDO uses a set of rules based on the amount of beta contamination, alpha contamination and the state of waste (liquid or solid) to give an indicative classification of the waste as either 'exempt', 'low level' or 'intermediate or high level' if the waste has been produced within the UK waste regulatory system.

III.1.3.2. Temporal and spatial discretization of the model

EXPURT assumes that the initial deposition on all surfaces occurs instantaneously at time zero; all other events and processes are relative to this deposition. Other instantaneous processes include the application of decontamination or soil mixing countermeasures, and the transfer of material from mobile to fixed compartments at the time of first rain. EXPURT can handle several countermeasure applied to different surfaces at up to three different times.

The slow processes of weathering of material from surfaces are modelled using first order differential equations solved for all the time steps between the times of instantaneous transfer and the output times requested by the user.

The CONDO temporal model differs slightly in that it considers that countermeasures will take a period to complete. From this period defined by the user, the number of teams and the worker doses are calculated.

Spatially, EXPURT assumes that conditions are constant i.e. that the environment and the deposition are homogeneous over surface within a sufficiently wide area so that the average dose rates indoors and outdoors are constant within the environment. EXPURT uses a library of unit dose rates generated using a Monte Carlo code for a number of different environments [III.1.11]. The inputs to the Monte Carlo code defined environments that were homogeneous with respect to building types and building spacing. A cell was defined consisting of various urban surfaces (buildings, trees and horizontal surfaces). In the Monte Carlo code inputs the cell was repeated a number of times to generate a region. Each cell is assumed contaminated to the same degree and so that the dose rates simulated in the centre of the region are not distorted significantly by edge effects, see Figure III.1.9.

CONDO allows a region to be represented by a number of EXPURT environments. For example, an area of the city might be represented by 20% multi-storey, 50% brick houses and 30% open green area. CONDO calls EXPURT for each environment in turn and weights the results to produce a dose estimate that is representative of the average individual dose for a person moving around the region.

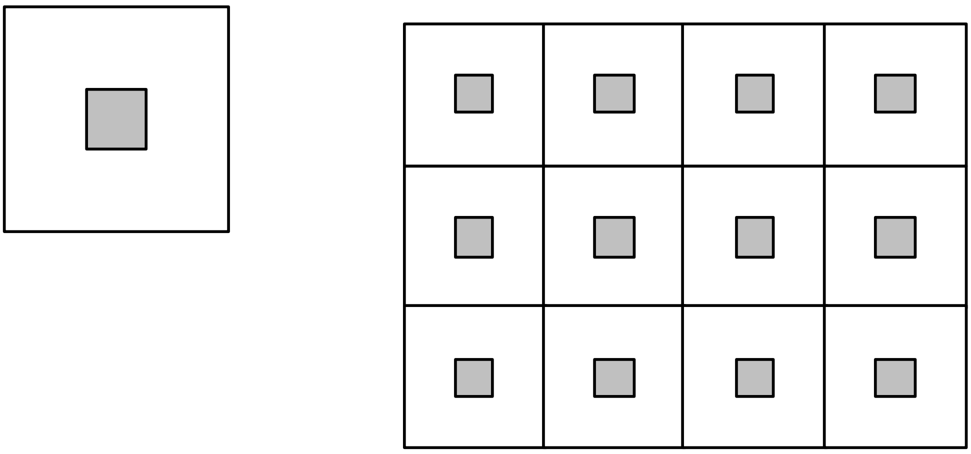


Fig. III.1.9. A number of environment cells is used to model an environment within MCNP, representative locations are selected in the centre of the grouping.

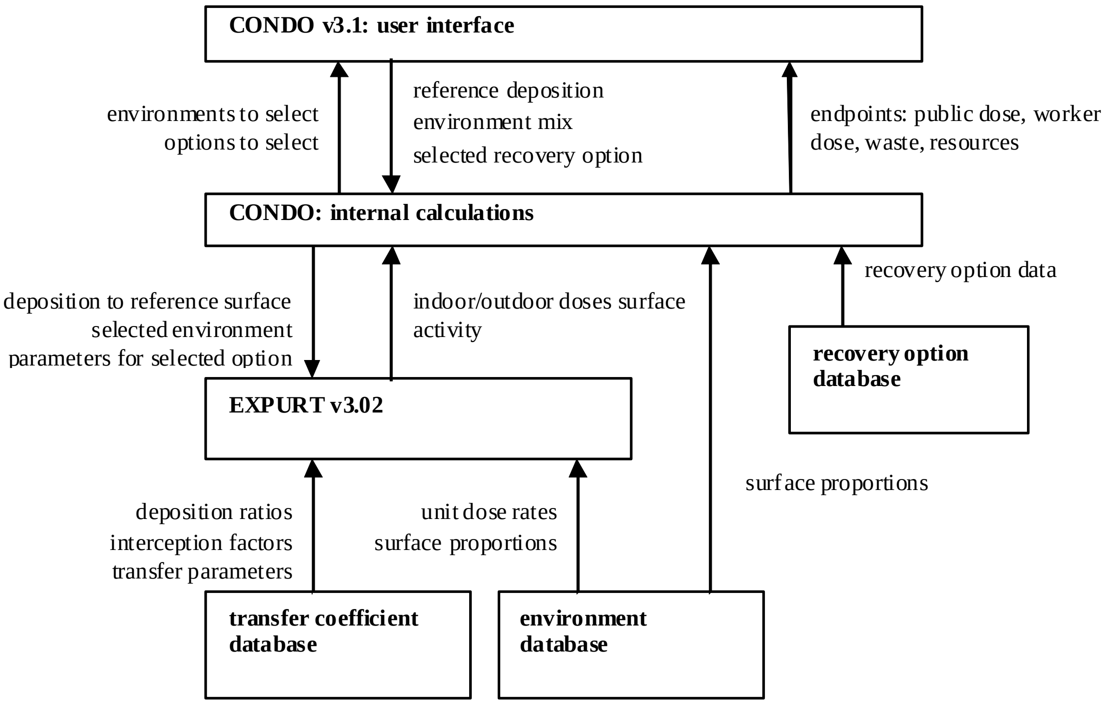


Fig. III.1.10. Relationship between CONDO v3.1 and EXPURT v3.02

III.1.3.3. Input data required

EXPURT requires an environment choice, an estimate of initial deposition to a reference grass/soil surface of each radionuclide of interest, an estimate of the wet to dry component of deposition and a description of the effect of the countermeasure on each radionuclide in each compartment.

CONDO presents a simple interface to the user. The user specifies the initial deposition of each radionuclide to a reference surface, the deposition conditions (wet or dry) and the mix of environments within the area of interest. The user can also select a recovery option from a large database; CONDO converts the named decontamination technique into the numerical description that EXPURT requires. Figure III.1.10 shows a diagram of the interaction between the components of CONDO.

III.1.4. Parameter values

III.1.4.1. Values of the parameters used in the model

Default values for the ratios and interception factors used in EXPURT are held in a database and given in Table III.1.1.

Default values for the parameters describing the movement of material within the environment are held in a database and given in Table III.1.2. These are typical values for the UK.

The EXPURT database contains four environments as listed in Table III.1.3. Each environment is assumed to be homogenous in building type.

Table III.1.1.Default values of the parameters describing the initial deposition within the environment.

Quantity	Iodine	Other elements
Ratio of dry deposition on roofs to reference lawn surface	0.7	0.4
Ratio of dry deposition on walls to reference lawn surface	0.06	0.05
Ratio of dry deposition on internal surfaces to reference lawn surface	0.07	0.07
Ratio of dry deposition on paved areas to reference lawn surface	0.1	0.1
Ratio of dry deposition on trees and large shrubs to reference lawn surface	10	10
Interception factor for wet deposited activity on roofs	0.4	0.7
Interception factor for wet deposited activity on walls	0.25	0.25
Interception factor for wet deposited activity on paved areas	0.4	0.7
Interception factor for wet deposited activity on trees and large shrubs	1.0	1.0

Table III.1.2. Default values of the parameters describing the rate of movement of material within the environment.

Quantity	Units	Value
Time of first heavy rain	days	1.25
Mean annual rainfall rate	mm	920
Mean residence time of activity in drains	days	7
Mean residence time of activity on internal surfaces	days	30
Angle at which rain falls from the vertical	degrees	5
Mean retention time of water on walls	seconds	60
Mean retention time of water on paved areas	seconds	50
Migration rate in soil, 0–1 cm compartment to 1–5 cm compartment	day^{-1}	$6.65\ 10^{-4}$
Migration rate in soil, 1–5 cm compartment to 5–15 cm compartment	day^{-1}	$1.72\ 10^{-4}$
Migration rate in soil, 5–15 cm compartment to 15–30 cm compartment	day^{-1}	$1.07\ 10^{-4}$
Migration rate in soil, 15–30 cm compartment to 5–15 cm compartment	day^{-1}	$4.03\ 10^{-6}$
Migration rate in soil, 15–30 cm compartment to deep soil compartment	day^{-1}	$3.\ 80\ 10^{-5}$
Fraction of mobile component fixed by roofs, walls and pavements per day	day^{-1}	1.4
Fraction of fixed component on roofs removed per mm of rainfall	mm^{-1}	$3\ 10^{-4}$
Fraction of fixed component on walls removed per mm of rainfall	mm^{-1}	10^{-4}
Fraction of fixed component on pavements removed per mm of rainfall, for "paved fixed fast" and "paved fixed slow" components	mm^{-1}	$3\ 10^{-3}$ $3\ 10^{-4}$
Fraction of dry deposition to roofs, walls and paved areas which is mobile		0.1
Fraction of fixed paved component in the fast clearance compartment.		0.67
Retention coefficient for trees/shrubs[a]	years	0.7
Fraction of activity weathering from trees and large shrubs that goes to paved rather than soil/grass areas		0.0

[a] This corresponds to a half life of 6 months.

Table III.1.3. The environments available in EXPURT.

Environment	Comment
Lightweight houses	Dose libraries in lightweight buildings have been calculated for houses where the walls consist of a timber framework with facing wood and plaster. They could also be used for other buildings where the walls offer relatively little shielding, such as mobile homes.
Brick housing	Dose libraries for brick houses have been calculated for houses where the walls consist of brick and breeze blocks. They could be used for any one or two storey building with brick walls.
Multi-storey	Doses for multi-storey buildings have been calculated for a block of flats with eight storeys. They could be used for other multi-storey buildings, such as office blocks or shops, but doses in three storey houses would be better represented by using the values for brick houses.
Open green area	Includes no building type and is mostly grass with a small amount of paved surface. Would be the most suitable to account for parks and playing fields within the region.

Table III.1.4. Default values for the surface areas and fractions of different surfaces.

Quantity	Light-weight buildings	Brick buildings	Multi-storey buildings	Open green areas
Surface area of building walls within an environment 'cell' (m^2)	240	360	2240	0
Surface area of roofs within an environment 'cell' (m^2)	162	243	400	0
Surface area of internal building surfaces within an environment 'cell' (m^2)	1240	1952	14 240	0
Projected ground area of building within an environment 'cell' (m^2)	140	224	400	0
Total area within an environment 'cell' (m^2)	1020	1224	1600	10 000
Ratio of area of building walls to total area of environment 'cell'	0.24	0.29	1.40	0
Ratio of area of building roof to total area of environment 'cell'	0.16	0.20	0.25	0
Ratio of area of internal surfaces to total area of environment 'cell'	1.22	1.59	8.90	0
Ratio of projected area of building to total area of environment 'cell'	0.14	0.18	0.25	0
Ratio of outdoor area to total area of environment 'cell'	0.86	0.82	0.75	1.00
Fraction of soil/grass surface that is covered by trees/shrubs	0.1	0.1	0.1	0.1
Surface area of building walls within an environment 'cell' (m^2)	240	360	2240	0

Table III.1.5. Parameter sets available for each environment.

Environment	Description	Building	Paved	Trees/ shrubs	Grass/ soil
Lightweight houses	Low paved, med trees	14%	32%	5%	49%
	Low paved, low trees	14%	32%	3%	52%
	Med paved (mainly other), low trees	14%	52%	2%	33%
	Med paved (mainly other), med trees	14%	52%	3%	31%
	Med paved (mainly road), low trees	14%	52%	2%	33%
	Med paved (mainly road), med trees	14%	52%	3%	31%
Multi storey buildings	Low paved, med trees	25%	28%	5%	43%
	Low paved, low trees	25%	28%	2%	45%
	Med paved (mainly parking), low trees	25%	45%	2%	29%
	Med paved (mainly parking), med trees	25%	45%	3%	27%
	City, high paved, low trees	25%	71%	0%	3%
Brick houses	Low paved, med trees	18%	30%	5%	46%
	Low paved, low trees	18%	30%	3%	49%
	Med paved (mainly other), low trees	18%	49%	2%	31%
	Med paved (mainly other), med trees	18%	49%	3%	29%
	Med paved (mainly road), low trees	18%	49%	2%	31%
	Med paved (mainly road), med trees	18%	49%	3%	29%
Open green areas	Green areas, low paved, med trees	0%	10%	9%	81%
	Car parks, high paved, low trees	0%	95%	1%	5%
	Play areas, med paved, low trees	0%	50%	5%	45%

Each environment has different default proportions and configurations of building types (see Table III.1.4).

Because the dose rate calculations are based on dose rate per Bq per m^{-2} deposition per m^2 of a given surface, it is possible to change the proportions of some of the surfaces provided that the overall geometry does not change; i.e. the size, position and spacing of buildings must remain constant. This means the fractions of non-building surfaces (soil/grass, paved and trees) can be varied within certain limits. For each environment a number of parameter sets are specified, which give allowable variations for non-building surfaces (see Table III.1.5).

III.1.4.2. Spatial and temporal averaging

EXPURT models average deposition and average weathering processes. EXPURT assumes that weathering occurs at a constant rate and the user is not required to give a rainfall pattern. In reality weathering rates change as environmental conditions change with time and deposition across the environment and across surfaces within the environment would be patchy. Material on different parts of the surface are removed at different rates because of differences in building material, exposure to weather and orientation of those surfaces. Similarly material transferred from one surface will deposit non-uniformly; for example material transferred from roofs to grass will not distribute itself evenly over the grass but will be deposited at the outlet of gutters or under the eves of houses without gutters.

III.1.5. Uncertainties

III.1.5.1. Approach to estimating uncertainties in the model predictions

Neither EXPURT nor CONDO estimate the uncertainties of predictions.

III.1.6. Application of the model to Scenario 1 (Pripyat scenario)

For this exercise the outputs required were estimates of external gamma dose rate at specific locations within the Zone 1 and Zone 4 of Pripyat at various times. This requirement goes beyond the capability of EXPURT which can only calculate average representative doses to individuals living in the environment. However, for the purposes of inter-comparison EXPURT 3.02 was used with the current default environments and parameter sets (i.e. they were not modified to make a more realistic assessment) to approximate the situations specified. This emulates the way EXPURT would have to be used in the event of a real incident. When evaluating the EXPURT results against the real measurements it is important to recognise that EXPURT is estimating the average dose rate an individual might experience over a prolonged period whereas the measured value is an actual dose rate that an individual might encounter for a short time and that would only be a small component of the overall period average.

In order to run EXPURT descriptions of the environment, the initial deposition and of any countermeasures are required. In addition in order to calculate the individual doses required for Zone 4 (that are not required for Zone 1) a breakdown of the time that the individual spends in different locations is required.

III.1.6.1. Description of the environment of Zone 1

Figure III.1.11 shows the locations in Pripyat Zone 1 and Table III.1.6 gives the basic statistics for the area.

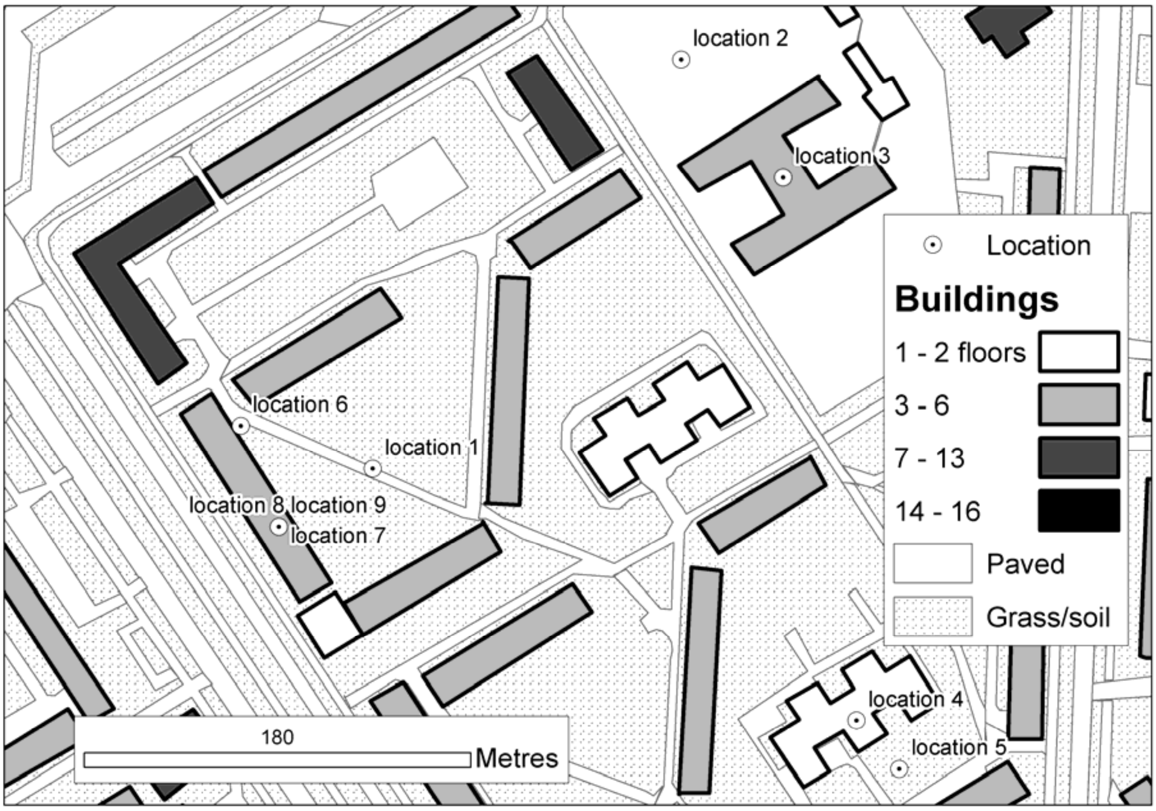


Fig. III.1.11. The locations to be modeled in Zone 1 of Pripyat. Points 1, 2, 5 & 6 are outdoor locations, points 3 & 4 are indoor locations (schools) and points 7, 8 & 9 are the 1st, 3rd & 5th floors of a 5-storey apartment building, respectively.

Table III.1.6. Surface statistics for Zone 1 Pripyat.

Surface	Area (m^2)	Fraction (%)
roofs (assumed flat)	46 798	18
artificial surface	67 506	26
natural surface	144 911	56
Total	**259 215**	**100**

Nearly half of the buildings in Zone 1 have 5 floors and 82% are made of concrete (18% being made of brick). The roofs are flat and most are of a rubber material. Overall the EXPURT multi-storey building environment with a low-paved parameter set is the most appropriate; however for the specific locations other environments or parameter sets may be more representative. The Pripyat scenario document states that "Microdistricts 1, 1a, 2, and 3 (closest to the NPP) are the oldest (5–15 years by 1986); these areas had developed tree and bush vegetation." and "during the 10-day acute period of the accident, all leaves were opened and were able to capture radioactive fallout", therefore it is most appropriate to use parameter sets with a medium coverage of trees in Zone 1. The environments and corresponding parameter sets selected for each Zone 1 location are shown in Table III.1.7 (Environments are described in Table III.1.4 and the corresponding parameter sets are given in Table III.1.5).

Table III.1.7. Environment type chosen for each location in Pripyat Zone 1.

Location	Environment	Parameter set	Indoor/ outdoor	Notes
1	Open green areas	Green areas, low paved, med trees	Outdoor	This location is far from buildings and in an area of natural (i.e. grass or soil) surface. Therefore the idealised outdoor location in the green area environment with low paved surface was chosen as the most representative of this location.
2	Open green areas	Car park, high paved, low trees	Outdoor	This location is far from buildings and in an area of artificial (i.e. paved) surface. Therefore the idealised outdoor location in the green area environment with high paved was chosen as the most representative of this real location.
3, 4	Brick houses	Low paved, medium trees	Indoor	These locations are indoors in relatively low buildings; EXPURT cannot distinguish between these situations. There is potentially a contribution to dose from both roof and surfaces outside. The idealised indoor location in the brick building environment was chosen as more representative than multi-storey indoor location of this real location.
5	Brick houses	Low paved, medium trees	Outdoor	This location is outside near a large low building so there is potential a dose contribution from roof. The idealised outdoor location in the brick building environment was chosen as more representative than the multi-storey outdoor location of this real location.
6	Multi-storey buildings	Low paved, medium trees	Outdoor	This location is outside but close to multi-storey building. The idealised outdoor location in the multi-storey building environment was chosen as most representative of this real location.
7	Brick houses (without roof component)	Low paved, medium trees	Indoor	This location is low in a large multi-storey building, so doses are likely to come from material outside on ground and trees and little from roof. The indoor location in the brick house environment subtracting the roof contribution was chosen as most representative of this location.
8, 9	Multi-storey buildings	Low paved, medium trees	Indoor	EXPURT cannot distinguish between these two locations which are in the middle floors of large multi-storey building. The indoor location in the multi-storey environment was the chosen as most representative.

III.1.6.2. Description of the environment of Zone 4

Figure III.1.12 shows the locations in Zone 4. Zone 4 has a similar physical environment to Zone 1 with large multi-storey buildings and a low amount of paved surfaces; therefore overall the multi-storey environment with a low-paved parameter set is appropriate. However, this zone is newer than Zone 1 and the scenario document states: “The wood vegetation of new microdistricts 4, 4a, and 5 (opposite side of the town from the NPP) was mainly developed after the accident”. Therefore a parameter set with low tree coverage is appropriate. There is forest to the south-west of the site but not close enough to affect the dose rates at the comparison locations – however in an individual dose assessment the amount of time spent in or near the forest would need to be considered. The environments and corresponding parameter sets selected for each Zone 2 location are shown in Table III.1.8.

Figures III.1.13 and III.1.14 show the contribution of each surface at each location to the dose rate at the time of initial deposition and 20 years later.

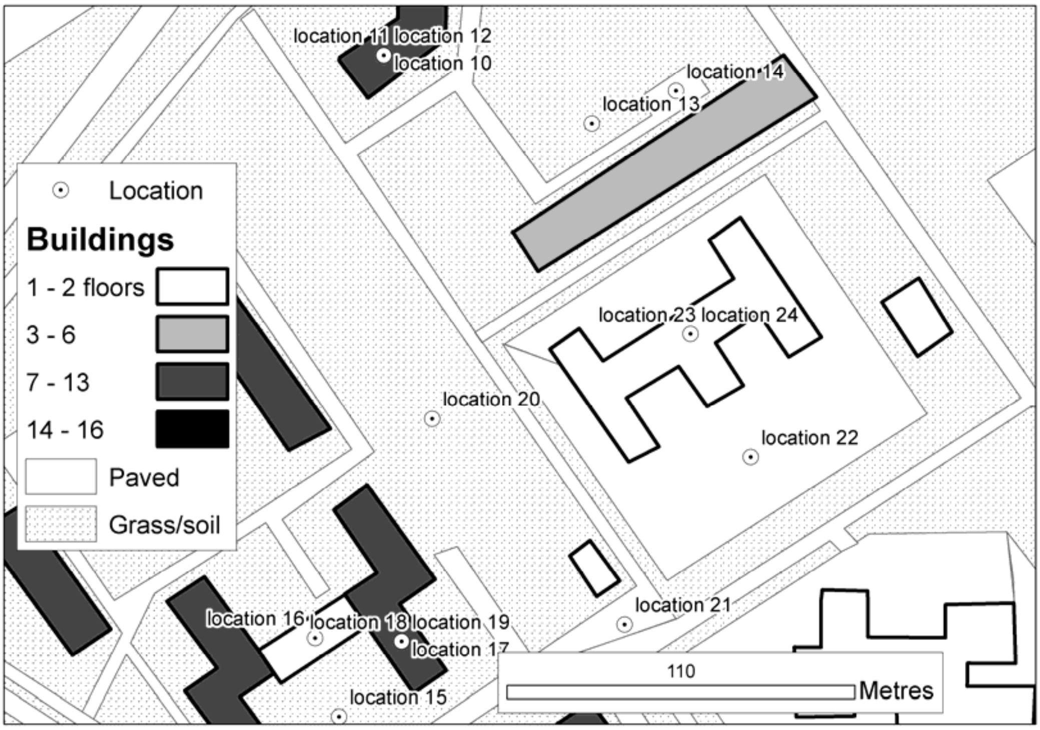
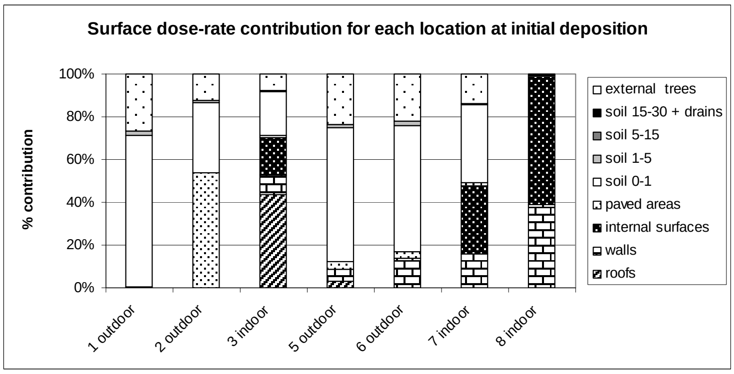


Fig. III.1.12. The locations to be modelled in Zone 4 of Pripyat. Points 1, 2, 5 & 6 are outdoor locations, points 3 & 4 are indoor locations (schools) and points 7, 8 & 9 are the 1st, 3rd & 5th floors of a 5-storey apartment building, respectively.



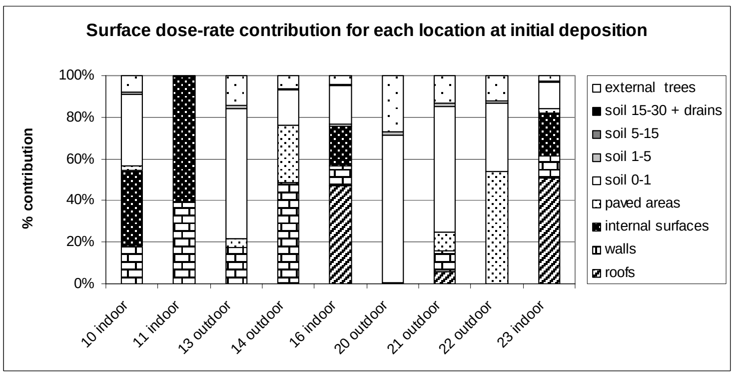
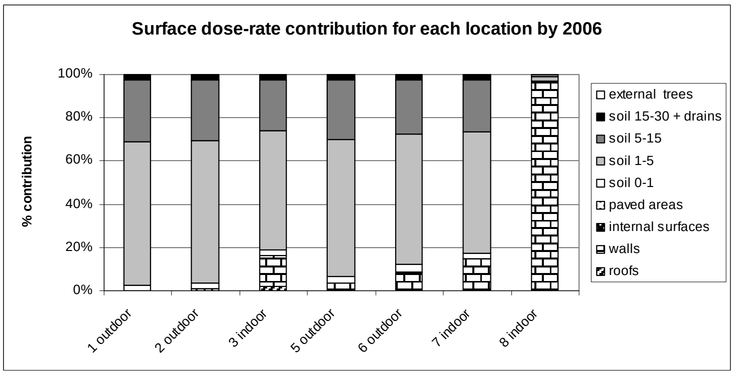


Fig. III.1.13. Contribution of each surface to dose rate at each location at time of initial deposition.

Table III.1.8. Environment type chosen for each location in Pripyat Zone 4.

Location	**Environment**	**Parameter set**	**Indoor/ outdoor**	**Notes**
10, 17	Brick houses (minus roof component)	Low paved, low trees	Indoor	Location 10 is on the 1st floor (considered ground floor in the UK) of an unfinished apartment building. Location 17 is on the first floor of a nine floor apartment building. As with location 7 it is more appropriate to use the brick house environment minus the roof component to represent these locations as it is likely that a significant component of dose comes from the radioactivity on the ground outside.
11, 12, 18, 19	Multi-storey	Low paved, low trees.	Indoor	Locations 11 and 12 are on the 5th and 7th floors (considered the 4th and 6th floors in the UK) of an unfinished apartment building. Locations 18 and 19 are on the 5th and 9th floors (considered 4th and 8th floors in the UK) of a 9 floor apartment building. EXPURT cannot distinguish between these locations and the multi-storey, low paved and low tree coverage is chosen as appropriate. For the 9th floor location the chosen environment would probably underestimate the contribution from deposition on the roof.
13, 15	Multi-storey	Low paved, low trees	Outdoor	These locations are outdoor on a grass/soil surface near large building. EXPURT cannot distinguish between these two locations.
14	Multi-storey	High paved, low trees	Outdoor	This location is outdoor near a 5 floor building. However it is situated on a paved surface and so a parameter set with a high paved coverage is appropriate
16	Brick house	Low paved, low tree	Indoor	This location is indoors on the 1st floor (considered the ground floor in the UK) of a one floor brick building which connects two larger multi-storey concrete buildings that might contribute a significant dose from material deposited on the walls entering through the rubberoid roof of the building. This is a complex situation and no idealised EXPURT environment is entirely appropriate. The brick house, high paved and low tree environment was used as the best approximation.
20	Open area	Low paved, medium tree	Outdoor	This location is outside on a large expanse of soil and grass. The nearest building is about 30 m away. So the open environment was used. There is no low tree version of this environment which is also low paved, therefore the medium tree had to be used.
21	Brick house	Medium paved, low tree	Outdoor	This location is outdoors on a paved surface and the nearest building has only one floor. There is a multi-storey building nearby but most of its bulk is away from this location. For this location the brick house, medium paved low tree was appropriate.
22	Open area	high paved, low tree	Outdoor	Location 22 is outdoors and over 20m from a low building. All other nearby buildings are low and 50m further away. It is in a large expanse of paved.
23, 24	Brick house	Medium paved, low tree	Indoor	Locations 23 and 24 are on the 1st and 2nd floor (considered the ground floor and 1st floor in the UK) of a two storey school. It is constructed of brick and set in a large paved area. EXPURT cannot distinguish between the upstairs and down stairs locations.



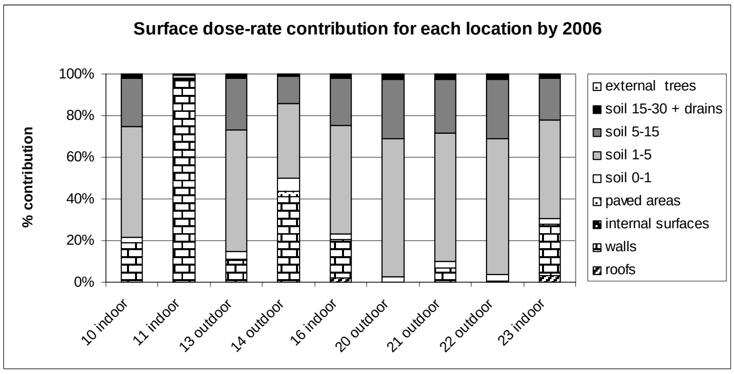


Fig. III.1.14. Contribution of each surface to dose rate at each location by 2006.

III.1.6.3. Description of the deposition

The EMRAS Urban Remediation Working Group provided deposition data measured on 26 September 1986 either in or near to Zone 1 and Zone 4. For the purposes of the exercise it was assumed that no material was lost other than by radioactive decay and no material was subsequently added by weathering from other surfaces. It is not clear how rigorous people making the measurement were in finding an appropriate location but for the purposes of the exercise it is assumed that the measurement was taken on a lawn at some distance from buildings and trees which is the appropriate reference surface for running EXPURT.

For Zone 1, in order to calculate the initial deposition, the contamination was summed over the soil profile – because material in the soil profile can only have come from deposition on the surface three months previously – and corrected for decay (see Table III.1.9). Deposition is known to have occurred under dry conditions. ^{95}Nb is a daughter radionuclide of ^{95}Zr and by September 1986 almost all of the measured ^{95}Nb would be due to in-growth. Therefore, the initial deposition of ^{95}Nb cannot be reliably calculated from the measurement of ^{95}Nb at this time. A reasonable assumption is that the ratio of ^{95}Nb to ^{137}Cs is the same as ^{95}Zr to ^{137}Cs [III.1.12].

Table III.1.9. Deposition estimated in April 1986 for Zone 1 based on measurements recommended by the EMRAS Working Group and corrected for radioactive decay.

Radionuclide	**Measured activity ($Bq\ m^{-2}$)**	**Percentage of total**	**Estimated initial deposition (decay corrected) ($Bq\ m^{-2}$)**	**Percentage of total**
^{95}Nb	$1.58\ 10^{7}$	29.2%	$4.94\ 10^{7}$ [a]	25.1%
^{95}Zr	$9.52\ 10^{6}$	17.6%	$4.94\ 10^{7}$	25.1%
^{103}Ru	$2.02\ 10^{6}$	3.7%	$2.93\ 10^{7}$	14.9%
^{106}Ru	$4.96\ 10^{6}$	9.2%	$6.60\ 10^{6}$	3.24%
^{134}Cs	$9.59\ 10^{5}$	1.8%	$1.10\ 10^{6}$	0.6%
^{137}Cs	$2.02\ 10^{6}$	3.7%	$2.04\ 10^{6}$	1.0%
^{141}Ce	$1.30\ 10^{6}$	2.4%	$3.33\ 10^{7}$	16.9%
^{144}Ce	$1.75\ 10^{7}$	32.3%	$2.53\ 10^{7}$	12.9%

[a] The ratio of ^{95}Nb to ^{137}Cs is assumed to be the same as the ratio of ^{95}Zr to ^{137}Cs.

Figure III.1.15 compares the ^{137}Cs activity measured soil profile with that predicted by EXPURT on the 26th September 1986. Two features are apparent. Firstly there is considerably more deposition predicted at the top of the profile than was measured – in fact there is more deposition after 3 months than was assumed for initial deposition. This is expected as the soil surface within EXPURT receives inputs from trees, walls and paved surfaces (see Figure III.1.1) whereas the measurement was assumed to be taken away from such processes. Secondly it is clear that material is moving down the soil profile more quickly than EXPURT predicted. This may be because migration down the soil column is faster than modelled or it may be because some of the material was initially deposited in cracks in the soil – although this initial deposition in cracks is not likely to be significant as the deposition occurred under dry conditions.

For Zone 4 only the total activity is given: there is no information about the distribution in the soil profile. Table III.1.10 gives the measured activity contamination and the estimated initial activity deposition corrected for decay.

EXPURT does not have data for ^{141}Ce or ^{144}Ce so these were not included in the modelling exercise.

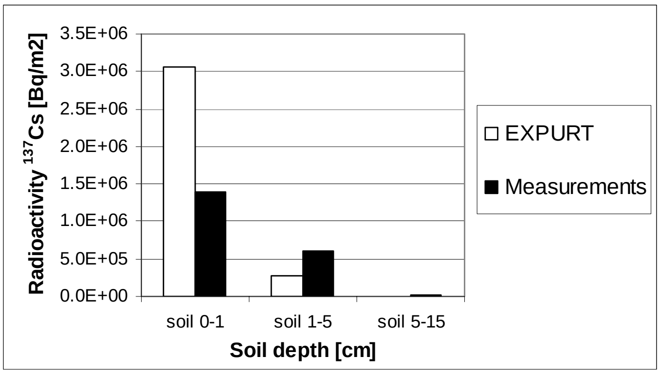


Fig. III.1.15. Comparison of the activity of ^{137}Cs in the soil profile predicted by the EXPURT model of a multi-storey building environment, low paved and medium trees, with the activity measurements in the soil profile.

Table III.1.10. Deposition estimated in April 1986 for Zone 4 based on measurements recommended by the EMRAS Working Group and corrected for radioactive decay.

Radionuclide	Measured activity (Bq m^{-2})	Percentage of total	Estimated initial deposition (decay corrected) (Bq m^{-2})	Percentage of total
^{95}Nb	5.00 10^6	30.1%	1.44 10^7 [a]	23.4%
^{95}Zr	2.84 10^6	17.1%	1.44 10^7	23.4%
^{103}Ru	5.78 10^5	3.5%	8.12 10^6	13.2%
^{106}Ru	1.44 10^6	8.7%	1.91 10^6	3.1%
^{134}Cs	2.96 10^5	1.8%	3.40 10^5	0.6%
^{137}Cs	5.23 10^5	3.1%	5.28 10^5	0.9%
^{141}Ce	5.74 10^5	3.5%	1.41 10^7	22.9%
^{144}Ce	5.37 10^6	32.3%	7.73 10^6	12.6%

[a] The ratio of ^{95}Nb to ^{137}Cs is assumed to be the same as the ratio of ^{95}Zr to ^{137}Cs.

III.1.6.4. Description of the countermeasures

For the purposes of the inter-comparison exercise several single hypothetical countermeasures were applied to Zone 1. The countermeasures chosen are given in Table III.1.11.

The scenario also calls for the simulation of temporary relocation in Zone 4. Three alternatives were modelled simulating the removal of the population for two weeks, six weeks and six months. Relocation is modelled for this exercise by assuming that no dose is accrued by the population during the period of relocation and that subsequently the occupancy of the population after return was as given below.

III.1.6.5. Description of the occupancy in Zone 4

In order to calculate normal living doses in an area it is necessary to weight the doses calculated by EXPURT to account for where people spend their time. The scenario gives five hypothetical individuals with suggested occupancy factors (Table III.1.12, column 3). These are fractions of time spent indoors at home, indoors at work, and on or in different outdoor surfaces. This information needs to be interpreted in order to select the mix and weights of EXPURT environments that are most representative of the mix or real environments in the area and the time spent in them.

It is clear from Figure III.1.16, which shows the dose rates predicted by EXPURT for each of the locations in Zone 4, that the most important factor is the overall amount of time spent indoors and outdoors and that the type of environment is of secondary importance. Fortunately this information is given explicitly for each individual. However, assumptions had to be made about where, indoors and outdoors, the individuals spent their time.

Table III.1.11. Countermeasures modelled in Zone 1 and Zone 4 of Pripyat.

Countermeasure	Time of application (after the accident)	EXPURT surface affected	Notes
Washing of roads	2 weeks	Paved	Roads might be washed using fire-hosing equipment or high pressure hoses. Brown et al. [III.1.8] give a DF range of between 2 and 4 for fire-hosing of a paved surface. Because the effectiveness of this technique drops off within a week the lower value has been chosen to represent fire-hosing at 2 weeks. Brown et al. [III.1.8] give a DF between 3 and 7 for high pressure hosing. A DF of 7 is used to give results that are reasonably different from fire-hosing, as both countermeasures are represented in the same way within EXPURT.
Washing of roofs and walls	2 weeks	Roofs and walls	Roofs and walls might be washed with fire-hosing equipment or high pressure hosing. Brown et al. [III.1.8] give a DF of 1.3 for fire-hosing which has been used for this exercise. Again the effectiveness drops off after a week. Brown et al. [III.1.8] give a DF of 1.5 and 5 for high pressure hosing, however, for this exercise only fire-hosing was simulated as the low contributions mean from these surfaces that there is very little effect from either technique.
Cutting and removal of grass	1 week	Grass, soil	Brown et al. [III.1.8] give a DF of between 2 and 10. Andersson [III.1.13] suggests that under favourable conditions, i.e. closely cut grass with no rain in the intervening period, a DF of 8–10 is appropriate for application over the first 2 weeks. For this exercise a value of 8 was used
Removal of trees	30 days	Trees and shrubs	Brown et al. [III.1.8] give a DF of 50, which was used for this technique.
Removal of soil (5cm)	6 months	Soil/grass	This technique was simulated by removing the activity in the top 5 cm.
Ploughing 30cm	6 months	Soil/grass	For soil mixing techniques such as ploughing EXPURT assumes that the activity is mixed to a uniform concentration to the depth that the technique is applied.
Vacuuming indoors	2 weeks	Interior surfaces	Brown et al. [III.1.8] give a DF range of 5 to 10 for this surface provided this is implemented within a few weeks of deposition and no cleaning has occurred in the meantime. For this exercise a DF of 10 was assumed.
Washing indoors	2 weeks	Interior surfaces	Brown et al. [III.1.8] give a DF range of 1.5 to 3 for this surface. Andersson [III.1.13] gives a DF of 3 to 5. For this exercise a DF of 3 is assumed.

Table III.1.12. Example individuals for the purposes of dose calculations.

Name		Suggested occupancy factors given in the Pripyat scenario	Occupancy of EXPURT environments assumed
Person 1	Indoor worker	Inside home 51% Inside work 32% Asphalt surfaces 7% Dirt surfaces 3% Kitchen gardens 5% Virgin land (inside city) 1% Forests and meadows 2%	51% indoors in multi-storey, low paved, low tree 31% indoors in brick house, low paved, low tree 10% outdoors in multi-storey, low paved, low tree 8% outdoors in open area environment, high paved, low trees
Person 2	Outdoor worker	Inside home 51% Insider work 10% Asphalt surfaces 8% Dirt surfaces 23% Kitchen gardens 5% Virgin land (inside city) 1% Forests and meadows 2%	51% indoors in multi-storey, low paved, low tree 10% indoors in brick house, low paved, low tree 11% outdoors in multi-storey, low paved, low tree 5% outdoors in open area environment, high paved, low trees 23% outdoors in open area environment low paved, medium trees
Person 3	Pensioner	Inside home 75% Inside work 0% Asphalt surfaces 7% Dirt surfaces 7% Kitchen gardens 8% Virgin land (inside city) 1% Forest and meadows 2%	75% indoors in multi-storey, low paved, low tree 0% indoors in brick house, low paved, low tree 25% outdoors in multi-storey, low paved, low tree 0% outdoors in open area environment, high paved low trees
Person 4	School children	Inside home 58% Inside school 15% Asphalt surfaces 8% Dirt surfaces 10% Kitchen gardens 4% Virgin land (inside city) 4% Forest and meadows 1%	58% indoors in multi-storey, low paved, low tree 15% indoors in brick house, low paved, low tree 21% outdoors in multi-storey, low paved, low tree 6% outdoors in open area environment, high paved low trees
Person 5	Pre-nursery children	Inside home 51% Inside nursery 25% Asphalt surfaces 8% Dirt surfaces 10% Kitchen gardens 4% Virgin land (inside city) 4% Forest and meadows 1%	51% indoors in multi-storey, low paved, low tree 25% indoors in brick house, low paved, low tree 16% outdoors in multi-storey, low paved, low tree 8% outdoors in open area environment, high paved low trees

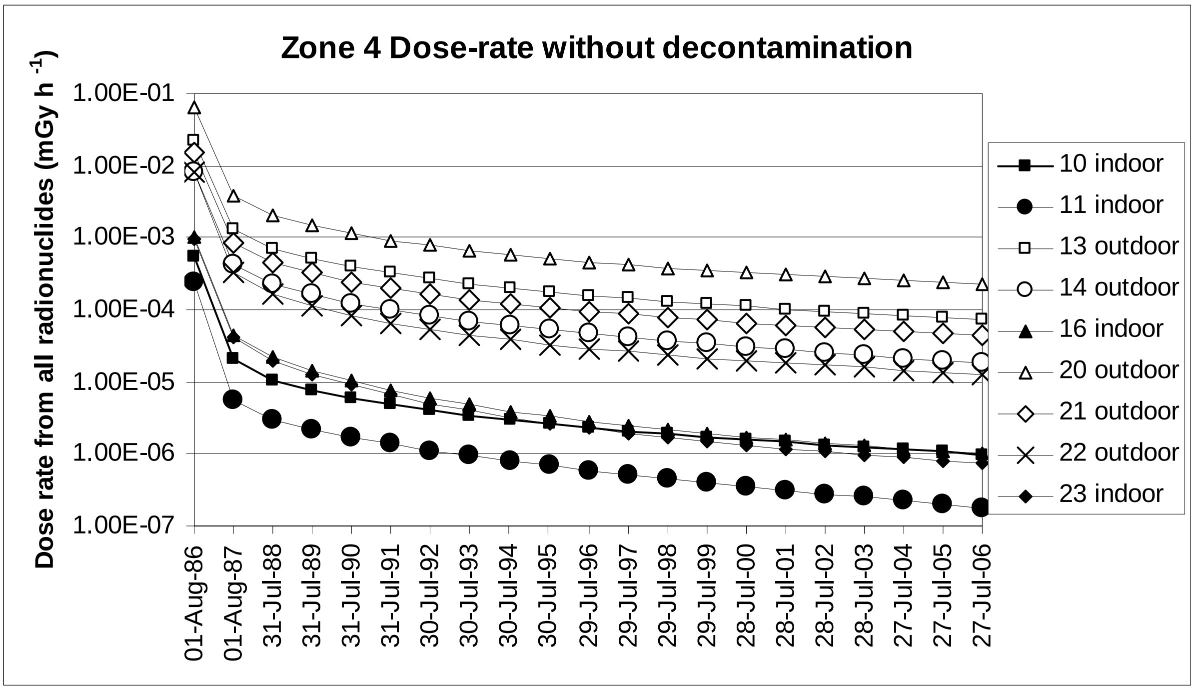


Fig. III.1.16. EXPURT results showing the calculated dose rates from all radionuclides for each of the environments in Table III.1.8.

III.1.6.6. Indoor occupancy assumptions

The suggested location factors for indoors (Table III.1.12, 3rd column) give no information about the type of buildings where the individuals spent most of their time. However, there is information about the fractions of time spent at home and fraction of time spent indoors at work or at school. The map (Figure III.1.12) indicates that most of the buildings, particularly the residential buildings, within Zone 4 are multi-storey. Therefore it is reasonable to assume that most of the time indoors at home was spent in multi storey buildings – corresponding to location 11 in Figure III.1.16. However, EXPURT predicted that location 11 gives the least dose and it is reasonable to assume that the individuals might spend some fraction of time in less protected indoor locations. Therefore an assumption was made that the fraction of time spent at home was in an environment most like the EXPURT multi-storey environment as represented by location 11, but that the fraction of time spent indoors at work or at school was in an environment like the EXPURT brick house environment as represented by location 16. The results of this assumption are given in Table III.1.12, 4th column.

III.1.6.7. Outdoor occupancy assumptions

The suggested location factors for outdoors (Table III.1.12, 3rd column) give the fraction of time spent on asphalt surfaces, dirt, kitchen gardens, virgin land and forest and meadows. The forest surface is particularly difficult for EXPURT to represent, as the initial deposition in a forest both onto the trees and onto the underlying soil is likely to be very different from the initial deposition onto trees and soil in environments which are sparsely covered with trees. For this exercise the amount of time spent in forests was ignored.

For simplicity it was assumed that individuals spent all the time outside in either the EXPURT multi-storey environment with low trees and low paved (corresponding to location 13 in Figure III.1.16), or the EXPURT open area with high paved and low trees (corresponding to location 22 in Figure III.1.16). The two environments were weighted using the ratio of time at home to time at work explicit in the indoor location factors. That is, when the individuals were at home outside they spent all their time in the outdoor multi-storey environment (low paved, low trees) and when the individual were at work but outside they spent all their time in the open area environment (high paved, low trees), an environment that would correspond to a car park or shopping precinct. An exception was made for the outdoor worker, for whom it is clear from the suggested occupancy factors that the additional time spent outdoors at work was associated with dirt surfaces. It was considered that in this case the EXPURT open green area low paved medium trees environment was the most appropriate. The results of these assumptions are given in Table III.1.12, 4th column

III.1.6.8. Other assumptions

The EXPURT data library contains only dose rates to adults; therefore the effective doses to adults calculated by EXPURT had to be used for the children in Table III.1.12 as well as the adults.

Figures III.1.17–III.1.20 are example results for individual dose based upon the occupancy factors in Table III.1.12.

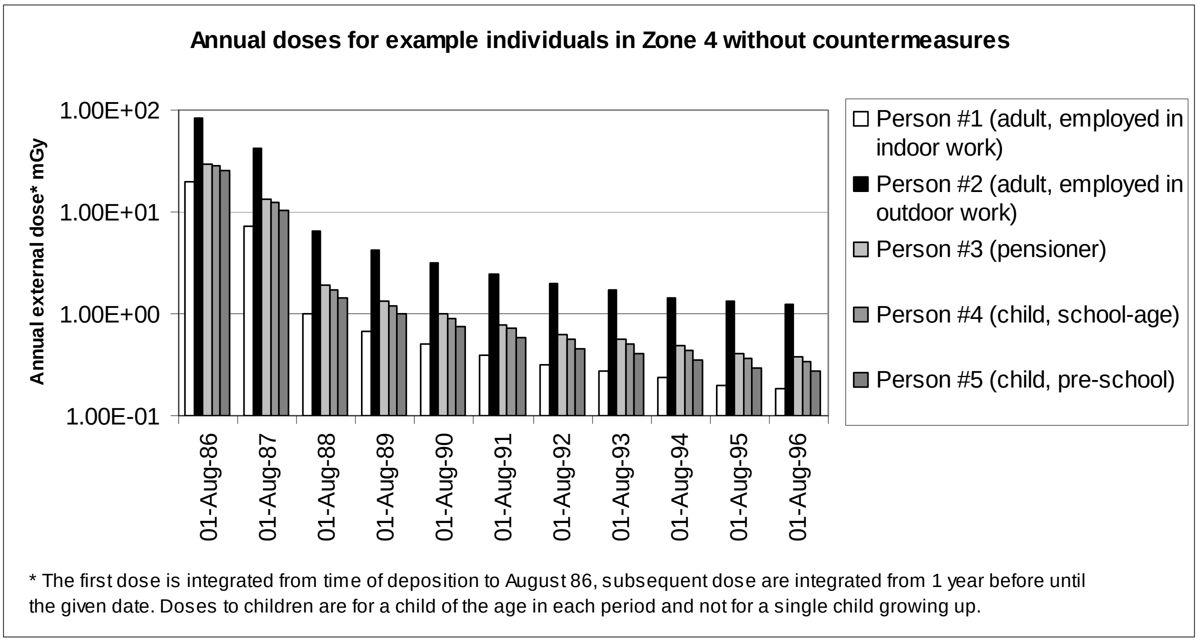


Fig. III.1.17. EXPURT results showing estimated individual annual doses for the five individuals identified in the Pripyat scenario in the absence of countermeasures.

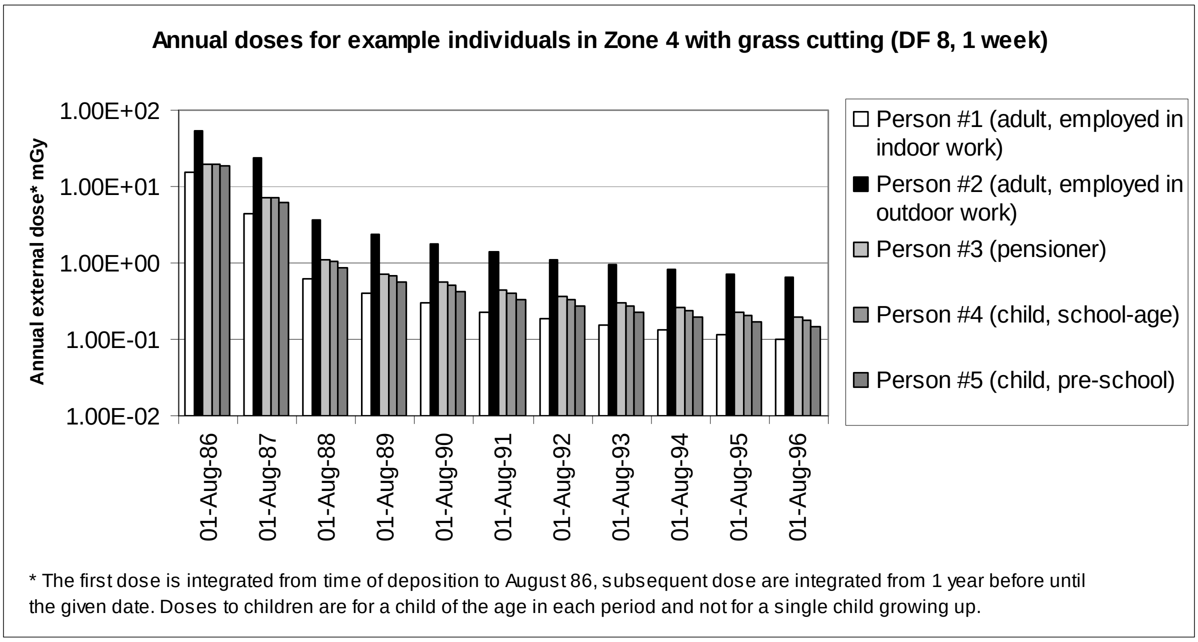


Fig. III.1.18. EXPURT results showing estimated individual annual doses for the five individuals identified in the Pripyat scenario with grass cut at 1 week assuming a DF of 8.

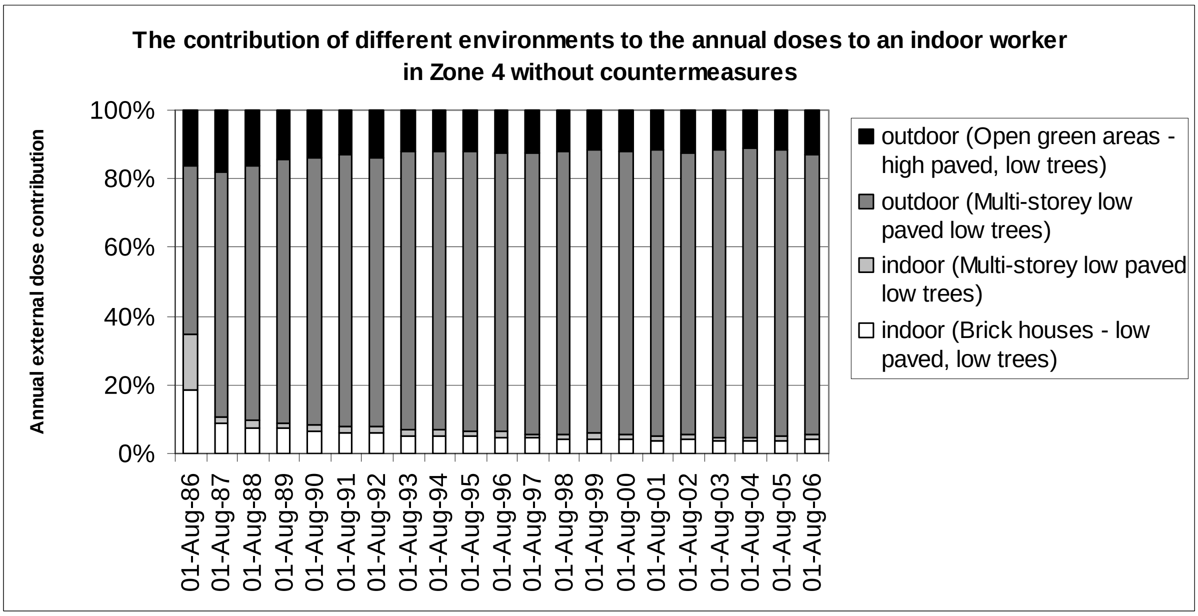


Fig. III.1.19. EXPURT results showing the contribution of different environments for the indoor worker individual.

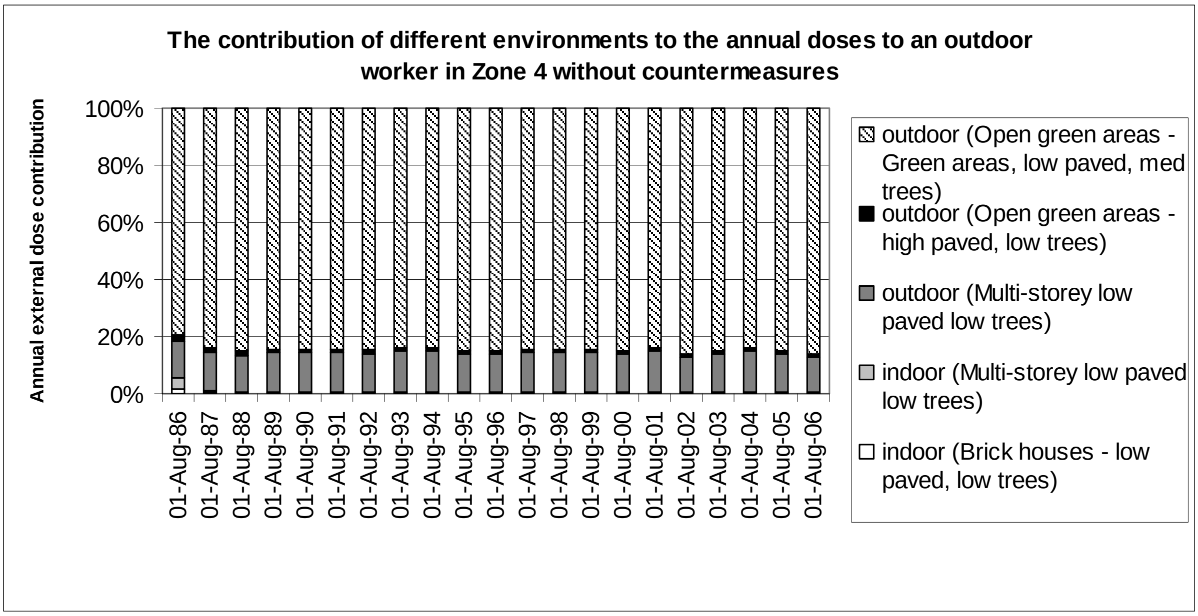


Fig. III.1.20. EXPURT results showing the contribution of different environments for the outdoor worker individual.

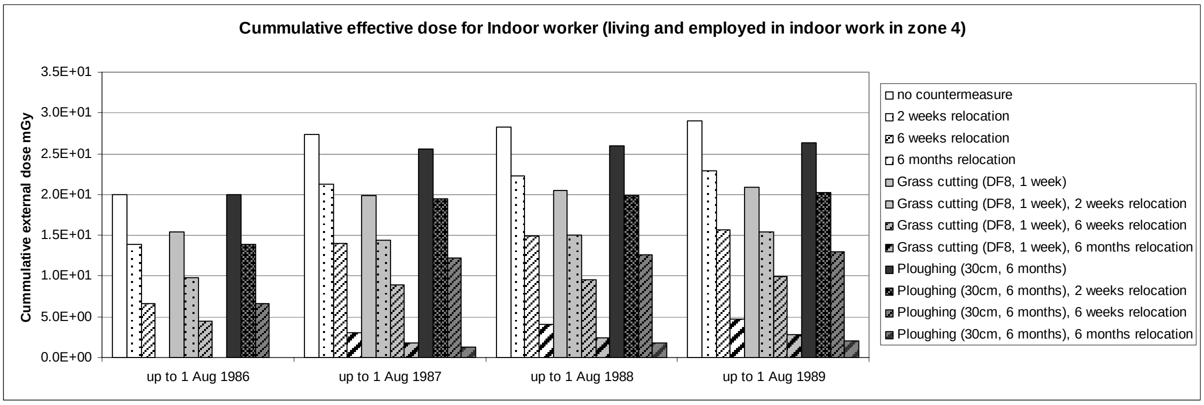


Fig. III.1.21. EXPURT results showing the effective of relocation with and without other countermeasures on the cumulative dose for Person 1 from Table III.1.12).

III.1.6.9. Overall performance of EXPURT on the Pripyat scenario

Comprehensive results from EXPURT for the Pripyat scenario are given in the main body of the Working Group Report in comparison with the results from other models and some real measurements; this section focuses on the performance of the EXPURT model when applied to the Pripyat scenario.

The input to which EXPURT is most sensitive is the initial deposition, both the amount and mix of radionuclides. Zone 1, with a higher overall deposition but similar radionuclide mix to Zone 4, inevitably has higher dose rates in similar environments.

A feature of the Pripyat scenario is that it includes short lived radionuclides with half-lives of the order of a few weeks. Consequently EXPURT shows a large initial dose rate that drops rapidly in the first few weeks and months. This pattern means that relocation is a very effective countermeasure. Figure III.1.21 illustrates the effectiveness of relocation with and without other countermeasures.

One of the problems in modelling the Pripyat scenario is the presence in the deposition of ^{95}Zr and its daughter ^{95}Nb. As mentioned in Chapter 3, EXPURT handles the dose rate from ingrown radionuclides by treating the parent and daughter as a composite. However, in the Pripyat scenario some of the daughter was deposited as well as the parent. This must be remember when interpreting the results as, the EXPURT dose rate calculated for ^{95}Zr includes the dose rate from the component of ^{95}Nb that has ingrown since deposition, this dose rate is decaying with the half-life of ^{95}Zr. The EXPURT dose rate predicted for ^{95}Nb includes only the dose rate from the component of ^{95}Nb that was originally deposited, a component that is decaying with the half-life of ^{95}Nb. The EXPURT surface contamination calculated for ^{95}Zr only includes ^{95}Zr and the surface contamination given for ^{95}Nb only includes that component of ^{95}Nb that was originally deposited. There is therefore a component of ^{95}Nb from ingrowth due to the decay of ^{95}Zr that is not calculated by EXPURT and even when EXPURT reports there is no ^{95}Nb contamination, if there is still ^{95}Zr contamination there will be an unreported component of ^{95}Nb and the dose rate from that ^{95}Nb contamination will be included with the ^{95}Zr dose rate.

The next most sensitive input is the overall indoor and outdoor occupancy. This was illustrated clearly in Figure III.1.16, where estimated indoor dose rates are consistently below outdoor dose rates for the same initial deposition. However, if an individual spends a large proportion of time indoors this can still be a significant proportion of the dose, Figure III.1.19 shows that the indoor worker receives over 30% of the total dose in the earliest period whilst indoors. The surfaces that contribute significantly to indoor dose rate can be very different from those that contribute to outdoor dose rates as illustrated by Figure III.1.3 and Figure III.1.4. So occupancy needs to be considered when deciding which surfaces to decontaminate.

After occupancy the next most sensitive input is the choice of environment. EXPURT has a number of different environments each with a number of different sets of proportions of outdoor surfaces (see Tables III.1.3–III.1.5). Figure III.1.16 shows a difference up to about an order of magnitude when comparing outside locations with other outside locations or inside locations with other inside locations. Given the larger difference between indoor and outdoor and the inevitable uncertainties of modelling it may be tempting to think that having different environments is an unnecessary refinement of the EXPURT model and that it would be sufficient to have one generic indoor and one generic outdoor location. However, it is important to remember that environments differ not just by the dose rates generated but also in how they respond to the application of countermeasures. Figure III.1.22 illustrates how the dose rate in different locations responds over time to the application of different countermeasures. The distinct responses come about because of the different environments used to represent these locations and the consequential differences in the contributions of surfaces to total doses rates. Therefore, for a reliable assessment of countermeasure options it is important for the EXPURT model to allow the user to specify different environments.

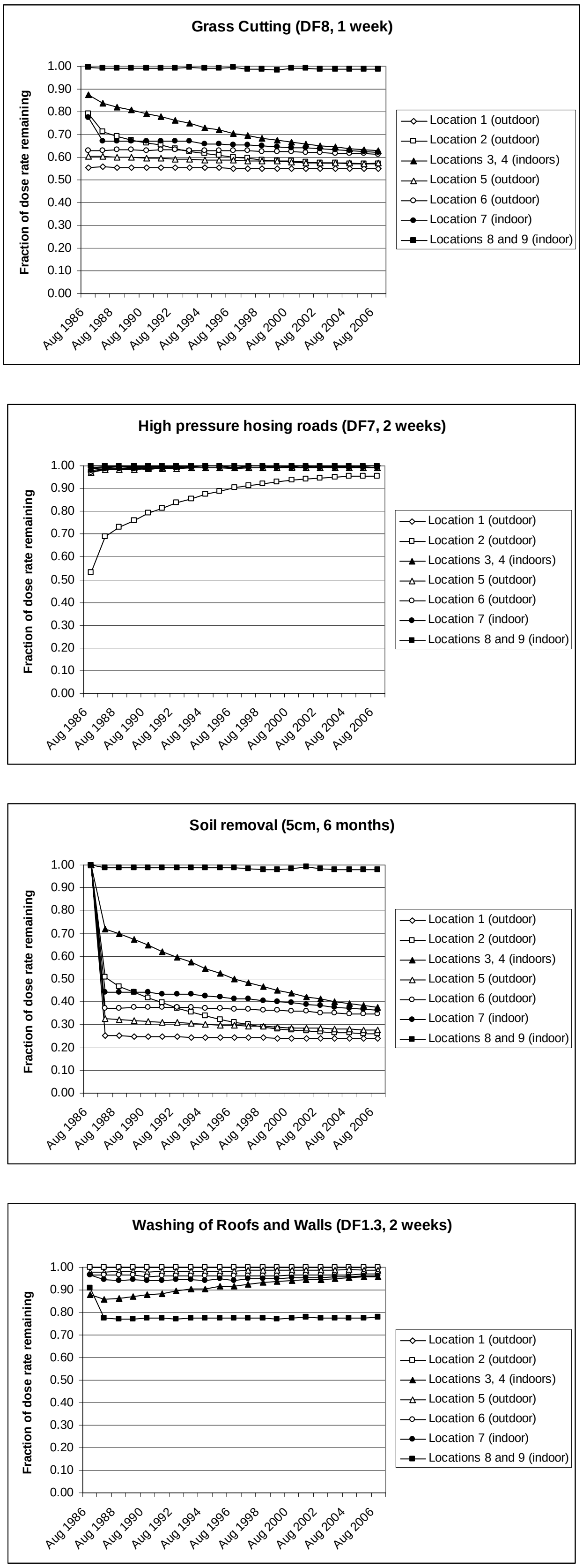


Fig. III.1.22. EXPURT results showing the fraction of dose rate remaining at each location following application of countermeasures.

From the overall results in the main body it is clear that EXPURT and the other models were able to represent some environments more convincingly than others. In particular, outdoor locations in Zone 1 with a higher proportion of grass surface appeared to be more successfully modelled than those with a higher proportion of paved surface when one looks at late measurements. An explanation for this may be the real build up of detritus on the paved surfaces in uninhabited Pripyat, this process is not accounted for in EXPURT, which assumes paved surfaces remain clear of detritus through the normal activity of habitation – e.g. traffic.

Each EXPURT environment other than the open environment has one indoor and one outdoor location. The indoor location represents an average of all the different floors and rooms in the building, and so equates to someone moving around the interior of the building. This is a reasonable assumption for single occupancy buildings such as houses where not only can the range of dose rates in different parts of the building be expected to be relatively small but an individual can be expected to visit all parts of the building. It is less reasonable when considering large multi-occupancy multi-storey buildings, not only will the range of dose rates be relatively large, particularly between the top, middle and bottom of the buildings, but different surfaces will be important in different parts. Also there will be less averaging of the dose rates due to movement about the building as people will spend most of their time within their own apartment. In the Pripyat scenario some locations were on different floors of the same or similar buildings, for example see locations 11, 12, 18 and 19 in Table III.1.8. These proved difficult to distinguish using the EXPURT model. Of particular difficulty was location 19 which, as the top most floor, can be expected to have a significant dose rate contribution from the roof that EXPURT does not account for.

EXPURT calculates surface contamination, dose and dose rate, over time, radionuclide and surface. This is a large amount of data that can overwhelm the model user. It is very easy for subtle but important signals to be hidden by other very strong signals. For example, the way the data are presented in Figure III.1.21 showing the large benefit of relocation, hides the more subtle but still important difference between the grass-cutting and ploughing countermeasures. These differences appear small compared to relocation, but they last for a much longer period and the final impact on total dose may be very significant. Having the flexibility to view the data in different ways and at different scales is very useful in drawing out these more subtle effects. For the Pripyat scenario this was achieved using a spreadsheet application, however such an approach may offer too much choice and potential for error in a real situation and an application such as CONDO that allows important patterns from the model to be drawn out whilst at the same time protecting the user from making mistakes is useful.

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III.2. Description of METRO-K
(Won Tae Hwang)

III.2.1. General description of METRO-K

METRO-K (**M**odel for **E**valuating the **T**ransient Behavior of **R**adi**O**active Materials in the **K**orean Urban Environment) has been developed for dose assessment due to radioactive contamination in the Korean urban environment by the Korea Atomic Energy Research Institute (KAERI) with funding from the Ministry of Science and Technology (MOST) in Korea. Modeling approaches are similar to those of the Canadian model CHERURB-95 [III.2.1], but an effort was made to describe the Korean urban environment as accurately as possible. Major features of METRO-K are as follows: (1) mathematical structures are simple, requiring fewer input parameters, and are understandable since they are based on analytic approaches using empirical and experimental data obtained following the Chernobyl accident; (2) a geometrically complex urban environment can be easily constructed by using just five types of surfaces (roofs, paved roads, outer walls, lawn or soil, trees); and (3) various remediation measures can be applied to different surfaces by calculating the exposure doses from each contaminated surface.

In case of accidental releases from nuclear facilities, radioactive materials released into the atmosphere will be deposited onto surfaces through not only dry processes (atmospheric turbulence and gravitation, etc.), but also wet ones (precipitation, etc.). From radionuclide concentrations in air, surface contamination through dry and wet processes can be predicted by the well-defined terminologies of deposition velocity and washout ratio. If there is no precipitation during a release of radioactive materials, radioactive materials will be deposited through dry processes. Dry deposited radionuclides are classified into mobile and fixed fractions. Mobile radionuclides can be readily removed from surfaces by environmental factors such as wind and precipitation. Conversely, fixed radionuclides cannot be easily removed. A certain fraction of the mobile radionuclides accumulated each day will be fixed due to moisture during the night following that day. Fixed radionuclides will increase fractionally from day to day.

In the case of wet processes, CAP (a critical amount of precipitation) is introduced to quantify run-off. CAP is the minimum precipitation at which run-off occurs. If there is a slight precipitation below CAP during a release of radioactive materials, both dry and wet processes will occur. Deposited radionuclides will all be fixed. All of the mobile radionuclides that have been deposited through dry processes during the previous days will be fixed. If there is a heavy precipitation exceeding a CAP during a release of radioactive materials, radionuclides will be deposited through wet processes. Some radionuclides will be fixed; however, other ones will be removed together with run-off water. A certain fraction of the radionuclides in run-off water will be retained on surfaces.

Following a completed deposition, radionuclide concentrations on surfaces will be affected by environmental removal processes including wind, pedestrians and traffic, and migration into soil. As shown in the Chernobyl experience, radioactive materials may be released for several days in case of a severe accident. Total depositions on different surfaces are calculated step by step from daily air concentration (Bq m^{-3}) and precipitation (mm). While being deposited, radionuclide concentrations on surfaces decrease because of radioactive decay, but environmental removals are not considered. Exposure dose rates are calculated as a function of location of a receptor using air kerma (pGy per photon mm^{-2}) and other related factors. To date, METRO-K calculates the external exposure from contaminated outer surfaces. Internal exposure by inhalation of contaminated air and external exposure from contaminated inner surfaces of buildings, which may play an important role in some cases, are not considered. Outputs of METRO-K are radionuclide concentrations on different surfaces and subsequent exposure doses as a function of time following a deposition for the residential location of a receptor. Three types of nuclides (Cs, Ru, I) and three types of iodine (elemental, organic, particulate) are considered. Figure III.2.1 shows a schematic diagram of METRO-K.

III.2.2. Surface contamination through deposition processes

Deposition onto surfaces through dry processes is quantified in terms of a deposition velocity (v_g, m s^{-1}) which is a proportional constant describing the relation between air and ground concentrations. A certain fraction of dry deposited radionuclides will show strong binding with surfaces due to moisture, therefore it is not easily removed environmental factors. On the other hand, a remaining fraction will show less binding with surfaces, therefore it can easily be removed. The former is called a fixed fraction, and the latter is called a mobile fraction. It is assumed that 90% of initial deposition is fixed and 10% is mobile regardless of radionuclide. The amount of daily deposition can be calculated as follows:

$$D_m(\Delta t, s) = 86400\ f_m(s)\ C_{air}(\Delta t)\ v_g(s) \qquad \text{(III.2.1)}$$

$$D_f(\Delta t, s) = 86400\ (1 - f_m)\ C_{air}(\Delta t)\ v_g(s) \qquad \text{(III.2.2)}$$

where:

$D_m(\Delta t, s)$ = daily initial deposition of mobile radionuclides for surface s (Bq m^{-2});
$D_f(\Delta t, s)$ = daily initial deposition of fixed radionuclides for surface s (Bq m^{-2});
$C_{air}(\Delta t)$ = daily air concentration (Bq m^{-3});
f_m = mobile fraction of deposited radionuclides; and
86 400 = unit conversion factor (s d^{-1}).

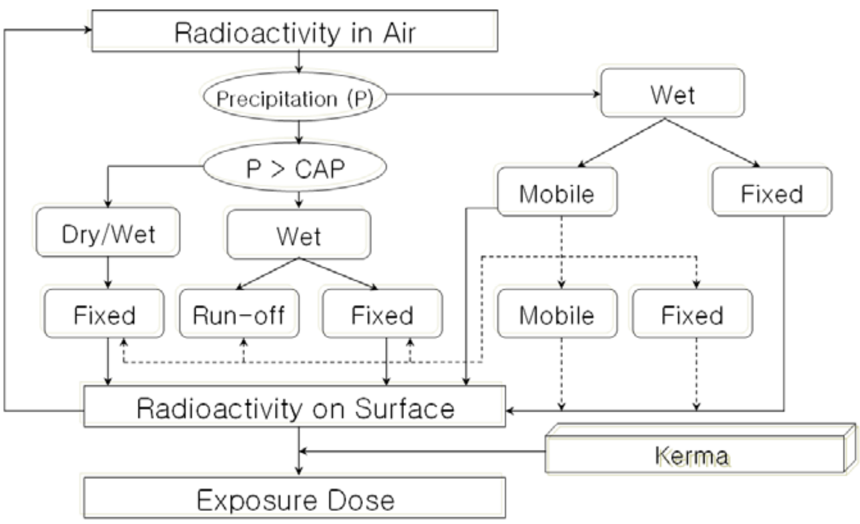

Fig. III.2.1. Schematic diagram of METRO-K. CAP represents a critical amount of precipitation. Dotted lines represent the behavior of the radionuclides deposited on previous days.

Table III.2.1. Deposition velocity of radionuclides.

Surface	Radionuclide				
	Cs	Ru	I (particulate)	I (organic)	I (elemental)
Roofs	4.32E-4	4.32E-4	1.07E-3	4.00E-6	4.26E-3
Paved roads	8.14E-5	8.14E-5	2.45E-4	4.00E-6	9.79E-4
Outer walls	1.80E-5	1.80E-5	1.28E-4	8.55E-7	5.13E-4
Lawn or Soil	6.12E-4	6.12E-4	1.62E-3	1.28E-5	7.43E-3
Trees	1.21E-3	1.21E-3	1.99E-3	2.00E-5	7.94E-3

It is assumed that mobile radionuclides will be fixed with the fraction of 70% per day following a deposition [III.2.1]. Table III.2.1 shows the deposition velocities used in METRO-K as a function of surfaces and radionuclides.

Deposition through wet processes can be quantified in terms of a washout ratio, which is a proportional constant describing the relation between air and precipitation concentrations. In METRO-K, it is taken to be 9.26×10^5 for particulates, 8.44×10^3 for organic iodine and 2.03×10^5 for elemental iodine. It is assumed that run-off occurs when daily precipitation exceeds a CAP during a release of radioactive materials. The values of CAP were taken to be 3 mm for roofs, 4.28 mm for paved roads, 0.06 mm for outer walls, 6 mm for lawn or soil, and 2 mm for trees. In case of a slight precipitation below a CAP during a release, deposition will be done by both dry processes and wet ones. It is assumed that all deposited radionuclides are fixed on the surfaces. In case of a heavy precipitation exceeding a CAP, deposition will be done by wet processes. Run-off will occur for the amount of precipitation exceeding a CAP, and a certain fraction of radionuclides in run-off water will be retained on surfaces. Table III.2.2 shows the fraction to be retained on the surfaces of radionuclides in run-off water applied to METRO-K as a function of types of surfaces and radionuclides. Mathematical expressions under these assumptions are as follows:

$$D_{SP} = 1\times10^{-3}\, C_{air}(\Delta t)\, P(\Delta t)\, \omega_p + 86400\, C_{air}(\Delta t)\, v_g(s) \qquad \text{(III.2.3)}$$

$$D_{HP} = 1\times10^{-3}\, C_{air}(\Delta t)\, [CAP(s) + (P(\Delta t) - CAP(s))\; f_{ret}(s)]\, \omega_p \qquad \text{(III.2.4)}$$

where:

$D_{SP}(\Delta t, s)$ = daily initial deposition on surfaces in a slight precipitation (Bq m^{-2});
$D_{HP}(\Delta t, s)$ = daily initial deposition on surfaces in a heavy precipitation (Bq m^{-2});
$P(\Delta t)$ = daily precipitation (mm);
f_{ret} = fraction to be retained on the surfaces of radionuclides in run-off water; and
1×10^{-3} = unit conversion factor (mm m^{-1}).

Table III.2.2. Fraction of radionuclides in run-off water to be retained on the surfaces.

Surface	Radionuclide		
	Cs	Ru	I
Roofs	0.86	0.86	0.02
Paved roads	0.60	0.60	0.02
Outer walls	0.02	0.02	0.02
Lawn/soil	0.90	0.90	0.75
Trees	0.75	0.75	0.02

III.2.3. Exposure dose assessment

Prediction of the exposure doses in an urban environment may be a difficult task because of the geometrical complexity of surrounding structures, including buildings. For simplicity of assessment, METRO-K uses predetermined kerma values which represent dose rate per unit deposition. Exposure dose rate for a specified location i can be calculated as follows:

$$\dot{H}_i(t) = 8.64 \times 10^{-14} DCF_i \sum_k y_k \sum_j \omega_j D_j(t) \ k_{ijk} \qquad \text{(III.2.5)}$$

where:

i = location of a receptor;
j = contaminated surface;
k = gamma energy;
$H_i(t)$ = effective dose rate (Sv d^{-1});
DCF_i = dose conversion factor (Sv Gy^{-1});
ω_j = dose reduction by surface roughness;
y_k = yield of gamma energy (γ s^{-1} Bq^{-1});
$D_j(t)$ = radionuclide concentration on surface (Bq m^{-2}); and
k_{ijk} = kerma (pGy per γ mm^{-2}).

Meckbach et al. calculated kerma values as a function of location of a receptor, contaminated surface, and gamma energy for four types of representative European buildings by using the Monte Carlo method [III.2.2]. Although types of buildings and surrounding environment are different not only from country to country, but also from region to region, kerma values derived by Meckbach et al. are widely used to predict exposure doses in existing urban models [III.2.1, III.2.3]. METRO-K considers seven types of representative Korean buildings: (1) prefabricated 1-story house, (2) 1-story semi-detached house with flat concrete roofs, (3) 2-story semi-detached house with flat concrete roofs, (4) 2-story semi-detached house with tile roofs, (5) 3-story terrace house with tile roofs, (6) 5-story large public or commercial building, and (7) 10-story apartment building. To obtain the kerma values for these buildings, the kerma values of Meckbach et al. are rearranged or modified. Figure III.2.2 shows an example for rearrangement between two different buildings. For the contamination of the roofs, it is assumed that kerma values on the top floor of a 10-story apartment building are the same as those on the top floor of a 5-story building, symbolized as K_1. For the contamination of the trees, it is assumed that kerma values on the 5^{th} floor of a 5-story building is the same as those on 5^{th} floor of a 10-story building, symbolized as K_A.

A data library for the kerma values of the seven types of buildings was made by using a method similar to that described above for three different gamma energies (0.3 MeV, 0.662MeV, 3 MeV). Table III.2.3 shows kerma values for a 10-story apartment as a representative example to be rearranged. Those for other buildings are presented elsewhere [III.2.4]. METRO-K considers not only the exposure doses resulting from a contaminated building where a receptor resides, but also those resulting from the contaminated surfaces of neighboring buildings and a large park. Kerma values for other energies and locations are estimated by a logarithmical interpolation. It should be noted that these kerma values are averaged for a residential location of a receptor, not a specified location.

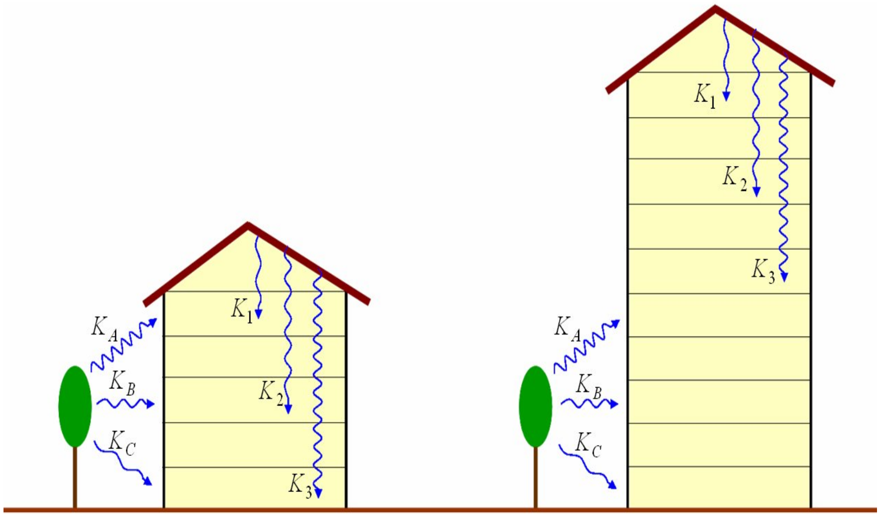

Fig. III.2.2. An example for the rearrangement of kerma values derived by Mechbach et al. to apply to the environment to be described in METRO-K. The house on the left-hand side represents a simplified European building, and the house on the right-hand side is a Korean building.

Table III.2.3. Kerma values for a 10-story apartment to be rearranged (pGy per γ mm^{-2}).

Location \ Surface		A near building					Neighboring buildings across roads			A park across roads				
		Walls	**Outer walls**	**Roofs**	**Garden**	**Garden trees**	**Paved roads**	**Outer wall**	**Roofs**	**Paved roads**	**Park**	**Outer walls**	**Roofs**	**Trees**
0.3 MeV	Basement	0.001	0.002	0	0.004	0	0.004	0.01	0	0.004	0.001	0.003	0	0.004
	1st floor	2.9	0.5	0	1.8	0.33	1	2	0	1.4	1.6	0.7	0	0.65
	5th floor	2.9	0.6	0	0.25	0.03	0.09	1.8	0.01	0.15	0.9	0.7	0.03	0.05
	10th floor	2.8	0.4	0.6	0	0	0	1.1	0.3	0	0.51	0.4	0.1	0
	Roads	8.1	57	0	0.25	0.01	200	130	2	230	66	32	1	25
	Garden	6.6	45	0	252	10	0.2	57	3	0.2	3	56	3	0.05
0.662 MeV	Basement	0.009	0.008	0	0.01	0.0005	0.018	0.042	0	0.013	0.004	0.024	0	0.013
	1st floor	6.5	2.1	0	5.1	0.9	2.6	5.4	0	3.9	4.8	2	0	1.8
	5th floor	6.5	2.1	0	0.5	0.06	0.15	5.3	0.08	0.3	2.2	2	0.05	0.09
	10th floor	6.5	2	3.8	0	0	0	3	0.6	0	1	0.9	0.25	0
	Roads	16	115	0	0.3	0.02	430	270	3	495	140	68	1.5	52
	Garden	14	89	0	530	21	0.4	110	4	0.5	4	110	4	0.1
3 MeV	Basement	0.05	0.4	0	0.2	0.02	0.3	1.7	0.2	0.2	0.07	1.2	0	0.2
	1st floor	24	26	0	39	4.7	2.4	32	0	34	43	14	0	10
	5th floor	25	28	0.01	3.3	0.4	1.1	33	1	2	20	14	0.7	0.8
	10th floor	24	26	56	0	0	0	21	3.3	0	9.3	10	2.1	0
	Roads	48	315	0	1	0.08	1260	810	8.5	1490	585	220	2.5	154
	Garden	38	250	0	1580	61	4	320	9.5	2	10	320	9	0.5

Additional exposures resulting from daughter products are implicitly included by considering the yields of gamma energies from their radioactive decay scheme. The range of gamma energy considered in calculations is between 0.3 MeV and 3 MeV. Table III.2.4 shows the yields of gamma energies for five types of radionuclides, as used in METRO-K.

Table III.2.4. Gamma energies of radionuclides and their yields.

Radionuclide	Energy (MeV)	Yield (%)
^{103}Ru	0.444/0.497/0.557 0.610/0.612	0.3/86.4/0.8 5.3/0.1
^{106}Ru	0.428/0.435/0.512 0.616/0.622/0.873 1.050/1.128/1.194 1.562	0.1/0.1/20.6 0.7/9.8/0.4 1.5/0.4/0.1 0.1
^{134}Cs	0.475/0.563/0.569 0.605/0.796/0.802 1.039/1.168/1.365	1.5/8.4/15.4 97.6/85.4/8.7 1.0/1.8/3.0
^{137}Cs	0.662	85.0
^{131}I	0.326/0.364/0.503 0.637/0.643/0.723	0.3/81.2/0.4 7.3/0.2/1.8

Dose conversion factors are taken to be 0.8 Sv Gy^{-1} for adults located outdoors and 0.7 Sv Gy^{-1} for adults located indoors [III.2.5]. Dose reductions by surface roughness are taken to be 1.0 for roofs, 0.9 for paved roads, 0.95 for outer walls, 0.8 for soil or lawn, and 0.9 for trees.

III.2.4. Time-dependent exposure dose

In METRO-K, an urban environment is composed of just five types of surfaces which are roofs, paved roads, soil or lawn, outer walls and trees. Radionuclides deposited onto surfaces will be removed or diluted due not only to natural processes such as wind, precipitation and migration into soil, but also artificial processes such as traffic and pedestrians. Time-dependent dose rates due to environmental removals following a deposition are described with two different exponential terms:

$$\dot{H}(t) = \dot{H}_0 \exp\left(-\frac{0.693\,t}{T_{1/2,d}}\right)\cdot\left[A\exp\left(-\frac{-0.693\,t}{T_{w,a}}\right) + (1-A)\exp\left(-\frac{0.693\,t}{T_{w,b}}\right)\right] \quad \text{(III.2.6)}$$

where:

$\dot{H}(t)$ = time-dependent exposure dose rate (Sv d^{-1});
$\dot{H}_0$ = exposure dose rate just after a deposition (Sv d^{-1});
A = fraction of short-term environmental removal;
$T_{w,a}$ = short-term environmental half-life (d);
$T_{w,b}$ = long-term environmental half-life (d); and
$T_{1/2,d}$ = half-life by radioactive decay (d).

Table III.2.5 shows the parameter values used to describe the time-dependent dose rate depending on the types of surfaces and radionuclides.

Table III.2.5. Parameter values to describe the environmental removals.

Parameter \ Surface		Roofs	Paved roads	Outer walls	Lawn or Soil	Trees
A	Cs	0.5	0.6	0.2	0.63	0.8
	Ru	0.29	0.3	0.17	0.95	0.95
	I	0.75	0.75	0.3	0.95	0.8
$T_{w,a}$ (days)	Cs	340	80	365	317.6	36.5
	Ru	29.2	69.4	314	91	36.5
	I	17	40	182.5	160	18
$T_{w,b}$ (days)	Cs	2420	10 100	6930	15 600	36 500
	Ru	2420	10 100	6930	4450	36 500
	I	2420	10 100	6930	15 600	36 500

Table III.2.6. Radionuclide concentrations measured in soil for two different districts of Pripyat.

Radionuclide	District 1 (Sept. 26, 1986, MBq m^{-2})	District 4 (Sept. 24, 1986, MBq m^{-2})
^{95}Nb	12.811	4.995
^{95}Zr	7.816	2.835
^{103}Ru	1.647	0.578
^{106}Ru	4.079	1.438
^{134}Cs	0.703	0.296
^{137}Cs	1.397	0.523
^{141}Ce	1.036	0.547
^{144}Ce	14.800	5.365

III.2.5. Predicted results of METRO-K for Pripyat contamination scenarios

A wide variety of data including meteorological conditions were offered from the Urban Working Group to predict time-dependent dose rates up to 20 years following the Chernobyl accident. Owing to the characteristics of METRO-K and for the simplification of prediction, radionuclide concentrations measured in soil for District 1 and District 4 of Pripyat in Sept. 26 and Sept. 24, 1986, respectively, were used to predict the initial air concentration as an input of METRO-K. It was assumed that all radionuclides are deposited onto surfaces through dry processes on May 1, 1986. It was assumed that the degree of contamination was equal for the same surfaces in the same district, and the changes of radionuclide concentrations on surfaces are the same as those of absorbed dose rates. Table III.2.6 shows radionuclide concentrations measured in soil for two different districts of Pripyat.

Calculation procedures to predict the time-dependent dose rates are as follows:

(1) Select the best descriptive environment in METRO-K as compared with the surrounding environment of calculation locations from maps;
(2) Predict radionuclide concentrations in soil on Sept. 26 and Sept. 24, 1986, for unit air concentrations of May 1, 1986;
(3) Compare predictive results with measured ones;
(4) Correct the initial air concentrations by scaling-up with an assumption that air concentrations are directly proportional to soil concentrations;
(5) Predict radionuclide concentrations on the different surfaces on Sept. 26 and Sept. 24, 1986

(6) Predict the absorbed dose rates resulting from each contaminated surface;
(7) Obtain the absorbed dose rate for a radionuclide by adding the absorbed dose rates of the contaminated surfaces affected for a specified location; and
(8) Obtain the total absorbed dose rate by adding the absorbed dose rate for each radionuclide.

The range of gamma energy considered in the calculations is between 0.3 MeV and 3 MeV. The dose contribution of ^{141}Ce was not considered in calculations because of its relatively low gamma energy (0.145 MeV with 48.2% yield). Table III.2.7 shows the gamma energies of radionuclides including daughter products and their yields, as used in the Pripyat calculations. The parameter values in Equation (III.2.6) that describe the environmental removals following a deposition were replaced with Andersson's recent study [III.2.6], which may give a better description of long-term radionuclide behavior in an urban environment. Although they are for ^{137}Cs, the same parameter values (except for radioactive decay) were applied to other radionuclides for the same surfaces. Table III.2.8 shows the parameter values used to predict long-term radionuclide behavior for Pripyat contamination scenarios.

Kerma values were rearranged or modified by considering the surrounding environment of calculation locations from the maps. It was assumed that kerma values are proportional to the contaminated area, and inversely proportional to the square of the distance from a calculation location. If surrounding surfaces of a calculation location are different from those of METRO-K, they are reconstructed with radionuclide concentrations and surface roughness of corresponding surfaces as shown in Figure III.2.3.

Table III.2.7. Gamma energies of radionuclides and their yields.

Radionuclide	**Energy (MeV)**	**Yield (%)**
^{95}Nb	0.562/0.582/0.766/ 0.786/0.821	0.013/0.055/99.813/ 0.0158/0.0004
^{95}Zr	0.562/0.582/0.724/ 0.757/0.766/0.786	0.013/0.055/44.2/ 54.5/99.8/0.16
^{103}Ru	0.444/0.497/0.557 0.610/0.612	0.3/86.4/0.8 5.3/0.1
^{106}Ru	0.428/0.435/0.512 0.616/0.622/0.873 1.050/1.128/1.194 1.562	0.1/0.1/20.6 0.7/9.8/0.4 1.5/0.4/0.1 0.1
^{134}Cs	0.475/0.563/0.569 0.605/0.796/0.802 1.039/1.168/1.365	1.5/8.4/15.4 97.6/85.4/8.7 1.0/1.8/3.0
^{137}Cs	0.662	85.0
^{144}Ce	0.697/2.186	0.134/0.694

Table III.2.8. Parameter values in Equation (III.2.6) used to predict the environmental removals for Pripyat contamination scenarios.

Parameter	**Roofs**	**Paved roads**	**Outer walls**	**Lawn or soil**	**Trees**
A	0.5	0.7	1	0.575	1
$T_{w,a}$ (day)	365	120	2740	1200	100
$T_{w,b}$ (day)	13700	1100	0	7670	0

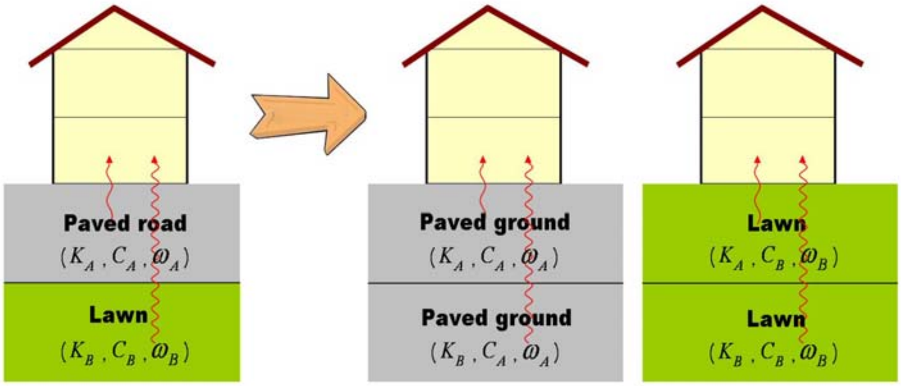

Fig. III.2.3. An example for application of the model to different environments. The left-hand side represents METRO-K's environment, and the right-hand side represents Pripyat's environment.

In METRO-K's environment (the house on the left-hand side in Figure III.2.3), a receptor living on the 1st floor may be exposed from the contaminated paved road which is located near his or her house, and from the contaminated lawn which is located farther away. If a receptor living on the 1st floor with a large paved ground in front of his or her house (see the house on the right-hand side in Figure III.2.3), the radionuclide concentration and surface roughness for a lawn in METRO-K are replaced with those for a paved ground. Similarly, for a receptor living on the 1st floor with a large lawn, the radionuclide concentration and surface roughness for a paved road in METRO-K are replaced with those for a lawn. One must keep in mind that the absorbed dose rate predicted for the 1st floor is an average over a space at the height of a receptor, not a specific dose rate at a point which is given by the Urban Working Group. If there is no kerma data for a calculation location, it was interpolated logarithmically between those from adjoining surfaces. Absorbed dose during a specified period was calculated as follows:

$$\int_{t_1}^{t_2} \dot{D}_1 \exp(-\lambda_d t) \cdot \left[A \exp(-\lambda_{w,a} t) + (1-A)\exp(-\lambda_{w,b} t)\right] dt =$$
$$\dot{D}_1 \left(\frac{A}{\lambda_d + \lambda_{w,a}} \{ [\exp -(\lambda_d + \lambda_{w,a}) t_1] - [\exp -(\lambda_d + \lambda_{w,a}) t_2] \} \right. \qquad \text{(III.2.7)}$$
$$\left. + \frac{(1-A)}{\lambda_d + \lambda_{w,b}} \{ [\exp -(\lambda_d + \lambda_{w,b}) t_1] - [\exp -(\lambda_d + \lambda_{w,b}) t_2] \} \right)$$

The absorbed dose for a receptor living at more than one location was calculated as follows:

$$D = \sum_i O_i \, D_i \qquad \text{(III.2.8)}$$

where:

i = location of a receptor;
D = absorbed dose (mGy); and
O = occupancy factor.

Table III.2.9 shows the locations of residence and the fraction of time spent for five types of Pripyat scenarios.

Dose reductions by application of remediation measures were calculated for 5 types of exposure scenarios. Table III.2.10 shows the remediation measures to be considered and time of application, and their dose rate reduction factors (DRFs) following application of a remediation measure (summarized in Section 2.3 of the report). DRF is defined as the reduction in gamma dose rate above a surface just following decontamination. Therefore, absorbed dose rates after a remediation measure were obtained by dividing by a corresponding DRF from those without the remediation measure. Each remediation measure was separately applied, without combination.

The predicted results of Pripyat contamination scenarios as requested from the Urban Working Group are shown in Tables III.2.11 to III.2.24. The absorbed dose rates contributing from a specific surface expressed in the tables include those contributing from neighboring surfaces to compare with the predicted results of the participating models. For example, the absorbed dose rates contributing from contaminated walls are those contributing from the walls of the nearest building to a receptor plus those contributing from the walls of surrounding buildings.

Table III.2.9. Locations of residence (upper rows) and fraction of time spent (lower rows) for exposure scenarios.

Scenario	Inside		Outside				
	Home	**Work or school**	**Asphalt**	**Dirt**	**Kitchen garden**	**Virgin**	**Forest meadow**
Indoor workers	BD 17	BD 16	BD 21	BD 15	BD 15	–	–
	0.51	0.31	0.07	0.03	0.05	0.01	0.02
Outdoor workers	BD 17	BD 16	BD 21	BD 20	BD 15	–	–
	0.51	0.10	0.08	0.23	0.05	0.01	0.02
Pensioner	BD 17	–	BD 21	BD 15	BD 15	–	–
	0.75	0.00	0.07	0.07	0.08	0.01	0.02
School children	BD 17	BD 23	BD 22	BD 15	BD 15	–	–
	0.58	0.15	0.08	0.10	0.04	0.04	0.01
Pre-school children	BD 17	BD 23	BD 22	BD 15	BD 15	–	–
	0.51	0.25	0.04	0.12	0.03	0.04	0.01

(Note) BD is an abbreviation of building.

Table III.2.10. Remediation measures and their dose rate reduction factors.

Remediation measure	Time of application after the accident	Dose rate reduction factor
Cutting and removal of grass	Day 7	5
Washing of roads	Day 14 (no rain)	3
Washing of roofs and walls	Day 14 (no rain)	5 for roofs, 7 for walls
Removal of trees and leaves	Day 30	20
Removal of soil (5 cm)	Day 180	20
Relocation of population	For the first 2 weeks	–
Relocation of population	For the first 6 weeks	–
Relocation of population	For the first 6 months	–

Table III.2.11. Predicted total dose rates at test locations in District 1 of Pripyat from all relevant surfaces and radionuclides, without remediation measures.

Date	Location (mGy h^{-1})								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
01-Aug-86	2.36E-01	3.10E-02	3.65E-03	2.62E-02	2.06E-01	1.31E-01	4.23E-03	1.60E-03	2.00E-03
01-Aug-87	1.71E-02	1.41E-03	2.64E-04	1.84E-03	1.47E-02	9.34E-03	2.91E-04	1.12E-04	1.34E-04
01-Aug-88	8.29E-03	5.96E-04	1.29E-04	8.75E-04	7.06E-03	4.48E-03	1.36E-04	5.34E-05	6.28E-05
01-Aug-89	4.77E-03	3.15E-04	7.48E-05	4.92E-04	4.01E-03	2.55E-03	7.63E-05	3.02E-05	3.60E-05
01-Aug-90	3.02E-03	1.86E-04	4.78E-05	3.05E-04	2.52E-03	1.60E-03	4.71E-05	1.89E-05	2.32E-05
01-Aug-91	2.10E-03	1.19E-04	3.35E-05	2.09E-04	1.73E-03	1.10E-03	3.19E-05	1.30E-05	1.65E-05
01-Aug-92	1.59E-03	8.31E-05	2.54E-05	1.54E-04	1.29E-03	8.18E-04	2.34E-05	9.67E-06	1.28E-05
01-Aug-93	1.27E-03	6.13E-05	2.05E-05	1.22E-04	1.02E-03	6.48E-04	1.84E-05	7.66E-06	1.06E-05
01-Aug-94	1.06E-03	4.71E-05	1.72E-05	1.00E-04	8.48E-04	5.36E-04	1.51E-05	6.37E-06	9.12E-06
01-Aug-95	9.14E-04	3.73E-05	1.49E-05	8.55E-05	7.22E-04	4.58E-04	1.28E-05	5.48E-06	8.10E-06
01-Aug-96	8.04E-04	3.03E-05	1.32E-05	7.44E-05	6.30E-04	4.00E-04	1.11E-05	4.80E-06	7.35E-06
01-Aug-97	7.16E-04	2.50E-05	1.19E-05	6.57E-05	5.60E-04	3.55E-04	9.78E-06	4.26E-06	6.76E-06
01-Aug-98	6.47E-04	2.09E-05	1.07E-05	5.90E-05	5.04E-04	3.19E-04	8.79E-06	3.85E-06	6.27E-06
01-Aug-99	5.89E-04	1.76E-05	9.87E-06	5.35E-05	4.57E-04	2.89E-04	7.94E-06	3.50E-06	5.86E-06
01-Aug-00	5.44E-04	1.51E-05	9.10E-06	4.89E-05	4.19E-04	2.65E-04	7.25E-06	3.20E-06	5.50E-06
01-Aug-01	5.01E-04	1.30E-05	8.38E-06	4.49E-05	3.85E-04	2.43E-04	6.65E-06	2.96E-06	5.19E-06
01-Aug-02	4.65E-04	1.12E-05	7.80E-06	4.15E-05	3.56E-04	2.24E-04	6.12E-06	2.74E-06	4.90E-06
01-Aug-03	4.32E-04	9.80E-06	7.29E-06	3.85E-05	3.31E-04	2.09E-04	5.69E-06	2.54E-06	4.65E-06
01-Aug-04	4.03E-04	8.61E-06	6.80E-06	3.59E-05	3.08E-04	1.94E-04	5.29E-06	2.37E-06	4.40E-06
01-Aug-05	3.77E-04	7.61E-06	6.35E-06	3.35E-05	2.87E-04	1.81E-04	4.93E-06	2.21E-06	4.18E-06
01-Aug-06	3.54E-04	6.75E-06	5.95E-06	3.13E-05	2.69E-04	1.69E-04	4.62E-06	2.07E-06	3.98E-06

Table III.2.12. Predicted dose rates from the most important surfaces, and their contribution (%) to the total dose rate, by location in District 1 of Pripyat.

Location	1			2			3		
Date	Surface	Dose rate (mGy h^{-1})	Percent	Surface	Dose rate (mGy h^{-1})	Percent	Surface	Dose rate (mGy h^{-1})	Percent
01-Aug-86	soil	2.02E-01	85.84%	paved	2.03E-02	65.46%	paved	3.28E-03	89.91%
	tree	3.33E-02	14.14%	tree	6.46E-03	20.85%	outer wall	2.12E-04	5.81%
	outer wall	4.79E-05	0.02%	outer wall	2.82E-03	9.09%	roof	1.56E-04	4.28%
01-Aug-91	soil	1.94E-03	92.35%	paved	4.43E-05	37.09%	paved	3.00E-05	89.51%
	tree	1.60E-04	7.62%	tree	3.10E-05	25.91%	outer wall	2.19E-06	6.55%
	outer wall	5.18E-07	0.02%	outer wall	3.04E-05	25.46%	roof	1.32E-06	3.94%
01-Aug-96	soil	7.77E-04	96.64%	outer wall	1.14E-05	37.49%	paved	1.17E-05	88.72%
	tree	2.68E-05	3.33%	paved	8.28E-06	27.35%	outer wall	8.07E-07	6.10%
	outer wall	1.93E-07	0.02%	soil	5.49E-06	18.15%	roof	6.86E-07	5.18%
01-Aug-01	soil	4.95E-04	98.70%	outer wall	6.02E-06	46.43%	paved	7.43E-06	88.64%
	tree	6.39E-06	1.27%	soil	3.51E-06	27.05%	roof	5.24E-07	6.25%
	outer wall	1.02E-07	0.02%	paved	2.21E-06	17.07%	outer wall	4.28E-07	5.11%
01-Aug-06	soil	3.52E-04	99.53%	outer wall	3.34E-06	49.48%	paved	5.30E-06	88.93%
	tree	1.58E-06	0.45%	soil	2.49E-06	36.88%	roof	4.21E-07	7.08%
	outer wall	5.69E-08	0.02%	paved	6.16E-07	9.12%	outer wall	2.38E-07	3.99%
Location	**4**			**5**			**6**		
Date	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	soil	1.87E-02	71.30%	soil	1.52E-01	73.73%	soil	9.49E-02	72.65%
	tree	7.29E-03	27.85%	tree	5.26E-02	25.59%	tree	3.33E-02	25.52%
	outer wall	1.46E-04	0.56%	outer wall	1.39E-03	0.68%	outer wall	2.39E-03	1.83%
01-Aug-91	soil	1.72E-04	82.62%	soil	1.46E-03	84.50%	soil	9.12E-04	83.05%
	tree	3.42E-05	16.39%	tree	2.53E-04	14.63%	tree	1.60E-04	14.59%
	outer wall	1.49E-06	0.71%	outer wall	1.50E-05	0.87%	outer wall	2.59E-05	2.35%
01-Aug-96	soil	6.79E-05	91.25%	soil	5.82E-04	92.40%	soil	3.63E-04	90.87%
	tree	5.68E-06	7.63%	tree	4.23E-05	6.71%	tree	2.68E-05	6.70%
	outer wall	5.47E-07	0.74%	outer wall	5.58E-06	0.89%	outer wall	9.67E-06	2.42%
01-Aug-01	soil	4.31E-05	95.88%	soil	3.72E-04	96.63%	soil	2.32E-04	95.27%
	tree	1.35E-06	2.99%	tree	1.00E-05	2.60%	tree	6.39E-06	2.63%
	outer wall	2.90E-07	0.64%	outer wall	2.96E-06	0.77%	outer wall	5.12E-06	2.10%
01-Aug-06	soil	3.06E-05	97.86%	soil	2.65E-04	98.46%	soil	1.65E-04	97.39%
	tree	3.35E-07	1.07%	tree	2.50E-06	0.93%	outer wall	2.85E-06	1.68%
	roof	1.74E-07	0.56%	outer wall	1.65E-06	0.61%	tree	1.58E-06	0.93%
Location	**7**			**8**			**9**		
Date	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	soil	2.84E-03	67.08%	soil	1.27E-03	79.59%	roof	1.08E-03	53.82%
	tree	1.21E-03	28.66%	tree	2.27E-04	14.19%	soil	7.90E-04	39.53%
	paved	1.53E-04	3.62%	paved	6.91E-05	4.32%	tree	6.38E-05	3.19%
01-Aug-91	soil	2.57E-05	80.51%	soil	1.15E-05	88.74%	roof	8.48E-06	51.28%
	tree	5.63E-06	17.66%	tree	1.03E-06	7.91%	soil	7.43E-06	44.93%
	paved	3.15E-07	0.99%	outer wall	2.71E-07	2.08%	tree	2.89E-07	1.75%
01-Aug-96	soil	1.00E-05	90.24%	soil	4.50E-06	93.73%	roof	4.32E-06	58.81%
	tree	9.29E-07	8.37%	tree	1.66E-07	3.46%	soil	2.88E-06	39.11%
	outer wall	9.77E-08	0.88%	outer wall	9.78E-08	2.04%	outer wall	8.93E-08	1.21%
01-Aug-01	soil	6.36E-06	95.68%	soil	2.85E-06	96.41%	roof	3.30E-06	63.56%
	tree	2.20E-07	3.31%	outer wall	5.15E-08	1.74%	soil	1.83E-06	35.23%
	outer wall	5.16E-08	0.78%	tree	3.92E-08	1.33%	outer wall	4.72E-08	0.91%
01-Aug-06	soil	4.54E-06	98.10%	soil	2.03E-06	97.72%	roof	2.65E-06	66.63%
	tree	5.49E-08	1.19%	outer wall	2.86E-08	1.38%	soil	1.30E-06	32.61%
	outer wall	2.87E-08	0.62%	tree	9.73E-09	0.47%	outer wall	2.63E-08	0.66%

Table III.2.13. Predicted dose rates from the most important radionuclides, and their contribution to the total dose rate, by location in District 1 of Pripyat.

Location	**1**			**2**			**3**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	1.16E-01	49.16%	Nb-95	1.53E-02	49.25%	Nb-95	1.81E-03	49.70%
	Zr-95	7.94E-02	33.70%	Zr-95	1.04E-02	33.64%	Zr-95	1.23E-03	33.77%
	Ru-106	2.45E-02	10.40%	Ru-106	3.23E-03	10.42%	Ru-106	3.72E-04	10.20%
01-Aug-91	Cs-137	1.30E-03	61.65%	Cs-137	7.37E-05	61.68%	Cs-137	2.02E-05	60.39%
	Ru-106	4.14E-04	19.67%	Ru-106	2.35E-05	19.67%	Ru-106	6.78E-06	20.23%
	Cs-134	3.88E-04	18.46%	Cs-134	2.20E-05	18.44%	Cs-134	6.36E-06	18.98%
01-Aug-96	Cs-137	7.49E-04	93.12%	Cs-137	2.82E-05	93.11%	Cs-137	1.23E-05	92.79%
	Cs-134	4.67E-05	5.80%	Cs-134	1.76E-06	5.81%	Cs-134	8.04E-07	6.07%
	Ru-106	8.62E-06	1.07%	Ru-106	3.26E-07	1.08%	Ru-106	1.49E-07	1.12%
01-Aug-01	Cs-137	4.94E-04	98.67%	Cs-137	1.28E-05	98.67%	Cs-137	8.26E-06	98.60%
	Cs-134	6.44E-06	1.28%	Cs-134	1.67E-07	1.29%	Cs-134	1.14E-07	1.36%
	Ru-106	2.06E-07	0.04%	Ru-106	5.32E-09	0.04%	Ru-106	3.63E-09	0.04%
01-Aug-06	Cs-137	3.53E-04	99.73%	Cs-137	6.74E-06	99.73%	Cs-137	5.94E-06	99.71%
	Cs-134	9.63E-07	0.27%	Cs-134	1.84E-08	0.27%	Cs-134	1.70E-08	0.29%
	Ru-106	5.29E-09	0.00%	Ru-106	1.01E-10	0.00%	Ru-106	9.42E-11	0.00%
Location	**4**			**5**			**6**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	1.30E-02	49.74%	Nb-95	1.01E-01	49.15%	Nb-95	6.44E-02	49.25%
	Zr-95	8.85E-03	33.80%	Zr-95	6.92E-02	33.64%	Zr-95	4.39E-02	33.62%
	Ru-106	2.67E-03	10.20%	Ru-106	2.14E-02	10.43%	Ru-106	1.36E-02	10.38%
01-Aug-91	Cs-137	1.27E-04	60.83%	Cs-137	1.07E-03	61.67%	Cs-137	6.77E-04	61.66%
	Ru-106	4.18E-05	20.03%	Ru-106	3.40E-04	19.67%	Ru-106	2.16E-04	19.68%
	Cs-134	3.92E-05	18.79%	Cs-134	3.19E-04	18.45%	Cs-134	2.03E-04	18.43%
01-Aug-96	Cs-137	6.91E-05	92.89%	Cs-137	5.86E-04	93.10%	Cs-137	3.72E-04	93.10%
	Cs-134	4.47E-06	6.00%	Cs-134	3.67E-05	5.82%	Cs-134	2.33E-05	5.82%
	Ru-106	8.22E-07	1.10%	Ru-106	6.76E-06	1.07%	Ru-106	4.30E-06	1.08%
01-Aug-01	Cs-137	4.43E-05	98.62%	Cs-137	3.80E-04	98.67%	Cs-137	2.40E-04	98.67%
	Cs-134	6.01E-07	1.34%	Cs-134	4.96E-06	1.29%	Cs-134	3.14E-06	1.29%
	Ru-106	1.92E-08	0.04%	Ru-106	1.58E-07	0.04%	Ru-106	1.00E-07	0.04%
01-Aug-06	Cs-137	3.12E-05	99.72%	Cs-137	2.68E-04	99.73%	Cs-137	1.69E-04	99.73%
	Cs-134	8.83E-08	0.28%	Cs-134	7.30E-07	0.27%	Cs-134	4.61E-07	0.27%
	Ru-106	4.89E-10	0.00%	Ru-106	4.04E-09	0.00%	Ru-106	2.55E-09	0.00%
Location	**7**			**8**			**9**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	2.10E-03	49.76%	Nb-95	7.97E-04	49.82%	Nb-95	1.01E-03	50.72%
	Zr-95	1.43E-03	33.75%	Zr-95	5.38E-04	33.64%	Zr-95	6.84E-04	34.24%
	Ru-106	4.30E-04	10.18%	Ru-106	1.63E-04	10.20%	Ru-106	2.03E-04	10.17%
01-Aug-91	Cs-137	1.92E-05	60.15%	Cs-137	7.78E-06	59.83%	Cs-137	9.88E-06	59.76%
	Ru-106	6.48E-06	20.33%	Ru-106	2.66E-06	20.48%	Ru-106	3.39E-06	20.47%
	Cs-134	6.09E-06	19.08%	Cs-134	2.50E-06	19.21%	Cs-134	3.17E-06	19.20%
01-Aug-96	Cs-137	1.03E-05	92.70%	Cs-137	4.45E-06	92.66%	Cs-137	6.81E-06	92.63%
	Cs-134	6.84E-07	6.16%	Cs-134	2.97E-07	6.19%	Cs-134	4.57E-07	6.21%
	Ru-106	1.26E-07	1.13%	Ru-106	5.47E-08	1.14%	Ru-106	8.43E-08	1.15%
01-Aug-01	Cs-137	6.55E-06	98.59%	Cs-137	2.91E-06	98.58%	Cs-137	5.11E-06	98.57%
	Cs-134	9.11E-08	1.37%	Cs-134	4.08E-08	1.38%	Cs-134	7.17E-08	1.38%
	Ru-106	2.91E-09	0.04%	Ru-106	1.30E-09	0.04%	Ru-106	2.29E-09	0.04%
01-Aug-06	Cs-137	4.61E-06	99.71%	Cs-137	2.07E-06	99.71%	Cs-137	3.97E-06	99.71%
	Cs-134	1.33E-08	0.29%	Cs-134	6.05E-09	0.29%	Cs-134	1.16E-08	0.29%
	Ru-106	7.36E-11	0.00%	Ru-106	3.34E-11	0.00%	Ru-106	6.42E-11	0.00%

Table III.2.14. Predicted radionuclide contamination densities at outdoor test locations in District 1 of Pripyat (Bq m^{-2}).

Location	**1 (Surface: Soil)**			**2 (Surface: Paved)**		
Date	**Cs-137**	**Cs-134**	**Ru-106**	**Cs-137**	**Cs-134**	**Ru-106**
01-Aug-86	1.43E+06	7.63E+05	4.71E+06	1.38E+05	7.34E+04	4.53E+05
01-Aug-87	1.23E+06	4.78E+05	2.07E+06	5.30E+04	2.06E+04	8.94E+04
01-Aug-88	1.07E+06	3.03E+05	9.24E+05	3.48E+04	9.89E+03	3.02E+04
01-Aug-89	9.29E+05	1.93E+05	4.15E+05	2.63E+04	5.46E+03	1.17E+04
01-Aug-90	8.17E+05	1.24E+05	1.88E+05	2.03E+04	3.09E+03	4.67E+03
01-Aug-91	7.24E+05	8.03E+04	8.57E+04	1.58E+04	1.75E+03	1.87E+03
01-Aug-92	6.46E+05	5.24E+04	3.93E+04	1.22E+04	9.94E+02	7.46E+02
01-Aug-93	5.80E+05	3.44E+04	1.82E+04	9.51E+03	5.64E+02	2.98E+02
01-Aug-94	5.24E+05	2.27E+04	8.46E+03	7.38E+03	3.20E+02	1.19E+02
01-Aug-95	4.76E+05	1.51E+04	3.96E+03	5.73E+03	1.82E+02	4.77E+01
01-Aug-96	4.35E+05	1.01E+04	1.86E+03	4.45E+03	1.03E+02	1.91E+01
01-Aug-97	3.99E+05	6.78E+03	8.80E+02	3.46E+03	6.21E+01	7.62E+00
01-Aug-98	3.68E+05	4.57E+03	4.18E+02	2.68E+03	3.33E+01	3.04E+00
01-Aug-99	3.41E+05	3.09E+03	1.99E+02	2.08E+03	1.89E+01	1.22E+00
01-Aug-00	3.16E+05	2.10E+03	9.50E+01	1.62E+03	1.07E+01	4.87E-01
01-Aug-01	2.94E+05	1.43E+03	4.55E+01	1.26E+03	6.09E+00	1.94E-01
01-Aug-02	2.74E+05	9.73E+02	2.19E+01	9.76E+02	3.46E+00	7.77E-02
01-Aug-03	2.57E+05	6.65E+02	1.05E+01	7.58E+02	1.96E+00	3.11E-02
01-Aug-04	2.40E+05	4.55E+02	5.07E+00	5.88E+02	1.12E+00	1.24E-02
01-Aug-05	2.25E+05	3.12E+02	2.45E+00	4.57E+02	6.33E-01	4.97E-03
01-Aug-06	2.12E+05	2.14E+02	1.18E+00	3.55E+02	3.60E-01	1.99E-03
Location	**5 (Surface: Soil)**			**6 (Surface: Soil)**		
Date	**Cs-137**	**Cs-134**	**Ru-106**	**Cs-137**	**Cs-134**	**Ru-106**
01-Aug-86	1.43E+06	7.63E+05	4.71E+06	1.43E+06	7.63E+05	4.71E+06
01-Aug-87	1.23E+06	4.78E+05	2.07E+06	1.23E+06	4.78E+05	2.07E+06
01-Aug-88	1.07E+06	3.03E+05	9.24E+05	1.07E+06	3.03E+05	9.24E+05
01-Aug-89	9.29E+05	1.93E+05	4.15E+05	9.29E+05	1.93E+05	4.15E+05
01-Aug-90	8.17E+05	1.24E+05	1.88E+05	8.17E+05	1.24E+05	1.88E+05
01-Aug-91	7.24E+05	8.03E+04	8.57E+04	7.24E+05	8.03E+04	8.57E+04
01-Aug-92	6.46E+05	5.24E+04	3.93E+04	6.46E+05	5.24E+04	3.93E+04
01-Aug-93	5.80E+05	3.44E+04	1.82E+04	5.80E+05	3.44E+04	1.82E+04
01-Aug-94	5.24E+05	2.27E+04	8.46E+03	5.24E+05	2.27E+04	8.46E+03
01-Aug-95	4.76E+05	1.51E+04	3.96E+03	4.76E+05	1.51E+04	3.96E+03
01-Aug-96	4.35E+05	1.01E+04	1.86E+03	4.35E+05	1.01E+04	1.86E+03
01-Aug-97	3.99E+05	6.78E+03	8.80E+02	3.99E+05	6.78E+03	8.80E+02
01-Aug-98	3.68E+05	4.57E+03	4.18E+02	3.68E+05	4.57E+03	4.18E+02
01-Aug-99	3.41E+05	3.09E+03	1.99E+02	3.41E+05	3.09E+03	1.99E+02
01-Aug-00	3.16E+05	2.10E+03	9.50E+01	3.16E+05	2.10E+03	9.50E+01
01-Aug-01	2.94E+05	1.43E+03	4.55E+01	2.94E+05	1.43E+03	4.55E+01
01-Aug-02	2.74E+05	9.73E+02	2.19E+01	2.74E+05	9.73E+02	2.19E+01
01-Aug-03	2.57E+05	6.65E+02	1.05E+01	2.57E+05	6.65E+02	1.05E+01
01-Aug-04	2.40E+05	4.55E+02	5.07E+00	2.40E+05	4.55E+02	5.07E+00
01-Aug-05	2.25E+05	3.12E+02	2.45E+00	2.25E+05	3.12E+02	2.45E+00
01-Aug-06	2.12E+05	2.14E+02	1.18E+00	2.12E+05	2.14E+02	1.18E+00

Table III.2.15. Predicted total dose rates at test locations in District 4 of Pripyat from all relevant surfaces and radionuclides, without remediation measures.

Date	**Location (mGy h^{-1})**							
	10	**11**	**12**	**13**	**14**	**15**	**16**	**17**
01-Aug-86	2.52E-03	5.24E-04	2.49E-04	7.68E-02	7.68E-02	1.37E-01	7.24E-02	2.08E-03
01-Aug-87	1.71E-04	3.69E-05	1.79E-05	5.47E-03	5.47E-03	9.78E-03	4.90E-03	1.41E-04
01-Aug-88	8.09E-05	1.80E-05	8.83E-06	2.71E-03	2.71E-03	4.86E-03	2.35E-03	6.82E-05
01-Aug-89	4.53E-05	1.04E-05	5.14E-06	1.59E-03	1.59E-03	2.86E-03	1.35E-03	3.91E-05
01-Aug-90	2.80E-05	6.57E-06	3.29E-06	1.02E-03	1.02E-03	1.83E-03	8.61E-04	2.46E-05
01-Aug-91	1.89E-05	4.56E-06	2.30E-06	7.21E-04	7.21E-04	1.30E-03	6.03E-04	1.70E-05
01-Aug-92	1.39E-05	3.42E-06	1.74E-06	5.46E-04	5.46E-04	9.90E-04	4.58E-04	1.27E-05
01-Aug-93	1.08E-05	2.72E-06	1.39E-06	4.39E-04	4.39E-04	7.99E-04	3.69E-04	9.96E-06
01-Aug-94	8.78E-06	2.26E-06	1.16E-06	3.68E-04	3.68E-04	6.68E-04	3.10E-04	8.23E-06
01-Aug-95	7.40E-06	1.94E-06	1.00E-06	3.17E-04	3.17E-04	5.79E-04	2.69E-04	7.03E-06
01-Aug-96	6.39E-06	1.70E-06	8.86E-07	2.80E-04	2.80E-04	5.11E-04	2.39E-04	6.12E-06
01-Aug-97	5.62E-06	1.52E-06	7.91E-07	2.50E-04	2.50E-04	4.58E-04	2.15E-04	5.43E-06
01-Aug-98	5.01E-06	1.37E-06	7.19E-07	2.26E-04	2.26E-04	4.15E-04	1.96E-04	4.88E-06
01-Aug-99	4.51E-06	1.25E-06	6.52E-07	2.07E-04	2.07E-04	3.79E-04	1.81E-04	4.42E-06
01-Aug-00	4.10E-06	1.15E-06	6.00E-07	1.90E-04	1.90E-04	3.49E-04	1.68E-04	4.04E-06
01-Aug-01	3.76E-06	1.06E-06	5.55E-07	1.76E-04	1.76E-04	3.22E-04	1.56E-04	3.72E-06
01-Aug-02	3.46E-06	9.75E-07	5.15E-07	1.63E-04	1.63E-04	2.99E-04	1.46E-04	3.44E-06
01-Aug-03	3.20E-06	9.08E-07	4.79E-07	1.52E-04	1.52E-04	2.79E-04	1.37E-04	3.19E-06
01-Aug-04	2.98E-06	8.49E-07	4.47E-07	1.41E-04	1.41E-04	2.60E-04	1.29E-04	2.97E-06
01-Aug-05	2.77E-06	7.91E-07	4.18E-07	1.33E-04	1.33E-04	2.44E-04	1.22E-04	2.77E-06
01-Aug-06	2.59E-06	7.41E-07	3.91E-07	1.24E-04	1.24E-04	2.28E-04	1.15E-04	2.59E-06

Date	**Location (mGy h^{-1})**						
	18	**19**	**20**	**21**	**22**	**23**	**24**
01-Aug-86	5.10E-04	6.00E-04	1.46E-01	3.49E-02	1.59E-02	1.03E-03	1.15E-03
01-Aug-87	3.85E-05	3.83E-05	1.03E-02	2.14E-03	8.20E-04	4.63E-05	6.56E-05
01-Aug-88	1.85E-05	1.82E-05	5.09E-03	9.96E-04	3.71E-04	2.03E-05	3.03E-05
01-Aug-89	1.04E-05	1.06E-05	2.96E-03	5.53E-04	2.06E-04	1.12E-05	1.74E-05
01-Aug-90	6.54E-06	6.91E-06	1.89E-03	3.40E-04	1.27E-04	6.87E-06	1.12E-05
01-Aug-91	4.51E-06	5.00E-06	1.33E-03	2.28E-04	8.57E-05	4.62E-06	8.03E-06
01-Aug-92	3.37E-06	3.92E-06	9.98E-04	1.65E-04	6.23E-05	3.36E-06	6.22E-06
01-Aug-93	2.69E-06	3.27E-06	7.98E-04	1.28E-04	4.81E-05	2.58E-06	5.13E-06
01-Aug-94	2.24E-06	2.84E-06	6.66E-04	1.03E-04	3.88E-05	2.08E-06	4.40E-06
01-Aug-95	1.92E-06	2.54E-06	5.73E-04	8.55E-05	3.23E-05	1.74E-06	3.90E-06
01-Aug-96	1.69E-06	2.32E-06	5.03E-04	7.31E-05	2.76E-05	1.48E-06	3.53E-06
01-Aug-97	1.51E-06	2.14E-06	4.49E-04	6.37E-05	2.39E-05	1.28E-06	3.23E-06
01-Aug-98	1.36E-06	1.99E-06	4.06E-04	5.64E-05	2.11E-05	1.13E-06	2.99E-06
01-Aug-99	1.24E-06	1.87E-06	3.70E-04	5.04E-05	1.88E-05	1.01E-06	2.79E-06
01-Aug-00	1.14E-06	1.76E-06	3.40E-04	4.56E-05	1.69E-05	9.03E-07	2.62E-06
01-Aug-01	1.05E-06	1.67E-06	3.13E-04	4.15E-05	1.53E-05	8.18E-07	2.46E-06
01-Aug-02	9.73E-07	1.58E-06	2.90E-04	3.80E-05	1.40E-05	7.45E-07	2.33E-06
01-Aug-03	9.07E-07	1.50E-06	2.70E-04	3.50E-05	1.29E-05	6.82E-07	2.20E-06
01-Aug-04	8.48E-07	1.43E-06	2.52E-04	3.24E-05	1.19E-05	6.28E-07	2.09E-06
01-Aug-05	7.91E-07	1.36E-06	2.36E-04	3.01E-05	1.10E-05	5.80E-07	1.99E-06
01-Aug-06	7.41E-07	1.29E-06	2.21E-04	2.81E-05	1.02E-05	5.37E-07	1.89E-06

Table III.2.16. Predicted dose rates from the most important surfaces, and their contribution to the total dose rate, by location in District 4 of Pripyat.

Location	**10**			**11**			**12**		
Date	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	soil	1.60E-03	63.48%	soil	4.59E-04	87.70%	soil	2.38E-04	95.76%
	tree	9.10E-04	36.15%	tree	5.51E-05	10.52%	outer wall	9.14E-06	3.67%
	outer wall	9.31E-06	0.37%	outer wall	9.36E-06	1.79%	roof	1.41E-06	0.57%
01-Aug-91	soil	1.46E-05	76.99%	soil	4.21E-06	92.39%	soil	2.20E-06	95.59%
	tree	4.26E-06	22.53%	tree	2.54E-07	5.57%	outer wall	9.07E-08	3.95%
	outer wall	9.27E-08	0.49%	outer wall	9.34E-08	2.05%	roof	1.07E-08	0.46%
01-Aug-96	soil	5.65E-06	88.48%	soil	1.63E-06	95.62%	soil	8.49E-07	95.81%
	tree	7.03E-07	11.00%	tree	4.10E-08	2.41%	outer wall	3.26E-08	3.69%
	outer wall	3.34E-08	0.52%	outer wall	3.35E-08	1.97%	roof	4.51E-09	0.51%
01-Aug-01	soil	3.57E-06	95.14%	soil	1.03E-06	97.42%	soil	5.34E-07	96.32%
	tree	1.65E-07	4.39%	outer wall	1.75E-08	1.66%	outer wall	1.71E-08	3.09%
	outer wall	1.75E-08	0.47%	tree	9.68E-09	0.92%	roof	3.29E-09	0.59%
01-Aug-06	soil	2.54E-06	98.04%	soil	7.29E-07	98.36%	soil	3.79E-07	96.90%
	tree	4.11E-08	1.59%	outer wall	9.74E-09	1.31%	outer wall	9.50E-09	2.43%
	outer wall	9.73E-09	0.38%	tree	2.39E-09	0.32%	roof	2.62E-09	0.67%
Location	**13**			**14**			**15**		
Date	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	soil	7.13E-02	92.84%	soil	7.13E-02	92.84%	soil	1.30E-01	95.49%
	tree	5.05E-03	6.58%	tree	5.05E-03	6.58%	tree	5.05E-03	3.70%
	outer wall	4.50E-04	0.59%	outer wall	4.50E-04	0.59%	outer wall	1.11E-03	0.81%
01-Aug-91	soil	6.92E-04	95.92%	soil	6.92E-04	95.92%	soil	1.26E-03	97.15%
	tree	2.45E-05	3.40%	tree	2.45E-05	3.40%	tree	2.45E-05	1.89%
	outer wall	4.89E-06	0.68%	outer wall	4.89E-06	0.68%	outer wall	1.25E-05	0.96%
01-Aug-96	soil	2.74E-04	97.89%	soil	2.74E-04	97.89%	soil	5.02E-04	98.28%
	tree	4.08E-06	1.46%	tree	4.08E-06	1.46%	outer wall	4.72E-06	0.92%
	outer wall	1.82E-06	0.65%	outer wall	1.82E-06	0.65%	tree	4.08E-06	0.80%
01-Aug-01	soil	1.74E-04	98.91%	soil	1.74E-04	98.91%	soil	3.19E-04	98.92%
	tree	9.62E-07	0.55%	tree	9.62E-07	0.55%	outer wall	2.50E-06	0.78%
	outer wall	9.62E-07	0.55%	outer wall	9.62E-07	0.55%	tree	9.63E-07	0.30%
01-Aug-06	soil	1.23E-04	99.38%	soil	1.23E-04	99.38%	soil	2.27E-04	99.29%
	outer wall	5.33E-07	0.43%	outer wall	5.33E-07	0.43%	outer wall	1.39E-06	0.61%
	tree	2.40E-07	0.19%	tree	2.40E-07	0.19%	tree	2.40E-07	0.11%
Location	**16**			**17**			**18**		
Date	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	soil	3.82E-02	52.79%	soil	1.59E-03	76.69%	soil	4.66E-04	91.51%
	roof	1.76E-02	24.25%	tree	4.52E-04	21.78%	tree	3.29E-05	6.45%
	tree	1.61E-02	22.20%	outer wall	3.17E-05	1.53%	outer wall	1.04E-05	2.04%
01-Aug-91	soil	3.66E-04	60.73%	soil	1.45E-05	85.57%	soil	4.26E-06	94.39%
	roof	1.52E-04	25.25%	tree	2.12E-06	12.51%	tree	1.50E-07	3.33%
	tree	7.74E-05	12.83%	outer wall	3.26E-07	1.92%	outer wall	1.03E-07	2.28%
01-Aug-96	soil	1.44E-04	60.39%	soil	5.65E-06	92.34%	soil	1.63E-06	96.42%
	roof	7.92E-05	33.14%	tree	3.50E-07	5.72%	outer wall	3.69E-08	2.19%
	tree	1.28E-05	5.36%	outer wall	1.19E-07	1.94%	tree	2.34E-08	1.39%
01-Aug-01	soil	9.13E-05	58.55%	soil	3.57E-06	96.08%	soil	1.03E-06	97.64%
	roof	6.02E-05	38.61%	tree	8.28E-08	2.23%	outer wall	1.93E-08	1.83%
	tree	3.03E-06	1.94%	outer wall	6.29E-08	1.69%	tree	5.52E-09	0.52%
01-Aug-06	soil	6.51E-05	56.64%	soil	2.54E-06	97.87%	soil	7.29E-07	98.37%
	roof	4.83E-05	42.03%	outer wall	3.48E-08	1.34%	outer wall	1.07E-08	1.44%
	outer wall	7.76E-07	0.68%	tree	2.05E-08	0.79%	tree	1.37E-09	0.18%

Table III.2.16. (Conitnued)

Location	19			20			21		
Date	Surface	Dose rate (mGy h^{-1})	Percent	Surface	Dose rate (mGy h^{-1})	Percent	Surface	Dose rate (mGy h^{-1})	Percent
01-Aug-86	roof	4.04E-04	67.46%	soil	1.26E-01	86.77%	soil	1.64E-02	46.82%
	soil	1.86E-04	30.97%	tree	1.92E-02	13.17%	tree	1.25E-02	35.89%
	outer wall	9.39E-06	1.57%	outer wall	9.00E-05	0.06%	paved	5.99E-03	17.16%
01-Aug-91	roof	3.21E-06	64.22%	soil	1.23E-03	92.71%	soil	1.53E-04	67.32%
	soil	1.70E-06	33.91%	tree	9.57E-05	7.22%	tree	6.08E-05	26.67%
	outer wall	9.35E-08	1.87%	outer wall	9.79E-07	0.07%	paved	1.32E-05	5.79%
01-Aug-96	roof	1.63E-06	70.32%	soil	4.87E-04	96.76%	soil	6.04E-05	82.60%
	soil	6.54E-07	28.22%	tree	1.59E-05	3.16%	tree	1.01E-05	13.79%
	outer wall	3.37E-08	1.45%	outer wall	3.64E-07	0.07%	paved	2.45E-06	3.36%
01-Aug-01	roof	1.24E-06	74.31%	soil	3.09E-04	98.74%	soil	3.83E-05	92.45%
	soil	4.11E-07	24.63%	tree	3.76E-06	1.20%	tree	2.38E-06	5.75%
	outer wall	1.77E-08	1.06%	outer wall	1.92E-07	0.06%	paved	6.50E-07	1.57%
01-Aug-06	roof	9.91E-07	76.65%	soil	2.20E-04	99.53%	soil	2.72E-05	97.04%
	soil	2.92E-07	22.58%	tree	9.35E-07	0.42%	tree	5.96E-07	2.12%
	outer wall	9.85E-09	0.76%	outer wall	1.07E-07	0.05%	paved	1.82E-07	0.65%
Location	**22**			**23**			**24**		
Date	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	paved	7.64E-03	48.08%	paved	6.67E-04	64.61%	roof	5.77E-04	49.94%
	soil	5.36E-03	33.71%	soil	2.32E-04	22.51%	paved	2.57E-04	22.29%
	tree	2.47E-03	15.54%	outer wall	5.57E-05	5.39%	soil	2.42E-04	20.99%
01-Aug-91	soil	5.23E-05	61.00%	soil	2.20E-06	47.52%	roof	4.62E-06	57.53%
	paved	1.68E-05	19.61%	paved	1.41E-06	30.47%	soil	2.24E-06	27.89%
	tree	1.20E-05	14.02%	outer wall	5.74E-07	12.42%	paved	5.42E-07	6.74%
01-Aug-96	soil	2.07E-05	75.22%	soil	8.64E-07	58.37%	roof	2.36E-06	66.89%
	paved	3.13E-06	11.34%	paved	2.59E-07	17.49%	soil	8.67E-07	24.58%
	tree	1.99E-06	7.23%	outer wall	2.10E-07	14.17%	outer wall	1.78E-07	5.05%
01-Aug-01	soil	1.31E-05	85.61%	soil	5.48E-07	66.95%	roof	1.79E-06	72.66%
	outer wall	9.04E-07	5.90%	outer wall	1.11E-07	13.53%	soil	5.48E-07	22.24%
	paved	8.30E-07	5.42%	roof	8.12E-08	9.93%	outer wall	9.37E-08	3.80%
01-Aug-06	soil	9.35E-06	91.68%	soil	3.89E-07	72.40%	roof	1.44E-06	76.20%
	outer wall	5.00E-07	4.91%	roof	6.50E-08	12.11%	soil	3.89E-07	20.58%
	paved	2.31E-07	2.27%	outer wall	6.15E-08	11.46%	outer wall	5.20E-08	2.75%

Table III.2.17. Predicted dose rates from the most important radionuclides, and their contribution to the total dose rate, by location in District 4 of Pripyat.

Location	10			11			12		
Date	Nuclide	Dose rate (mGy h^{-1})	Percent	Nuclide	Dose rate (mGy h^{-1})	Percent	Nuclide	Dose rate (mGy h^{-1})	Percent
01-Aug-86	Nb-95	1.30E-03	51.69%	Nb-95	5.42E-02	51.54%	Nb-95	2.26E+00	51.18%
	Zr-95	8.19E-04	32.51%	Zr-95	3.41E-02	32.38%	Zr-95	1.42E+00	32.20%
	Ru-106	2.40E-04	9.52%	Ru-106	9.98E-03	9.60%	Ru-106	4.16E-01	9.73%
01-Aug-91	Cs-137	1.13E-05	59.48%	Cs-137	4.69E-04	59.03%	Cs-137	1.95E-02	58.72%
	Cs-134	4.01E-06	21.21%	Cs-134	1.67E-04	21.47%	Cs-134	6.97E-03	21.63%
	Ru-106	3.58E-06	18.90%	Ru-106	1.49E-04	19.07%	Ru-106	6.21E-03	19.25%
01-Aug-96	Cs-137	5.88E-06	92.05%	Cs-137	2.45E-04	91.92%	Cs-137	1.02E-02	91.88%
	Cs-134	4.40E-07	6.88%	Cs-134	1.83E-05	7.00%	Cs-134	7.63E-04	7.03%
	Ru-106	6.77E-08	1.06%	Ru-106	2.82E-06	1.07%	Ru-106	1.17E-04	1.08%
01-Aug-01	Cs-137	3.70E-06	98.42%	Cs-137	1.54E-04	98.40%	Cs-137	6.42E-03	98.37%
	Cs-134	5.79E-08	1.54%	Cs-134	2.41E-06	1.56%	Cs-134	1.01E-04	1.59%
	Ru-106	1.54E-09	0.04%	Ru-106	6.43E-08	0.04%	Ru-106	2.68E-06	0.04%
01-Aug-06	Cs-137	2.58E-06	99.67%	Cs-137	1.08E-04	99.67%	Cs-137	4.48E-03	99.66%
	Cs-134	8.44E-09	0.33%	Cs-134	3.51E-07	0.33%	Cs-134	1.46E-05	0.34%
	Ru-106	3.90E-11	0.00%	Ru-106	1.62E-09	0.00%	Ru-106	6.76E-08	0.00%
Location	**13**			**14**			**15**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	3.93E-02	51.11%	Nb-95	1.64E+00	51.11%	Nb-95	6.82E+01	51.10%
	Zr-95	2.50E-02	32.49%	Zr-95	1.04E+00	32.49%	Zr-95	4.33E+01	32.46%
	Ru-106	7.46E-03	9.71%	Ru-106	3.11E-01	9.71%	Ru-106	1.30E+01	9.74%
01-Aug-91	Cs-137	4.39E-04	60.94%	Cs-137	1.83E-02	60.94%	Cs-137	7.63E-01	60.97%
	Cs-134	1.48E-04	20.56%	Cs-134	6.18E-03	20.56%	Cs-134	2.57E-01	20.54%
	Ru-106	1.32E-04	18.30%	Ru-106	5.50E-03	18.30%	Ru-106	2.29E-01	18.28%
01-Aug-96	Cs-137	2.59E-04	92.47%	Cs-137	1.08E-02	92.47%	Cs-137	4.49E-01	92.50%
	Cs-134	1.82E-05	6.52%	Cs-134	7.60E-04	6.52%	Cs-134	3.17E-02	6.50%
	Ru-106	2.80E-06	1.00%	Ru-106	1.17E-04	1.00%	Ru-106	4.87E-03	1.00%
01-Aug-01	Cs-137	1.73E-04	98.51%	Cs-137	7.22E-03	98.51%	Cs-137	3.01E-01	98.51%
	Cs-134	2.55E-06	1.45%	Cs-134	1.06E-04	1.45%	Cs-134	4.42E-03	1.45%
	Ru-106	6.79E-08	0.04%	Ru-106	2.83E-06	0.04%	Ru-106	1.18E-04	0.04%
01-Aug-06	Cs-137	1.24E-04	99.69%	Cs-137	5.15E-03	99.69%	Cs-137	2.15E-01	99.69%
	Cs-134	3.82E-07	0.31%	Cs-134	1.59E-05	0.31%	Cs-134	6.62E-04	0.31%
	Ru-106	1.76E-09	0.00%	Ru-106	7.32E-08	0.00%	Ru-106	3.05E-06	0.00%
Location	**16**			**17**			**18**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	3.70E-02	51.14%	Nb-95	1.08E-03	51.94%	Nb-95	2.58E-04	50.65%
	Zr-95	2.35E-02	32.50%	Zr-95	6.77E-04	32.63%	Zr-95	1.62E-04	31.82%
	Ru-106	7.08E-03	9.78%	Ru-106	1.98E-04	9.55%	Ru-106	4.81E-05	9.43%
01-Aug-91	Cs-137	3.65E-04	60.54%	Cs-137	1.01E-05	59.57%	Cs-137	2.63E-06	58.35%
	Cs-134	1.25E-04	20.75%	Cs-134	3.62E-06	21.32%	Cs-134	9.58E-07	21.21%
	Ru-106	1.11E-04	18.47%	Ru-106	3.22E-06	18.99%	Ru-106	8.51E-07	18.84%
01-Aug-96	Cs-137	2.21E-04	92.36%	Cs-137	5.64E-06	92.05%	Cs-137	1.55E-06	91.90%
	Cs-134	1.58E-05	6.62%	Cs-134	4.22E-07	6.89%	Cs-134	1.18E-07	6.99%
	Ru-106	2.44E-06	1.02%	Ru-106	6.50E-08	1.06%	Ru-106	1.81E-08	1.07%
01-Aug-01	Cs-137	1.54E-04	98.48%	Cs-137	3.66E-06	98.42%	Cs-137	1.04E-06	98.40%
	Cs-134	2.31E-06	1.48%	Cs-134	5.74E-08	1.54%	Cs-134	1.64E-08	1.56%
	Ru-106	6.14E-08	0.04%	Ru-106	1.53E-09	0.04%	Ru-106	4.37E-10	0.04%
01-Aug-06	Cs-137	1.15E-04	99.69%	Cs-137	2.58E-06	99.67%	Cs-137	7.38E-07	99.67%
	Cs-134	3.59E-07	0.31%	Cs-134	8.45E-09	0.33%	Cs-134	2.45E-09	0.33%
	Ru-106	1.75E-09	0.00%	Ru-106	3.90E-11	0.00%	Ru-106	1.13E-11	0.00%

Table III.2.17. (Conitnued)

Location	**19**			**20**			**21**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	3.12E-04	52.04%	Nb-95	7.47E-02	51.27%	Nb-95	1.77E-02	50.72%
	Zr-95	1.95E-04	32.58%	Zr-95	4.70E-02	32.21%	Zr-95	1.12E-02	32.17%
	Ru-106	5.61E-05	9.36%	Ru-106	1.43E-02	9.80%	Ru-106	3.66E-03	10.48%
01-Aug-91	Cs-137	2.95E-06	58.96%	Cs-137	8.09E-04	61.02%	Cs-137	1.38E-04	60.63%
	Cs-134	1.07E-06	21.43%	Cs-134	2.72E-04	20.51%	Cs-134	4.72E-05	20.69%
	Ru-106	9.52E-07	19.03%	Ru-106	2.42E-04	18.27%	Ru-106	4.20E-05	18.43%
01-Aug-96	Cs-137	2.13E-06	91.95%	Cs-137	4.66E-04	92.49%	Cs-137	6.75E-05	92.35%
	Cs-134	1.62E-07	6.97%	Cs-134	3.27E-05	6.50%	Cs-134	4.84E-06	6.63%
	Ru-106	2.48E-08	1.07%	Ru-106	5.04E-06	1.00%	Ru-106	7.47E-07	1.02%
01-Aug-01	Cs-137	1.64E-06	98.40%	Cs-137	3.09E-04	98.51%	Cs-137	4.08E-05	98.48%
	Cs-134	2.60E-08	1.56%	Cs-134	4.53E-06	1.45%	Cs-134	6.13E-07	1.48%
	Ru-106	6.92E-10	0.04%	Ru-106	1.21E-07	0.04%	Ru-106	1.63E-08	0.04%
01-Aug-06	Cs-137	1.29E-06	99.67%	Cs-137	2.20E-04	99.69%	Cs-137	2.80E-05	99.69%
	Cs-134	4.28E-09	0.33%	Cs-134	6.75E-07	0.31%	Cs-134	8.79E-08	0.31%
	Ru-106	1.97E-11	0.00%	Ru-106	3.11E-09	0.00%	Ru-106	4.04E-10	0.00%

Location	**22**			**23**			**24**		
Date	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**	**Nuclide**	**Dose rate (mGy h^{-1})**	**Percent**
01-Aug-86	Nb-95	8.11E-03	51.04%	Nb-95	5.33E-04	51.62%	Nb-95	5.99E-04	51.87%
	Zr-95	5.15E-03	32.42%	Zr-95	3.37E-04	32.60%	Zr-95	3.77E-04	32.63%
	Ru-106	1.55E-03	9.77%	Ru-106	9.82E-05	9.51%	Ru-106	1.09E-04	9.41%
01-Aug-91	Cs-137	5.22E-05	60.94%	Cs-137	2.80E-06	60.57%	Cs-137	4.77E-06	59.43%
	Cs-134	1.76E-05	20.57%	Cs-134	9.56E-07	20.69%	Cs-134	1.71E-06	21.24%
	Ru-106	1.57E-05	18.29%	Ru-106	8.51E-07	18.42%	Ru-106	1.51E-06	18.84%
01-Aug-96	Cs-137	2.55E-05	92.47%	Cs-137	1.37E-06	92.45%	Cs-137	3.25E-06	92.06%
	Cs-134	1.80E-06	6.52%	Cs-134	9.68E-08	6.54%	Cs-134	2.42E-07	6.87%
	Ru-106	2.76E-07	1.00%	Ru-106	1.49E-08	1.01%	Ru-106	3.73E-08	1.06%
01-Aug-01	Cs-137	1.51E-05	98.51%	Cs-137	8.06E-07	98.52%	Cs-137	2.42E-06	98.42%
	Cs-134	2.23E-07	1.46%	Cs-134	1.18E-08	1.44%	Cs-134	3.79E-08	1.54%
	Ru-106	5.93E-09	0.04%	Ru-106	3.14E-10	0.04%	Ru-106	1.01E-09	0.04%
01-Aug-06	Cs-137	1.02E-05	99.69%	Cs-137	5.35E-07	99.70%	Cs-137	1.88E-06	99.67%
	Cs-134	3.13E-08	0.31%	Cs-134	1.63E-09	0.30%	Cs-134	6.14E-09	0.33%
	Ru-106	1.44E-10	0.00%	Ru-106	7.49E-12	0.00%	Ru-106	2.83E-11	0.00%

Table III.2.18. Predicted radionuclide contamination densities at outdoor test locations in District 4 of Pripyat (Bq m^{-2}).

Location	13 (Surface : Soil)			14 (Surface : Paved)		
Date	Cs-137	Cs-134	Ru-106	Cs-137	Cs-134	Ru-106
01-Aug-86	5.37E+05	3.22E+05	1.66E+06	5.17E+04	3.09E+04	1.59E+05
01-Aug-87	4.61E+05	2.02E+05	7.30E+05	1.99E+04	8.69E+03	3.15E+04
01-Aug-88	3.99E+05	1.28E+05	3.25E+05	1.30E+04	4.17E+03	1.06E+04
01-Aug-89	3.48E+05	8.14E+04	1.46E+05	9.84E+03	2.30E+03	4.13E+03
01-Aug-90	3.06E+05	5.23E+04	6.61E+04	7.61E+03	1.30E+03	1.64E+03
01-Aug-91	2.71E+05	3.39E+04	3.01E+04	5.90E+03	7.38E+02	6.57E+02
01-Aug-92	2.42E+05	2.21E+04	1.38E+04	4.58E+03	4.19E+02	2.63E+02
01-Aug-93	2.17E+05	1.45E+04	6.40E+03	3.56E+03	2.38E+02	1.05E+02
01-Aug-94	1.96E+05	9.59E+03	2.98E+03	2.76E+03	1.35E+02	4.20E+01
01-Aug-95	1.78E+05	6.37E+03	1.39E+03	2.15E+03	7.67E+01	1.68E+01
01-Aug-96	1.63E+05	4.26E+03	6.55E+02	1.67E+03	4.36E+01	6.70E+00
01-Aug-97	1.50E+05	2.86E+03	3.10E+02	1.29E+03	2.47E+01	2.68E+00
01-Aug-98	1.38E+05	1.93E+03	1.47E+02	1.00E+03	1.40E+01	1.07E+00
01-Aug-99	1.28E+05	1.30E+03	7.00E+01	7.80E+02	7.97E+00	4.28E-01
01-Aug-00	1.18E+05	8.84E+02	3.34E+01	6.06E+02	4.53E+00	1.71E-01
01-Aug-01	1.10E+05	6.01E+02	1.60E+01	4.71E+02	2.57E+00	6.84E-02
01-Aug-02	1.03E+05	4.10E+02	7.69E+00	3.65E+02	1.46E+00	2.74E-02
01-Aug-03	9.60E+04	2.80E+02	3.70E+00	2.84E+02	8.28E-01	1.09E-02
01-Aug-04	8.99E+04	1.92E+02	1.78E+00	2.20E+02	4.70E-01	4.37E-03
01-Aug-05	8.43E+04	1.32E+02	8.61E-01	1.71E+02	2.67E-01	1.75E-03
01-Aug-06	7.92E+04	9.04E+01	4.16E-01	1.33E+02	1.52E-01	6.98E-04
Location	15 (Surface : Soil)			20 (Surface : Soil)		
Date	Cs-137	Cs-134	Ru-106	Cs-137	Cs-134	Ru-106
01-Aug-86	5.37E+05	3.22E+05	1.66E+06	5.37E+05	3.22E+05	1.66E+06
01-Aug-87	4.61E+05	2.02E+05	7.30E+05	4.61E+05	2.02E+05	7.30E+05
01-Aug-88	3.99E+05	1.28E+05	3.25E+05	3.99E+05	1.28E+05	3.25E+05
01-Aug-89	3.48E+05	8.14E+04	1.46E+05	3.48E+05	8.14E+04	1.46E+05
01-Aug-90	3.06E+05	5.23E+04	6.61E+04	3.06E+05	5.23E+04	6.61E+04
01-Aug-91	2.71E+05	3.39E+04	3.01E+04	2.71E+05	3.39E+04	3.01E+04
01-Aug-92	2.42E+05	2.21E+04	1.38E+04	2.42E+05	2.21E+04	1.38E+04
01-Aug-93	2.17E+05	1.45E+04	6.40E+03	2.17E+05	1.45E+04	6.40E+03
01-Aug-94	1.96E+05	9.59E+03	2.98E+03	1.96E+05	9.59E+03	2.98E+03
01-Aug-95	1.78E+05	6.37E+03	1.39E+03	1.78E+05	6.37E+03	1.39E+03
01-Aug-96	1.63E+05	4.26E+03	6.55E+02	1.63E+05	4.26E+03	6.55E+02
01-Aug-97	1.50E+05	2.86E+03	3.10E+02	1.50E+05	2.86E+03	3.10E+02
01-Aug-98	1.38E+05	1.93E+03	1.47E+02	1.38E+05	1.93E+03	1.47E+02
01-Aug-99	1.28E+05	1.30E+03	7.00E+01	1.28E+05	1.30E+03	7.00E+01
01-Aug-00	1.18E+05	8.84E+02	3.34E+01	1.18E+05	8.84E+02	3.34E+01
01-Aug-01	1.10E+05	6.01E+02	1.60E+01	1.10E+05	6.01E+02	1.60E+01
01-Aug-02	1.03E+05	4.10E+02	7.69E+00	1.03E+05	4.10E+02	7.69E+00
01-Aug-03	9.60E+04	2.80E+02	3.70E+00	9.60E+04	2.80E+02	3.70E+00
01-Aug-04	8.99E+04	1.92E+02	1.78E+00	8.99E+04	1.92E+02	1.78E+00
01-Aug-05	8.43E+04	1.32E+02	8.61E-01	8.43E+04	1.32E+02	8.61E-01
01-Aug-06	7.92E+04	9.04E+01	4.16E-01	7.92E+04	9.04E+01	4.16E-01
Location	21 (Surface : Paved)			22 (Surface : Paved)		
Date	Cs-137	Cs-134	Ru-106	Cs-137	Cs-134	Ru-106
01-Aug-86	5.17E+04	3.09E+04	1.59E+05	5.17E+04	3.09E+04	1.59E+05
01-Aug-87	1.99E+04	8.69E+03	3.15E+04	1.99E+04	8.69E+03	3.15E+04
01-Aug-88	1.30E+04	4.17E+03	1.06E+04	1.30E+04	4.17E+03	1.06E+04
01-Aug-89	9.84E+03	2.30E+03	4.13E+03	9.84E+03	2.30E+03	4.13E+03
01-Aug-90	7.61E+03	1.30E+03	1.64E+03	7.61E+03	1.30E+03	1.64E+03
01-Aug-91	5.90E+03	7.38E+02	6.57E+02	5.90E+03	7.38E+02	6.57E+02
01-Aug-92	4.58E+03	4.19E+02	2.63E+02	4.58E+03	4.19E+02	2.63E+02
01-Aug-93	3.56E+03	2.38E+02	1.05E+02	3.56E+03	2.38E+02	1.05E+02
01-Aug-94	2.76E+03	1.35E+02	4.20E+01	2.76E+03	1.35E+02	4.20E+01
01-Aug-95	2.15E+03	7.67E+01	1.68E+01	2.15E+03	7.67E+01	1.68E+01
01-Aug-96	1.67E+03	4.36E+01	6.70E+00	1.67E+03	4.36E+01	6.70E+00
01-Aug-97	1.29E+03	2.47E+01	2.68E+00	1.29E+03	2.47E+01	2.68E+00
01-Aug-98	1.00E+03	1.40E+01	1.07E+00	1.00E+03	1.40E+01	1.07E+00
01-Aug-99	7.80E+02	7.97E+00	4.28E-01	7.80E+02	7.97E+00	4.28E-01
01-Aug-00	6.06E+02	4.53E+00	1.71E-01	6.06E+02	4.53E+00	1.71E-01
01-Aug-01	4.71E+02	2.57E+00	6.84E-02	4.71E+02	2.57E+00	6.84E-02
01-Aug-02	3.65E+02	1.46E+00	2.74E-02	3.65E+02	1.46E+00	2.74E-02
01-Aug-03	2.84E+02	8.28E-01	1.09E-02	2.84E+02	8.28E-01	1.09E-02
01-Aug-04	2.20E+02	4.70E-01	4.37E-03	2.20E+02	4.70E-01	4.37E-03
01-Aug-05	1.71E+02	2.67E-01	1.75E-03	1.71E+02	2.67E-01	1.75E-03
01-Aug-06	1.33E+02	1.52E-01	6.98E-04	1.33E+02	1.52E-01	6.98E-04

Table III.2.19. Predicted external doses to reference individuals living and working in District 4 of Pripyat.

Date	Person 1		Person 2		Person 3		Person 4	Person 5
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})
01-Aug-86	1.36E+02	1.36E+02	1.83E+02	1.83E+02	8.72E+01	8.72E+01	7.78E+01	8.05E+01
01-Aug-87	3.00E+01	1.66E+02	4.22E+01	2.25E+02	2.09E+01	1.08E+02	1.87E+01	1.95E+01
01-Aug-88	6.19E+00	1.72E+02	9.07E+00	2.34E+02	4.63E+00	1.13E+02	4.17E+00	4.38E+00
01-Aug-89	2.59E+00	1.75E+02	3.82E+00	2.38E+02	1.95E+00	1.15E+02	1.76E+00	1.84E+00
01-Aug-90	1.48E+00	1.76E+02	2.18E+00	2.40E+02	1.11E+00	1.16E+02	1.00E+00	1.05E+00
01-Aug-91	1.01E+00	1.77E+02	1.48E+00	2.42E+02	7.50E-01	1.17E+02	6.77E-01	7.11E-01
01-Aug-92	7.58E-01	1.78E+02	1.10E+00	2.43E+02	5.55E-01	1.17E+02	5.01E-01	5.26E-01
01-Aug-93	5.98E-01	1.79E+02	8.52E-01	2.44E+02	4.30E-01	1.18E+02	3.88E-01	4.08E-01
01-Aug-94	4.84E-01	1.79E+02	6.82E-01	2.44E+02	3.44E-01	1.18E+02	3.10E-01	3.26E-01
01-Aug-95	3.99E-01	1.80E+02	5.56E-01	2.45E+02	2.78E-01	1.18E+02	2.51E-01	2.64E-01
01-Aug-96	3.35E-01	1.80E+02	4.61E-01	2.45E+02	2.30E-01	1.18E+02	2.08E-01	2.18E-01
01-Aug-97	2.84E-01	1.80E+02	3.87E-01	2.46E+02	1.92E-01	1.19E+02	1.73E-01	1.82E-01
01-Aug-98	2.43E-01	1.80E+02	3.27E-01	2.46E+02	1.62E-01	1.19E+02	1.46E-01	1.53E-01
01-Aug-99	2.10E-01	1.81E+02	2.79E-01	2.46E+02	1.38E-01	1.19E+02	1.24E-01	1.30E-01
01-Aug-00	1.82E-01	1.81E+02	2.40E-01	2.47E+02	1.18E-01	1.19E+02	1.06E-01	1.12E-01
01-Aug-01	1.59E-01	1.81E+02	2.08E-01	2.47E+02	1.02E-01	1.19E+02	9.15E-02	9.62E-02
01-Aug-02	1.39E-01	1.81E+02	1.80E-01	2.47E+02	8.80E-02	1.19E+02	7.93E-02	8.33E-02
01-Aug-03	1.23E-01	1.81E+02	1.58E-01	2.47E+02	7.66E-02	1.19E+02	6.91E-02	7.26E-02
01-Aug-04	1.09E-01	1.81E+02	1.38E-01	2.47E+02	6.70E-02	1.19E+02	6.03E-02	6.34E-02
01-Aug-05	9.64E-02	1.81E+02	1.22E-01	2.47E+02	5.87E-02	1.19E+02	5.29E-02	5.56E-02
01-Aug-06	8.57E-02	1.82E+02	1.07E-01	2.48E+02	5.17E-02	1.19E+02	4.65E-02	4.89E-02

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.20. Summary of predicted external doses to a reference individual (person 1) living and working in District 4 of Pripyat, showing the effect of specific countermeasures.

Date	Person 1					
	No countermeasure		Cutting and removal of grass			
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Dose reduction (%)	Cumulative (mGy)	Dose reduction (%)
01-Aug-86	1.36E+02	1.36E+02	7.89E+01	42.02	7.89E+01	42.02
01-Aug-87	3.00E+01	1.66E+02	1.15E+01	61.49	9.04E+01	45.54
01-Aug-88	6.19E+00	1.72E+02	2.16E+00	65.11	9.26E+01	46.24
01-Aug-89	2.59E+00	1.75E+02	8.90E-01	65.60	9.35E+01	46.53
01-Aug-90	1.48E+00	1.76E+02	5.14E-01	65.26	9.40E+01	46.68
01-Aug-91	1.01E+00	1.77E+02	3.59E-01	64.51	9.44E+01	46.79
01-Aug-92	7.58E-01	1.78E+02	2.76E-01	63.60	9.46E+01	46.86
01-Aug-93	5.98E-01	1.79E+02	2.24E-01	62.60	9.49E+01	46.91
01-Aug-94	4.84E-01	1.79E+02	1.86E-01	61.58	9.51E+01	46.95
01-Aug-95	3.99E-01	1.80E+02	1.58E-01	60.53	9.52E+01	46.98
01-Aug-96	3.35E-01	1.80E+02	1.35E-01	59.65	9.54E+01	47.00
01-Aug-97	2.84E-01	1.80E+02	1.17E-01	58.72	9.55E+01	47.02
01-Aug-98	2.43E-01	1.80E+02	1.02E-01	57.86	9.56E+01	47.04
01-Aug-99	2.10E-01	1.81E+02	8.99E-02	57.10	9.57E+01	47.05
01-Aug-00	1.82E-01	1.81E+02	7.92E-02	56.42	9.57E+01	47.06
01-Aug-01	1.59E-01	1.81E+02	7.05E-02	55.70	9.58E+01	47.07
01-Aug-02	1.39E-01	1.81E+02	6.26E-02	55.04	9.59E+01	47.07
01-Aug-03	1.23E-01	1.81E+02	5.59E-02	54.44	9.59E+01	47.08
01-Aug-04	1.09E-01	1.81E+02	5.01E-02	53.85	9.60E+01	47.08
01-Aug-05	9.64E-02	1.81E+02	4.50E-02	53.32	9.60E+01	47.08
01-Aug-06	8.57E-02	1.82E+02	4.05E-02	52.74	9.61E+01	47.09

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.20. Summary of predicted external doses to a reference individual (person 1) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 1							
	Washing of roads				Washing of roofs and walls			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	1.36E+02	0.45	1.36E+02	0.45	1.21E+02	11.00	1.21E+02	11.00
01-Aug-87	2.98E+01	0.49	1.65E+02	0.46	2.35E+01	21.61	1.45E+02	12.92
01-Aug-88	6.18E+00	0.14	1.71E+02	0.45	5.30E+00	14.49	1.50E+02	12.97
01-Aug-89	2.59E+00	0.09	1.74E+02	0.44	2.22E+00	14.36	1.52E+02	12.99
01-Aug-90	1.48E+00	0.07	1.76E+02	0.44	1.26E+00	14.74	1.53E+02	13.01
01-Aug-91	1.01E+00	0.05	1.77E+02	0.44	8.54E-01	15.51	1.54E+02	13.02
01-Aug-92	7.58E-01	0.04	1.77E+02	0.43	6.34E-01	16.44	1.55E+02	13.04
01-Aug-93	5.98E-01	0.03	1.78E+02	0.43	4.94E-01	17.44	1.55E+02	13.05
01-Aug-94	4.84E-01	0.02	1.78E+02	0.43	3.95E-01	18.47	1.56E+02	13.07
01-Aug-95	3.99E-01	0.02	1.79E+02	0.43	3.21E-01	19.52	1.56E+02	13.08
01-Aug-96	3.35E-01	0.01	1.79E+02	0.43	2.67E-01	20.40	1.56E+02	13.09
01-Aug-97	2.84E-01	0.01	1.79E+02	0.43	2.24E-01	21.32	1.57E+02	13.11
01-Aug-98	2.43E-01	0.01	1.80E+02	0.43	1.89E-01	22.19	1.57E+02	13.12
01-Aug-99	2.10E-01	0.00	1.80E+02	0.43	1.62E-01	22.95	1.57E+02	13.13
01-Aug-00	1.82E-01	0.00	1.80E+02	0.43	1.39E-01	23.62	1.57E+02	13.14
01-Aug-01	1.59E-01	0.00	1.80E+02	0.43	1.20E-01	24.34	1.57E+02	13.15
01-Aug-02	1.39E-01	0.00	1.80E+02	0.43	1.04E-01	25.00	1.57E+02	13.16
01-Aug-03	1.23E-01	0.00	1.80E+02	0.43	9.14E-02	25.59	1.57E+02	13.17
01-Aug-04	1.09E-01	0.00	1.81E+02	0.43	8.02E-02	26.18	1.57E+02	13.18
01-Aug-05	9.64E-02	0.00	1.81E+02	0.43	7.06E-02	26.71	1.58E+02	13.18
01-Aug-06	8.57E-02	0.00	1.81E+02	0.43	6.23E-02	27.28	1.58E+02	13.19

Date	Person 1							
	Removal of trees or leaves				Removal of soil (5 cm)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	1.31E+02	4.05	1.31E+02	4.05	1.36E+02	0.00	1.36E+02	0.00
01-Aug-87	2.81E+01	6.12	1.59E+02	4.42	1.92E+01	35.76	1.55E+02	6.45
01-Aug-88	6.17E+00	0.38	1.65E+02	4.27	1.40E+00	77.32	1.57E+02	9.00
01-Aug-89	2.59E+00	0.03	1.67E+02	4.21	5.72E-01	77.90	1.57E+02	10.02
01-Aug-90	1.48E+00	0.00	1.69E+02	4.18	3.33E-01	77.50	1.58E+02	10.58
01-Aug-91	1.01E+00	0.00	1.70E+02	4.15	2.36E-01	76.61	1.58E+02	10.96
01-Aug-92	7.58E-01	0.00	1.71E+02	4.13	1.86E-01	75.52	1.58E+02	11.24
01-Aug-93	5.98E-01	0.00	1.71E+02	4.12	1.54E-01	74.34	1.58E+02	11.45
01-Aug-94	4.84E-01	0.00	1.72E+02	4.11	1.30E-01	73.12	1.58E+02	11.61
01-Aug-95	3.99E-01	0.00	1.72E+02	4.10	1.12E-01	71.88	1.58E+02	11.75
01-Aug-96	3.35E-01	0.00	1.73E+02	4.09	9.78E-02	70.83	1.59E+02	11.86
01-Aug-97	2.84E-01	0.00	1.73E+02	4.09	8.61E-02	69.73	1.59E+02	11.95
01-Aug-98	2.43E-01	0.00	1.73E+02	4.08	7.61E-02	68.70	1.59E+02	12.03
01-Aug-99	2.10E-01	0.00	1.73E+02	4.08	6.75E-02	67.80	1.59E+02	12.09
01-Aug-00	1.82E-01	0.00	1.73E+02	4.07	6.00E-02	67.00	1.59E+02	12.15
01-Aug-01	1.59E-01	0.00	1.74E+02	4.07	5.39E-02	66.14	1.59E+02	12.19
01-Aug-02	1.39E-01	0.00	1.74E+02	4.07	4.83E-02	65.36	1.59E+02	12.23
01-Aug-03	1.23E-01	0.00	1.74E+02	4.06	4.34E-02	64.65	1.59E+02	12.27
01-Aug-04	1.09E-01	0.00	1.74E+02	4.06	3.92E-02	63.94	1.59E+02	12.30
01-Aug-05	9.64E-02	0.00	1.74E+02	4.06	3.54E-02	63.31	1.59E+02	12.33
01-Aug-06	8.57E-02	0.00	1.74E+02	4.06	3.20E-02	62.63	1.59E+02	12.35

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.20. Summary of predicted external doses to a reference individual (person 1) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 1							
	Relocation (first 2 weeks)				Relocation (first 6 weeks)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	8.72E+01	35.97	8.72E+01	35.97	3.39E+01	75.08	3.39E+01	75.08
01-Aug-87	3.00E+01	0.00	1.17E+02	29.49	3.00E+01	0.00	6.39E+01	61.53
01-Aug-88	6.19E+00	0.00	1.23E+02	28.43	6.19E+00	0.00	7.01E+01	59.32
01-Aug-89	2.59E+00	0.00	1.26E+02	28.00	2.59E+00	0.00	7.27E+01	58.44
01-Aug-90	1.48E+00	0.00	1.27E+02	27.77	1.48E+00	0.00	7.41E+01	57.95
01-Aug-91	1.01E+00	0.00	1.28E+02	27.61	1.01E+00	0.00	7.52E+01	57.62
01-Aug-92	7.58E-01	0.00	1.29E+02	27.49	7.58E-01	0.00	7.59E+01	57.38
01-Aug-93	5.98E-01	0.00	1.30E+02	27.40	5.98E-01	0.00	7.65E+01	57.19
01-Aug-94	4.84E-01	0.00	1.30E+02	27.33	4.84E-01	0.00	7.70E+01	57.03
01-Aug-95	3.99E-01	0.00	1.31E+02	27.27	3.99E-01	0.00	7.74E+01	56.90
01-Aug-96	3.35E-01	0.00	1.31E+02	27.22	3.35E-01	0.00	7.77E+01	56.80
01-Aug-97	2.84E-01	0.00	1.31E+02	27.17	2.84E-01	0.00	7.80E+01	56.71
01-Aug-98	2.43E-01	0.00	1.31E+02	27.14	2.43E-01	0.00	7.83E+01	56.63
01-Aug-99	2.10E-01	0.00	1.32E+02	27.10	2.10E-01	0.00	7.85E+01	56.57
01-Aug-00	1.82E-01	0.00	1.32E+02	27.08	1.82E-01	0.00	7.86E+01	56.51
01-Aug-01	1.59E-01	0.00	1.32E+02	27.05	1.59E-01	0.00	7.88E+01	56.46
01-Aug-02	1.39E-01	0.00	1.32E+02	27.03	1.39E-01	0.00	7.89E+01	56.42
01-Aug-03	1.23E-01	0.00	1.32E+02	27.01	1.23E-01	0.00	7.91E+01	56.38
01-Aug-04	1.09E-01	0.00	1.32E+02	27.00	1.09E-01	0.00	7.92E+01	56.34
01-Aug-05	9.64E-02	0.00	1.32E+02	26.98	9.64E-02	0.00	7.93E+01	56.31
01-Aug-06	8.57E-02	0.00	1.33E+02	26.97	8.57E-02	0.00	7.94E+01	56.29

Date	Person 1			
	Relocation (first 6 months)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	0.00E+00	100.00	0.00E+00	100.00
01-Aug-87	1.12E+01	62.52	1.12E+01	93.24
01-Aug-88	6.19E+00	0.00	1.74E+01	89.89
01-Aug-89	2.59E+00	0.00	2.00E+01	88.56
01-Aug-90	1.48E+00	0.00	2.15E+01	87.81
01-Aug-91	1.01E+00	0.00	2.25E+01	87.31
01-Aug-92	7.58E-01	0.00	2.33E+01	86.94
01-Aug-93	5.98E-01	0.00	2.39E+01	86.65
01-Aug-94	4.84E-01	0.00	2.43E+01	86.42
01-Aug-95	3.99E-01	0.00	2.47E+01	86.22
01-Aug-96	3.35E-01	0.00	2.51E+01	86.06
01-Aug-97	2.84E-01	0.00	2.54E+01	85.93
01-Aug-98	2.43E-01	0.00	2.56E+01	85.81
01-Aug-99	2.10E-01	0.00	2.58E+01	85.71
01-Aug-00	1.82E-01	0.00	2.60E+01	85.63
01-Aug-01	1.59E-01	0.00	2.62E+01	85.55
01-Aug-02	1.39E-01	0.00	2.63E+01	85.49
01-Aug-03	1.23E-01	0.00	2.64E+01	85.43
01-Aug-04	1.09E-01	0.00	2.65E+01	85.38
01-Aug-05	9.64E-02	0.00	2.66E+01	85.33
01-Aug-06	8.57E-02	0.00	2.67E+01	85.29

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.21. Summary of predicted external doses to a reference individual (person 2) living and working in District 4 of Pripyat, showing the effect of specific countermeasures.

Date	Person 2					
	No countermeasure		Cutting and removal of grass			
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	1.83E+02	1.83E+02	8.50E+01	53.57	8.50E+01	53.57
01-Aug-87	4.22E+01	2.25E+02	1.07E+01	74.59	9.57E+01	57.51
01-Aug-88	9.07E+00	2.34E+02	2.15E+00	76.33	9.79E+01	58.24
01-Aug-89	3.82E+00	2.38E+02	8.92E-01	76.66	9.88E+01	58.53
01-Aug-90	2.18E+00	2.40E+02	5.10E-01	76.60	9.93E+01	58.70
01-Aug-91	1.48E+00	2.42E+02	3.48E-01	76.41	9.96E+01	58.81
01-Aug-92	1.10E+00	2.43E+02	2.61E-01	76.18	9.99E+01	58.88
01-Aug-93	8.52E-01	2.44E+02	2.05E-01	75.91	1.00E+02	58.94
01-Aug-94	6.82E-01	2.44E+02	1.66E-01	75.63	1.00E+02	58.99
01-Aug-95	5.56E-01	2.45E+02	1.37E-01	75.35	1.00E+02	59.03
01-Aug-96	4.61E-01	2.45E+02	1.15E-01	75.10	1.00E+02	59.06
01-Aug-97	3.87E-01	2.46E+02	9.73E-02	74.83	1.01E+02	59.08
01-Aug-98	3.27E-01	2.46E+02	8.31E-02	74.58	1.01E+02	59.10
01-Aug-99	2.79E-01	2.46E+02	7.16E-02	74.35	1.01E+02	59.12
01-Aug-00	2.40E-01	2.47E+02	6.20E-02	74.14	1.01E+02	59.14
01-Aug-01	2.08E-01	2.47E+02	5.42E-02	73.91	1.01E+02	59.15
01-Aug-02	1.80E-01	2.47E+02	4.74E-02	73.71	1.01E+02	59.16
01-Aug-03	1.58E-01	2.47E+02	4.18E-02	73.51	1.01E+02	59.17
01-Aug-04	1.38E-01	2.47E+02	3.69E-02	73.31	1.01E+02	59.18
01-Aug-05	1.22E-01	2.47E+02	3.27E-02	73.13	1.01E+02	59.18
01-Aug-06	1.07E-01	2.48E+02	2.90E-02	72.93	1.01E+02	59.19

Date	Person 2							
	Washing of roads				Washing of roofs and walls			
	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	1.82E+02	0.38	1.82E+02	0.55	1.78E+02	2.72	1.78E+02	2.72
01-Aug-87	4.20E+01	0.40	2.24E+02	0.45	3.78E+01	10.54	2.16E+02	4.18
01-Aug-88	9.06E+00	0.11	2.33E+02	0.43	8.77E+00	3.32	2.25E+02	4.15
01-Aug-89	3.82E+00	0.07	2.37E+02	0.42	3.70E+00	3.28	2.28E+02	4.13
01-Aug-90	2.18E+00	0.05	2.39E+02	0.42	2.10E+00	3.38	2.30E+02	4.13
01-Aug-91	1.48E+00	0.04	2.41E+02	0.42	1.42E+00	3.58	2.32E+02	4.12
01-Aug-92	1.10E+00	0.03	2.42E+02	0.41	1.06E+00	3.81	2.33E+02	4.12
01-Aug-93	8.52E-01	0.02	2.43E+02	0.41	8.17E-01	4.10	2.34E+02	4.12
01-Aug-94	6.82E-01	0.02	2.44E+02	0.41	6.52E-01	4.37	2.34E+02	4.12
01-Aug-95	5.56E-01	0.01	2.44E+02	0.41	5.30E-01	4.66	2.35E+02	4.12
01-Aug-96	4.61E-01	0.01	2.45E+02	0.41	4.39E-01	4.91	2.35E+02	4.13
01-Aug-97	3.86E-01	0.01	2.45E+02	0.41	3.66E-01	5.18	2.36E+02	4.13
01-Aug-98	3.27E-01	0.00	2.45E+02	0.41	3.09E-01	5.44	2.36E+02	4.13
01-Aug-99	2.79E-01	0.00	2.46E+02	0.41	2.63E-01	5.66	2.36E+02	4.13
01-Aug-00	2.40E-01	0.00	2.46E+02	0.41	2.26E-01	5.87	2.36E+02	4.13
01-Aug-01	2.08E-01	0.00	2.46E+02	0.41	1.95E-01	6.10	2.37E+02	4.13
01-Aug-02	1.80E-01	0.00	2.46E+02	0.41	1.69E-01	6.31	2.37E+02	4.14
01-Aug-03	1.58E-01	0.00	2.46E+02	0.41	1.47E-01	6.50	2.37E+02	4.14
01-Aug-04	1.38E-01	0.00	2.46E+02	0.41	1.29E-01	6.70	2.37E+02	4.14
01-Aug-05	1.22E-01	0.00	2.47E+02	0.41	1.13E-01	6.88	2.37E+02	4.14
01-Aug-06	1.07E-01	0.00	2.47E+02	0.41	9.97E-02	7.08	2.37E+02	4.14

(Note) Annual doses for the 1^{st} year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.21. Summary of predicted external doses to a reference individual (person 2) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 2							
	Removal of trees or leaves				Removal of soil (5 cm)			
	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	1.77E+02	3.48	1.77E+02	3.48	1.83E+02	0.00	1.83E+02	0.00
01-Aug-87	4.01E+01	5.05	2.17E+02	3.77	2.39E+01	43.27	2.07E+02	8.11
01-Aug-88	9.05E+00	0.30	2.26E+02	3.64	8.49E-01	90.65	2.08E+02	11.30
01-Aug-89	3.82E+00	0.02	2.30E+02	3.58	3.43E-01	91.03	2.08E+02	12.58
01-Aug-90	2.18E+00	0.00	2.32E+02	3.55	1.97E-01	90.96	2.08E+02	13.29
01-Aug-91	1.48E+00	0.00	2.33E+02	3.53	1.37E-01	90.74	2.09E+02	13.77
01-Aug-92	1.10E+00	0.00	2.34E+02	3.51	1.05E-01	90.47	2.09E+02	14.11
01-Aug-93	8.52E-01	0.00	2.35E+02	3.50	8.41E-02	90.14	2.09E+02	14.38
01-Aug-94	6.82E-01	0.00	2.36E+02	3.49	6.95E-02	89.82	2.09E+02	14.59
01-Aug-95	5.56E-01	0.00	2.36E+02	3.48	5.85E-02	89.48	2.09E+02	14.76
01-Aug-96	4.61E-01	0.00	2.37E+02	3.48	4.99E-02	89.18	2.09E+02	14.90
01-Aug-97	3.87E-01	0.00	2.37E+02	3.47	4.30E-02	88.86	2.09E+02	15.01
01-Aug-98	3.27E-01	0.00	2.38E+02	3.47	3.74E-02	88.56	2.09E+02	15.11
01-Aug-99	2.79E-01	0.00	2.38E+02	3.46	3.27E-02	88.29	2.09E+02	15.19
01-Aug-00	2.40E-01	0.00	2.38E+02	3.46	2.87E-02	88.04	2.09E+02	15.27
01-Aug-01	2.08E-01	0.00	2.38E+02	3.46	2.54E-02	87.77	2.09E+02	15.33
01-Aug-02	1.80E-01	0.00	2.39E+02	3.45	2.25E-02	87.53	2.09E+02	15.38
01-Aug-03	1.58E-01	0.00	2.39E+02	3.45	2.00E-02	87.30	2.09E+02	15.43
01-Aug-04	1.38E-01	0.00	2.39E+02	3.45	1.79E-02	87.05	2.09E+02	15.47
01-Aug-05	1.22E-01	0.00	2.39E+02	3.45	1.60E-02	86.84	2.09E+02	15.50
01-Aug-06	1.07E-01	0.00	2.39E+02	3.45	1.44E-02	86.61	2.09E+02	15.53

Date	Person 2							
	Relocation (first 2 weeks)				Relocation (first 6 weeks)			
	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual ($mGy\ y^{-1}$)	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	1.17E+02	35.84	1.17E+02	35.84	4.59E+01	74.94	4.59E+01	74.94
01-Aug-87	4.22E+01	0.00	1.60E+02	29.13	4.22E+01	0.00	8.81E+01	60.90
01-Aug-88	9.07E+00	0.00	1.69E+02	28.00	9.07E+00	0.00	9.71E+01	58.54
01-Aug-89	3.82E+00	0.00	1.73E+02	27.55	3.82E+00	0.00	1.01E+02	57.60
01-Aug-90	2.18E+00	0.00	1.75E+02	27.30	2.18E+00	0.00	1.03E+02	57.08
01-Aug-91	1.48E+00	0.00	1.76E+02	27.13	1.48E+00	0.00	1.05E+02	56.73
01-Aug-92	1.10E+00	0.00	1.77E+02	27.01	1.10E+00	0.00	1.06E+02	56.48
01-Aug-93	8.52E-01	0.00	1.78E+02	26.91	8.52E-01	0.00	1.07E+02	56.28
01-Aug-94	6.82E-01	0.00	1.79E+02	26.84	6.82E-01	0.00	1.07E+02	56.12
01-Aug-95	5.56E-01	0.00	1.79E+02	26.78	5.56E-01	0.00	1.08E+02	56.00
01-Aug-96	4.61E-01	0.00	1.80E+02	26.73	4.61E-01	0.00	1.08E+02	55.89
01-Aug-97	3.87E-01	0.00	1.80E+02	26.69	3.87E-01	0.00	1.09E+02	55.80
01-Aug-98	3.27E-01	0.00	1.81E+02	26.65	3.27E-01	0.00	1.09E+02	55.73
01-Aug-99	2.79E-01	0.00	1.81E+02	26.62	2.79E-01	0.00	1.09E+02	55.66
01-Aug-00	2.40E-01	0.00	1.81E+02	26.59	2.40E-01	0.00	1.10E+02	55.61
01-Aug-01	2.08E-01	0.00	1.81E+02	26.57	2.08E-01	0.00	1.10E+02	55.56
01-Aug-02	1.80E-01	0.00	1.81E+02	26.55	1.80E-01	0.00	1.10E+02	55.52
01-Aug-03	1.58E-01	0.00	1.82E+02	26.54	1.58E-01	0.00	1.10E+02	55.49
01-Aug-04	1.38E-01	0.00	1.82E+02	26.52	1.38E-01	0.00	1.10E+02	55.46
01-Aug-05	1.22E-01	0.00	1.82E+02	26.51	1.22E-01	0.00	1.10E+02	55.43
01-Aug-06	1.07E-01	0.00	1.82E+02	26.50	1.07E-01	0.00	1.10E+02	55.41

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.21. Summary of predicted external doses to a reference individual (person 2) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 2			
	Relocation (first 6 months)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGv)	Reduction (%)
01-Aug-86	0.00E+00	100.00	0.00E+00	100.00
01-Aug-87	1.55E+01	63.20	1.55E+01	93.11
01-Aug-88	9.07E+00	0.00	2.46E+01	89.50
01-Aug-89	3.82E+00	0.00	2.84E+01	88.06
01-Aug-90	2.18E+00	0.00	3.06E+01	87.27
01-Aug-91	1.48E+00	0.00	3.21E+01	86.73
01-Aug-92	1.10E+00	0.00	3.32E+01	86.34
01-Aug-93	8.52E-01	0.00	3.40E+01	86.04
01-Aug-94	6.82E-01	0.00	3.47E+01	85.80
01-Aug-95	5.56E-01	0.00	3.53E+01	85.60
01-Aug-96	4.61E-01	0.00	3.57E+01	85.44
01-Aug-97	3.87E-01	0.00	3.61E+01	85.31
01-Aug-98	3.27E-01	0.00	3.64E+01	85.20
01-Aug-99	2.79E-01	0.00	3.67E+01	85.10
01-Aug-00	2.40E-01	0.00	3.70E+01	85.02
01-Aug-01	2.08E-01	0.00	3.72E+01	84.95
01-Aug-02	1.80E-01	0.00	3.74E+01	84.88
01-Aug-03	1.58E-01	0.00	3.75E+01	84.83
01-Aug-04	1.38E-01	0.00	3.76E+01	84.78
01-Aug-05	1.22E-01	0.00	3.78E+01	84.74
01-Aug-06	1.07E-01	0.00	3.79E+01	84.70

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.22. Summary of predicted external doses to a reference individual (person 3) living and working in District 4 of Pripyat, showing the effect of specific countermeasures.

Date	Person 3					
	No countermeasure		Cutting and removal of grass			
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	8.72E+01	8.72E+01	3.55E+01	59.31	3.55E+01	59.31
01-Aug-87	2.09E+01	1.08E+02	4.40E+00	78.94	3.99E+01	63.10
01-Aug-88	4.63E+00	1.13E+02	9.76E-01	78.91	4.09E+01	63.75
01-Aug-89	1.95E+00	1.15E+02	4.08E-01	79.05	4.13E+01	64.01
01-Aug-90	1.11E+00	1.16E+02	2.33E-01	79.05	4.15E+01	64.16
01-Aug-91	7.50E-01	1.17E+02	1.57E-01	79.05	4.17E+01	64.25
01-Aug-92	5.55E-01	1.17E+02	1.16E-01	79.06	4.18E+01	64.32
01-Aug-93	4.30E-01	1.18E+02	9.00E-02	79.08	4.19E+01	64.38
01-Aug-94	3.44E-01	1.18E+02	7.18E-02	79.12	4.19E+01	64.42
01-Aug-95	2.78E-01	1.18E+02	5.80E-02	79.15	4.20E+01	64.45
01-Aug-96	2.30E-01	1.18E+02	4.79E-02	79.20	4.20E+01	64.48
01-Aug-97	1.92E-01	1.19E+02	3.98E-02	79.25	4.21E+01	64.51
01-Aug-98	1.62E-01	1.19E+02	3.35E-02	79.30	4.21E+01	64.53
01-Aug-99	1.38E-01	1.19E+02	2.84E-02	79.35	4.21E+01	64.54
01-Aug-00	1.18E-01	1.19E+02	2.43E-02	79.40	4.22E+01	64.56
01-Aug-01	1.02E-01	1.19E+02	2.09E-02	79.45	4.22E+01	64.57
01-Aug-02	8.80E-02	1.19E+02	1.80E-02	79.50	4.22E+01	64.58
01-Aug-03	7.66E-02	1.19E+02	1.57E-02	79.55	4.22E+01	64.59
01-Aug-04	6.70E-02	1.19E+02	1.37E-02	79.60	4.22E+01	64.60
01-Aug-05	5.87E-02	1.19E+02	1.19E-02	79.64	4.22E+01	64.61
01-Aug-06	5.17E-02	1.19E+02	1.05E-02	79.67	4.23E+01	64.61

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.22. Summary of predicted external doses to a reference individual (person 3) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 3							
	Washing of roads				Washing of roofs and walls			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	8.66E+01	0.70	8.66E+01	0.70	8.68E+01	0.48	8.68E+01	0.49
01-Aug-87	2.08E+01	0.71	1.07E+02	0.70	1.93E+01	7.75	1.06E+02	1.93
01-Aug-88	4.62E+00	0.19	1.12E+02	0.68	4.59E+00	0.83	1.11E+02	1.88
01-Aug-89	1.95E+00	0.12	1.14E+02	0.67	1.93E+00	0.89	1.13E+02	1.86
01-Aug-90	1.11E+00	0.09	1.15E+02	0.67	1.10E+00	0.92	1.14E+02	1.86
01-Aug-91	7.50E-01	0.07	1.16E+02	0.66	7.43E-01	0.95	1.14E+02	1.85
01-Aug-92	5.55E-01	0.05	1.16E+02	0.66	5.50E-01	0.95	1.15E+02	1.85
01-Aug-93	4.30E-01	0.04	1.17E+02	0.66	4.26E-01	0.94	1.15E+02	1.84
01-Aug-94	3.44E-01	0.03	1.17E+02	0.66	3.41E-01	0.92	1.16E+02	1.84
01-Aug-95	2.78E-01	0.02	1.17E+02	0.66	2.76E-01	0.89	1.16E+02	1.84
01-Aug-96	2.30E-01	0.02	1.18E+02	0.65	2.28E-01	0.84	1.16E+02	1.84
01-Aug-97	1.92E-01	0.01	1.18E+02	0.65	1.90E-01	0.79	1.16E+02	1.83
01-Aug-98	1.62E-01	0.01	1.18E+02	0.65	1.61E-01	0.74	1.17E+02	1.83
01-Aug-99	1.38E-01	0.01	1.18E+02	0.65	1.37E-01	0.69	1.17E+02	1.83
01-Aug-00	1.18E-01	0.00	1.18E+02	0.65	1.17E-01	0.64	1.17E+02	1.83
01-Aug-01	1.02E-01	0.00	1.18E+02	0.65	1.01E-01	0.58	1.17E+02	1.83
01-Aug-02	8.80E-02	0.00	1.18E+02	0.65	8.75E-02	0.53	1.17E+02	1.83
01-Aug-03	7.66E-02	0.00	1.18E+02	0.65	7.63E-02	0.48	1.17E+02	1.83
01-Aug-04	6.70E-02	0.00	1.19E+02	0.65	6.67E-02	0.43	1.17E+02	1.83
01-Aug-05	5.87E-02	0.00	1.19E+02	0.65	5.85E-02	0.39	1.17E+02	1.82
01-Aug-06	5.17E-02	0.00	1.19E+02	0.65	5.15E-02	0.35	1.17E+02	1.82

Date	Person 3							
	Removal of trees or leaves				Removal of soil (5 cm)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	8.55E+01	1.92	8.55E+01	1.92	8.72E+01	0.00	8.72E+01	0.00
01-Aug-87	2.03E+01	2.67	1.06E+02	2.07	1.14E+01	45.62	9.86E+01	8.82
01-Aug-88	4.62E+00	0.15	1.10E+02	1.99	2.91E-01	93.70	9.88E+01	12.31
01-Aug-89	1.95E+00	0.01	1.12E+02	1.95	1.19E-01	93.87	9.90E+01	13.69
01-Aug-90	1.11E+00	0.00	1.14E+02	1.93	6.81E-02	93.87	9.90E+01	14.46
01-Aug-91	7.50E-01	0.00	1.14E+02	1.92	4.60E-02	93.87	9.91E+01	14.97
01-Aug-92	5.55E-01	0.00	1.15E+02	1.91	3.40E-02	93.88	9.91E+01	15.35
01-Aug-93	4.30E-01	0.00	1.15E+02	1.91	2.62E-02	93.91	9.91E+01	15.63
01-Aug-94	3.44E-01	0.00	1.16E+02	1.90	2.08E-02	93.95	9.92E+01	15.86
01-Aug-95	2.78E-01	0.00	1.16E+02	1.90	1.67E-02	93.99	9.92E+01	16.05
01-Aug-96	2.30E-01	0.00	1.16E+02	1.89	1.37E-02	94.05	9.92E+01	16.20
01-Aug-97	1.92E-01	0.00	1.16E+02	1.89	1.13E-02	94.11	9.92E+01	16.32
01-Aug-98	1.62E-01	0.00	1.16E+02	1.89	9.44E-03	94.17	9.92E+01	16.43
01-Aug-99	1.38E-01	0.00	1.17E+02	1.88	7.94E-03	94.23	9.92E+01	16.52
01-Aug-00	1.18E-01	0.00	1.17E+02	1.88	6.72E-03	94.29	9.92E+01	16.60
01-Aug-01	1.02E-01	0.00	1.17E+02	1.88	5.73E-03	94.35	9.92E+01	16.66
01-Aug-02	8.80E-02	0.00	1.17E+02	1.88	4.92E-03	94.41	9.92E+01	16.72
01-Aug-03	7.66E-02	0.00	1.17E+02	1.88	4.24E-03	94.47	9.92E+01	16.77
01-Aug-04	6.70E-02	0.00	1.17E+02	1.88	3.67E-03	94.52	9.92E+01	16.82
01-Aug-05	5.87E-02	0.00	1.17E+02	1.88	3.19E-03	94.57	9.92E+01	16.85
01-Aug-06	5.17E-02	0.00	1.17E+02	1.88	2.78E-03	94.61	9.92E+01	16.89

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.22. Summary of predicted external doses to a reference individual (person 3) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 3							
	Relocation (first 2 weeks)				Relocation (first 6 weeks)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	5.63E+01	35.42	5.63E+01	35.42	2.22E+01	74.54	2.22E+01	74.54
01-Aug-87	2.09E+01	0.00	7.72E+01	28.57	2.09E+01	0.00	4.31E+01	60.12
01-Aug-88	4.63E+00	0.00	8.18E+01	27.40	4.63E+00	0.00	4.77E+01	57.65
01-Aug-89	1.95E+00	0.00	8.38E+01	26.93	1.95E+00	0.00	4.97E+01	56.68
01-Aug-90	1.11E+00	0.00	8.49E+01	26.67	1.11E+00	0.00	5.08E+01	56.13
01-Aug-91	7.50E-01	0.00	8.56E+01	26.50	7.50E-01	0.00	5.15E+01	55.77
01-Aug-92	5.55E-01	0.00	8.62E+01	26.37	5.55E-01	0.00	5.21E+01	55.51
01-Aug-93	4.30E-01	0.00	8.66E+01	26.28	4.30E-01	0.00	5.25E+01	55.30
01-Aug-94	3.44E-01	0.00	8.70E+01	26.20	3.44E-01	0.00	5.29E+01	55.14
01-Aug-95	2.78E-01	0.00	8.73E+01	26.14	2.78E-01	0.00	5.31E+01	55.01
01-Aug-96	2.30E-01	0.00	8.75E+01	26.09	2.30E-01	0.00	5.34E+01	54.90
01-Aug-97	1.92E-01	0.00	8.77E+01	26.05	1.92E-01	0.00	5.36E+01	54.81
01-Aug-98	1.62E-01	0.00	8.78E+01	26.01	1.62E-01	0.00	5.37E+01	54.74
01-Aug-99	1.38E-01	0.00	8.80E+01	25.98	1.38E-01	0.00	5.39E+01	54.68
01-Aug-00	1.18E-01	0.00	8.81E+01	25.96	1.18E-01	0.00	5.40E+01	54.62
01-Aug-01	1.02E-01	0.00	8.82E+01	25.93	1.02E-01	0.00	5.41E+01	54.58
01-Aug-02	8.80E-02	0.00	8.83E+01	25.91	8.80E-02	0.00	5.42E+01	54.54
01-Aug-03	7.66E-02	0.00	8.84E+01	25.90	7.66E-02	0.00	5.43E+01	54.50
01-Aug-04	6.70E-02	0.00	8.84E+01	25.88	6.70E-02	0.00	5.43E+01	54.47
01-Aug-05	5.87E-02	0.00	8.85E+01	25.87	5.87E-02	0.00	5.44E+01	54.44
01-Aug-06	5.17E-02	0.00	8.85E+01	25.86	5.17E-02	0.00	5.44E+01	54.42

Date	Person 3			
	Relocation (first 6 months)			
	Annual (mGy y^{-1})	Reduction (%)	Cumulative (mGy)	Reduction (%)
01-Aug-86	0.00E+00	100.00	0.00E+00	100.00
01-Aug-87	7.75E+00	62.94	7.75E+00	92.83
01-Aug-88	4.63E+00	0.00	1.24E+01	89.02
01-Aug-89	1.95E+00	0.00	1.43E+01	87.51
01-Aug-90	1.11E+00	0.00	1.54E+01	86.67
01-Aug-91	7.50E-01	0.00	1.62E+01	86.11
01-Aug-92	5.55E-01	0.00	1.67E+01	85.70
01-Aug-93	4.30E-01	0.00	1.72E+01	85.39
01-Aug-94	3.44E-01	0.00	1.75E+01	85.14
01-Aug-95	2.78E-01	0.00	1.78E+01	84.94
01-Aug-96	2.30E-01	0.00	1.80E+01	84.77
01-Aug-97	1.92E-01	0.00	1.82E+01	84.64
01-Aug-98	1.62E-01	0.00	1.84E+01	84.52
01-Aug-99	1.38E-01	0.00	1.85E+01	84.42
01-Aug-00	1.18E-01	0.00	1.86E+01	84.34
01-Aug-01	1.02E-01	0.00	1.87E+01	84.27
01-Aug-02	8.80E-02	0.00	1.88E+01	84.21
01-Aug-03	7.66E-02	0.00	1.89E+01	84.15
01-Aug-04	6.70E-02	0.00	1.90E+01	84.10
01-Aug-05	5.87E-02	0.00	1.90E+01	84.06
01-Aug-06	5.17E-02	0.00	1.91E+01	84.03

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.23. Summary of predicted external doses to a reference individual (person 4) living and working in District 4 of Pripyat, showing the effect of specific countermeasures.

Date	Person 4				
	No countermeasure	Cutting and removal of grass		Washing of roads	
	Annual ($mGy\ y^{-1}$)	Annual ($mGy\ y^{-1}$)	Reduction (%)	Annual ($mGy\ y^{-1}$)	Reduction (%)
01-Aug-86	7.78E+01	3.14E+01	59.67	7.67E+01	1.34
01-Aug-87	1.87E+01	3.98E+00	78.72	1.85E+01	1.33
01-Aug-88	4.17E+00	8.94E-01	78.59	4.16E+00	0.36
01-Aug-89	1.76E+00	3.74E-01	78.74	1.75E+00	0.22
01-Aug-90	1.00E+00	2.13E-01	78.76	1.00E+00	0.17
01-Aug-91	6.77E-01	1.44E-01	78.77	6.76E-01	0.13
01-Aug-92	5.01E-01	1.06E-01	78.80	5.01E-01	0.10
01-Aug-93	3.88E-01	8.22E-02	78.83	3.88E-01	0.07
01-Aug-94	3.10E-01	6.55E-02	78.88	3.10E-01	0.06
01-Aug-95	2.51E-01	5.29E-02	78.92	2.51E-01	0.04
01-Aug-96	2.08E-01	4.36E-02	78.98	2.07E-01	0.03
01-Aug-97	1.73E-01	3.63E-02	79.05	1.73E-01	0.02
01-Aug-98	1.46E-01	3.05E-02	79.11	1.46E-01	0.02
01-Aug-99	1.24E-01	2.58E-02	79.17	1.24E-01	0.01
01-Aug-00	1.06E-01	2.20E-02	79.24	1.06E-01	0.01
01-Aug-01	9.15E-02	1.89E-02	79.30	9.15E-02	0.01
01-Aug-02	7.93E-02	1.64E-02	79.36	7.93E-02	0.00
01-Aug-03	6.91E-02	1.42E-02	79.42	6.91E-02	0.00
01-Aug-04	6.03E-02	1.24E-02	79.47	6.03E-02	0.00
01-Aug-05	5.29E-02	1.08E-02	79.52	5.29E-02	0.00
01-Aug-06	4.65E-02	9.51E-03	79.57	4.65E-02	0.00

Date	Person 4					
	Washing of roofs and walls		Removal of trees or leaves		Removal of soil (5 cm)	
	Annual ($mGy\ y^{-1}$)	Reduction (%)	Annual ($mGy\ y^{-1}$)	Reduction (%)	Annual ($mGy\ y^{-1}$)	Reduction (%)
01-Aug-86	7.73E+01	0.62	7.68E+01	1.28	7.78E+01	0.00
01-Aug-87	1.72E+01	7.93	1.84E+01	1.77	1.02E+01	45.40
01-Aug-88	4.13E+00	1.04	4.17E+00	0.10	2.79E-01	93.33
01-Aug-89	1.74E+00	1.10	1.76E+00	0.01	1.14E-01	93.51
01-Aug-90	9.92E-01	1.15	1.00E+00	0.00	6.49E-02	93.53
01-Aug-91	6.69E-01	1.18	6.77E-01	0.00	4.37E-02	93.54
01-Aug-92	4.95E-01	1.18	5.01E-01	0.00	3.22E-02	93.57
01-Aug-93	3.84E-01	1.18	3.88E-01	0.00	2.48E-02	93.61
01-Aug-94	3.07E-01	1.14	3.10E-01	0.00	1.97E-02	93.67
01-Aug-95	2.48E-01	1.11	2.51E-01	0.00	1.58E-02	93.72
01-Aug-96	2.05E-01	1.06	2.08E-01	0.00	1.29E-02	93.79
01-Aug-97	1.71E-01	1.00	1.73E-01	0.00	1.06E-02	93.87
01-Aug-98	1.45E-01	0.94	1.46E-01	0.00	8.84E-03	93.94
01-Aug-99	1.23E-01	0.87	1.24E-01	0.00	7.42E-03	94.02
01-Aug-00	1.05E-01	0.81	1.06E-01	0.00	6.27E-03	94.09
01-Aug-01	9.08E-02	0.74	9.15E-02	0.00	5.33E-03	94.17
01-Aug-02	7.87E-02	0.68	7.93E-02	0.00	4.57E-03	94.24
01-Aug-03	6.86E-02	0.62	6.91E-02	0.00	3.93E-03	94.31
01-Aug-04	6.00E-02	0.56	6.03E-02	0.00	3.39E-03	94.37
01-Aug-05	5.26E-02	0.51	5.29E-02	0.00	2.94E-03	94.43
01-Aug-06	4.63E-02	0.46	4.65E-02	0.00	2.57E-03	94.49

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.23. Summary of predicted external doses to a reference individual (person 4) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	**Person 4**					
	Relocation (first 2 weeks)		**Relocation (first 6 weeks)**		**Relocation (first 6 months)**	
	Annual ($mGy\ y^{-1}$)	**Reduction (%)**	**Annual ($mGy\ y^{-1}$)**	**Reduction (%)**	**Annual ($mGy\ y^{-1}$)**	**Reduction (%)**
01-Aug-86	5.03E+01	35.31	1.99E+01	74.44	0.00E+00	100.00
01-Aug-87	1.87E+01	0.00	1.87E+01	0.00	6.96E+00	62.83
01-Aug-88	4.17E+00	0.00	4.17E+00	0.00	4.17E+00	0.00
01-Aug-89	1.76E+00	0.00	1.76E+00	0.00	1.76E+00	0.00
01-Aug-90	1.00E+00	0.00	1.00E+00	0.00	1.00E+00	0.00
01-Aug-91	6.77E-01	0.00	6.77E-01	0.00	6.77E-01	0.00
01-Aug-92	5.01E-01	0.00	5.01E-01	0.00	5.01E-01	0.00
01-Aug-93	3.88E-01	0.00	3.88E-01	0.00	3.88E-01	0.00
01-Aug-94	3.10E-01	0.00	3.10E-01	0.00	3.10E-01	0.00
01-Aug-95	2.51E-01	0.00	2.51E-01	0.00	2.51E-01	0.00
01-Aug-96	2.08E-01	0.00	2.08E-01	0.00	2.08E-01	0.00
01-Aug-97	1.73E-01	0.00	1.73E-01	0.00	1.73E-01	0.00
01-Aug-98	1.46E-01	0.00	1.46E-01	0.00	1.46E-01	0.00
01-Aug-99	1.24E-01	0.00	1.24E-01	0.00	1.24E-01	0.00
01-Aug-00	1.06E-01	0.00	1.06E-01	0.00	1.06E-01	0.00
01-Aug-01	9.15E-02	0.00	9.15E-02	0.00	9.15E-02	0.00
01-Aug-02	7.93E-02	0.00	7.93E-02	0.00	7.93E-02	0.00
01-Aug-03	6.91E-02	0.00	6.91E-02	0.00	6.91E-02	0.00
01-Aug-04	6.03E-02	0.00	6.03E-02	0.00	6.03E-02	0.00
01-Aug-05	5.29E-02	0.00	5.29E-02	0.00	5.29E-02	0.00
01-Aug-06	4.65E-02	0.00	4.65E-02	0.00	4.65E-02	0.00

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.24. Summary of predicted external doses to a reference individual (person 5) living and working in District 4 of Pripyat, showing the effect of specific countermeasures.

Date	**Person 5**				
	No countermeasure	**Cutting and removal of grass**		**Washing of roads**	
	Annual ($mGy\ y^{-1}$)	**Annual ($mGy\ y^{-1}$)**	**Reduction (%)**	**Annual ($mGy\ y^{-1}$)**	**Reduction (%)**
01-Aug-86	8.05E+01	3.17E+01	60.60	7.98E+01	0.86
01-Aug-87	1.95E+01	4.02E+00	79.39	1.93E+01	0.85
01-Aug-88	4.38E+00	9.29E-01	78.78	4.37E+00	0.22
01-Aug-89	1.84E+00	3.90E-01	78.88	1.84E+00	0.14
01-Aug-90	1.05E+00	2.23E-01	78.88	1.05E+00	0.10
01-Aug-91	7.11E-01	1.50E-01	78.87	7.10E-01	0.08
01-Aug-92	5.26E-01	1.11E-01	78.89	5.26E-01	0.06
01-Aug-93	4.08E-01	8.60E-02	78.91	4.08E-01	0.05
01-Aug-94	3.26E-01	6.86E-02	78.95	3.26E-01	0.03
01-Aug-95	2.64E-01	5.54E-02	78.99	2.64E-01	0.03
01-Aug-96	2.18E-01	4.57E-02	79.04	2.18E-01	0.02
01-Aug-97	1.82E-01	3.81E-02	79.09	1.82E-01	0.01
01-Aug-98	1.53E-01	3.20E-02	79.15	1.53E-01	0.01
01-Aug-99	1.30E-01	2.71E-02	79.21	1.30E-01	0.01
01-Aug-00	1.12E-01	2.31E-02	79.27	1.12E-01	0.00
01-Aug-01	9.62E-02	1.99E-02	79.33	9.62E-02	0.00
01-Aug-02	8.33E-02	1.72E-02	79.38	8.33E-02	0.00
01-Aug-03	7.26E-02	1.49E-02	79.43	7.26E-02	0.00
01-Aug-04	6.34E-02	1.30E-02	79.48	6.34E-02	0.00
01-Aug-05	5.56E-02	1.14E-02	79.53	5.56E-02	0.00
01-Aug-06	4.89E-02	1.00E-02	79.57	4.89E-02	0.00

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

Table III.2.24. Summary of predicted external doses to a reference individual (person 5) living and working in District 4 of Pripyat, showing the effect of specific countermeasures (cont.).

Date	Person 5					
	Washing of roofs and walls		Removal of trees or leaves		Removal of soil (5 cm)	
	Annual (mGy y^{-1})	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)
01-Aug-86	8.00E+01	0.60	7.95E+01	1.16	8.05E+01	0.00
01-Aug-87	1.80E+01	7.93	1.92E+01	1.59	1.06E+01	45.78
01-Aug-88	4.34E+00	0.98	4.37E+00	0.09	2.82E-01	93.55
01-Aug-89	1.83E+00	1.05	1.84E+00	0.01	1.17E-01	93.67
01-Aug-90	1.04E+00	1.09	1.05E+00	0.00	6.67E-02	93.67
01-Aug-91	7.03E-01	1.12	7.11E-01	0.00	4.50E-02	93.66
01-Aug-92	5.21E-01	1.13	5.26E-01	0.00	3.33E-02	93.68
01-Aug-93	4.03E-01	1.12	4.08E-01	0.00	2.57E-02	93.70
01-Aug-94	3.22E-01	1.09	3.26E-01	0.00	2.04E-02	93.75
01-Aug-95	2.61E-01	1.06	2.64E-01	0.00	1.64E-02	93.80
01-Aug-96	2.16E-01	1.01	2.18E-01	0.00	1.34E-02	93.86
01-Aug-97	1.80E-01	0.96	1.82E-01	0.00	1.11E-02	93.92
01-Aug-98	1.52E-01	0.90	1.53E-01	0.00	9.22E-03	93.99
01-Aug-99	1.29E-01	0.84	1.30E-01	0.00	7.75E-03	94.06
01-Aug-00	1.11E-01	0.78	1.12E-01	0.00	6.55E-03	94.13
01-Aug-01	9.55E-02	0.72	9.62E-02	0.00	5.58E-03	94.20
01-Aug-02	8.28E-02	0.66	8.33E-02	0.00	4.78E-03	94.26
01-Aug-03	7.22E-02	0.60	7.26E-02	0.00	4.12E-03	94.33
01-Aug-04	6.31E-02	0.55	6.34E-02	0.00	3.56E-03	94.39
01-Aug-05	5.53E-02	0.50	5.56E-02	0.00	3.09E-03	94.44
01-Aug-06	4.87E-02	0.46	4.89E-02	0.00	2.70E-03	94.49

Date	Person 5					
	Relocation (first 2 weeks)		Relocation (first 6 weeks)		Relocation (first 6 months)	
	Annual (mGy y^{-1})	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)	Annual (mGy y^{-1})	Reduction (%)
01-Aug-86	5.21E+01	35.22	2.06E+01	74.35	0.00E+00	100.00
01-Aug-87	1.95E+01	0.00	1.95E+01	0.00	7.26E+00	62.77
01-Aug-88	4.38E+00	0.00	4.38E+00	0.00	4.38E+00	0.00
01-Aug-89	1.84E+00	0.00	1.84E+00	0.00	1.84E+00	0.00
01-Aug-90	1.05E+00	0.00	1.05E+00	0.00	1.05E+00	0.00
01-Aug-91	7.11E-01	0.00	7.11E-01	0.00	7.11E-01	0.00
01-Aug-92	5.26E-01	0.00	5.26E-01	0.00	5.26E-01	0.00
01-Aug-93	4.08E-01	0.00	4.08E-01	0.00	4.08E-01	0.00
01-Aug-94	3.26E-01	0.00	3.26E-01	0.00	3.26E-01	0.00
01-Aug-95	2.64E-01	0.00	2.64E-01	0.00	2.64E-01	0.00
01-Aug-96	2.18E-01	0.00	2.18E-01	0.00	2.18E-01	0.00
01-Aug-97	1.82E-01	0.00	1.82E-01	0.00	1.82E-01	0.00
01-Aug-98	1.53E-01	0.00	1.53E-01	0.00	1.53E-01	0.00
01-Aug-99	1.30E-01	0.00	1.30E-01	0.00	1.30E-01	0.00
01-Aug-00	1.12E-01	0.00	1.12E-01	0.00	1.12E-01	0.00
01-Aug-01	9.62E-02	0.00	9.62E-02	0.00	9.62E-02	0.00
01-Aug-02	8.33E-02	0.00	8.33E-02	0.00	8.33E-02	0.00
01-Aug-03	7.26E-02	0.00	7.26E-02	0.00	7.26E-02	0.00
01-Aug-04	6.34E-02	0.00	6.34E-02	0.00	6.34E-02	0.00
01-Aug-05	5.56E-02	0.00	5.56E-02	0.00	5.56E-02	0.00
01-Aug-06	4.89E-02	0.00	4.89E-02	0.00	4.89E-02	0.00

(Note) Annual doses for the 1st year after the Chernobyl accident represent total doses received from May 1, 1986, to August 1, 1986.

III.2.6. Predicted results of METRO-K for the Hypothetical scenario

Initial air concentrations for inputs to METRO-K were predicted from a reference surface on the ground (soil or lawn) which were predicted by using HOTSPOT. Calculation procedures to predict absorbed dose rates for the hypothetical scenario are similar to those described for the Pripyat scenario, except for the correction of radionuclide concentration in air with the building heights. In other words, the contamination of each surface at corresponding heights for calculations was corrected from the predicted results of HOTSPOT with an assumption that it is directly proportional to the air concentration. For example, the air concentration on the 60th floor of Building 1 is as much as 20 000 times lower than that on the 1st floor. Therefore, the contamination on the 60th floor for the same surfaces may be as low as 20 000 times less than that on the 1st floor. The 8th floor of Building 2 is the parking level on the top of the building, and it was simulated as if it is a paved ground because of traffic and pedestrians. Calculations were performed for each type of exposure separately, without trying to combine exposures received at different locations. Table III.2.25 shows ^{137}Cs concentrations on a reference surface (soil) predicted from HOTSPOT; this was used as a basic input of METRO-K. Table III.2.26 shows the locations of receptors and the fraction of time spent for four types of exposure scenarios.

The predicted results of the hypothetical scenarios, which were requested from the Urban Working Group, are shown in Tables III.2.27 to III.2.38.

Table III.2.25. ^{137}Cs concentrations on a reference surface (soil) predicted from HOTSPOT.

Building No.		Reference surface contamination (MBq m^{-2})
1	Office	9.1
2	Parking garage	6.6
3	School	0.50
4	Supermarket	0.49
5	One family house	0.51
6	Apartment building	0.87

Table III.2.26. Locations of receptors and fractions of time spent.

Scenario	Location	Fraction of time spent
Occupational exposure	Building 1 (1st, 5th, 20th, 60th) Building 2 (1st, 4th, 8th)	0.24 for each floor 0.24 for each floor
Residential exposure	Building 5 (1st + outside) Building 6 (1st + outside) Building 6 (5th + outside)	0.71 (inside), 0.09 (outside) 0.71 (inside), 0.09 (outside) 0.71 (inside), 0.09 (outside)
School exposure	Building 3 (1st)	0.21
Occasional exposure	Building 4 (1st)	0.01

(Note) The 8th floor of Building 2 is the parking level on the top of the building.

Table III.2.27. Predicted dose rates at test locations in the hypothetical scenario, without remediation measures (mGy h^{-1}).

Date	No countermeasures				
	Building 1				
	Outside	Inside Floor 1	Inside Floor 5	Inside Floor 20	Inside Floor 60
Year 0, 1 July	6.51E-03	2.11E-04	5.69E-05	3.35E-06	3.81E-09
Year 0, 8 July	6.35E-03	2.05E-04	5.64E-05	3.33E-06	3.80E-09
Year 0, 1 August	5.97E-03	1.90E-04	5.52E-05	3.30E-06	3.77E-09
Year 1, 1 July	3.44E-03	1.04E-04	4.48E-05	2.93E-06	3.38E-09
Year 2, 1 July	2.74E-03	8.35E-05	3.84E-05	2.58E-06	3.01E-09
Year 3, 1 July	2.34E-03	7.21E-05	3.34E-05	2.27E-06	2.71E-09
Year 4, 1 July	2.02E-03	6.31E-05	2.93E-05	2.01E-06	2.45E-09
Year 5, 1 July	1.77E-03	5.54E-05	2.59E-05	1.78E-06	2.23E-09
Year 6, 1 July	1.56E-03	4.92E-05	2.30E-05	1.58E-06	2.03E-09
Year 7, 1 July	1.39E-03	4.40E-05	2.06E-05	1.40E-06	1.85E-09
Year 8, 1 July	1.24E-03	3.96E-05	1.86E-05	1.24E-06	1.71E-09
Year 9, 1 July	1.12E-03	3.59E-05	1.69E-05	1.11E-06	1.58E-09
Year 10, 1 July	1.01E-03	3.27E-05	1.53E-05	9.86E-07	1.46E-09
Year 11, 1 July	9.19E-04	2.99E-05	1.41E-05	8.86E-07	1.36E-09
Year 12, 1 July	8.41E-04	2.75E-05	1.29E-05	7.91E-07	1.27E-09
Year 13, 1 July	7.70E-04	2.54E-05	1.19E-05	7.09E-07	1.19E-09
Year 14, 1 July	7.10E-04	2.35E-05	1.10E-05	6.36E-07	1.12E-09
Year 15, 1 July	6.57E-04	2.18E-05	1.02E-05	5.71E-07	1.05E-09
Year 16, 1 July	6.11E-04	2.03E-05	9.52E-06	5.14E-07	9.87E-10
Year 17, 1 July	5.70E-04	1.89E-05	8.88E-06	4.64E-07	9.26E-10
Year 18, 1 July	5.30E-04	1.77E-05	8.31E-06	4.18E-07	8.78E-10
Year 19, 1 July	4.96E-04	1.66E-05	7.74E-06	3.78E-07	8.29E-10
Year 20, 1 July	4.64E-04	1.56E-05	7.30E-06	3.42E-07	7.87E-10

Date	No countermeasures					
	Building 2				Building 3	
	Outside	Inside Floor 1	Inside Floor 4	Inside Floor 8	Inside	Inside Floor 1
Year 0, 1 July	3.17E-03	7.49E-05	6.28E-06	5.99E-04	5.52E-04	4.91E-05
Year 0, 8 July	3.03E-03	7.27E-05	6.08E-06	5.78E-04	5.52E-04	4.89E-05
Year 0, 1 August	2.68E-03	6.31E-05	5.56E-06	5.26E-04	5.47E-04	4.84E-05
Year 1, 1 July	6.16E-04	1.01E-05	2.54E-06	1.89E-04	4.73E-04	4.21E-05
Year 2, 1 July	3.21E-04	4.01E-06	1.97E-06	1.14E-04	4.09E-04	3.63E-05
Year 3, 1 July	2.42E-04	2.97E-06	1.71E-06	8.44E-05	3.56E-04	3.17E-05
Year 4, 1 July	1.94E-04	2.45E-06	1.50E-06	6.51E-05	3.12E-04	2.78E-05
Year 5, 1 July	1.57E-04	2.06E-06	1.32E-06	5.05E-05	2.76E-04	2.46E-05
Year 6, 1 July	1.28E-04	1.73E-06	1.16E-06	3.92E-05	2.46E-04	2.19E-05
Year 7, 1 July	1.05E-04	1.47E-06	1.02E-06	3.04E-05	2.21E-04	1.97E-05
Year 8, 1 July	5.10E-04	1.25E-06	9.04E-07	2.35E-05	1.99E-04	1.77E-05
Year 9, 1 July	7.10E-05	1.06E-06	7.96E-07	1.83E-05	1.81E-04	1.61E-05
Year 10, 1 July	5.89E-05	9.08E-07	7.02E-07	1.42E-05	1.65E-04	1.47E-05
Year 11, 1 July	4.90E-05	7.80E-07	6.20E-07	1.10E-05	1.51E-04	1.34E-05
Year 12, 1 July	4.10E-05	6.70E-07	5.46E-07	8.54E-06	1.39E-04	1.24E-05
Year 13, 1 July	3.44E-05	5.79E-07	4.82E-07	6.61E-06	1.28E-04	1.14E-05
Year 14, 1 July	2.90E-05	5.01E-07	4.26E-07	5.14E-06	1.19E-04	1.06E-05
Year 15, 1 July	2.46E-05	4.34E-07	3.76E-07	3.98E-06	1.11E-04	9.83E-06
Year 16, 1 July	2.09E-05	3.78E-07	3.33E-07	3.09E-06	1.03E-04	9.16E-06
Year 17, 1 July	1.78E-05	3.29E-07	2.94E-07	2.40E-06	9.60E-05	8.55E-06
Year 18, 1 July	1.52E-05	2.87E-07	2.60E-07	1.86E-06	9.02E-05	8.00E-06
Year 19, 1 July	1.31E-05	2.51E-07	2.30E-07	1.44E-06	8.44E-05	7.51E-06
Year 20, 1 July	1.12E-05	2.19E-07	2.03E-07	1.12E-06	7.91E-05	7.02E-06

Table III.2.27. Predicted dose rates at test locations in the hypothetical scenario, without remediation measures (mGy h^{-1}) (cont.).

Date	No countermeasures						
	Building 4		Building 5		Building 6		
	Outside	Inside Floor 1	Outside	Inside Floor 1	Outside	Inside Floor 1	Inside Floor 5
Year 0, 1 July	1.56E-04	1.70E-05	5.55E-04	1.09E-05	1.24E-03	4.39E-05	1.51E-05
Year 0, 8 July	1.50E-04	1.66E-05	5.50E-04	1.09E-05	1.24E-03	4.31E-05	1.50E-05
Year 0, 1 August	1.37E-04	1.56E-05	5.49E-04	1.07E-05	1.22E-03	4.12E-05	1.48E-05
Year 1, 1 July	5.08E-05	8.99E-06	4.76E-04	9.37E-06	9.90E-04	2.81E-05	1.27E-05
Year 2, 1 July	3.14E-05	7.06E-06	4.11E-04	8.13E-06	8.51E-04	2.36E-05	1.11E-05
Year 3, 1 July	2.36E-05	6.02E-06	3.58E-04	7.12E-06	7.40E-04	2.05E-05	9.98E-06
Year 4, 1 July	1.84E-05	5.23E-06	3.15E-04	6.26E-06	6.50E-04	1.80E-05	8.94E-06
Year 5, 1 July	1.45E-05	4.59E-06	2.79E-04	5.56E-06	5.76E-04	1.59E-05	8.06E-06
Year 6, 1 July	1.14E-05	4.05E-06	2.48E-04	4.95E-06	5.11E-04	1.42E-05	7.32E-06
Year 7, 1 July	9.01E-06	3.61E-06	2.23E-04	4.45E-06	4.58E-04	1.27E-05	6.68E-06
Year 8, 1 July	7.14E-06	3.24E-06	2.01E-04	4.02E-06	4.13E-04	1.14E-05	6.12E-06
Year 9, 1 July	5.67E-06	2.92E-06	1.83E-04	3.64E-06	3.75E-04	1.04E-05	5.63E-06
Year 10, 1 July	4.51E-06	2.66E-06	1.67E-04	3.33E-06	3.42E-04	9.47E-06	5.20E-06
Year 11, 1 July	3.59E-06	2.43E-06	1.53E-04	3.05E-06	3.14E-04	8.67E-06	4.83E-06
Year 12, 1 July	2.88E-06	2.22E-06	1.40E-04	2.80E-06	2.88E-04	8.00E-06	4.49E-06
Year 13, 1 July	2.31E-06	2.05E-06	1.30E-04	2.58E-06	2.67E-04	7.39E-06	4.19E-06
Year 14, 1 July	1.86E-06	1.90E-06	1.21E-04	2.39E-06	2.47E-04	6.85E-06	3.93E-06
Year 15, 1 July	1.51E-06	1.76E-06	1.12E-04	2.22E-06	2.30E-04	6.36E-06	3.68E-06
Year 16, 1 July	1.22E-06	1.65E-06	1.05E-04	2.07E-06	2.14E-04	5.92E-06	3.46E-06
Year 17, 1 July	9.94E-07	1.55E-06	9.77E-05	1.93E-06	2.00E-04	5.53E-06	3.26E-06
Year 18, 1 July	8.13E-07	1.44E-06	9.16E-05	1.80E-06	1.87E-04	5.18E-06	3.07E-06
Year 19, 1 July	6.68E-07	1.36E-06	8.56E-05	1.69E-06	1.76E-04	4.85E-06	2.90E-06
Year 20, 1 July	3.21E-07	1.28E-06	8.06E-05	1.58E-06	1.64E-04	4.55E-06	2.74E-06

Table III.2.28. Predicted dose rates from the most important surfaces, and their contribution to the total dose rate, by location for the hypothetical scenario.

Date	No countermeasures					
	Building 1 (outside)			Building 1 (inside, floor 1)		
	Surface	Dose rate (mGy h^{-1})	Percent	Surface	Dose rate (mGy h^{-1})	Percent
Year 0, 1 July	1. soil/lawn	3.11E-03	47.85%	1. soil/lawn	1.07E-04	50.77%
	2. paved	1.65E-03	25.36%	2. tree	8.93E-05	42.31%
	3. tree	1.61E-03	24.72%	3. paved	1.30E-05	6.15%
Year 5, 1 July	1. soil/lawn	1.56E-03	88.02%	1. soil/lawn	5.35E-05	96.42%
	2. paved	1.39E-04	7.86%	2. paved	1.10E-06	1.98%
	3. outer wall	7.29E-05	4.12%	3. outer wall	8.87E-07	1.60%
Year 10, 1 July	1. soil/lawn	9.32E-04	92.23%	1. soil/lawn	3.19E-05	97.59%
	2. outer wall	3.96E-05	3.92%	2. outer wall	4.82E-07	1.47%
	3. paved	3.90E-05	3.86%	3. paved	3.07E-07	0.94%
Year 15, 1 July	1. soil/lawn	6.25E-04	95.06%	1. soil/lawn	2.15E-05	98.41%
	2. outer wall	2.15E-05	3.27%	2. outer wall	2.62E-07	1.20%
	3. paved	1.09E-05	1.66%	3. paved	8.63E-08	0.40%
Year 20, 1 July	1. soil/lawn	4.49E-04	96.82%	1. soil/lawn	1.54E-05	98.93%
	2. outer wall	1.17E-05	2.52%	2. outer wall	1.42E-07	0.91%
	3. paved	3.08E-06	0.66%	3. paved	2.42E-08	0.16%

Table III.2.28. Predicted dose rates from the most important surfaces, and their contribution to the total dose rate, by location for the hypothetical scenario (cont.).

Date	No countermeasures					
	Building 1 (inside, floor 5)			**Building 1 (inside, floor 20)**		
	Surface	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
Year 0, 1 July	1. soil/lawn	4.90E-05	86.09%	1. outer wall	2.45E-06	73.31%
	2. tree	4.46E-06	7.85%	2. soil/lawn	8.93E-07	26.69%
	3. outer wall	2.45E-06	4.31%			
Year 5, 1 July	1. soil/lawn	2.45E-05	94.52%	1. outer wall	1.33E-06	74.97%
	2. outer wall	1.33E-06	5.15%	2. soil/lawn	4.45E-07	25.03%
	3. paved	8.39E-08	0.32%			
Year 10, 1 July	1. soil/lawn	1.46E-05	95.15%	1. outer wall	7.20E-07	73.07%
	2. outer wall	7.20E-07	4.70%	2. soil/lawn	2.65E-07	26.93%
	3. paved	2.36E-08	0.15%			
Year 15, 1 July	1. soil/lawn	9.82E-06	96.09%	1. outer wall	3.93E-07	68.75%
	2. outer wall	3.93E-07	3.84%	2. soil/lawn	1.79E-07	31.25%
	3. paved	6.67E-09	0.07%			
Year 20, 1 July	1. soil/lawn	7.08E-06	97.05%	1. outer wall	2.14E-07	62.43%
	2. outer wall	2.14E-07	2.93%	2. soil/lawn	1.29E-07	37.57%
	3. paved	1.86E-09	0.03%			

Date	No countermeasures					
	Building 1 (inside, floor 60)			**Building 2 (outside)**		
	Surface	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
Year 0, 1 July	1 roof	3.73E-09	97.95%	1. tree	1.87E-03	58.96%
	2 outer wall	7.80E-11	2.05%	2. paved	1.20E-03	37.77%
				3. outer wall	1.04E-04	3.27%
Year 5, 1 July	1 roof	2.18E-09	98.10%	1. paved	1.01E-04	64.24%
	2 outer wall	4.23E-11	1.90%	2. outer wall	5.63E-05	35.76%
				3. tree	5.36E-09	0.00%
Year 10, 1 July	1 roof	1.44E-09	98.43%	1. outer wall	3.05E-05	51.86%
	2 outer wall	2.30E-11	1.57%	2. paved	2.83E-05	48.14%
Year 15, 1 July	1 roof	1.04E-09	98.81%	1. outer wall	1.66E-05	67.58%
	2 outer wall	1.25E-11	1.19%	2. paved	7.97E-06	32.42%
Year 20, 1 July	1 roof	7.80E-10	99.14%	1. outer wall	9.01E-06	80.13%
	2 outer wall	6.79E-12	0.86%	2. paved	2.23E-06	19.87%

Date	No countermeasures					
	Building 2 (inside, floor 1)			**Building 2 (inside, floor 4)**		
	Surface	**Dose rate (mGy h^{-1})**	**Percent**	**Surface**	**Dose rate (mGy h^{-1})**	**Percent**
Year 0, 1 July	1. tree	6.31E-05	84.27%	1. tree	3.24E-06	51.56%
	2. paved	9.46E-06	12.64%	2. outer wall	2.32E-06	36.87%
	3. outer wall	2.32E-06	3.09%	3. paved	7.26E-07	11.56%
Year 5, 1 July	1. outer wall	1.26E-06	61.27%	1. outer wall	1.26E-06	95.37%
	2. paved	7.98E-07	38.72%	2. paved	6.13E-08	4.63%
	3. tree	1.86E-10	0.01%	3. tree	9.29E-12	0.00%
Year 10, 1 July	1. outer wall	6.85E-07	75.41%	1. outer wall	6.85E-07	97.55%
	2. paved	2.23E-07	24.59%	2. paved	1.72E-08	2.45%
Year 15, 1 July	1. outer wall	3.71E-07	85.60%	1. outer wall	3.71E-07	98.72%
	2. paved	6.25E-08	14.40%	2. paved	4.83E-09	1.28%
Year 20, 1 July	1. outer wall	2.02E-07	91.97%	1. outer wall	2.02E-07	99.33%
	2. paved	1.76E-08	8.03%	2. paved	1.36E-09	0.67%

Table III.2.28. Predicted dose rates from the most important surfaces, and their contribution to the total dose rate, by location for the hypothetical scenario (cont.).

Date	No countermeasures					
	Building 2 (top, floor 8)			Building 3 (outside)		
	Surface	Dose rate ($mGy\ h^{-1}$)	Percent	Surface	Dose rate ($mGy\ h^{-1}$)	Percent
Year 0, 1 July	1. roof	5.99E-04	100.00%	1. soil/lawn	5.47E-04	98.99%
				2. outer wall	5.57E-06	1.01%
Year 5, 1 July	1. roof	5.05E-05	100.00%	1. soil/lawn	2.73E-04	98.91%
				2. outer wall	3.02E-06	1.09%
Year 10, 1 July	1. roof	1.42E-05	100.00%	1. soil/lawn	1.63E-04	99.00%
				2. outer wall	1.64E-06	1.00%
Year 15, 1 July	1. roof	3.98E-06	100.00%	1. soil/lawn	1.10E-04	99.20%
				2. outer wall	8.91E-07	0.80%
Year 20, 1 July	1. roof	1.12E-06	100.00%	1. soil/lawn	7.86E-05	99.39%
				2. outer wall	4.84E-07	0.61%

Date	No countermeasures					
	Building 3 (inside, floor 1)			Building 4 (outside)		
	Surface	Dose rate ($mGy\ h^{-1}$)	Percent	Surface	Dose rate ($mGy\ h^{-1}$)	Percent
Year 0, 1 July	1. soil/lawn	4.81E-05	98.04%	1. paved	1.53E-04	98.04%
	2. outer wall	6.90E-07	1.41%	2. outer wall	3.06E-06	1.96%
	3. roof	2.70E-07	0.55%			
Year 5, 1 July	1. soil/lawn	2.40E-05	97.84%	1. paved	1.29E-05	88.56%
	2. outer wall	3.74E-07	1.52%	2. outer wall	1.66E-06	11.44%
	3. roof	1.58E-07	0.64%			
Year 10, 1 July	1. soil/lawn	1.43E-05	97.90%	1. paved	3.61E-06	80.02%
	2. outer wall	2.03E-07	1.39%	2. outer wall	9.01E-07	19.98%
	3. roof	1.04E-07	0.71%			
Year 15, 1 July	1. soil/lawn	9.64E-06	98.12%	1. paved	1.02E-06	67.45%
	2. outer wall	1.10E-07	1.12%	2. outer wall	4.90E-07	32.55%
	3. roof	7.44E-08	0.76%			
Year 20, 1 July	1. soil/lawn	6.90E-06	98.34%	1. paved	2.84E-07	51.66%
	2. outer wall	6.01E-08	0.86%	2. outer wall	2.66E-07	48.34%
	3. roof	5.63E-08	0.80%			

Date	No countermeasures					
	Building 4 (inside, floor 1)			Building 5 (outside)		
	Surface	Dose rate ($mGy\ h^{-1}$)	Percent	Surface	Dose rate ($mGy\ h^{-1}$)	Percent
Year 0, 1 July	1. paved	1.06E-05	62.49%	1. soil/lawn	5.31E-04	95.75%
	2. roof	5.82E-06	34.30%	2. roof	1.65E-05	2.98%
	3. outer wall	5.44E-07	3.21%	3. outer wall	7.08E-06	1.28%
Year 5, 1 July	1. roof	3.40E-06	74.09%	1. soil/lawn	2.65E-04	95.16%
	2. paved	8.93E-07	19.46%	2. roof	9.64E-06	3.46%
	3. outer wall	2.96E-07	6.45%	3. outer wall	3.85E-06	1.38%
Year 10, 1 July	1. roof	2.24E-06	84.51%	1. soil/lawn	1.58E-04	94.94%
	2. paved	2.51E-07	9.44%	2. roof	6.35E-06	3.81%
	3. outer wall	1.61E-07	6.05%	3. outer wall	2.09E-06	1.25%
Year 15, 1 July	1. roof	1.61E-06	91.06%	1. soil/lawn	1.06E-04	94.90%
	2. outer wall	8.75E-08	4.96%	2. roof	4.57E-06	4.08%
	3. paved	7.02E-08	3.98%	3. outer wall	1.14E-06	1.01%
Year 20, 1 July	1. roof	1.21E-06	94.76%	1. soil/lawn	7.66E-05	94.96%
	2. outer wall	4.74E-08	3.70%	2. roof	3.45E-06	4.28%
	3. paved	1.98E-08	1.54%	3. outer wall	6.20E-07	0.77%

Table III.2.28. Predicted dose rates from the most important surfaces, and their contribution to the total dose rate, by location for the hypothetical scenario (cont.).

Date	No countermeasures					
	Building 5 (inside, floor 1)			Building 6 (outside)		
	Surface	**Dose rate ($mGy\ h^{-1}$)**	**Percent**	**Surface**	**Dose rate ($mGy\ h^{-1}$)**	**Percent**
Year 0, 1 July	1. soil/lawn	9.11E-06	83.70%	1. soil/lawn	1.13E-03	90.78%
	2. roof	9.35E-07	8.59%	2. tree	1.00E-04	8.03%
	3. outer wall	8.39E-07	7.71%	3. outer wall	1.33E-05	1.07%
Year 5, 1 July	1. soil/lawn	4.55E-06	81.97%	1. soil/lawn	5.68E-04	98.59%
	2. roof	5.47E-07	9.85%	2. outer wall	7.24E-06	1.26%
	3. outer wall	4.55E-07	8.19%	3. roof	8.80E-07	0.15%
Year 10, 1 July	1. soil/lawn	2.72E-06	81.74%	1. soil/lawn	3.38E-04	98.68%
	2. roof	3.61E-07	10.84%	2. outer wall	3.92E-06	1.15%
	3. outer wall	2.47E-07	7.42%	3. roof	5.83E-07	0.17%
Year 15, 1 July	1. soil/lawn	1.83E-06	82.28%	1. soil/lawn	2.27E-04	98.89%
	2. roof	2.59E-07	11.66%	2. outer wall	2.13E-06	0.93%
	3. outer wall	1.35E-07	6.06%	3. roof	4.17E-07	0.18%
Year 20, 1 July	1. soil/lawn	1.32E-06	83.05%	1. soil/lawn	1.63E-04	99.11%
	2. roof	1.95E-07	12.33%	2. outer wall	1.16E-06	0.70%
	3. outer wall	7.32E-08	4.62%	3. roof	3.15E-07	0.19%

Date	No countermeasures					
	Building 6 (inside, floor 1)			Building 6 (inside, floor 5)		
	Surface	**Dose rate ($mGy\ h^{-1}$)**	**Percent**	**Surface**	**Dose rate ($mGy\ h^{-1}$)**	**Percent**
Year 0, 1 July	1. soil/lawn	3.11E-05	70.90%	1. roof	1.09E-05	72.28%
	2. tree	1.22E-05	27.79%	2. soil/lawn	3.05E-06	20.26%
	3. outer wall	4.37E-07	1.00%	3. tree	8.15E-07	5.41%
Year 5, 1 July	1. soil/lawn	1.55E-05	98.01%	1. roof	6.37E-06	79.01%
	2. outer wall	2.38E-07	1.50%	2. soil/lawn	1.52E-06	18.90%
	3. roof	7.86E-08	0.50%	3. outer wall	1.68E-07	2.08%
Year 10, 1 July	1. soil/lawn	9.29E-06	98.09%	1. roof	4.20E-06	80.75%
	2. outer wall	1.29E-07	1.36%	2. soil/lawn	9.11E-07	17.50%
	3. roof	5.20E-08	0.55%	3. outer wall	9.11E-08	1.75%
Year 15, 1 July	1. soil/lawn	6.25E-06	98.31%	1. roof	3.02E-06	82.00%
	2. outer wall	7.02E-08	1.10%	2. soil/lawn	6.13E-07	16.66%
	3. roof	3.73E-08	0.59%	3. outer wall	4.96E-08	1.35%
Year 20, 1 July	1. soil/lawn	4.48E-06	98.54%	1. roof	2.27E-06	82.97%
	2. outer wall	3.81E-08	0.84%	2. soil/lawn	4.40E-07	16.05%
	3. roof	2.82E-08	0.62%	3. outer wall	2.70E-08	0.98%

Table III.2.29. Predicted ^{137}Cs contamination densities at outdoor test locations in the hypothetical city (Bq m^{-2}).

Date	No countermeasures					
	Building 1		Building 2		Building 3	
	Soil / Lawn	Paved	Soil / Lawn	Paved	Soil / Lawn	Paved
Year 0, 1 July	9.09E+06	1.21E+06	6.61E+06	8.79E+05	5.00E+05	6.65E+04
Year 0, 8 July	9.06E+06	1.17E+06	6.59E+06	8.50E+05	4.98E+05	6.42E+04
Year 0, 1 August	8.98E+06	1.07E+06	6.52E+06	7.75E+05	4.93E+05	5.86E+04
Year 1, 1 July	7.79E+06	3.82E+05	5.66E+06	2.78E+05	4.28E+05	2.10E+04
Year 2, 1 July	6.73E+06	2.30E+05	4.89E+06	1.67E+05	3.70E+05	1.27E+04
Year 3, 1 July	5.86E+06	1.71E+05	4.26E+06	1.24E+05	3.22E+05	9.38E+03
Year 4, 1 July	5.14E+06	1.32E+05	3.74E+06	9.56E+04	2.83E+05	7.23E+03
Year 5, 1 July	4.55E+06	1.02E+05	3.30E+06	7.41E+04	2.50E+05	5.60E+03
Year 6, 1 July	4.05E+06	7.91E+04	2.94E+06	5.75E+04	2.22E+05	4.34E+03
Year 7, 1 July	3.63E+06	6.13E+04	2.64E+06	4.46E+04	1.99E+05	3.37E+03
Year 8, 1 July	3.28E+06	4.76E+04	2.38E+06	3.46E+04	1.80E+05	2.61E+03
Year 9, 1 July	2.97E+06	3.69E+04	2.16E+06	2.68E+04	1.63E+05	2.03E+03
Year 10, 1 July	2.71E+06	2.86E+04	1.97E+06	2.08E+04	1.49E+05	1.57E+03
Year 11, 1 July	2.49E+06	2.22E+04	1.81E+06	1.61E+04	1.37E+05	1.22E+03
Year 12, 1 July	2.29E+06	1.72E+04	1.66E+06	1.25E+04	1.26E+05	9.46E+02
Year 13, 1 July	2.12E+06	1.34E+04	1.54E+06	9.71E+03	1.16E+05	7.34E+02
Year 14, 1 July	1.96E+06	1.04E+04	1.43E+06	7.53E+03	1.08E+05	5.69E+02
Year 15, 1 July	1.83E+06	8.04E+03	1.33E+06	5.84E+03	1.00E+05	4.42E+02
Year 16, 1 July	1.70E+06	6.24E+03	1.24E+06	4.53E+03	9.35E+04	3.43E+02
Year 17, 1 July	1.59E+06	4.84E+03	1.16E+06	3.51E+03	8.74E+04	2.66E+02
Year 18, 1 July	1.49E+06	3.75E+03	1.08E+06	2.73E+03	8.18E+04	2.06E+02
Year 19, 1 July	1.40E+06	2.91E+03	1.01E+06	2.11E+03	7.67E+04	1.60E+02
Year 20, 1 July	1.31E+06	2.26E+03	9.52E+05	1.64E+03	7.20E+04	1.24E+02

Date	No countermeasures					
	Building 4		Building 5		Building 6	
	Soil / Lawn	Paved	Soil / Lawn	Paved	Soil / Lawn	Paved
Year 0, 1 July	4.90E+05	6.51E+04	5.10E+05	6.78E+04	8.72E+05	1.16E+05
Year 0, 8 July	4.88E+05	6.29E+04	5.08E+05	6.55E+04	8.69E+05	1.12E+05
Year 0, 1 August	4.83E+05	5.74E+04	5.03E+05	5.98E+04	8.61E+05	1.02E+05
Year 1, 1 July	4.20E+05	2.06E+04	4.37E+05	2.14E+04	7.48E+05	3.66E+04
Year 2, 1 July	3.62E+05	1.24E+04	3.77E+05	1.29E+04	6.46E+05	2.21E+04
Year 3, 1 July	3.16E+05	9.20E+03	3.29E+05	9.57E+03	5.62E+05	1.64E+04
Year 4, 1 July	2.77E+05	7.08E+03	2.88E+05	7.37E+03	4.93E+05	1.26E+04
Year 5, 1 July	2.45E+05	5.49E+03	2.55E+05	5.71E+03	4.36E+05	9.78E+03
Year 6, 1 July	2.18E+05	4.26E+03	2.27E+05	4.43E+03	3.88E+05	7.58E+03
Year 7, 1 July	1.95E+05	3.30E+03	2.03E+05	3.44E+03	3.48E+05	5.88E+03
Year 8, 1 July	1.76E+05	2.56E+03	1.84E+05	2.67E+03	3.14E+05	4.56E+03
Year 9, 1 July	1.60E+05	1.99E+03	1.67E+05	2.07E+03	2.85E+05	3.54E+03
Year 10, 1 July	1.46E+05	1.54E+03	1.52E+05	1.60E+03	2.60E+05	2.75E+03
Year 11, 1 July	1.34E+05	1.20E+03	1.39E+05	1.24E+03	2.39E+05	2.13E+03
Year 12, 1 July	1.23E+05	9.27E+02	1.28E+05	9.65E+02	2.20E+05	1.65E+03
Year 13, 1 July	1.14E+05	7.19E+02	1.19E+05	7.49E+02	2.03E+05	1.28E+03
Year 14, 1 July	1.06E+05	5.58E+02	1.10E+05	5.81E+02	1.88E+05	9.94E+02
Year 15, 1 July	9.83E+04	4.33E+02	1.02E+05	4.51E+02	1.75E+05	7.71E+02
Year 16, 1 July	9.17E+04	3.36E+02	9.54E+04	3.49E+02	1.63E+05	5.98E+02
Year 17, 1 July	8.56E+04	2.60E+02	8.92E+04	2.71E+02	1.53E+05	4.64E+02
Year 18, 1 July	8.02E+04	2.02E+02	8.35E+04	2.10E+02	1.43E+05	3.60E+02
Year 19, 1 July	7.52E+04	1.57E+02	7.82E+04	1.63E+02	1.34E+05	2.79E+02
Year 20, 1 July	7.06E+04	1.22E+02	7.35E+04	1.27E+02	1.26E+05	2.17E+02

Table III.2.30. Exposure doses for the hypothetical scenario, without remediation measures.

Date	No countermeasures					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.81E-01	1.81E-01	6.88E-02	6.88E-02	4.41E-03	4.41E-03
Year 2, 1 July	1.10E-01	2.91E-01	5.16E-02	1.20E-01	3.52E-03	7.93E-03
Year 3, 1 July	8.18E-02	3.73E-01	3.87E-02	1.59E-01	2.73E-03	1.07E-02
Year 4, 1 July	6.23E-02	4.35E-01	2.94E-02	1.88E-01	2.12E-03	1.28E-02
Year 5, 1 July	4.82E-02	4.83E-01	2.28E-02	2.11E-01	1.66E-03	1.44E-02
Year 6, 1 July	3.76E-02	5.21E-01	1.79E-02	2.29E-01	1.30E-03	1.57E-02
Year 7, 1 July	2.99E-02	5.50E-01	1.42E-02	2.43E-01	1.02E-03	1.68E-02
Year 8, 1 July	2.41E-02	5.75E-01	1.14E-02	2.55E-01	8.06E-04	1.76E-02
Year 9, 1 July	1.96E-02	5.94E-01	9.30E-03	2.64E-01	6.38E-04	1.82E-02
Year 10, 1 July	1.62E-02	6.10E-01	7.67E-03	2.72E-01	5.06E-04	1.87E-02
Year 11, 1 July	1.35E-02	6.24E-01	6.37E-03	2.78E-01	4.03E-04	1.91E-02
Year 12, 1 July	1.14E-02	6.35E-01	5.36E-03	2.83E-01	3.24E-04	1.94E-02
Year 13, 1 July	9.63E-03	6.45E-01	4.54E-03	2.88E-01	2.59E-04	1.97E-02
Year 14, 1 July	8.24E-03	6.53E-01	3.88E-03	2.92E-01	2.09E-04	1.99E-02
Year 15, 1 July	7.09E-03	6.60E-01	3.33E-03	2.95E-01	1.69E-04	2.01E-02
Year 16, 1 July	6.14E-03	6.66E-01	2.87E-03	2.98E-01	1.37E-04	2.02E-02
Year 17, 1 July	5.33E-03	6.72E-01	2.49E-03	3.01E-01	1.12E-04	2.03E-02
Year 18, 1 July	4.65E-03	6.76E-01	2.17E-03	3.03E-01	9.17E-05	2.04E-02
Year 19, 1 July	4.08E-03	6.80E-01	1.90E-03	3.05E-01	7.54E-05	2.05E-02
Year 20, 1 July	3.59E-03	6.84E-01	1.66E-03	3.06E-01	6.23E-05	2.06E-02

Date	No countermeasures					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	5.06E-06	5.06E-06	3.17E-02	3.17E-02	4.68E-03	4.68E-03
Year 2, 1 July	4.15E-06	9.21E-06	3.75E-03	3.54E-02	2.59E-03	7.27E-03
Year 3, 1 July	3.31E-06	1.25E-05	2.39E-03	3.78E-02	1.99E-03	9.26E-03
Year 4, 1 July	2.68E-06	1.52E-05	1.77E-03	3.96E-02	1.55E-03	1.08E-02
Year 5, 1 July	2.19E-06	1.74E-05	1.34E-03	4.09E-02	1.21E-03	1.20E-02
Year 6, 1 July	1.81E-06	1.92E-05	1.03E-03	4.20E-02	9.49E-04	1.30E-02
Year 7, 1 July	1.51E-06	2.07E-05	7.88E-04	4.27E-02	7.40E-04	1.37E-02
Year 8, 1 July	1.27E-06	2.20E-05	6.09E-04	4.34E-02	5.80E-04	1.43E-02
Year 9, 1 July	1.07E-06	2.31E-05	4.72E-04	4.38E-02	4.55E-04	1.47E-02
Year 10, 1 July	9.20E-07	2.40E-05	3.66E-04	4.42E-02	3.56E-04	1.51E-02
Year 11, 1 July	7.91E-07	2.48E-05	2.85E-04	4.45E-02	2.78E-04	1.54E-02
Year 12, 1 July	6.85E-07	2.55E-05	2.22E-04	4.47E-02	2.18E-04	1.56E-02
Year 13, 1 July	5.97E-07	2.60E-05	1.73E-04	4.49E-02	1.70E-04	1.58E-02
Year 14, 1 July	5.24E-07	2.66E-05	1.35E-04	4.50E-02	1.34E-04	1.59E-02
Year 15, 1 July	4.62E-07	2.70E-05	1.05E-04	4.51E-02	1.05E-04	1.60E-02
Year 16, 1 July	4.09E-07	2.74E-05	8.24E-05	4.52E-02	8.19E-05	1.61E-02
Year 17, 1 July	3.63E-07	2.78E-05	6.45E-05	4.53E-02	6.42E-05	1.61E-02
Year 18, 1 July	3.22E-07	2.81E-05	5.05E-05	4.53E-02	5.03E-05	1.62E-02
Year 19, 1 July	2.89E-07	2.84E-05	3.95E-05	4.53E-02	3.94E-05	1.62E-02
Year 20, 1 July	2.58E-07	2.87E-05	3.09E-05	4.54E-02	3.08E-05	1.63E-02

Table III.2.30. Exposure doses for the hypothetical scenario, without remediation measures (cont.).

Date	No countermeasures				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	4.09E-01	4.09E-01	5.55E-02	3.70E-04	3.70E-04
Year 2, 1 July	7.57E-02	4.85E-01	4.29E-02	2.02E-04	5.72E-04
Year 3, 1 July	3.11E-02	5.16E-01	3.21E-02	1.50E-04	7.22E-04
Year 4, 1 July	1.75E-02	5.33E-01	2.45E-02	1.18E-04	8.41E-04
Year 5, 1 July	1.04E-02	5.44E-01	1.89E-02	9.49E-05	9.35E-04
Year 6, 1 July	6.27E-03	5.50E-01	1.48E-02	7.72E-05	1.01E-03
Year 7, 1 July	3.77E-03	5.54E-01	1.18E-02	6.36E-05	1.08E-03
Year 8, 1 July	2.27E-03	5.56E-01	9.54E-03	5.29E-05	1.13E-03
Year 9, 1 July	1.36E-03	5.57E-01	7.78E-03	4.45E-05	1.17E-03
Year 10, 1 July	8.21E-04	5.58E-01	6.42E-03	3.77E-05	1.21E-03
Year 11, 1 July	4.94E-04	5.59E-01	5.36E-03	3.23E-05	1.24E-03
Year 12, 1 July	2.97E-04	5.59E-01	4.51E-03	2.78E-05	1.27E-03
Year 13, 1 July	1.79E-04	5.59E-01	3.84E-03	2.41E-05	1.30E-03
Year 14, 1 July	1.08E-04	5.59E-01	3.27E-03	2.10E-05	1.32E-03
Year 15, 1 July	6.48E-05	5.59E-01	2.83E-03	1.85E-05	1.34E-03
Year 16, 1 July	3.90E-05	5.59E-01	2.43E-03	1.63E-05	1.35E-03
Year 17, 1 July	2.34E-05	5.59E-01	2.12E-03	1.44E-05	1.37E-03
Year 18, 1 July	1.41E-05	5.59E-01	1.85E-03	1.28E-05	1.38E-03
Year 19, 1 July	8.49E-06	5.59E-01	1.62E-03	1.14E-05	1.39E-03
Year 20, 1 July	5.11E-06	5.59E-01	1.43E-03	1.02E-05	1.40E-03

Date	No countermeasures					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside on the 5th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	3.50E-01	3.50E-01	7.86E-01	7.86E-01	7.08E-01	7.08E-01
Year 2, 1 July	2.71E-01	6.21E-01	5.85E-01	1.37E+00	5.36E-01	1.24E+00
Year 3, 1 July	2.03E-01	8.24E-01	4.39E-01	1.81E+00	4.04E-01	1.65E+00
Year 4, 1 July	1.55E-01	9.79E-01	3.34E-01	2.14E+00	3.09E-01	1.96E+00
Year 5, 1 July	1.20E-01	1.10E+00	2.58E-01	2.40E+00	2.40E-01	2.20E+00
Year 6, 1 July	9.46E-02	1.19E+00	2.03E-01	2.61E+00	1.89E-01	2.38E+00
Year 7, 1 July	7.54E-02	1.27E+00	1.61E-01	2.77E+00	1.51E-01	2.54E+00
Year 8, 1 July	6.09E-02	1.33E+00	1.30E-01	2.90E+00	1.22E-01	2.66E+00
Year 9, 1 July	4.99E-02	1.38E+00	1.06E-01	3.00E+00	1.00E-01	2.76E+00
Year 10, 1 July	4.12E-02	1.42E+00	8.76E-02	3.09E+00	8.28E-02	2.84E+00
Year 11, 1 July	3.44E-02	1.46E+00	7.30E-02	3.16E+00	6.92E-02	2.91E+00
Year 12, 1 July	2.90E-02	1.49E+00	6.15E-02	3.22E+00	5.85E-02	2.97E+00
Year 13, 1 July	2.46E-02	1.51E+00	5.22E-02	3.28E+00	4.97E-02	3.02E+00
Year 14, 1 July	2.11E-02	1.53E+00	4.46E-02	3.32E+00	4.27E-02	3.06E+00
Year 15, 1 July	1.82E-02	1.55E+00	3.84E-02	3.36E+00	3.68E-02	3.10E+00
Year 16, 1 July	1.57E-02	1.56E+00	3.32E-02	3.39E+00	3.19E-02	3.13E+00
Year 17, 1 July	1.37E-02	1.58E+00	2.89E-02	3.42E+00	2.79E-02	3.16E+00
Year 18, 1 July	1.20E-02	1.59E+00	2.52E-02	3.45E+00	2.44E-02	3.18E+00
Year 19, 1 July	1.05E-02	1.60E+00	2.21E-02	3.47E+00	2.14E-02	3.20E+00
Year 20, 1 July	9.23E-03	1.61E+00	1.95E-02	3.49E+00	1.89E-02	3.22E+00

Table III.2.31. Exposure doses for the hypothetical scenario, with removal of trees.

Date	Removal of tree					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.59E-01	1.59E-01	6.77E-02	6.77E-02	4.41E-03	4.41E-03
Year 2, 1 July	1.10E-01	2.68E-01	5.16E-02	1.19E-01	3.52E-03	7.93E-03
Year 3, 1 July	8.18E-02	3.50E-01	3.87E-02	1.58E-01	2.73E-03	1.07E-02
Year 4, 1 July	6.23E-02	4.12E-01	2.94E-02	1.87E-01	2.12E-03	1.28E-02
Year 5, 1 July	4.82E-02	4.61E-01	2.28E-02	2.10E-01	1.66E-03	1.44E-02
Year 6, 1 July	3.76E-02	4.98E-01	1.79E-02	2.28E-01	1.30E-03	1.58E-02
Year 7, 1 July	2.99E-02	5.28E-01	1.42E-02	2.42E-01	1.02E-03	1.68E-02
Year 8, 1 July	2.41E-02	5.52E-01	1.14E-02	2.54E-01	8.07E-04	1.76E-02
Year 9, 1 July	1.96E-02	5.72E-01	9.31E-03	2.63E-01	6.39E-04	1.82E-02
Year 10, 1 July	1.62E-02	5.88E-01	7.67E-03	2.71E-01	5.07E-04	1.87E-02
Year 11, 1 July	1.35E-02	6.02E-01	6.37E-03	2.77E-01	4.03E-04	1.91E-02
Year 12, 1 July	1.14E-02	6.13E-01	5.36E-03	2.82E-01	3.25E-04	1.95E-02
Year 13, 1 July	9.63E-03	6.23E-01	4.54E-03	2.87E-01	2.60E-04	1.97E-02
Year 14, 1 July	8.24E-03	6.31E-01	3.88E-03	2.91E-01	2.09E-04	1.99E-02
Year 15, 1 July	7.09E-03	6.38E-01	3.33E-03	2.94E-01	1.69E-04	2.01E-02
Year 16, 1 July	6.14E-03	6.44E-01	2.87E-03	2.97E-01	1.37E-04	2.02E-02
Year 17, 1 July	5.33E-03	6.49E-01	2.49E-03	2.99E-01	1.12E-04	2.03E-02
Year 18, 1 July	4.65E-03	6.54E-01	2.17E-03	3.02E-01	9.18E-05	2.04E-02
Year 19, 1 July	4.08E-03	6.58E-01	1.90E-03	3.03E-01	7.56E-05	2.05E-02
Year 20, 1 July	3.59E-03	6.62E-01	1.66E-03	3.05E-01	6.25E-05	2.06E-02

Date	Removal of tree					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	5.06E-06	5.06E-06	1.60E-02	1.60E-02	3.88E-03	3.88E-03
Year 2, 1 July	4.15E-06	9.21E-06	3.56E-03	1.96E-02	2.58E-03	6.46E-03
Year 3, 1 July	3.31E-06	1.25E-05	2.39E-03	2.20E-02	1.99E-03	8.45E-03
Year 4, 1 July	2.68E-06	1.52E-05	1.78E-03	2.37E-02	1.55E-03	1.00E-02
Year 5, 1 July	2.19E-06	1.74E-05	1.35E-03	2.51E-02	1.21E-03	1.12E-02
Year 6, 1 July	1.81E-06	1.92E-05	1.03E-03	2.61E-02	9.50E-04	1.22E-02
Year 7, 1 July	1.51E-06	2.07E-05	7.89E-04	2.69E-02	7.41E-04	1.29E-02
Year 8, 1 July	1.27E-06	2.20E-05	6.10E-04	2.75E-02	5.81E-04	1.35E-02
Year 9, 1 July	1.08E-06	2.31E-05	4.73E-04	2.80E-02	4.55E-04	1.39E-02
Year 10, 1 July	9.21E-07	2.40E-05	3.67E-04	2.83E-02	3.56E-04	1.43E-02
Year 11, 1 July	7.92E-07	2.48E-05	2.85E-04	2.86E-02	2.79E-04	1.46E-02
Year 12, 1 July	6.86E-07	2.55E-05	2.23E-04	2.89E-02	2.19E-04	1.48E-02
Year 13, 1 July	5.98E-07	2.61E-05	1.73E-04	2.90E-02	1.71E-04	1.50E-02
Year 14, 1 July	5.25E-07	2.66E-05	1.35E-04	2.92E-02	1.34E-04	1.51E-02
Year 15, 1 July	4.63E-07	2.70E-05	1.06E-04	2.93E-02	1.05E-04	1.52E-02
Year 16, 1 July	4.10E-07	2.75E-05	8.27E-05	2.94E-02	8.22E-05	1.53E-02
Year 17, 1 July	3.64E-07	2.78E-05	6.48E-05	2.94E-02	6.44E-05	1.53E-02
Year 18, 1 July	3.22E-07	2.81E-05	5.06E-05	2.95E-02	5.04E-05	1.54E-02
Year 19, 1 July	2.89E-07	2.84E-05	3.97E-05	2.95E-02	3.95E-05	1.54E-02
Year 20, 1 July	2.59E-07	2.87E-05	3.10E-05	2.95E-02	3.10E-05	1.55E-02

Table III.2.31. Exposure doses for the hypothetical scenario, with removal of trees (cont.).

Date	Removal of tree				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	4.09E-01	4.09E-01	5.55E-02	3.70E-04	3.70E-04
Year 2, 1 July	7.57E-02	4.85E-01	4.29E-02	2.02E-04	5.72E-04
Year 3, 1 July	3.11E-02	5.16E-01	3.21E-02	1.50E-04	7.22E-04
Year 4, 1 July	1.75E-02	5.33E-01	2.45E-02	1.18E-04	8.41E-04
Year 5, 1 July	1.04E-02	5.44E-01	1.89E-02	9.49E-05	9.35E-04
Year 6, 1 July	6.27E-03	5.50E-01	1.48E-02	7.72E-05	1.01E-03
Year 7, 1 July	3.77E-03	5.54E-01	1.18E-02	6.36E-05	1.08E-03
Year 8, 1 July	2.27E-03	5.56E-01	9.54E-03	5.30E-05	1.13E-03
Year 9, 1 July	1.36E-03	5.57E-01	7.78E-03	4.46E-05	1.17E-03
Year 10, 1 July	8.21E-04	5.58E-01	6.42E-03	3.77E-05	1.21E-03
Year 11, 1 July	4.94E-04	5.59E-01	5.36E-03	3.23E-05	1.24E-03
Year 12, 1 July	2.97E-04	5.59E-01	4.51E-03	2.79E-05	1.27E-03
Year 13, 1 July	1.79E-04	5.59E-01	3.84E-03	2.41E-05	1.30E-03
Year 14, 1 July	1.08E-04	5.59E-01	3.27E-03	2.10E-05	1.32E-03
Year 15, 1 July	6.48E-05	5.59E-01	2.83E-03	1.85E-05	1.34E-03
Year 16, 1 July	3.90E-05	5.59E-01	2.43E-03	1.63E-05	1.35E-03
Year 17, 1 July	2.34E-05	5.59E-01	2.12E-03	1.44E-05	1.37E-03
Year 18, 1 July	1.41E-05	5.59E-01	1.85E-03	1.29E-05	1.38E-03
Year 19, 1 July	8.49E-06	5.59E-01	1.62E-03	1.14E-05	1.39E-03
Year 20, 1 July	5.11E-06	5.59E-01	1.43E-03	1.02E-05	1.40E-03

Date	Removal of tree					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside on the 5th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	3.50E-01	3.50E-01	7.68E-01	7.68E-01	6.98E-01	6.98E-01
Year 2, 1 July	2.71E-01	6.21E-01	5.85E-01	1.35E+00	5.36E-01	1.23E+00
Year 3, 1 July	2.03E-01	8.24E-01	4.39E-01	1.79E+00	4.04E-01	1.64E+00
Year 4, 1 July	1.55E-01	9.79E-01	3.34E-01	2.13E+00	3.09E-01	1.95E+00
Year 5, 1 July	1.20E-01	1.10E+00	2.58E-01	2.38E+00	2.40E-01	2.19E+00
Year 6, 1 July	9.46E-02	1.19E+00	2.03E-01	2.59E+00	1.89E-01	2.38E+00
Year 7, 1 July	7.54E-02	1.27E+00	1.61E-01	2.75E+00	1.51E-01	2.53E+00
Year 8, 1 July	6.09E-02	1.33E+00	1.30E-01	2.88E+00	1.22E-01	2.65E+00
Year 9, 1 July	4.99E-02	1.38E+00	1.06E-01	2.98E+00	1.00E-01	2.75E+00
Year 10, 1 July	4.12E-02	1.42E+00	8.76E-02	3.07E+00	8.28E-02	2.83E+00
Year 11, 1 July	3.44E-02	1.46E+00	7.30E-02	3.14E+00	6.92E-02	2.90E+00
Year 12, 1 July	2.90E-02	1.49E+00	6.15E-02	3.21E+00	5.85E-02	2.96E+00
Year 13, 1 July	2.46E-02	1.51E+00	5.22E-02	3.26E+00	4.98E-02	3.01E+00
Year 14, 1 July	2.11E-02	1.53E+00	4.46E-02	3.30E+00	4.27E-02	3.05E+00
Year 15, 1 July	1.82E-02	1.55E+00	3.84E-02	3.34E+00	3.68E-02	3.09E+00
Year 16, 1 July	1.57E-02	1.56E+00	3.32E-02	3.37E+00	3.19E-02	3.12E+00
Year 17, 1 July	1.37E-02	1.58E+00	2.89E-02	3.40E+00	2.79E-02	3.15E+00
Year 18, 1 July	1.20E-02	1.59E+00	2.52E-02	3.43E+00	2.44E-02	3.17E+00
Year 19, 1 July	1.05E-02	1.60E+00	2.21E-02	3.45E+00	2.14E-02	3.19E+00
Year 20, 1 July	9.23E-03	1.61E+00	1.95E-02	3.47E+00	1.89E-02	3.21E+00

Table III.2.32. Exposure doses for the hypothetical scenario, with removal of grass.

Date	Removal of grass					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	7.23E-02	7.23E-02	1.92E-02	1.92E-02	3.50E-03	3.50E-03
Year 2, 1 July	2.48E-02	9.71E-02	1.25E-02	3.17E-02	2.81E-03	6.32E-03
Year 3, 1 July	1.79E-02	1.15E-01	9.42E-03	4.12E-02	2.20E-03	8.51E-03
Year 4, 1 July	1.36E-02	1.29E-01	7.20E-03	4.84E-02	1.72E-03	1.02E-02
Year 5, 1 July	1.05E-02	1.39E-01	5.58E-03	5.40E-02	1.35E-03	1.16E-02
Year 6, 1 July	8.14E-03	1.47E-01	4.37E-03	5.83E-02	1.06E-03	1.26E-02
Year 7, 1 July	6.44E-03	1.54E-01	3.47E-03	6.18E-02	8.28E-04	1.35E-02
Year 8, 1 July	5.17E-03	1.59E-01	2.77E-03	6.46E-02	6.49E-04	1.41E-02
Year 9, 1 July	4.20E-03	1.63E-01	2.24E-03	6.68E-02	5.10E-04	1.46E-02
Year 10, 1 July	3.45E-03	1.67E-01	1.83E-03	6.86E-02	4.00E-04	1.50E-02
Year 11, 1 July	2.87E-03	1.69E-01	1.51E-03	7.02E-02	3.14E-04	1.53E-02
Year 12, 1 July	2.40E-03	1.72E-01	1.26E-03	7.14E-02	2.49E-04	1.56E-02
Year 13, 1 July	2.03E-03	1.74E-01	1.05E-03	7.25E-02	1.96E-04	1.58E-02
Year 14, 1 July	1.72E-03	1.76E-01	8.89E-04	7.34E-02	1.55E-04	1.59E-02
Year 15, 1 July	1.48E-03	1.77E-01	7.55E-04	7.41E-02	1.22E-04	1.61E-02
Year 16, 1 July	1.27E-03	1.78E-01	6.43E-04	7.48E-02	9.67E-05	1.62E-02
Year 17, 1 July	1.10E-03	1.79E-01	5.52E-04	7.53E-02	7.66E-05	1.62E-02
Year 18, 1 July	9.59E-04	1.80E-01	4.77E-04	7.58E-02	6.08E-05	1.63E-02
Year 19, 1 July	8.38E-04	1.81E-01	4.14E-04	7.62E-02	4.84E-05	1.63E-02
Year 20, 1 July	7.35E-04	1.82E-01	3.58E-04	7.66E-02	3.86E-05	1.64E-02

Date	Removal of grass					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	5.06E-06	5.06E-06	3.17E-02	3.17E-02	4.68E-03	4.68E-03
Year 2, 1 July	4.15E-06	9.21E-06	3.75E-03	3.54E-02	2.59E-03	7.27E-03
Year 3, 1 July	3.31E-06	1.25E-05	2.39E-03	3.78E-02	1.99E-03	9.26E-03
Year 4, 1 July	2.68E-06	1.52E-05	1.77E-03	3.96E-02	1.55E-03	1.08E-02
Year 5, 1 July	2.19E-06	1.74E-05	1.34E-03	4.09E-02	1.21E-03	1.20E-02
Year 6, 1 July	1.81E-06	1.92E-05	1.03E-03	4.20E-02	9.49E-04	1.30E-02
Year 7, 1 July	1.51E-06	2.07E-05	7.88E-04	4.27E-02	7.40E-04	1.37E-02
Year 8, 1 July	1.27E-06	2.20E-05	6.09E-04	4.34E-02	5.80E-04	1.43E-02
Year 9, 1 July	1.07E-06	2.31E-05	4.72E-04	4.38E-02	4.55E-04	1.47E-02
Year 10, 1 July	9.20E-07	2.40E-05	3.66E-04	4.42E-02	3.56E-04	1.51E-02
Year 11, 1 July	7.91E-07	2.48E-05	2.85E-04	4.45E-02	2.78E-04	1.54E-02
Year 12, 1 July	6.85E-07	2.55E-05	2.22E-04	4.47E-02	2.18E-04	1.56E-02
Year 13, 1 July	5.97E-07	2.60E-05	1.73E-04	4.49E-02	1.70E-04	1.58E-02
Year 14, 1 July	5.24E-07	2.66E-05	1.35E-04	4.50E-02	1.34E-04	1.59E-02
Year 15, 1 July	4.62E-07	2.70E-05	1.05E-04	4.51E-02	1.05E-04	1.60E-02
Year 16, 1 July	4.09E-07	2.74E-05	8.24E-05	4.52E-02	8.19E-05	1.61E-02
Year 17, 1 July	3.63E-07	2.78E-05	6.45E-05	4.53E-02	6.42E-05	1.61E-02
Year 18, 1 July	3.22E-07	2.81E-05	5.05E-05	4.53E-02	5.03E-05	1.62E-02
Year 19, 1 July	2.89E-07	2.84E-05	3.95E-05	4.53E-02	3.94E-05	1.62E-02
Year 20, 1 July	2.58E-07	2.87E-05	3.09E-05	4.54E-02	3.08E-05	1.63E-02

Table III.2.32. Exposure doses for the hypothetical scenario, with removal of grass (cont.).

Date	Removal of grass: Occupational (Building 2) Work on the top floor (outside) Annual (mGy y^{-1})	Cumulative (mGy)	School (Building 3) Annual (mGy y^{-1})	Occasional (Building 4) Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	4.09E-01	4.09E-01	1.29E-02	3.70E-04	3.70E-04
Year 2, 1 July	7.57E-02	4.85E-01	9.30E-03	2.02E-04	5.72E-04
Year 3, 1 July	3.11E-02	5.16E-01	7.00E-03	1.50E-04	7.22E-04
Year 4, 1 July	1.75E-02	5.33E-01	5.35E-03	1.18E-04	8.41E-04
Year 5, 1 July	1.04E-02	5.44E-01	4.14E-03	9.49E-05	9.35E-04
Year 6, 1 July	6.27E-03	5.50E-01	3.25E-03	7.72E-05	1.01E-03
Year 7, 1 July	3.77E-03	5.54E-01	2.59E-03	6.36E-05	1.08E-03
Year 8, 1 July	2.27E-03	5.56E-01	2.09E-03	5.29E-05	1.13E-03
Year 9, 1 July	1.36E-03	5.57E-01	1.70E-03	4.45E-05	1.17E-03
Year 10, 1 July	8.21E-04	5.58E-01	1.40E-03	3.77E-05	1.21E-03
Year 11, 1 July	4.94E-04	5.59E-01	1.17E-03	3.23E-05	1.24E-03
Year 12, 1 July	2.97E-04	5.59E-01	9.81E-04	2.78E-05	1.27E-03
Year 13, 1 July	1.79E-04	5.59E-01	8.33E-04	2.41E-05	1.30E-03
Year 14, 1 July	1.08E-04	5.59E-01	7.08E-04	2.10E-05	1.32E-03
Year 15, 1 July	6.48E-05	5.59E-01	6.10E-04	1.85E-05	1.34E-03
Year 16, 1 July	3.90E-05	5.59E-01	5.24E-04	1.63E-05	1.35E-03
Year 17, 1 July	2.34E-05	5.59E-01	4.55E-04	1.44E-05	1.37E-03
Year 18, 1 July	1.41E-05	5.59E-01	3.96E-04	1.28E-05	1.38E-03
Year 19, 1 July	8.49E-06	5.59E-01	3.47E-04	1.14E-05	1.39E-03
Year 20, 1 July	5.11E-06	5.59E-01	3.05E-04	1.02E-05	1.40E-03

Date	Removal of grass: Residential (Building 5) Annual (mGy y^{-1})	Cumulative (mGy)	Residential (Building 6) Reside on the 1st floor Annual (mGy y^{-1})	Cumulative (mGy)	Residential (Building 6) Reside on the 5th floor Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	9.21E-02	9.21E-02	2.02E-01	2.02E-01	2.08E-01	2.08E-01
Year 2, 1 July	6.75E-02	1.60E-01	1.24E-01	3.26E-01	1.42E-01	3.50E-01
Year 3, 1 July	5.13E-02	2.11E-01	9.33E-02	4.19E-01	1.08E-01	4.59E-01
Year 4, 1 July	3.95E-02	2.51E-01	7.11E-02	4.90E-01	8.41E-02	5.43E-01
Year 5, 1 July	3.09E-02	2.81E-01	5.50E-02	5.45E-01	6.61E-02	6.09E-01
Year 6, 1 July	2.45E-02	3.06E-01	4.33E-02	5.89E-01	5.27E-02	6.62E-01
Year 7, 1 July	1.96E-02	3.26E-01	3.44E-02	6.23E-01	4.25E-02	7.04E-01
Year 8, 1 July	1.59E-02	3.41E-01	2.77E-02	6.51E-01	3.47E-02	7.39E-01
Year 9, 1 July	1.31E-02	3.55E-01	2.25E-02	6.73E-01	2.86E-02	7.67E-01
Year 10, 1 July	1.08E-02	3.65E-01	1.86E-02	6.92E-01	2.39E-02	7.91E-01
Year 11, 1 July	9.07E-03	3.74E-01	1.54E-02	7.07E-01	2.01E-02	8.11E-01
Year 12, 1 July	7.66E-03	3.82E-01	1.30E-02	7.20E-01	1.70E-02	8.28E-01
Year 13, 1 July	6.50E-03	3.89E-01	1.10E-02	7.31E-01	1.46E-02	8.43E-01
Year 14, 1 July	5.57E-03	3.94E-01	9.37E-03	7.40E-01	1.25E-02	8.55E-01
Year 15, 1 July	4.80E-03	3.99E-01	8.03E-03	7.49E-01	1.09E-02	8.66E-01
Year 16, 1 July	4.16E-03	4.03E-01	6.93E-03	7.55E-01	9.47E-03	8.76E-01
Year 17, 1 July	3.63E-03	4.07E-01	6.02E-03	7.61E-01	8.29E-03	8.84E-01
Year 18, 1 July	3.17E-03	4.10E-01	5.24E-03	7.67E-01	7.28E-03	8.91E-01
Year 19, 1 July	2.79E-03	4.13E-01	4.59E-03	7.71E-01	6.42E-03	8.98E-01
Year 20, 1 July	2.45E-03	4.15E-01	4.03E-03	7.75E-01	5.68E-03	9.03E-01

Table III.2.33. Exposure doses for the hypothetical scenario, with removal of soil.

Date	Removal of soil					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.19E-01	1.19E-01	4.04E-02	4.04E-02	3.89E-03	3.89E-03
Year 2, 1 July	8.81E-03	1.27E-01	5.20E-03	4.56E-02	2.68E-03	6.57E-03
Year 3, 1 July	5.96E-03	1.33E-01	3.94E-03	4.95E-02	2.10E-03	8.67E-03
Year 4, 1 July	4.45E-03	1.38E-01	3.03E-03	5.26E-02	1.64E-03	1.03E-02
Year 5, 1 July	3.40E-03	1.41E-01	2.36E-03	5.49E-02	1.29E-03	1.16E-02
Year 6, 1 July	2.62E-03	1.44E-01	1.85E-03	5.68E-02	1.01E-03	1.26E-02
Year 7, 1 July	2.05E-03	1.46E-01	1.45E-03	5.82E-02	7.91E-04	1.34E-02
Year 8, 1 July	1.63E-03	1.47E-01	1.15E-03	5.94E-02	6.19E-04	1.40E-02
Year 9, 1 July	1.31E-03	1.49E-01	9.21E-04	6.03E-02	4.86E-04	1.45E-02
Year 10, 1 July	1.06E-03	1.50E-01	7.40E-04	6.10E-02	3.80E-04	1.49E-02
Year 11, 1 July	8.70E-04	1.51E-01	5.97E-04	6.16E-02	2.98E-04	1.52E-02
Year 12, 1 July	7.19E-04	1.51E-01	4.88E-04	6.21E-02	2.36E-04	1.54E-02
Year 13, 1 July	5.99E-04	1.52E-01	3.98E-04	6.25E-02	1.84E-04	1.56E-02
Year 14, 1 July	5.03E-04	1.53E-01	3.28E-04	6.28E-02	1.45E-04	1.57E-02
Year 15, 1 July	4.26E-04	1.53E-01	2.72E-04	6.31E-02	1.13E-04	1.59E-02
Year 16, 1 July	3.63E-04	1.53E-01	2.26E-04	6.33E-02	8.91E-05	1.60E-02
Year 17, 1 July	3.10E-04	1.54E-01	1.89E-04	6.35E-02	7.00E-05	1.60E-02
Year 18, 1 July	2.67E-04	1.54E-01	1.59E-04	6.37E-02	5.51E-05	1.61E-02
Year 19, 1 July	2.30E-04	1.54E-01	1.35E-04	6.38E-02	4.34E-05	1.61E-02
Year 20, 1 July	2.00E-04	1.54E-01	1.14E-04	6.39E-02	3.41E-05	1.62E-02

Date	Removal of soil					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	5.06E-06	5.06E-06	3.17E-02	3.17E-02	4.68E-03	4.68E-03
Year 2, 1 July	4.15E-06	9.21E-06	3.75E-03	3.54E-02	2.59E-03	7.27E-03
Year 3, 1 July	3.31E-06	1.25E-05	2.39E-03	3.78E-02	1.99E-03	9.26E-03
Year 4, 1 July	2.68E-06	1.52E-05	1.77E-03	3.96E-02	1.55E-03	1.08E-02
Year 5, 1 July	2.19E-06	1.74E-05	1.34E-03	4.09E-02	1.21E-03	1.20E-02
Year 6, 1 July	1.81E-06	1.92E-05	1.03E-03	4.20E-02	9.49E-04	1.30E-02
Year 7, 1 July	1.51E-06	2.07E-05	7.88E-04	4.27E-02	7.40E-04	1.37E-02
Year 8, 1 July	1.27E-06	2.20E-05	6.09E-04	4.34E-02	5.80E-04	1.43E-02
Year 9, 1 July	1.07E-06	2.31E-05	4.72E-04	4.38E-02	4.55E-04	1.47E-02
Year 10, 1 July	9.20E-07	2.40E-05	3.66E-04	4.42E-02	3.56E-04	1.51E-02
Year 11, 1 July	7.91E-07	2.48E-05	2.85E-04	4.45E-02	2.78E-04	1.54E-02
Year 12, 1 July	6.85E-07	2.55E-05	2.22E-04	4.47E-02	2.18E-04	1.56E-02
Year 13, 1 July	5.97E-07	2.60E-05	1.73E-04	4.49E-02	1.70E-04	1.58E-02
Year 14, 1 July	5.24E-07	2.66E-05	1.35E-04	4.50E-02	1.34E-04	1.59E-02
Year 15, 1 July	4.62E-07	2.70E-05	1.05E-04	4.51E-02	1.05E-04	1.60E-02
Year 16, 1 July	4.09E-07	2.74E-05	8.24E-05	4.52E-02	8.19E-05	1.61E-02
Year 17, 1 July	3.63E-07	2.78E-05	6.45E-05	4.53E-02	6.42E-05	1.61E-02
Year 18, 1 July	3.22E-07	2.81E-05	5.05E-05	4.53E-02	5.03E-05	1.62E-02
Year 19, 1 July	2.89E-07	2.84E-05	3.95E-05	4.53E-02	3.94E-05	1.62E-02
Year 20, 1 July	2.58E-07	2.87E-05	3.09E-05	4.54E-02	3.08E-05	1.63E-02

Table III.2.33. Exposure doses for the hypothetical scenario, with removal of soil (cont.).

Date	Removal of soil				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	4.09E-01	4.09E-01	3.11E-02	3.70E-04	3.70E-04
Year 2, 1 July	7.57E-02	4.85E-01	3.00E-03	2.02E-04	5.72E-04
Year 3, 1 July	3.11E-02	5.16E-01	2.28E-03	1.50E-04	7.22E-04
Year 4, 1 July	1.75E-02	5.33E-01	1.76E-03	1.18E-04	8.41E-04
Year 5, 1 July	1.04E-02	5.44E-01	1.37E-03	9.49E-05	9.35E-04
Year 6, 1 July	6.27E-03	5.50E-01	1.08E-03	7.72E-05	1.01E-03
Year 7, 1 July	3.77E-03	5.54E-01	8.62E-04	6.36E-05	1.08E-03
Year 8, 1 July	2.27E-03	5.56E-01	6.95E-04	5.29E-05	1.13E-03
Year 9, 1 July	1.36E-03	5.57E-01	5.64E-04	4.45E-05	1.17E-03
Year 10, 1 July	8.21E-04	5.58E-01	4.63E-04	3.77E-05	1.21E-03
Year 11, 1 July	4.94E-04	5.59E-01	3.83E-04	3.23E-05	1.24E-03
Year 12, 1 July	2.97E-04	5.59E-01	3.20E-04	2.78E-05	1.27E-03
Year 13, 1 July	1.79E-04	5.59E-01	2.69E-04	2.41E-05	1.30E-03
Year 14, 1 July	1.08E-04	5.59E-01	2.28E-04	2.10E-05	1.32E-03
Year 15, 1 July	6.48E-05	5.59E-01	1.94E-04	1.85E-05	1.34E-03
Year 16, 1 July	3.90E-05	5.59E-01	1.66E-04	1.63E-05	1.35E-03
Year 17, 1 July	2.34E-05	5.59E-01	1.43E-04	1.44E-05	1.37E-03
Year 18, 1 July	1.41E-05	5.59E-01	1.24E-04	1.28E-05	1.38E-03
Year 19, 1 July	8.49E-06	5.59E-01	1.08E-04	1.14E-05	1.39E-03
Year 20, 1 July	5.11E-06	5.59E-01	9.44E-05	1.02E-05	1.40E-03

Date	Removal of soil					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside on the 5th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	2.02E-01	2.02E-01	4.51E-01	4.51E-01	4.21E-01	4.21E-01
Year 2, 1 July	2.94E-02	2.32E-01	3.77E-02	4.89E-01	6.83E-02	4.90E-01
Year 3, 1 July	2.28E-02	2.55E-01	2.84E-02	5.18E-01	5.31E-02	5.43E-01
Year 4, 1 July	1.79E-02	2.72E-01	2.18E-02	5.39E-01	4.20E-02	5.85E-01
Year 5, 1 July	1.42E-02	2.87E-01	1.69E-02	5.56E-01	3.35E-02	6.18E-01
Year 6, 1 July	1.13E-02	2.98E-01	1.33E-02	5.70E-01	2.71E-02	6.45E-01
Year 7, 1 July	9.16E-03	3.07E-01	1.06E-02	5.80E-01	2.21E-02	6.67E-01
Year 8, 1 July	7.50E-03	3.15E-01	8.49E-03	5.89E-01	1.83E-02	6.86E-01
Year 9, 1 July	6.19E-03	3.21E-01	6.88E-03	5.96E-01	1.52E-02	7.01E-01
Year 10, 1 July	5.15E-03	3.26E-01	5.64E-03	6.01E-01	1.28E-02	7.14E-01
Year 11, 1 July	4.31E-03	3.30E-01	4.66E-03	6.06E-01	1.08E-02	7.25E-01
Year 12, 1 July	3.65E-03	3.34E-01	3.88E-03	6.10E-01	9.27E-03	7.34E-01
Year 13, 1 July	3.10E-03	3.37E-01	3.26E-03	6.13E-01	7.98E-03	7.42E-01
Year 14, 1 July	2.66E-03	3.40E-01	2.75E-03	6.16E-01	6.90E-03	7.49E-01
Year 15, 1 July	2.30E-03	3.42E-01	2.34E-03	6.18E-01	6.01E-03	7.55E-01
Year 16, 1 July	1.99E-03	3.44E-01	2.00E-03	6.20E-01	5.26E-03	7.60E-01
Year 17, 1 July	1.74E-03	3.46E-01	1.73E-03	6.22E-01	4.63E-03	7.65E-01
Year 18, 1 July	1.52E-03	3.47E-01	1.49E-03	6.23E-01	4.08E-03	7.69E-01
Year 19, 1 July	1.34E-03	3.48E-01	1.30E-03	6.25E-01	3.61E-03	7.72E-01
Year 20, 1 July	1.18E-03	3.50E-01	1.13E-03	6.26E-01	3.21E-03	7.76E-01

Table III.2.34. Exposure doses for the hypothetical scenario, with washing of roads.

Date	Washing of roads					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.75E-01	1.75E-01	6.84E-02	6.84E-02	4.41E-03	4.41E-03
Year 2, 1 July	1.09E-01	2.84E-01	5.15E-02	1.20E-01	3.52E-03	7.93E-03
Year 3, 1 July	8.13E-02	3.65E-01	3.86E-02	1.58E-01	2.73E-03	1.07E-02
Year 4, 1 July	6.20E-02	4.27E-01	2.94E-02	1.88E-01	2.12E-03	1.28E-02
Year 5, 1 July	4.80E-02	4.75E-01	2.28E-02	2.11E-01	1.66E-03	1.44E-02
Year 6, 1 July	3.75E-02	5.13E-01	1.78E-02	2.28E-01	1.30E-03	1.57E-02
Year 7, 1 July	2.98E-02	5.43E-01	1.42E-02	2.43E-01	1.02E-03	1.68E-02
Year 8, 1 July	2.40E-02	5.67E-01	1.14E-02	2.54E-01	8.06E-04	1.76E-02
Year 9, 1 July	1.96E-02	5.86E-01	9.30E-03	2.63E-01	6.38E-04	1.82E-02
Year 10, 1 July	1.62E-02	6.02E-01	7.67E-03	2.71E-01	5.06E-04	1.87E-02
Year 11, 1 July	1.35E-02	6.16E-01	6.37E-03	2.77E-01	4.03E-04	1.91E-02
Year 12, 1 July	1.14E-02	6.27E-01	5.36E-03	2.83E-01	3.24E-04	1.94E-02
Year 13, 1 July	9.63E-03	6.37E-01	4.54E-03	2.87E-01	2.59E-04	1.97E-02
Year 14, 1 July	8.24E-03	6.45E-01	3.88E-03	2.91E-01	2.09E-04	1.99E-02
Year 15, 1 July	7.09E-03	6.52E-01	3.33E-03	2.95E-01	1.69E-04	2.01E-02
Year 16, 1 July	6.14E-03	6.58E-01	2.87E-03	2.97E-01	1.37E-04	2.02E-02
Year 17, 1 July	5.33E-03	6.64E-01	2.49E-03	3.00E-01	1.12E-04	2.03E-02
Year 18, 1 July	4.65E-03	6.68E-01	2.17E-03	3.02E-01	9.17E-05	2.04E-02
Year 19, 1 July	4.08E-03	6.72E-01	1.90E-03	3.04E-01	7.54E-05	2.05E-02
Year 20, 1 July	3.59E-03	6.76E-01	1.66E-03	3.06E-01	6.23E-05	2.06E-02

Date	Washing of roads					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	5.06E-06	5.06E-06	2.76E-02	2.76E-02	4.36E-03	4.36E-03
Year 2, 1 July	4.15E-06	9.21E-06	2.91E-03	3.05E-02	2.52E-03	6.89E-03
Year 3, 1 July	3.31E-06	1.25E-05	2.04E-03	3.25E-02	1.96E-03	8.85E-03
Year 4, 1 July	2.68E-06	1.52E-05	1.58E-03	3.41E-02	1.54E-03	1.04E-02
Year 5, 1 July	2.19E-06	1.74E-05	1.23E-03	3.53E-02	1.20E-03	1.16E-02
Year 6, 1 July	1.81E-06	1.92E-05	9.60E-04	3.63E-02	9.44E-04	1.25E-02
Year 7, 1 July	1.51E-06	2.07E-05	7.46E-04	3.70E-02	7.36E-04	1.33E-02
Year 8, 1 July	1.27E-06	2.20E-05	5.84E-04	3.76E-02	5.79E-04	1.38E-02
Year 9, 1 July	1.07E-06	2.31E-05	4.57E-04	3.81E-02	4.53E-04	1.43E-02
Year 10, 1 July	9.20E-07	2.40E-05	3.57E-04	3.84E-02	3.55E-04	1.47E-02
Year 11, 1 July	7.91E-07	2.48E-05	2.79E-04	3.87E-02	2.78E-04	1.49E-02
Year 12, 1 July	6.85E-07	2.55E-05	2.19E-04	3.89E-02	2.18E-04	1.51E-02
Year 13, 1 July	5.97E-07	2.60E-05	1.71E-04	3.91E-02	1.70E-04	1.53E-02
Year 14, 1 July	5.24E-07	2.66E-05	1.34E-04	3.92E-02	1.33E-04	1.55E-02
Year 15, 1 July	4.62E-07	2.70E-05	1.05E-04	3.93E-02	1.05E-04	1.56E-02
Year 16, 1 July	4.09E-07	2.74E-05	8.20E-05	3.94E-02	8.19E-05	1.56E-02
Year 17, 1 July	3.63E-07	2.78E-05	6.43E-05	3.95E-02	6.42E-05	1.57E-02
Year 18, 1 July	3.22E-07	2.81E-05	5.03E-05	3.95E-02	5.03E-05	1.58E-02
Year 19, 1 July	2.89E-07	2.84E-05	3.94E-05	3.96E-02	3.94E-05	1.58E-02
Year 20, 1 July	2.58E-07	2.87E-05	3.09E-05	3.96E-02	3.08E-05	1.58E-02

Table III.2.34. Exposure doses for the hypothetical scenario, with washing of roads (cont.).

Date	Washing of roads				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	4.09E-01	4.09E-01	5.55E-02	2.54E-04	2.54E-04
Year 2, 1 July	7.57E-02	4.85E-01	4.29E-02	1.79E-04	4.33E-04
Year 3, 1 July	3.11E-02	5.16E-01	3.21E-02	1.41E-04	5.74E-04
Year 4, 1 July	1.75E-02	5.33E-01	2.45E-02	1.13E-04	6.87E-04
Year 5, 1 July	1.04E-02	5.44E-01	1.89E-02	9.17E-05	7.78E-04
Year 6, 1 July	6.27E-03	5.50E-01	1.48E-02	7.53E-05	8.54E-04
Year 7, 1 July	3.77E-03	5.54E-01	1.18E-02	6.24E-05	9.16E-04
Year 8, 1 July	2.27E-03	5.56E-01	9.54E-03	5.22E-05	9.68E-04
Year 9, 1 July	1.36E-03	5.57E-01	7.78E-03	4.41E-05	1.01E-03
Year 10, 1 July	8.21E-04	5.58E-01	6.42E-03	3.75E-05	1.05E-03
Year 11, 1 July	4.94E-04	5.59E-01	5.36E-03	3.21E-05	1.08E-03
Year 12, 1 July	2.97E-04	5.59E-01	4.51E-03	2.77E-05	1.11E-03
Year 13, 1 July	1.79E-04	5.59E-01	3.84E-03	2.40E-05	1.13E-03
Year 14, 1 July	1.08E-04	5.59E-01	3.27E-03	2.10E-05	1.15E-03
Year 15, 1 July	6.48E-05	5.59E-01	2.83E-03	1.85E-05	1.17E-03
Year 16, 1 July	3.90E-05	5.59E-01	2.43E-03	1.62E-05	1.19E-03
Year 17, 1 July	2.34E-05	5.59E-01	2.12E-03	1.44E-05	1.20E-03
Year 18, 1 July	1.41E-05	5.59E-01	1.85E-03	1.28E-05	1.22E-03
Year 19, 1 July	8.49E-06	5.59E-01	1.62E-03	1.14E-05	1.23E-03
Year 20, 1 July	5.11E-06	5.59E-01	1.43E-03	1.02E-05	1.24E-03

Date	Washing of roads					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside on the 5th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	3.50E-01	3.50E-01	7.86E-01	7.86E-01	7.08E-01	7.08E-01
Year 2, 1 July	2.71E-01	6.21E-01	5.85E-01	1.37E+00	5.36E-01	1.24E+00
Year 3, 1 July	2.03E-01	8.24E-01	4.39E-01	1.81E+00	4.04E-01	1.65E+00
Year 4, 1 July	1.55E-01	9.79E-01	3.34E-01	2.14E+00	3.09E-01	1.96E+00
Year 5, 1 July	1.20E-01	1.10E+00	2.58E-01	2.40E+00	2.40E-01	2.20E+00
Year 6, 1 July	9.46E-02	1.19E+00	2.03E-01	2.61E+00	1.89E-01	2.38E+00
Year 7, 1 July	7.54E-02	1.27E+00	1.61E-01	2.77E+00	1.51E-01	2.54E+00
Year 8, 1 July	6.09E-02	1.33E+00	1.30E-01	2.90E+00	1.22E-01	2.66E+00
Year 9, 1 July	4.99E-02	1.38E+00	1.06E-01	3.00E+00	1.00E-01	2.76E+00
Year 10, 1 July	4.12E-02	1.42E+00	8.76E-02	3.09E+00	8.28E-02	2.84E+00
Year 11, 1 July	3.44E-02	1.46E+00	7.30E-02	3.16E+00	6.92E-02	2.91E+00
Year 12, 1 July	2.90E-02	1.49E+00	6.15E-02	3.22E+00	5.85E-02	2.97E+00
Year 13, 1 July	2.46E-02	1.51E+00	5.22E-02	3.28E+00	4.97E-02	3.02E+00
Year 14, 1 July	2.11E-02	1.53E+00	4.46E-02	3.32E+00	4.27E-02	3.06E+00
Year 15, 1 July	1.82E-02	1.55E+00	3.84E-02	3.36E+00	3.68E-02	3.10E+00
Year 16, 1 July	1.57E-02	1.56E+00	3.32E-02	3.39E+00	3.19E-02	3.13E+00
Year 17, 1 July	1.37E-02	1.58E+00	2.89E-02	3.42E+00	2.79E-02	3.16E+00
Year 18, 1 July	1.20E-02	1.59E+00	2.52E-02	3.45E+00	2.44E-02	3.18E+00
Year 19, 1 July	1.05E-02	1.60E+00	2.21E-02	3.47E+00	2.14E-02	3.20E+00
Year 20, 1 July	9.23E-03	1.61E+00	1.95E-02	3.49E+00	1.89E-02	3.22E+00

Table III.2.35. Exposure doses for the hypothetical scenario, with washing of roofs and walls.

Date	Washing of roofs and walls					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.79E-01	1.79E-01	6.61E-02	6.61E-02	1.74E-03	1.74E-03
Year 2, 1 July	1.09E-01	2.87E-01	4.93E-02	1.15E-01	1.26E-03	3.00E-03
Year 3, 1 July	8.06E-02	3.68E-01	3.69E-02	1.52E-01	9.61E-04	3.96E-03
Year 4, 1 July	6.13E-02	4.29E-01	2.81E-02	1.80E-01	7.37E-04	4.70E-03
Year 5, 1 July	4.74E-02	4.77E-01	2.17E-02	2.02E-01	5.72E-04	5.27E-03
Year 6, 1 July	3.70E-02	5.14E-01	1.70E-02	2.19E-01	4.49E-04	5.72E-03
Year 7, 1 July	2.94E-02	5.43E-01	1.35E-02	2.33E-01	3.55E-04	6.07E-03
Year 8, 1 July	2.37E-02	5.67E-01	1.09E-02	2.43E-01	2.84E-04	6.36E-03
Year 9, 1 July	1.94E-02	5.86E-01	8.90E-03	2.52E-01	2.29E-04	6.59E-03
Year 10, 1 July	1.60E-02	6.02E-01	7.35E-03	2.60E-01	1.86E-04	6.77E-03
Year 11, 1 July	1.33E-02	6.16E-01	6.12E-03	2.66E-01	1.52E-04	6.92E-03
Year 12, 1 July	1.12E-02	6.27E-01	5.16E-03	2.71E-01	1.26E-04	7.05E-03
Year 13, 1 July	9.53E-03	6.36E-01	4.38E-03	2.75E-01	1.05E-04	7.16E-03
Year 14, 1 July	8.16E-03	6.45E-01	3.76E-03	2.79E-01	8.80E-05	7.24E-03
Year 15, 1 July	7.03E-03	6.52E-01	3.24E-03	2.82E-01	7.42E-05	7.32E-03
Year 16, 1 July	6.09E-03	6.58E-01	2.79E-03	2.85E-01	6.29E-05	7.38E-03
Year 17, 1 July	5.29E-03	6.63E-01	2.43E-03	2.88E-01	5.37E-05	7.43E-03
Year 18, 1 July	4.62E-03	6.68E-01	2.12E-03	2.90E-01	4.61E-05	7.48E-03
Year 19, 1 July	4.05E-03	6.72E-01	1.87E-03	2.92E-01	3.97E-05	7.52E-03
Year 20, 1 July	3.57E-03	6.75E-01	1.63E-03	2.93E-01	3.44E-05	7.55E-03

Date	Washing of roofs and walls					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.18E-06	1.18E-06	2.92E-02	2.92E-02	2.16E-03	2.16E-03
Year 2, 1 July	8.25E-07	2.00E-06	1.61E-03	3.08E-02	4.48E-04	2.60E-03
Year 3, 1 July	6.58E-07	2.66E-06	7.10E-04	3.15E-02	3.12E-04	2.92E-03
Year 4, 1 July	5.34E-07	3.19E-06	4.60E-04	3.19E-02	2.37E-04	3.15E-03
Year 5, 1 July	4.36E-07	3.63E-06	3.16E-04	3.22E-02	1.83E-04	3.34E-03
Year 6, 1 July	3.61E-07	3.99E-06	2.21E-04	3.25E-02	1.41E-04	3.48E-03
Year 7, 1 July	3.00E-07	4.29E-06	1.57E-04	3.26E-02	1.09E-04	3.59E-03
Year 8, 1 July	2.52E-07	4.54E-06	1.14E-04	3.27E-02	8.50E-05	3.67E-03
Year 9, 1 July	2.14E-07	4.76E-06	8.36E-05	3.28E-02	6.62E-05	3.74E-03
Year 10, 1 July	1.83E-07	4.94E-06	6.20E-05	3.29E-02	5.15E-05	3.79E-03
Year 11, 1 July	1.58E-07	5.10E-06	4.65E-05	3.29E-02	4.02E-05	3.83E-03
Year 12, 1 July	1.37E-07	5.23E-06	3.52E-05	3.30E-02	3.15E-05	3.86E-03
Year 13, 1 July	1.19E-07	5.35E-06	2.68E-05	3.30E-02	2.45E-05	3.89E-03
Year 14, 1 July	1.05E-07	5.46E-06	2.05E-05	3.30E-02	1.92E-05	3.90E-03
Year 15, 1 July	9.23E-08	5.55E-06	1.58E-05	3.30E-02	1.50E-05	3.92E-03
Year 16, 1 July	8.16E-08	5.63E-06	1.22E-05	3.30E-02	1.17E-05	3.93E-03
Year 17, 1 July	7.25E-08	5.70E-06	9.50E-06	3.30E-02	9.20E-06	3.94E-03
Year 18, 1 July	6.43E-08	5.77E-06	7.37E-06	3.31E-02	7.20E-06	3.95E-03
Year 19, 1 July	5.76E-08	5.83E-06	5.74E-06	3.31E-02	5.64E-06	3.95E-03
Year 20, 1 July	5.16E-08	5.88E-06	4.48E-06	3.31E-02	4.41E-06	3.96E-03

Table III.2.35. Exposure doses for the hypothetical scenario, with washing of roofs and walls (cont.).

Date	Washing of roofs and walls				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	1.11E-01	1.11E-01	5.46E-02	2.07E-04	2.07E-04
Year 2, 1 July	1.51E-02	1.26E-01	4.21E-02	6.30E-05	2.70E-04
Year 3, 1 July	6.22E-03	1.32E-01	3.15E-02	3.90E-05	3.09E-04
Year 4, 1 July	3.49E-03	1.36E-01	2.40E-02	2.86E-05	3.37E-04
Year 5, 1 July	2.08E-03	1.38E-01	1.85E-02	2.18E-05	3.59E-04
Year 6, 1 July	1.25E-03	1.39E-01	1.45E-02	1.71E-05	3.76E-04
Year 7, 1 July	7.54E-04	1.40E-01	1.16E-02	1.36E-05	3.90E-04
Year 8, 1 July	4.53E-04	1.40E-01	9.35E-03	1.11E-05	4.01E-04
Year 9, 1 July	2.73E-04	1.41E-01	7.62E-03	9.17E-06	4.10E-04
Year 10, 1 July	1.64E-04	1.41E-01	6.29E-03	7.68E-06	4.18E-04
Year 11, 1 July	9.87E-05	1.41E-01	5.25E-03	6.52E-06	4.24E-04
Year 12, 1 July	5.94E-05	1.41E-01	4.43E-03	5.58E-06	4.30E-04
Year 13, 1 July	3.58E-05	1.41E-01	3.77E-03	4.82E-06	4.35E-04
Year 14, 1 July	2.15E-05	1.41E-01	3.22E-03	4.19E-06	4.39E-04
Year 15, 1 July	1.30E-05	1.41E-01	2.78E-03	3.68E-06	4.42E-04
Year 16, 1 July	7.80E-06	1.41E-01	2.40E-03	3.24E-06	4.46E-04
Year 17, 1 July	4.69E-06	1.41E-01	2.08E-03	2.87E-06	4.49E-04
Year 18, 1 July	2.82E-06	1.41E-01	1.82E-03	2.55E-06	4.51E-04
Year 19, 1 July	1.70E-06	1.41E-01	1.60E-03	2.27E-06	4.53E-04
Year 20, 1 July	1.02E-06	1.41E-01	1.41E-03	2.03E-06	4.55E-04

Date	Washing of roofs and walls					
	Residential (Building 5)		Residential (Building 6) Reside at 1st floor		Residential (Building 6) Reside at 5th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	3.34E-01	3.34E-01	7.78E-01	7.78E-01	6.66E-01	6.66E-01
Year 2, 1 July	2.57E-01	5.91E-01	5.77E-01	1.36E+00	5.00E-01	1.17E+00
Year 3, 1 July	1.92E-01	7.83E-01	4.33E-01	1.79E+00	3.76E-01	1.54E+00
Year 4, 1 July	1.46E-01	9.30E-01	3.29E-01	2.12E+00	2.86E-01	1.83E+00
Year 5, 1 July	1.13E-01	1.04E+00	2.55E-01	2.37E+00	2.21E-01	2.05E+00
Year 6, 1 July	8.89E-02	1.13E+00	2.00E-01	2.57E+00	1.74E-01	2.22E+00
Year 7, 1 July	7.07E-02	1.20E+00	1.59E-01	2.73E+00	1.38E-01	2.36E+00
Year 8, 1 July	5.71E-02	1.26E+00	1.28E-01	2.86E+00	1.12E-01	2.47E+00
Year 9, 1 July	4.67E-02	1.31E+00	1.05E-01	2.96E+00	9.13E-02	2.57E+00
Year 10, 1 July	3.86E-02	1.35E+00	8.65E-02	3.05E+00	7.55E-02	2.64E+00
Year 11, 1 July	3.22E-02	1.38E+00	7.21E-02	3.12E+00	6.30E-02	2.70E+00
Year 12, 1 July	2.72E-02	1.40E+00	6.08E-02	3.18E+00	5.31E-02	2.76E+00
Year 13, 1 July	2.30E-02	1.43E+00	5.16E-02	3.24E+00	4.51E-02	2.80E+00
Year 14, 1 July	1.97E-02	1.45E+00	4.42E-02	3.28E+00	3.86E-02	2.84E+00
Year 15, 1 July	1.70E-02	1.46E+00	3.80E-02	3.32E+00	3.33E-02	2.87E+00
Year 16, 1 July	1.47E-02	1.48E+00	3.29E-02	3.35E+00	2.88E-02	2.90E+00
Year 17, 1 July	1.28E-02	1.49E+00	2.87E-02	3.38E+00	2.51E-02	2.93E+00
Year 18, 1 July	1.12E-02	1.50E+00	2.50E-02	3.40E+00	2.19E-02	2.95E+00
Year 19, 1 July	9.83E-03	1.51E+00	2.20E-02	3.43E+00	1.93E-02	2.97E+00
Year 20, 1 July	8.62E-03	1.52E+00	1.93E-02	3.45E+00	1.70E-02	2.99E+00

Table III.2.36. Exposure doses for the hypothetical scenario, with relocation for 2 weeks.

Date	Relocation (2 weeks)					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.69E-01	1.69E-01	6.56E-02	6.56E-02	4.22E-03	4.22E-03
Year 2, 1 July	1.10E-01	2.79E-01	5.16E-02	1.17E-01	3.52E-03	7.74E-03
Year 3, 1 July	8.18E-02	3.61E-01	3.87E-02	1.56E-01	2.73E-03	1.05E-02
Year 4, 1 July	6.23E-02	4.23E-01	2.94E-02	1.85E-01	2.12E-03	1.26E-02
Year 5, 1 July	4.82E-02	4.72E-01	2.28E-02	2.08E-01	1.66E-03	1.43E-02
Year 6, 1 July	3.76E-02	5.09E-01	1.79E-02	2.26E-01	1.30E-03	1.56E-02
Year 7, 1 July	2.99E-02	5.39E-01	1.42E-02	2.40E-01	1.02E-03	1.66E-02
Year 8, 1 July	2.41E-02	5.63E-01	1.14E-02	2.52E-01	8.06E-04	1.74E-02
Year 9, 1 July	1.96E-02	5.83E-01	9.30E-03	2.61E-01	6.38E-04	1.80E-02
Year 10, 1 July	1.62E-02	5.99E-01	7.67E-03	2.69E-01	5.06E-04	1.85E-02
Year 11, 1 July	1.35E-02	6.12E-01	6.37E-03	2.75E-01	4.03E-04	1.89E-02
Year 12, 1 July	1.14E-02	6.24E-01	5.36E-03	2.80E-01	3.24E-04	1.93E-02
Year 13, 1 July	9.63E-03	6.33E-01	4.54E-03	2.85E-01	2.59E-04	1.95E-02
Year 14, 1 July	8.24E-03	6.42E-01	3.88E-03	2.89E-01	2.09E-04	1.97E-02
Year 15, 1 July	7.09E-03	6.49E-01	3.33E-03	2.92E-01	1.69E-04	1.99E-02
Year 16, 1 July	6.14E-03	6.55E-01	2.87E-03	2.95E-01	1.37E-04	2.00E-02
Year 17, 1 July	5.33E-03	6.60E-01	2.49E-03	2.97E-01	1.12E-04	2.01E-02
Year 18, 1 July	4.65E-03	6.65E-01	2.17E-03	3.00E-01	9.17E-05	2.02E-02
Year 19, 1 July	4.08E-03	6.69E-01	1.90E-03	3.01E-01	7.54E-05	2.03E-02
Year 20, 1 July	3.59E-03	6.73E-01	1.66E-03	3.03E-01	6.23E-05	2.04E-02

Date	Relocation (2 weeks)					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	4.85E-06	4.85E-06	2.77E-02	2.77E-02	4.34E-03	4.34E-03
Year 2, 1 July	4.15E-06	9.00E-06	3.75E-03	3.15E-02	2.59E-03	6.93E-03
Year 3, 1 July	3.31E-06	1.23E-05	2.39E-03	3.39E-02	1.99E-03	8.92E-03
Year 4, 1 July	2.68E-06	1.50E-05	1.77E-03	3.56E-02	1.55E-03	1.05E-02
Year 5, 1 July	2.19E-06	1.72E-05	1.34E-03	3.70E-02	1.21E-03	1.17E-02
Year 6, 1 July	1.81E-06	1.90E-05	1.03E-03	3.80E-02	9.49E-04	1.26E-02
Year 7, 1 July	1.51E-06	2.05E-05	7.88E-04	3.88E-02	7.40E-04	1.34E-02
Year 8, 1 July	1.27E-06	2.18E-05	6.09E-04	3.94E-02	5.80E-04	1.40E-02
Year 9, 1 July	1.07E-06	2.28E-05	4.72E-04	3.99E-02	4.55E-04	1.44E-02
Year 10, 1 July	9.20E-07	2.38E-05	3.66E-04	4.02E-02	3.56E-04	1.48E-02
Year 11, 1 July	7.91E-07	2.46E-05	2.85E-04	4.05E-02	2.78E-04	1.50E-02
Year 12, 1 July	6.85E-07	2.52E-05	2.22E-04	4.07E-02	2.18E-04	1.53E-02
Year 13, 1 July	5.97E-07	2.58E-05	1.73E-04	4.09E-02	1.70E-04	1.54E-02
Year 14, 1 July	5.24E-07	2.64E-05	1.35E-04	4.11E-02	1.34E-04	1.56E-02
Year 15, 1 July	4.62E-07	2.68E-05	1.05E-04	4.12E-02	1.05E-04	1.57E-02
Year 16, 1 July	4.09E-07	2.72E-05	8.24E-05	4.12E-02	8.19E-05	1.57E-02
Year 17, 1 July	3.63E-07	2.76E-05	6.45E-05	4.13E-02	6.42E-05	1.58E-02
Year 18, 1 July	3.22E-07	2.79E-05	5.05E-05	4.14E-02	5.03E-05	1.59E-02
Year 19, 1 July	2.89E-07	2.82E-05	3.95E-05	4.14E-02	3.94E-05	1.59E-02
Year 20, 1 July	2.58E-07	2.85E-05	3.09E-05	4.14E-02	3.08E-05	1.59E-02

Table III.2.36. Exposure doses for the hypothetical scenario, with relocation for 2 weeks (cont.).

Date	Relocation (2 weeks)				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	3.72E-01	3.72E-01	5.31E-02	3.47E-04	3.47E-04
Year 2, 1 July	7.57E-02	4.48E-01	4.29E-02	2.02E-04	5.49E-04
Year 3, 1 July	3.11E-02	4.79E-01	3.21E-02	1.50E-04	6.99E-04
Year 4, 1 July	1.75E-02	4.97E-01	2.45E-02	1.18E-04	8.17E-04
Year 5, 1 July	1.04E-02	5.07E-01	1.89E-02	9.49E-05	9.12E-04
Year 6, 1 July	6.27E-03	5.13E-01	1.48E-02	7.72E-05	9.90E-04
Year 7, 1 July	3.77E-03	5.17E-01	1.18E-02	6.36E-05	1.05E-03
Year 8, 1 July	2.27E-03	5.19E-01	9.54E-03	5.29E-05	1.11E-03
Year 9, 1 July	1.36E-03	5.21E-01	7.78E-03	4.45E-05	1.15E-03
Year 10, 1 July	8.21E-04	5.22E-01	6.42E-03	3.77E-05	1.19E-03
Year 11, 1 July	4.94E-04	5.22E-01	5.36E-03	3.23E-05	1.22E-03
Year 12, 1 July	2.97E-04	5.22E-01	4.51E-03	2.78E-05	1.25E-03
Year 13, 1 July	1.79E-04	5.23E-01	3.84E-03	2.41E-05	1.27E-03
Year 14, 1 July	1.08E-04	5.23E-01	3.27E-03	2.10E-05	1.29E-03
Year 15, 1 July	6.48E-05	5.23E-01	2.83E-03	1.85E-05	1.31E-03
Year 16, 1 July	3.90E-05	5.23E-01	2.43E-03	1.63E-05	1.33E-03
Year 17, 1 July	2.34E-05	5.23E-01	2.12E-03	1.44E-05	1.34E-03
Year 18, 1 July	1.41E-05	5.23E-01	1.85E-03	1.28E-05	1.36E-03
Year 19, 1 July	8.49E-06	5.23E-01	1.62E-03	1.14E-05	1.37E-03
Year 20, 1 July	5.11E-06	5.23E-01	1.43E-03	1.02E-05	1.38E-03

Date	Relocation (2 weeks)					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside on the 5th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	3.35E-01	3.35E-01	7.50E-01	7.50E-01	6.75E-01	6.75E-01
Year 2, 1 July	2.71E-01	6.06E-01	5.85E-01	1.33E+00	5.36E-01	1.21E+00
Year 3, 1 July	2.03E-01	8.09E-01	4.39E-01	1.77E+00	4.04E-01	1.61E+00
Year 4, 1 July	1.55E-01	9.64E-01	3.34E-01	2.11E+00	3.09E-01	1.92E+00
Year 5, 1 July	1.20E-01	1.08E+00	2.58E-01	2.37E+00	2.40E-01	2.16E+00
Year 6, 1 July	9.46E-02	1.18E+00	2.03E-01	2.57E+00	1.89E-01	2.35E+00
Year 7, 1 July	7.54E-02	1.25E+00	1.61E-01	2.73E+00	1.51E-01	2.50E+00
Year 8, 1 July	6.09E-02	1.32E+00	1.30E-01	2.86E+00	1.22E-01	2.63E+00
Year 9, 1 July	4.99E-02	1.37E+00	1.06E-01	2.97E+00	1.00E-01	2.73E+00
Year 10, 1 July	4.12E-02	1.41E+00	8.76E-02	3.05E+00	8.28E-02	2.81E+00
Year 11, 1 July	3.44E-02	1.44E+00	7.30E-02	3.13E+00	6.92E-02	2.88E+00
Year 12, 1 July	2.90E-02	1.47E+00	6.15E-02	3.19E+00	5.85E-02	2.94E+00
Year 13, 1 July	2.46E-02	1.49E+00	5.22E-02	3.24E+00	4.97E-02	2.99E+00
Year 14, 1 July	2.11E-02	1.52E+00	4.46E-02	3.28E+00	4.27E-02	3.03E+00
Year 15, 1 July	1.82E-02	1.53E+00	3.84E-02	3.32E+00	3.68E-02	3.07E+00
Year 16, 1 July	1.57E-02	1.55E+00	3.32E-02	3.36E+00	3.19E-02	3.10E+00
Year 17, 1 July	1.37E-02	1.56E+00	2.89E-02	3.39E+00	2.79E-02	3.12E+00
Year 18, 1 July	1.20E-02	1.58E+00	2.52E-02	3.41E+00	2.44E-02	3.15E+00
Year 19, 1 July	1.05E-02	1.59E+00	2.21E-02	3.43E+00	2.14E-02	3.17E+00
Year 20, 1 July	9.23E-03	1.59E+00	1.95E-02	3.45E+00	1.89E-02	3.19E+00

Table III.2.37. Exposure doses for the hypothetical scenario, with relocation for 6 weeks.

Date	Relocation (6 weeks)					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.49E-01	1.49E-01	5.95E-02	5.95E-02	3.85E-03	3.85E-03
Year 2, 1 July	1.10E-01	2.59E-01	5.16E-02	1.11E-01	3.52E-03	7.38E-03
Year 3, 1 July	8.18E-02	3.41E-01	3.87E-02	1.50E-01	2.73E-03	1.01E-02
Year 4, 1 July	6.23E-02	4.03E-01	2.94E-02	1.79E-01	2.12E-03	1.22E-02
Year 5, 1 July	4.82E-02	4.51E-01	2.28E-02	2.02E-01	1.66E-03	1.39E-02
Year 6, 1 July	3.76E-02	4.89E-01	1.79E-02	2.20E-01	1.30E-03	1.52E-02
Year 7, 1 July	2.99E-02	5.19E-01	1.42E-02	2.34E-01	1.02E-03	1.62E-02
Year 8, 1 July	2.41E-02	5.43E-01	1.14E-02	2.45E-01	8.06E-04	1.70E-02
Year 9, 1 July	1.96E-02	5.63E-01	9.30E-03	2.55E-01	6.38E-04	1.77E-02
Year 10, 1 July	1.62E-02	5.79E-01	7.67E-03	2.62E-01	5.06E-04	1.82E-02
Year 11, 1 July	1.35E-02	5.92E-01	6.37E-03	2.69E-01	4.03E-04	1.86E-02
Year 12, 1 July	1.14E-02	6.04E-01	5.36E-03	2.74E-01	3.24E-04	1.89E-02
Year 13, 1 July	9.63E-03	6.13E-01	4.54E-03	2.79E-01	2.59E-04	1.92E-02
Year 14, 1 July	8.24E-03	6.22E-01	3.88E-03	2.83E-01	2.09E-04	1.94E-02
Year 15, 1 July	7.09E-03	6.29E-01	3.33E-03	2.86E-01	1.69E-04	1.95E-02
Year 16, 1 July	6.14E-03	6.35E-01	2.87E-03	2.89E-01	1.37E-04	1.97E-02
Year 17, 1 July	5.33E-03	6.40E-01	2.49E-03	2.91E-01	1.12E-04	1.98E-02
Year 18, 1 July	4.65E-03	6.45E-01	2.17E-03	2.93E-01	9.17E-05	1.99E-02
Year 19, 1 July	4.08E-03	6.49E-01	1.90E-03	2.95E-01	7.54E-05	1.99E-02
Year 20, 1 July	3.59E-03	6.52E-01	1.66E-03	2.97E-01	6.23E-05	2.00E-02

Date	Relocation (6 weeks)					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	4.43E-06	4.43E-06	2.15E-02	2.15E-02	3.76E-03	3.76E-03
Year 2, 1 July	4.15E-06	8.58E-06	3.75E-03	2.53E-02	2.59E-03	6.35E-03
Year 3, 1 July	3.31E-06	1.19E-05	2.39E-03	2.76E-02	1.99E-03	8.34E-03
Year 4, 1 July	2.68E-06	1.46E-05	1.77E-03	2.94E-02	1.55E-03	9.89E-03
Year 5, 1 July	2.19E-06	1.68E-05	1.34E-03	3.08E-02	1.21E-03	1.11E-02
Year 6, 1 July	1.81E-06	1.86E-05	1.03E-03	3.18E-02	9.49E-04	1.20E-02
Year 7, 1 July	1.51E-06	2.01E-05	7.88E-04	3.26E-02	7.40E-04	1.28E-02
Year 8, 1 July	1.27E-06	2.13E-05	6.09E-04	3.32E-02	5.80E-04	1.34E-02
Year 9, 1 July	1.07E-06	2.24E-05	4.72E-04	3.37E-02	4.55E-04	1.38E-02
Year 10, 1 July	9.20E-07	2.33E-05	3.66E-04	3.40E-02	3.56E-04	1.42E-02
Year 11, 1 July	7.91E-07	2.41E-05	2.85E-04	3.43E-02	2.78E-04	1.45E-02
Year 12, 1 July	6.85E-07	2.48E-05	2.22E-04	3.45E-02	2.18E-04	1.47E-02
Year 13, 1 July	5.97E-07	2.54E-05	1.73E-04	3.47E-02	1.70E-04	1.48E-02
Year 14, 1 July	5.24E-07	2.59E-05	1.35E-04	3.48E-02	1.34E-04	1.50E-02
Year 15, 1 July	4.62E-07	2.64E-05	1.05E-04	3.49E-02	1.05E-04	1.51E-02
Year 16, 1 July	4.09E-07	2.68E-05	8.24E-05	3.50E-02	8.19E-05	1.52E-02
Year 17, 1 July	3.63E-07	2.72E-05	6.45E-05	3.51E-02	6.42E-05	1.52E-02
Year 18, 1 July	3.22E-07	2.75E-05	5.05E-05	3.51E-02	5.03E-05	1.53E-02
Year 19, 1 July	2.89E-07	2.78E-05	3.95E-05	3.52E-02	3.94E-05	1.53E-02
Year 20, 1 July	2.58E-07	2.80E-05	3.09E-05	3.52E-02	3.08E-05	1.54E-02

Table III.2.37. Exposure doses for the hypothetical scenario, with relocation for 6 weeks (cont.).

Date	Relocation (6 weeks)				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	3.10E-01	3.10E-01	4.84E-02	3.05E-04	3.05E-04
Year 2, 1 July	7.57E-02	3.86E-01	4.29E-02	2.02E-04	5.07E-04
Year 3, 1 July	3.11E-02	4.17E-01	3.21E-02	1.50E-04	6.57E-04
Year 4, 1 July	1.75E-02	4.34E-01	2.45E-02	1.18E-04	7.76E-04
Year 5, 1 July	1.04E-02	4.45E-01	1.89E-02	9.49E-05	8.71E-04
Year 6, 1 July	6.27E-03	4.51E-01	1.48E-02	7.72E-05	9.48E-04
Year 7, 1 July	3.77E-03	4.55E-01	1.18E-02	6.36E-05	1.01E-03
Year 8, 1 July	2.27E-03	4.57E-01	9.54E-03	5.29E-05	1.06E-03
Year 9, 1 July	1.36E-03	4.58E-01	7.78E-03	4.45E-05	1.11E-03
Year 10, 1 July	8.21E-04	4.59E-01	6.42E-03	3.77E-05	1.15E-03
Year 11, 1 July	4.94E-04	4.60E-01	5.36E-03	3.23E-05	1.18E-03
Year 12, 1 July	2.97E-04	4.60E-01	4.51E-03	2.78E-05	1.21E-03
Year 13, 1 July	1.79E-04	4.60E-01	3.84E-03	2.41E-05	1.23E-03
Year 14, 1 July	1.08E-04	4.60E-01	3.27E-03	2.10E-05	1.25E-03
Year 15, 1 July	6.48E-05	4.60E-01	2.83E-03	1.85E-05	1.27E-03
Year 16, 1 July	3.90E-05	4.60E-01	2.43E-03	1.63E-05	1.29E-03
Year 17, 1 July	2.34E-05	4.60E-01	2.12E-03	1.44E-05	1.30E-03
Year 18, 1 July	1.41E-05	4.60E-01	1.85E-03	1.28E-05	1.31E-03
Year 19, 1 July	8.49E-06	4.60E-01	1.62E-03	1.14E-05	1.33E-03
Year 20, 1 July	5.11E-06	4.60E-01	1.43E-03	1.02E-05	1.34E-03

Date	Relocation (6 weeks)					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside on the 5th floor	
	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)	Annual ($mGy\ y^{-1}$)	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	3.05E-01	3.05E-01	6.79E-01	6.79E-01	6.13E-01	6.13E-01
Year 2, 1 July	2.71E-01	5.76E-01	5.85E-01	1.26E+00	5.36E-01	1.15E+00
Year 3, 1 July	2.03E-01	7.79E-01	4.39E-01	1.70E+00	4.04E-01	1.55E+00
Year 4, 1 July	1.55E-01	9.35E-01	3.34E-01	2.04E+00	3.09E-01	1.86E+00
Year 5, 1 July	1.20E-01	1.05E+00	2.58E-01	2.29E+00	2.40E-01	2.10E+00
Year 6, 1 July	9.46E-02	1.15E+00	2.03E-01	2.50E+00	1.89E-01	2.29E+00
Year 7, 1 July	7.54E-02	1.22E+00	1.61E-01	2.66E+00	1.51E-01	2.44E+00
Year 8, 1 July	6.09E-02	1.29E+00	1.30E-01	2.79E+00	1.22E-01	2.56E+00
Year 9, 1 July	4.99E-02	1.34E+00	1.06E-01	2.90E+00	1.00E-01	2.66E+00
Year 10, 1 July	4.12E-02	1.38E+00	8.76E-02	2.98E+00	8.28E-02	2.75E+00
Year 11, 1 July	3.44E-02	1.41E+00	7.30E-02	3.06E+00	6.92E-02	2.82E+00
Year 12, 1 July	2.90E-02	1.44E+00	6.15E-02	3.12E+00	5.85E-02	2.87E+00
Year 13, 1 July	2.46E-02	1.46E+00	5.22E-02	3.17E+00	4.97E-02	2.92E+00
Year 14, 1 July	2.11E-02	1.49E+00	4.46E-02	3.21E+00	4.27E-02	2.97E+00
Year 15, 1 July	1.82E-02	1.50E+00	3.84E-02	3.25E+00	3.68E-02	3.00E+00
Year 16, 1 July	1.57E-02	1.52E+00	3.32E-02	3.29E+00	3.19E-02	3.03E+00
Year 17, 1 July	1.37E-02	1.53E+00	2.89E-02	3.31E+00	2.79E-02	3.06E+00
Year 18, 1 July	1.20E-02	1.55E+00	2.52E-02	3.34E+00	2.44E-02	3.09E+00
Year 19, 1 July	1.05E-02	1.56E+00	2.21E-02	3.36E+00	2.14E-02	3.11E+00
Year 20, 1 July	9.23E-03	1.57E+00	1.95E-02	3.38E+00	1.89E-02	3.13E+00

Table III.2.38. Exposure doses for the hypothetical scenario, with relocation for 6 months.

Date	Relocation (6 months)					
	Occupational (Building 1) Work on the 1st floor		Occupational (Building 1) Work on the 5th floor		Occupational (Building 1) Work on the 20th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	7.14E-02	7.14E-02	3.18E-02	3.18E-02	2.11E-03	2.11E-03
Year 2, 1 July	1.10E-01	1.81E-01	5.16E-02	8.33E-02	3.52E-03	5.63E-03
Year 3, 1 July	8.18E-02	2.63E-01	3.87E-02	1.22E-01	2.73E-03	8.36E-03
Year 4, 1 July	6.23E-02	3.26E-01	2.94E-02	1.51E-01	2.12E-03	1.05E-02
Year 5, 1 July	4.82E-02	3.74E-01	2.28E-02	1.74E-01	1.66E-03	1.21E-02
Year 6, 1 July	3.76E-02	4.11E-01	1.79E-02	1.92E-01	1.30E-03	1.34E-02
Year 7, 1 July	2.99E-02	4.41E-01	1.42E-02	2.06E-01	1.02E-03	1.45E-02
Year 8, 1 July	2.41E-02	4.65E-01	1.14E-02	2.18E-01	8.06E-04	1.53E-02
Year 9, 1 July	1.96E-02	4.85E-01	9.30E-03	2.27E-01	6.38E-04	1.59E-02
Year 10, 1 July	1.62E-02	5.01E-01	7.67E-03	2.35E-01	5.06E-04	1.64E-02
Year 11, 1 July	1.35E-02	5.15E-01	6.37E-03	2.41E-01	4.03E-04	1.68E-02
Year 12, 1 July	1.14E-02	5.26E-01	5.36E-03	2.46E-01	3.24E-04	1.71E-02
Year 13, 1 July	9.63E-03	5.36E-01	4.54E-03	2.51E-01	2.59E-04	1.74E-02
Year 14, 1 July	8.24E-03	5.44E-01	3.88E-03	2.55E-01	2.09E-04	1.76E-02
Year 15, 1 July	7.09E-03	5.51E-01	3.33E-03	2.58E-01	1.69E-04	1.78E-02
Year 16, 1 July	6.14E-03	5.57E-01	2.87E-03	2.61E-01	1.37E-04	1.79E-02
Year 17, 1 July	5.33E-03	5.62E-01	2.49E-03	2.63E-01	1.12E-04	1.80E-02
Year 18, 1 July	4.65E-03	5.67E-01	2.17E-03	2.66E-01	9.17E-05	1.81E-02
Year 19, 1 July	4.08E-03	5.71E-01	1.90E-03	2.68E-01	7.54E-05	1.82E-02
Year 20, 1 July	3.59E-03	5.75E-01	1.66E-03	2.69E-01	6.23E-05	1.83E-02

Date	Relocation (6 months)					
	Occupational (Building 1) Work on the 60th floor		Occupational (Building 2) Work on the 1st floor		Occupational (Building 2) Work on the 4th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	2.43E-06	2.43E-06	5.00E-03	5.00E-03	1.69E-03	1.69E-03
Year 2, 1 July	4.15E-06	6.58E-06	3.75E-03	8.75E-03	2.59E-03	4.28E-03
Year 3, 1 July	3.31E-06	9.89E-06	2.39E-03	1.11E-02	1.99E-03	6.27E-03
Year 4, 1 July	2.68E-06	1.26E-05	1.77E-03	1.29E-02	1.55E-03	7.82E-03
Year 5, 1 July	2.19E-06	1.48E-05	1.34E-03	1.43E-02	1.21E-03	9.03E-03
Year 6, 1 July	1.81E-06	1.66E-05	1.03E-03	1.53E-02	9.49E-04	9.98E-03
Year 7, 1 July	1.51E-06	1.81E-05	7.88E-04	1.61E-02	7.40E-04	1.07E-02
Year 8, 1 July	1.27E-06	1.93E-05	6.09E-04	1.67E-02	5.80E-04	1.13E-02
Year 9, 1 July	1.07E-06	2.04E-05	4.72E-04	1.72E-02	4.55E-04	1.18E-02
Year 10, 1 July	9.20E-07	2.13E-05	3.66E-04	1.75E-02	3.56E-04	1.21E-02
Year 11, 1 July	7.91E-07	2.21E-05	2.85E-04	1.78E-02	2.78E-04	1.24E-02
Year 12, 1 July	6.85E-07	2.28E-05	2.22E-04	1.80E-02	2.18E-04	1.26E-02
Year 13, 1 July	5.97E-07	2.34E-05	1.73E-04	1.82E-02	1.70E-04	1.28E-02
Year 14, 1 July	5.24E-07	2.39E-05	1.35E-04	1.83E-02	1.34E-04	1.29E-02
Year 15, 1 July	4.62E-07	2.44E-05	1.05E-04	1.84E-02	1.05E-04	1.30E-02
Year 16, 1 July	4.09E-07	2.48E-05	8.24E-05	1.85E-02	8.19E-05	1.31E-02
Year 17, 1 July	3.63E-07	2.52E-05	6.45E-05	1.86E-02	6.42E-05	1.32E-02
Year 18, 1 July	3.22E-07	2.55E-05	5.05E-05	1.86E-02	5.03E-05	1.32E-02
Year 19, 1 July	2.89E-07	2.58E-05	3.95E-05	1.87E-02	3.94E-05	1.32E-02
Year 20, 1 July	2.58E-07	2.60E-05	3.09E-05	1.87E-02	3.08E-05	1.33E-02

Table III.2.38. Exposure doses for the hypothetical scenario, with relocation for 6 months (cont.).

Date	Relocation (6 months)				
	Occupational (Building 2) Work on the top floor (outside)		School (Building 3)	Occasional (Building 4)	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July					
Year 1, 1 July	1.03E-01	1.03E-01	2.62E-02	1.41E-04	1.41E-04
Year 2, 1 July	7.57E-02	1.78E-01	4.29E-02	2.02E-04	3.43E-04
Year 3, 1 July	3.11E-02	2.09E-01	3.21E-02	1.50E-04	4.94E-04
Year 4, 1 July	1.75E-02	2.27E-01	2.45E-02	1.18E-04	6.12E-04
Year 5, 1 July	1.04E-02	2.37E-01	1.89E-02	9.49E-05	7.07E-04
Year 6, 1 July	6.27E-03	2.44E-01	1.48E-02	7.72E-05	7.84E-04
Year 7, 1 July	3.77E-03	2.47E-01	1.18E-02	6.36E-05	8.48E-04
Year 8, 1 July	2.27E-03	2.50E-01	9.54E-03	5.29E-05	9.01E-04
Year 9, 1 July	1.36E-03	2.51E-01	7.78E-03	4.45E-05	9.45E-04
Year 10, 1 July	8.21E-04	2.52E-01	6.42E-03	3.77E-05	9.83E-04
Year 11, 1 July	4.94E-04	2.52E-01	5.36E-03	3.23E-05	1.02E-03
Year 12, 1 July	2.97E-04	2.53E-01	4.51E-03	2.78E-05	1.04E-03
Year 13, 1 July	1.79E-04	2.53E-01	3.84E-03	2.41E-05	1.07E-03
Year 14, 1 July	1.08E-04	2.53E-01	3.27E-03	2.10E-05	1.09E-03
Year 15, 1 July	6.48E-05	2.53E-01	2.83E-03	1.85E-05	1.11E-03
Year 16, 1 July	3.90E-05	2.53E-01	2.43E-03	1.63E-05	1.12E-03
Year 17, 1 July	2.34E-05	2.53E-01	2.12E-03	1.44E-05	1.14E-03
Year 18, 1 July	1.41E-05	2.53E-01	1.85E-03	1.28E-05	1.15E-03
Year 19, 1 July	8.49E-06	2.53E-01	1.62E-03	1.14E-05	1.16E-03
Year 20, 1 July	5.11E-06	2.53E-01	1.43E-03	1.02E-05	1.17E-03

Date	Relocation (6 months)					
	Residential (Building 5)		Residential (Building 6) Reside on the 1st floor		Residential (Building 6) Reside one the 5th floor	
	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)	Annual (mGy y^{-1})	Cumulative (mGy)
Year 0, 1 July						
Year 1, 1 July	1.65E-01	1.65E-01	3.60E-01	3.60E-01	3.28E-01	3.28E-01
Year 2, 1 July	2.71E-01	4.36E-01	5.85E-01	9.45E-01	5.36E-01	8.64E-01
Year 3, 1 July	2.03E-01	6.39E-01	4.39E-01	1.38E+00	4.04E-01	1.27E+00
Year 4, 1 July	1.55E-01	7.95E-01	3.34E-01	1.72E+00	3.09E-01	1.58E+00
Year 5, 1 July	1.20E-01	9.15E-01	2.58E-01	1.98E+00	2.40E-01	1.82E+00
Year 6, 1 July	9.46E-02	1.01E+00	2.03E-01	2.18E+00	1.89E-01	2.01E+00
Year 7, 1 July	7.54E-02	1.08E+00	1.61E-01	2.34E+00	1.51E-01	2.16E+00
Year 8, 1 July	6.09E-02	1.15E+00	1.30E-01	2.47E+00	1.22E-01	2.28E+00
Year 9, 1 July	4.99E-02	1.20E+00	1.06E-01	2.58E+00	1.00E-01	2.38E+00
Year 10, 1 July	4.12E-02	1.24E+00	8.76E-02	2.66E+00	8.28E-02	2.46E+00
Year 11, 1 July	3.44E-02	1.27E+00	7.30E-02	2.74E+00	6.92E-02	2.53E+00
Year 12, 1 July	2.90E-02	1.30E+00	6.15E-02	2.80E+00	5.85E-02	2.59E+00
Year 13, 1 July	2.46E-02	1.32E+00	5.22E-02	2.85E+00	4.97E-02	2.64E+00
Year 14, 1 July	2.11E-02	1.35E+00	4.46E-02	2.90E+00	4.27E-02	2.68E+00
Year 15, 1 July	1.82E-02	1.36E+00	3.84E-02	2.93E+00	3.68E-02	2.72E+00
Year 16, 1 July	1.57E-02	1.38E+00	3.32E-02	2.97E+00	3.19E-02	2.75E+00
Year 17, 1 July	1.37E-02	1.39E+00	2.89E-02	3.00E+00	2.79E-02	2.78E+00
Year 18, 1 July	1.20E-02	1.41E+00	2.52E-02	3.02E+00	2.44E-02	2.80E+00
Year 19, 1 July	1.05E-02	1.42E+00	2.21E-02	3.04E+00	2.14E-02	2.82E+00
Year 20, 1 July	9.23E-03	1.43E+00	1.95E-02	3.06E+00	1.89E-02	2.84E+00

III.2.7. Lessons learned

The lessons learned from Pripyat and the hypothetical scenarios are as follows:

(1) Exposure doses are distinctly different with different receptor locations, because of the differences in contamination of various surfaces and their contributions;
(2) Reduction of exposure dose rates with time following a deposition varies with receptor location, because of the differences in contributions of various surfaces and their environmental removals;
(3) As time passes, for the Pripyat contamination scenario, the contribution of ^{137}Cs to exposure doses is dominant because of its long radioactive half-life;
(4) METRO-K estimates only the external exposure from radionuclides deposited onto outdoor surfaces. In some cases, exposure pathways that are not considered in METRO-K, such as the external exposure from indoor surfaces and internal exposure from resuspended radioactive materials, may be important contributors. Additional efforts would be necessary to increase understanding of these exposure pathways in an urban environment;
(5) Radionuclide behavior on surfaces may be different before and after specific remediation measures. Therefore, further studies may be necessary for radionuclide behavior after remediation measures, depending on the types of surfaces; and
(6) In the Pripyat and hypothetical scenarios, the effects of remediation measures are described in terms of just dose reduction. Additional efforts including economic and social impacts of remediation measures will be necessary.

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III.3. Description of EDEM
(Vladislav Golikov)

III.3.1. Description of model and calculations

For calculations two models were used:

- EDEM model (Effective Dose Estimation Module) – so-called simple model where the exposure of an individual at a given location is obtained by directly multiplying the dose received in the reference site by the location factors. The variation in time of the kerma rate in air, 1 m above the reference surface by migration of radionuclides into the soil, was expressed by attenuation functions derived from measurements in Russia, Ukraine (during 13 years after the Chernobyl accident) [III.3.1– III.3.5], USA [III.3.6], Germany [III.3.7]. The location factors are derived from the results of dose rate measurements performed in Russia over a ten-year period after the Chernobyl accident [III.3.8]; and
- For calculation of decontamination efficiency in the urban area, a compartment model similar to EXPURT and URGENT models was used.

III.3.1.1. Description of the EDEM model

The model is designed to calculate external exposures due to the Chernobyl accident for several population groups living in a given settlement. It consists of four sub-models for the following issues:

- Absorbed dose rate in air at a reference site in the settlement;
- Location factors, defined by the ratio of gamma-dose rates in air at a location of interest and at the reference site;
- Occupancy times of different population groups at various types of locations; and
- Conversion factors from absorbed dose rate in air to effective dose rate.

The first sub-model calculates the absorbed dose rate $\dot{d}(t)$ in air at a height of 1 m above an undisturbed open field, normally lawns or meadows (reference site) according to:

$$\dot{d}(t) = r(t) \cdot A_{Cs137} \cdot \sum_l \left(\frac{A_l}{A_{Cs137}}\right) \cdot \dot{d}_l \cdot \exp(-\lambda_l \cdot t), \qquad \text{(III.3.1)}$$

where:

the summation index *l* is for the radionuclides deposited after the Chernobyl accident;
λ_l is the decay constant;
$\dot{d}_l$ is the gamma-dose rate in air at a height of 1 m due to a reference activity distribution of radionuclide *l* in the ground. An exponential source in a soil with relaxation mass per unit area of 0.2 g cm^{-2} was chosen as reference distribution for Pripyat scenario;
A_l is the activity of radionuclide *l* deposited per unit area of ground; and
r(t) is the ratio of the gamma-dose rates in air above an undisturbed open field and above the reference distribution.

In the second sub-model, absorbed dose rates in air at urban locations of type *j* are obtained by multiplying the absorbed dose rate $\dot{d}(t)$ in air at a height of 1 m above an undisturbed open field by so called location factors f_j .

The third sub-model calculates dose rates in air for population groups *i* by weighting the dose rates in air at locations of type *j* with occupancy factors p_{ij} and summing over the locations of interest. Five population groups were defined according to age, social factors and occupation: indoor workers, outdoor workers, pensioners, school-age children, and pre-school children. Occupancy factors p_{ij}, are defined by the part of time spent by representatives of the *i*-th population group at locations of type *j*.

In the fourth sub-model, the effective dose rate $\dot{E}_i(t)$ to the population group *i* is calculated according to:

$$\dot{E}_i(t) = \dot{d}(t) \cdot k_i \cdot \sum_j f_j \cdot p_{ij} \ . \qquad \text{(III.3.2)}$$

The conversion factors k_i of the absorbed dose rate in air to the effective dose rate in principle depend on the characteristics of the radiation field, *i.e.*, on the location and on the time after the accident. However, for environmental contaminations with gamma emitting radionuclides, this dependence is relatively weak. Therefore, the model uses conversion factors k_i that are independent of location and time after the accident: 0.75 Sv Gy^{-1} for the adults, 0.80 Sv Gy^{-1} for the teenagers (7–17 years) and 0.90 Sv Gy^{-1} for the children of less than seven years [III.3.2].

Input data and parameters of EDEM model for Pripyat scenario

Radionuclide-specific parameter values used for the Pripyat scenario are provided in Table III.3.1. For both districts D1 and D4, the value of A_{137} = 1.4 MBq m^{-2} was used, according to the results of measurements in D1.

Table III.3.1. List of radionuclides and d_l values.

Radionuclide	$T_{1/2}$	$A_l/A_{Cs\text{-}137}$ (26.09.86)	$A_l/A_{Cs\text{-}137}$ (26.04.86)	d_l , (nGy h^{-1})/ (kBq m^{-2})*
$^{137}Cs+^{137m}Ba$	30 y	1	1	2.26**
^{134}Cs	2.06 y	0.5	0.57	5.8
^{103}Ru	39.4 d	1.2	17.8	1.87
$^{106}Ru+^{106}Rh$	368 d	2.9	3.9	0.81**
^{95}Zr	64 d	5.6	29.4	2.74
^{95}Nb	35.2 d	9.2	29.4	2.84
^{141}Ce	32.5 d	0.7	19.5	0.29
$^{144}Ce+^{144}Pr$	284 d	10.6	15.2	0.078**

* According to ICRU-53.
** For condition of equilibrium mother and daughter radionuclides.

Attenuation function *r(t)*

The gamma dose rate at a height of 1 m above the ground surface was derived from the measured vertical distribution of radiocaesium in the soil. Division of the result by the gamma dose rate due to a plane source below a soil slab of 0.5 g cm^{-2} yielded the attenuation function $r(t)$. Results were fitted in the form:

$$r(t) = p_1 \cdot \exp\left(-\frac{\ln 2}{T_1} \cdot t\right) + p_2 \cdot \exp\left(-\frac{\ln 2}{T_2} \cdot t\right) \qquad \text{(III.3.3)}$$

The resulting parameter values for Ukraine (dry deposition) were p_1 = 0.34, p_2 = 0.66, T_1 = 1.5 years, and T_2 = 50 years.

Time dependence of location factors

The time dependence of location factors $f_{j,Cs}$ for radiocaesium in urban areas (asphalt, dirt and virgin surfaces) was modeled by fitting the available data in the form:

$$f_{j,Cs}(t) = a_1 \cdot \exp(-\frac{\ln(2) \cdot t}{T}) + a_2 \qquad \text{(III.3.4)}$$

where:

t is the time elapsed since the moment of the accident, years;
a_1, T, and a_2 are parameters as summarized in Table III.3.2.

Efficiency of decontamination was taken into account by one-time changes of location factors. Further the effect of decontamination was proposed as a constant in time. The efficiency of decontamination was estimated by a compartment model.

III.3.1.2. Description of the compartment model

For calculation of decontamination efficiency in the urban area, a compartment model similar to the EXPURT and URGENT models was used (see Figure III.3.1).

Table III.3.2. Parameters in Equation (III.3.4).

Location	**a_1**	**a_2**	**T (years)**
Virgin soil	0.32	0.68	1.4
Dirt surface	0.5	0.25	2.2
Asphalt	0.56	0.12	0.9
Indoor in 5-storey house block			
Ground floor	0.02	0.02	1.4
First floor	0.013	0.012	1.4
Last floor	0.009	0.010	1.4
Ground floor in school (kindergarten)	0.02	0.02	1.4

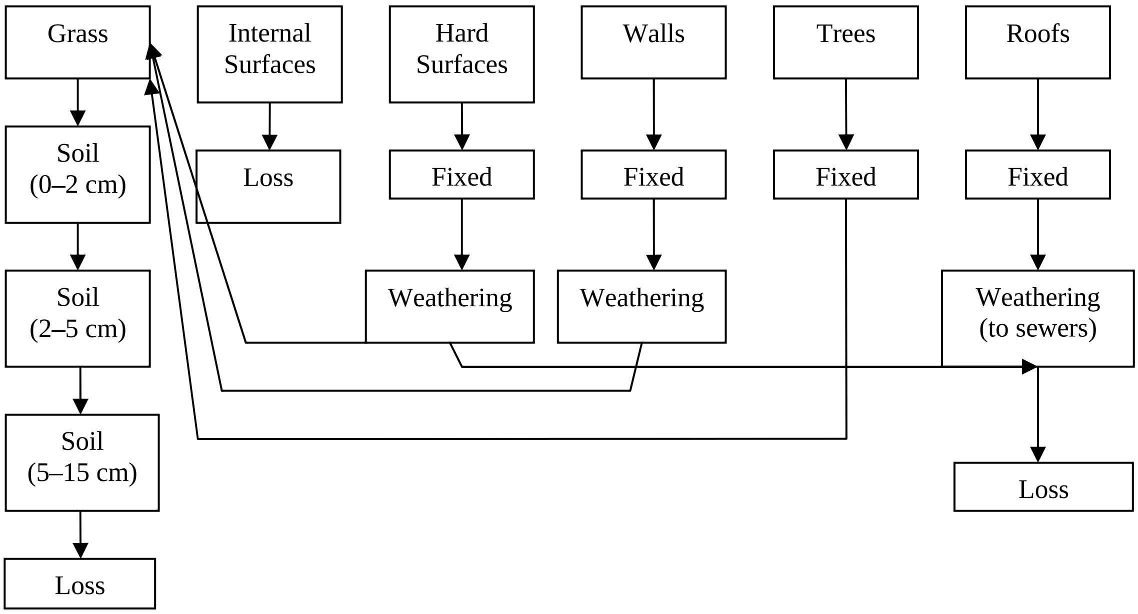

Fig. III.3.1. Urban contamination flow chart.

Parameters of compartment model

Values used for the various parameters in the compartment model are summarized below.

— Initial distribution of dry deposition (all radionuclides):

Surface	Dry deposition
Walls	0.1
Roofs	1.0
Roads	0.4
Leafy trees	3
Grass	0.3
Soil (0–2 cm)	0.7

— The transfer coefficient for fixation of activity of all dry-deposited radionuclides on walls, hard surfaces, roofs and trees has been set to 0.23 day^{-1}, corresponding to the assumption that 90% of the activity would be fixed within 10 days if no activity were removed by weathering processes. It is suggested that the residence time of sewage in sewage systems is also about 10 days. The weathering (transfer) processes were modelled by two, one-component functions [III.3.9]:

Compartment	Fraction	Half-life	Fraction	Half-life
Walls	0.8	10 years	0.2	60 days
Roads	0.5	5 years	0.5	70 days
Roofs	0.5	4 years	0.5	35 days
Trees	1	2 years		
Grass	1	15 days		
Soil (0–2 cm)	1	5 years		
Soil (2–5 cm)	1	6 years		
Soil (5–15 cm)	1	30 years		

- Dose calculations were performed on the basis of data for a multi-storey house block [III.3.8]. Decontamination effects assuming dry deposition and decontamination on day 15 are listed below.

	Countermeasure	*DF
1	Cutting and removal of grass	2
2	Washing of roads	5
3	Washing of roofs and walls	10
4	Removal of trees or leaves	10
5	Removal of soil (5 cm)	6

*DF – decontamination factor.

- Contribution to dose reduction, %:

Detector location	Windows	Walls	Roof	Yard	Trees	Street	*W_Win_N	**R_N	***DRF
Detector over soil	0.0	4.0	0.2	60.9	28.0	0.1	5.1	1.7	0.21
Detector over hard surfaces	0.0	6.1	0.1	0.0	0.0	78.3	14.2	1.3	0.19
Detector in ground floor	0.1	3.4	0.0	22.8	47.7	15.6	9.1	1.2	0.17
Detector in second floor	0.5	12.1	0.0	14.4	24.4	8.4	32.7	7.5	0.19
Detector in last floor	0.2	4.0	73.8	2.7	3.2	0.9	5.4	9.8	0.12

*W_Win_N – Walls and windows of neighbouring buildings.
**R_N – Roofs of neighbouring buildings.
*** DRF – dose reduction factor.

III.3.2. Comparison of model predictions and test measurements for District 4

It is necessary to compare measurement results and model predictions with care. For this purpose model calculations need to be run for conditions as similar as possible to conditions of measurements.

According to the scenario (Figure I.11 in Appendix I), not all of District 4 was decontaminated. Results of dose rate measurements over soil confirm this. So, dose rates above soil (with subtraction of background equal to 0.12 µSv h^{-1}) measured in location 15 (decontaminated part of District 4) and in locations 13 and 20 (non-decontaminated part of District 4) differ by more than a factor of three, 0.25 µSv h^{-1} and 0.90 µSv h^{-1} (mean value for locations 13 and 20), correspondingly.

To verify the model predictions, the following results of measurements of dose rates (P_j) in July 2006 in different locations of District 4 (with subtraction of background equal of 0.12 µSv h^{-1}) were used:

- Mean value for locations 13 and 20 (open area, over soil, not decontaminated part of District 4), $P_{13-20} = \frac{0.72 + 1.08}{2} = 0.90$ µSv h^{-1};
- Location 15 (open area, over soil, decontaminated part of District 4), $P_{15} = 0.25$ µSv h^{-1};

— Location 21 (open area, over asphalt, decontaminated part of District 4), $P_{21} = 0.092$ μSv h^{-1}; and

— Results of gamma-spectrometric measurements in 1987 [III.3.10].

Figure III.3.2 includes the results of model predictions of dose rate over soil (mean value for locations 13 and 20) in the non-decontaminated part of District 4, since April 1986. The results of gamma-spectrometric measurements in 1987 do not differ from model predictions by more than 10% [III.3.10]. The results of model calculations for July 2006 are below the respective results of measurements by only about 30%.

The results of model predictions of dose rate over soil (location 15) in decontaminated part of District 4, since April, 1986 are submitted in Figure III.3.3. In the same figure, results of measurements in September 1986 (immediately after decontamination) about which there is information in description of Pripyat scenario (Chapter 3) and results of measurements in July 2006 are shown. The value of the dose rate in July 2006 predicted by the model is less than the result of measurements by 50 %. Probably, one of the reasons for this was differences in values of dose reduction factors (DRF). In the model the value of DRF equal to 0.21 was used, and in reality according to measurements in July, 2006 the value of DRF was $\frac{0.25}{0.90} = 0.28$.

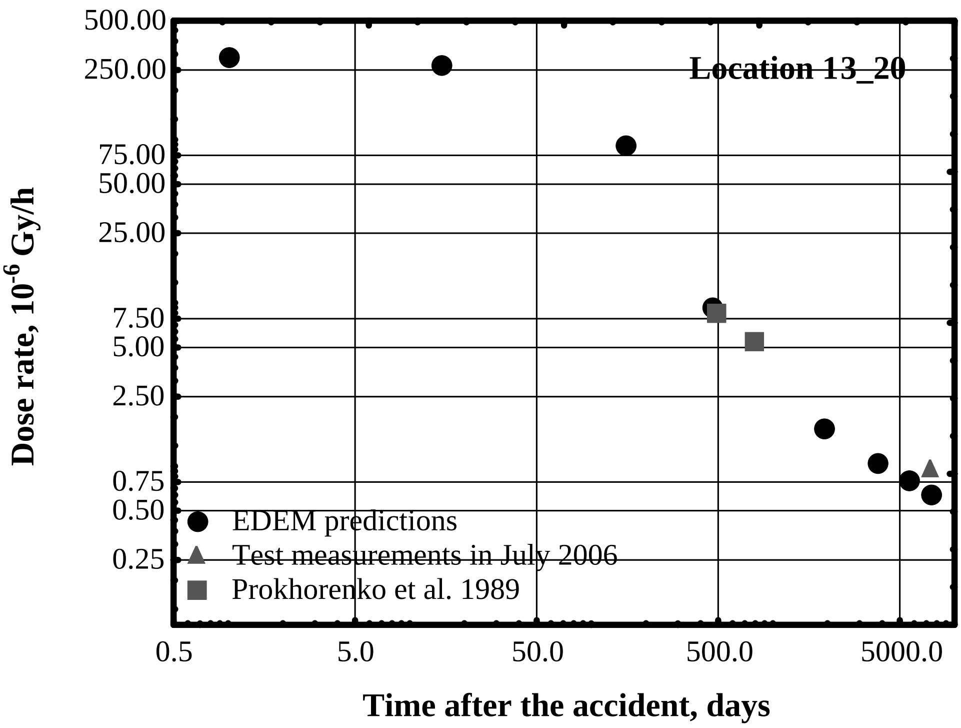

Fig. III.3.2. Example of model predictions for dose rate over non-decontaminated soil (locations 13 and 20) in District 4 of Pripyat, compared with measurements made in 1987–1988 [III.3.10] and in 2006 (S. Gaschak and A. Arkhipov; see Section 3.5 and Appendix I.8). The measurements have been corrected for an estimated contribution of 0.12 µGy h^{-1} from background (non-Chernobyl) sources of radiation.

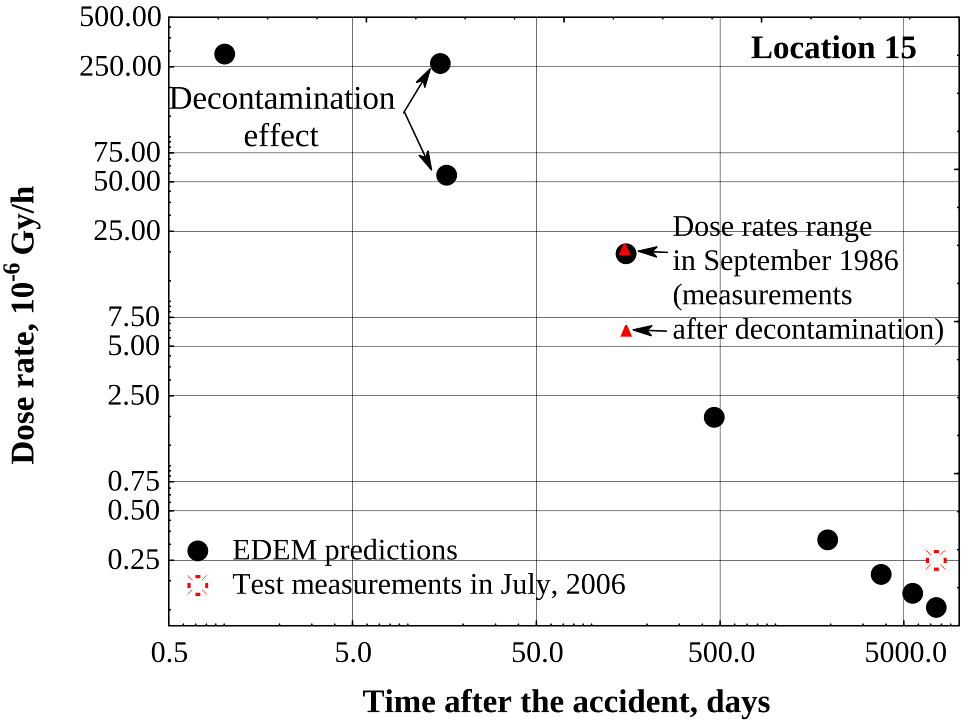

Fig. III.3.3. Example of model predictions for dose rate over decontaminated soil (location 15) in District 4 of Pripyat, compared with measurements made in 1986 (Pripyat scenario, Appendix I) and in 2006 (S. Gaschak and A. Arkhipov; see Section 3.5 and Appendix I.8). The measurements have been corrected for an estimated contribution of 0.12 µGy h^{-1} from background (non-Chernobyl) sources of radiation.

In the case of measurements at location 21, geometric conditions were more complex. In this case a part of the dose rate is caused by asphalt contamination, and a part by contamination of soil surrounding the asphalt. The model calculated the dose rate only over an infinite asphalt surface. Therefore, in this case, it is necessary based on the results of measurements in complex geometry to estimate the dose rate value over an infinite asphalt surface and to compare it to model predictions.

Table III.3.3 illustrates the values of the relative dose as a function of the size of the surrounding contaminated areas and the thickness of the contaminated layer. With increasing photon energy, the relative contributions to dose rate from remote areas increase. This is valid for all thicknesses of contaminated layers. However, the effect gets more pronounced with increasing thickness of the contaminated layer. For a source with a thickness of 1 cm, 50–66% of the dose is due to photons within a radius of about 5 m, whereas from a 15 cm thick source, this fraction is about 80%.

In our case (location 21), it is possible to assume that in the absence of asphalt, the contribution to the dose rate due to soil in the size equal to the area of asphalt equals about 70%, and the other 30% is caused by the contribution from surrounding soil. Then it is possible to write the following equation:

$$0.3 \cdot P_{15} + 0.7 \cdot P_{asph,\infty} = P_{21} \text{ or } 0.3 \cdot 0.25 \mu Sv \cdot h^{-1} + 0.7 \cdot P_{asph,\infty} = 0.092 \mu Sv \cdot h^{-1}. \quad \text{(III.3.5)}$$

and after that:

$$P_{asph,\infty} = \frac{0.092 - 0.075}{0.7} = 0.024 \mu Sv \cdot h^{-1}. \quad \text{(III.3.6)}$$

This will be in agreement with a model prediction for location 15 equal to 0.021 µSv h^{-1}.

Verification of model predictions concerning dose rates inside houses in this case is not meaningful, because after subtraction of the background from results of measurements, the final results will be very close to zero or negative. However, model predictions also are very close to zero (0.001–0.0026 µSv h^{-1}), which will qualitatively be in agreement with the results of measurements.

Table III.3.3. Relative dose at air-ground interface for soil contaminated to a depth of 1 cm (15 cm in brackets), for different areas and different energies.

Contaminated area (m^2) (equivalent radius, (m))	Relative dose (Infinite area = 1)			
	Energy (keV)			
	62	122	662	1250
10 (1.8)	0.29 (0.52)	0.18 (0.49)	0.20 (0.43)	0.20 (0.41)
100 (5.6)	0.67 (0.83)	0.47 (0.83)	0.48 (0.80)	0.47 (0.79)
1000 (18)	0.91 (0.92)	0.79 (0.95)	0.75 (0.94)	0.75 (0.94)
10 000 (56)	0.99 (0.97)	0.96 (0.97)	0.93 (0.98)	0.93 (0.98)
Infinite	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)	1.0 (1.0)

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III.4. Description of CPHR
(Juan Tomás Zerquera)

III.4.1. Introduction

As part of activities developed by the Centre for Radiation Protection and Hygiene of the Republic of Cuba in support of emergency preparedness in the country, a compartment model for assessing the impact of radioactive releases in an urban environment has been developed. Based on the use of the Ecolego® computer code, developed by the Facilia AB company in Sweden for simulation of environmental processes, the model's aim is to assess in a conservative approach the evolution with time of the distribution of radioactive contamination and the associated dose rates in different locations. For this, the model considers the contribution to the overall dose rate of each compartment in a specific configuration for each location "cluster", centering on the point of interest, on a percentage basis with the compartments that are included in a so-called "characteristic radius" specified as part of the cluster definition.

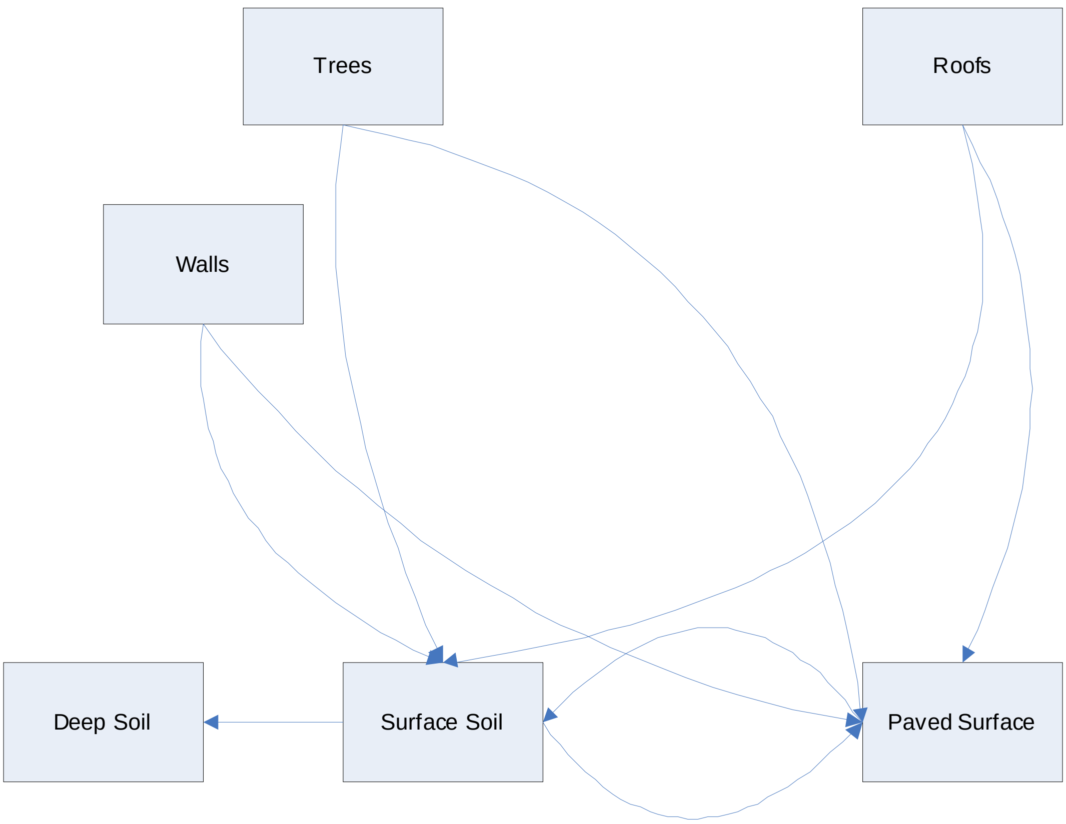

Fig. III.4.1. Compartments used in the model.

Compartments considered in the model are: “Paved Surface”, representing all surfaces artificially covered (mainly asphalt and cement); “Surface Soil”, which considers the open areas not covered artificially (gardens, yards, natural parks, undisturbed areas, etc.); “Roofs”, for all the building covers (both horizontal and slanted ones); “Trees”, which represents those areas covered by trees; and “Walls”, for considering all vertical surfaces in the existing buildings. An additional compartment, “Deep Soil”, has been included for considering the process of migration of radionuclides from the top layers of soil to the deeper ones, remaining there “undisturbed”. The model uses the traditional systems of linear differential equations for modelling the transfer between the defined compartments, to obtain as results of calculations the behaviour with time of average surface concentrations of the radioactive contaminants in each compartment, and averaged dose rate at the assessed points. Figure III.4.1 provides a general illustration of the model, as well as of the transfer processes considered.

III.4.2. Key assumptions

For the conformation of the model, the following key assumptions were made:

- Transport processes of suspension and resuspension were neglected, considering that the assessed scenarios have reached some degree of “stabilization” or “fixation” of the contamination in the considered compartments, so an hypothetical “Air” compartment was not included;
- All the radioactive materials remain distributed between the considered compartments and no transport of contaminants out of the considered system takes place. Also there is no additional later input of contaminants from outside the system; and
- Consideration of only external dose rates.

III.4.3. Modelling approaches (conceptual and mathematical)

Each of the compartments “Trees”, “Roofs”, Walls” and “Paved Surface” was divided into two sub-compartments, considering that a fraction of the radioactive material deposited on the surface remains fixed to the surface (fixed fraction) and the rest remains available for being transferred to the other compartments (labile fraction), so the model considers that only a fraction of the activity deposited on each of the surfaces is transferred between compartments. In this approach, the scheme represented in Figure III.4.1 can be transformed as shown in Figure III.4.2.

Concentrations in each compartment are calculated by solving a system of linear differential equations that describe the time variation of the radionuclide inventory in each compartment and have the traditional form:

$$\frac{dA_i}{dt} = (A_i)_0 - \sum_{j \neq i} \lambda_{i \to j} \times A_i + \sum_{j \neq i} \lambda_{j \to i} \times A_j \qquad \text{(III.4.1)}$$

where the second term in the right side of the equation describes the transfers from the i-th compartment to the other ones and the third term describes the transfers to the i-th compartment from the other ones.

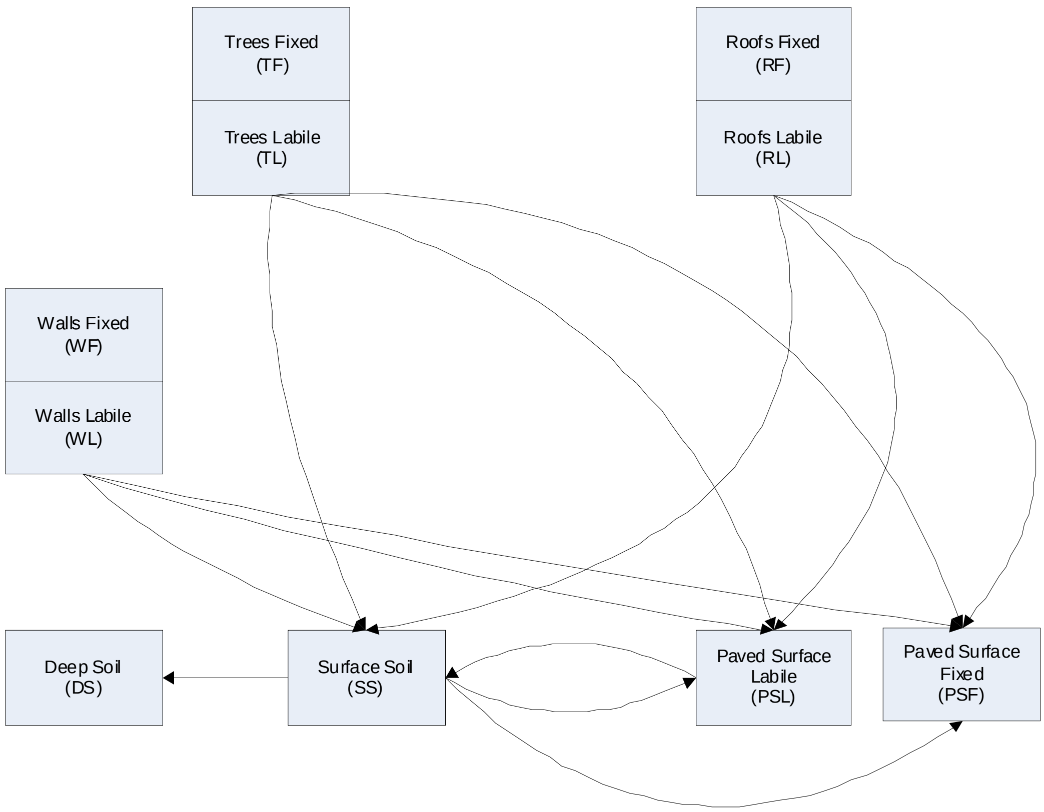

Fig. III. 4.2. Compartments used in the model, showing the sub-compartments and corresponding transfers.

For the compartments shown in Figure III.4.2, Equation (III.4.1) becomes:

"Trees Labile" compartment

$$\frac{dA_{TL}}{dt} = (1 - ff_{Trees}) \times InitialDep - \lambda_{TL \to SS} \times A_{TL} - \lambda_{TL \to PSL} \times A_{TL} - \lambda_{TL \to PSF} \times A_{TL}$$

"Roofs Labile" compartment

$$\frac{dA_{RL}}{dt} = (1 - ff_{Roofs}) \times InitialDep - \lambda_{RL \to SS} \times A_{RL} - \lambda_{RL \to PSL} \times A_{RL} - \lambda_{RL \to PSF} \times A_{RL}$$

"Walls Labile" compartment

$$\frac{dA_{WL}}{dt} = (1 - ff_{Walls}) \times InitialDep - \lambda_{WL \to SS} \times A_{WL} - \lambda_{WL \to PSL} \times A_{WL} - \lambda_{WL \to PSF} \times A_{WL}$$

"Paved Surface Labile" compartment

$$\frac{dA_{PSL}}{dt} = (1 - ff_{PavedSurface}) \times InitialDep - \lambda_{PSL \to SS} \times A_{PSL} + \lambda_{WL \to PSL} \times A_{WL} + \lambda_{TL \to PSL} \times A_{TL} + \\ + \lambda_{RL \to PSL} \times A_{RL}$$

“Surface Soil” compartment

$$\frac{dA_{SS}}{dt} = InitialDep - \lambda_{SS\to DS} \times A_{SS} - \lambda_{SS\to PSL} \times A_{SS} - \lambda_{SS\to PSF} \times A_{SS} + \lambda_{WL\to SS} \times A_{WL} +$$
$$+\lambda_{TL\to SS} \times A_{TL} + \lambda_{RL\to SS} \times A_{RL} \lambda_{RL\to SS} \times A_{RL}$$

“Paved Surface Fixed” compartment

$$\frac{dA_{PSF}}{dt} = ff_{PavedSurface} \times InitialDep + \lambda_{WL\to PSF} \times A_{WL} + \lambda_{RL\to PSF} \times A_{RL} + \lambda_{TL\to PSF} \times A_{TL}$$

“Deep Soil” compartment

$$\frac{dA_{DS}}{dt} = \lambda_{SS\to DS} \times A_{SS}$$

For “Trees Fixed”, “Walls Fixed” and “Roofs Fixed” compartments, the concentrations remain unaffected by the migration processes and they decrease due only to radioactive decay, with an initial value of concentration:

$$(A_i)_0 = ff_i \times InitialDep$$

Transfer functions in the equations described above have the form:

Transfer	Expression
$\lambda_{TL\to SS}$	$(\ln 2 / T_{1/2}{}^{Trees}) \times \%soil$
$\lambda_{TL\to PSL}$	$(\ln 2 / T_{1/2}{}^{Trees}) \times \%paved \times (1 - ff_{PavedSurface})$
$\lambda_{TL\to PSF}$	$(\ln 2 / T_{1/2}{}^{Trees}) \times \%paved \times ff_{PavedSurface}$
$\lambda_{RL\to SS}$	$\ln 2 \times \left(\frac{F_{RoofsFast}}{T_{1/2}{}^{RoofsFast}} + \frac{F_{RoofsSlow}}{T_{1/2}{}^{RoofsSlow}} \right) \times \%soil$
$\lambda_{RL\to PSL}$	$\ln 2 \times \left(\frac{F_{RoofsFast}}{T_{1/2}{}^{RoofsFast}} + \frac{F_{RoofsSlow}}{T_{1/2}{}^{RoofsSlow}} \right) \times \%paved \times (1 - ff_{PavedSurface})$
$\lambda_{RL\to PSF}$	$\ln 2 \times \left(\frac{F_{RoofsFast}}{T_{1/2}{}^{RoofsFast}} + \frac{F_{RoofsSlow}}{T_{1/2}{}^{RoofsSlow}} \right) \times \%paved \times ff_{PavedSurface}$
$\lambda_{WL\to SS}$	$\ln 2 \times \left(\frac{F_{WallsFast}}{T_{1/2}{}^{WallsFast}} + \frac{F_{WallsSlow}}{T_{1/2}{}^{WallsSlow}} \right) \times \%soil$
$\lambda_{WL\to PSL}$	$\ln 2 \times \left(\frac{F_{WallsFast}}{T_{1/2}{}^{WallsFast}} + \frac{F_{WallsSlow}}{T_{1/2}{}^{WallsSlow}} \right) \times \%paved \times (1 - ff_{PavedSurface})$
$\lambda_{WL\to PSF}$	$\ln 2 \times \left(\frac{F_{WallsFast}}{T_{1/2}{}^{WallsFast}} + \frac{F_{WallsSlow}}{T_{1/2}{}^{WallsSlow}} \right) \times \%paved \times ff_{PavedSurface}$

$\lambda_{PSL \to SS}$	$\ln 2 \times \left(\frac{F_{PavedFast}}{T_{1/2}^{PavedFast}} + \frac{F_{PavedSlow}}{T_{1/2}^{PavedSlow}} \right)$
$\lambda_{SS \to PSL}$	$\ln 2 \times \left(\frac{F_{SoilFast}}{T_{1/2}^{SoilFast}} + \frac{F_{SoilSlow}}{T_{1/2}^{SoilSlow}} \right) \times (1 - ff_{PavedSurface})$
$\lambda_{SS \to PSF}$	$\ln 2 \times \left(\frac{F_{SoilFast}}{T_{1/2}^{SoilFast}} + \frac{F_{SoilSlow}}{T_{1/2}^{SoilSlow}} \right) \times ff_{PavedSurface}$
$\lambda_{SS \to DS}$	$TC_{SS \to DS}$

The model assumes a temporal discretization in the form of variable-size time steps for calculations in the studied interval [$t_{initial}$,t_{final}] and therefore requires as input data the time when deposition occurred and the final time until which the calculations have to be made. Other input data include the radionuclides involved, the initial deposition for each radionuclide and for each compartment, the proportion of paved-soil surfaces in the specific environment, the contribution in percentage of each compartment to exposure at the evaluated point and the time of introduction and finishing of applied countermeasures.

III.4.4. Parameter values

For calculations the model uses the parameters and values that are shown below. Most of them were taken from reference values published for ^{137}Cs. Only for the case of compartment “Trees” the values were assumed by the modeller based on his own judgement.

Parameter	**Value(s)**
Slow Fraction Paved Surface	0.5
Slow Fraction Roofs	0.5
Slow Fraction Soil	0.8
Slow Fraction Trees	0.1
Slow Fraction Walls	0.8
Fixed Fraction Paved Surface	0.3
Fixed Fraction Roofs	0.3
Fixed Fraction Trees	0.3
Fixed Fraction Walls	0.3
Fast Half Life Paved Surface	0.19 y
Fast Half Life Roofs	0.93 y
Fast Half Life Soil	0.2 y
Fast Half Life Trees	0.5 y
Fast Half Life Walls	0.19 y
Slow Half Life Paved Surface	18.9 y
Slow Half Life Roofs	4.11 y
Slow Half Life Soil	20 y
Slow Half Life Walls	18.9 y
Transfer Coefficient Surface Soil – Deep Soil	0.01
Dose Conversion Factor Cs-137 – $DCF_{Cs\text{-}137}$	6.33×10^{-10} Gy m^2 MBq^{-1} s^{-1}
Dose Conversion Factor Cs-134 – $DCF_{Cs\text{-}134}$	2.05×10^{-9} Gy m^2 MBq^{-1} s^{-1}
Dose Conversion Factor Ru-106 – $DCF_{Ru\text{-}106}$	5.24×10^{-10} Gy m^2 MBq^{-1} s^{-1}

III.4.5. Uncertainties

Using the possibilities of the Ecolego® code, the calculations were carried out using a probabilistic approach, assuming for the initial deposition either normal or lognormal distributions of values and adopting as parameters for these distributions the extreme values found in the initial information provided. These distributions, different for each scenario (Pripyat and hypothetical), are described in the specific details given below for each scenario. As result of this probabilistic approximation, ranges of values instead of isolated values were obtained for dose rates associated with each evaluated point. It was assumed, therefore, that the only source of uncertainty for modelling was the uncertainty associated with the initial deposition values.

III.4.6. Application of the model to Ukrainian scenario (Pripyat)

Based on data provided for the exercise, calculations for modelling were carried out making the following assumptions:

- Initial deposition was homogeneously distributed. This is true for all the components in the studied environment. For initial deposition a normal distribution was assumed, with different parameters for each of the main radionuclides as shown in Table III.4.1; and
- Evaluation of dose rates due to radionuclides other than ^{134}Cs, ^{137}Cs and ^{106}Ru in the first month/years was made by extrapolating proportionalities on the basis of initial data provided and using the results of calculations obtained for these three radionuclides.

For the case of Pripyat, as data were available for performing a calibration of the model, some initial calculations were made and compared with results of real measurements. This way it was possible to adjust or verify some of the parameters used and to evaluate the dose rates due to radionuclides other than ^{134}Cs, ^{137}Cs and ^{106}Ru. This approach was important for obtaining definitive estimates of those dose conversion factors used later in the calculations. It was possible also to adjust the radius of the imaginary radiation "cluster" in 10 meters for considering the percentages of contribution of each compartment to dose rate at one studied point.

III.4.7. Application of the model to the hypothetical scenario

For the case of the hypothetical scenario the assumption of homogeneity for initial deposition in all of the considered area is no longer valid. The approach used was to subdivide the considered area into two subareas with normally distributed contamination and to specify for each area values for lower and upper cut-offs. The first area considered was the one with higher contamination defined by the isoline "2 MBq m^{-2}" in the figure provided to the modellers for describing the overall contamination, where the initial contamination ranged from 2 to 10 MBq m^{-2}. The second area corresponded with the rest of the area in the figure, where the initial contamination ranged from 0 to 2 MBq m^{-2}. The specific details of the distributions assumed for both areas are shown in Table III.4.2.

Additionally, for the exchange of contamination between subareas it was supposed that this exchange takes place only from "Soil" and "Paved" compartments of one subarea to the same compartments in the other subarea. These interactions are illustrated in Figure III.4.3. The remaining procedures and calculations were carried out as for the Pripyat scenario.

Table III.4.1. Parameters of normal distributions assumed for initial deposition of main considered radionuclides.

Radionuclide	Mean (kBq m^{-2})	Variance (kBq m^{-2})
Caesium-134	420	250
Caesium-137	870	470
Ruthenium-106	3010	1080

Table III.4.2. Parameters of normal distributions assumed for initial deposition in the two subareas considered in the hypothetical scenario.

Area	Mean (MBq m^{-2})	Variance (MBq m^{-2})	Lower cut-off (MBq m^{-2})	Upper cut-off (MBq m^{-2})
Area of higher initial contamination	2.0	1.0	2.0	10.0
Area of lower initial contamination	0.0	0.001	0.0	2.0

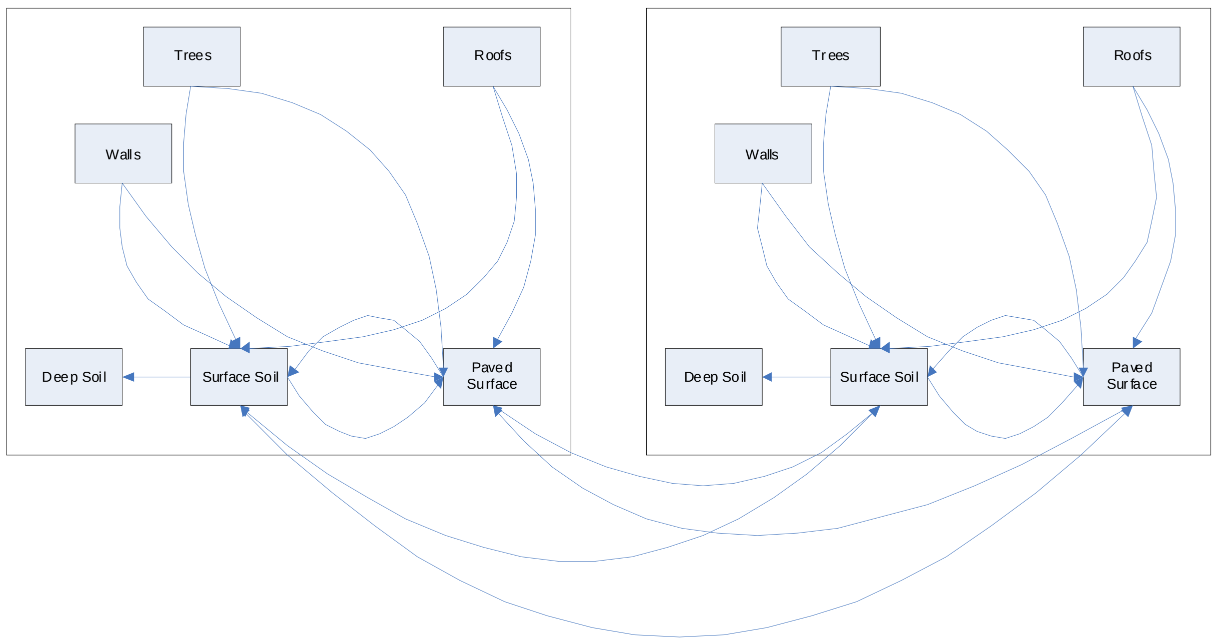

Fig. III.4.3. Exchange between subareas considered for the hypothetical scenario.

III.5. Description of RESRAD-RDD
(Sunita Kamboj, Jing-Jy Cheng and Charley Yu)

The modeling of the changes in the concentrations of radionuclides dispersed in an urban environment caused by a hypothetical radiological event was performed using a methodology consistent with that of RESRAD-RDD, a computer code developed by Argonne National Laboratory for the U.S. Department of Energy through the interagency Operational Guidelines Task (OGT) Group [III.5.1].

III.5.1. RESRAD-RDD conceptual model

The RESRAD-RDD code considers the dispersion of radionuclides and their subsequent partitioning in the environment following a radiological dispersal device event as illustrated in Figure III.5.1. It was assumed that the radiological dispersal device event occurred outdoors and resulted in surface contamination on the paved areas, lawn, and exterior walls and roofs of residential/commercial buildings. In addition, the contaminants were assumed to get inside the residential/commercial buildings and be deposited on indoor floors and walls, either directly during the event through open windows or indirectly after the event through indoor/outdoor air exchange or through contaminants trapped to the bottom or on the surface of shoes of people who entered the buildings. Currently there are 11 radionuclides included in the RESRAD-RDD code.

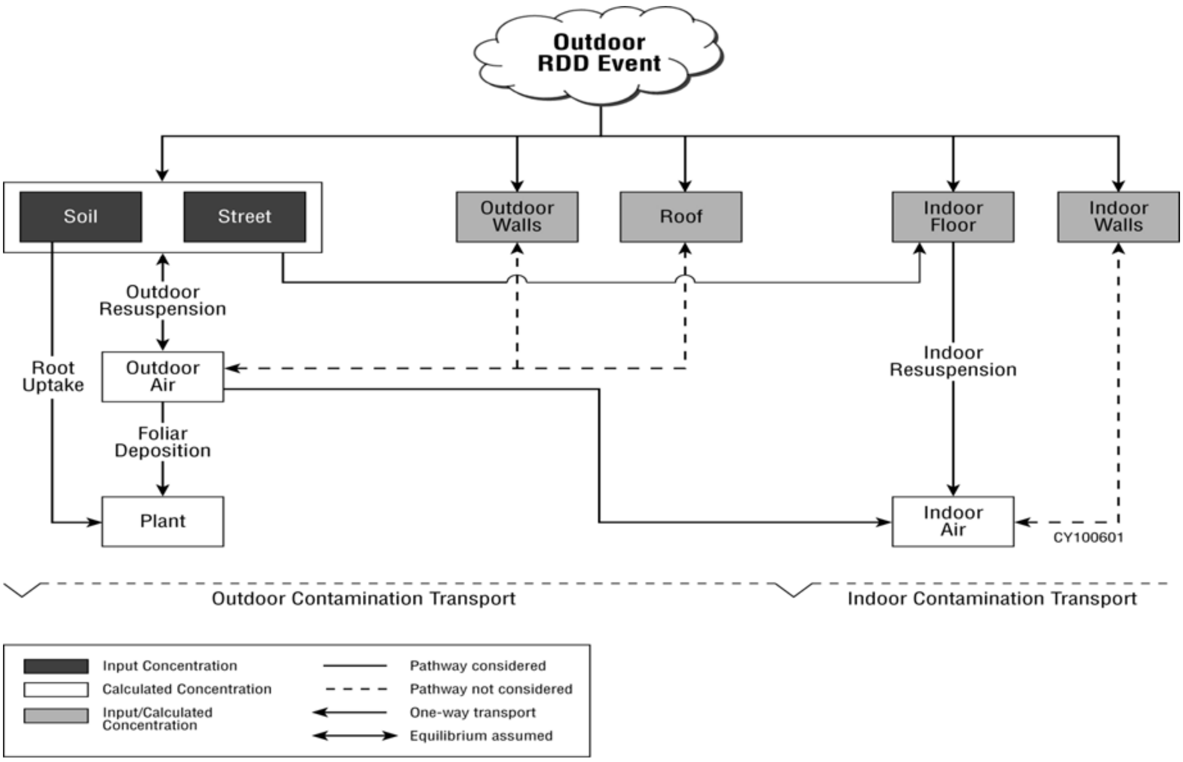

Fig. III.5.1. Conceptual model of environmental transport after an radiological dispersal device event.

The RESRAD-RDD code uses the partitioning factors to consider differences in the initial radionuclide concentrations on different surfaces, and employs the weathering parameters to consider the changes in radionuclide concentrations on various surfaces as time progresses. These considerations were incorporated on the basis of Chernobyl accident data which showed that, in an urban environment, different surfaces have different initial retentions when compared with the reference surface and that they behave differently over time [III.5.2]. The reference surface was defined as an infinite smooth (surface with no roughness associated with it) air-ground interface with radionuclides deposited on the ground with no initial penetration. According to the Andersson et al. study [III.5.2], the weathering process and the effect of migration generally follow a two-class exponential behavior with time, as represented by Equation III.5.1:

$$w(t) \quad = \quad a\, e^{-(bt)} + (1-a)\, e^{-(ct)}, \tag{III.5.1}$$

where $w(t)$ is the activity fraction retained after weathering at time t, and a, b, and c are weathering parameters for each surface. In this equation, there is a mobile fraction a with a shorter half-life b due to loose binding to the surface or due to the higher migration rate in the case of permeable surfaces. There is also a fixed fraction $(1 - a)$ with a longer half-life c due to strong binding to the surface or a lower migration rate.

III.5.2. Source

The median values from the inverse distance weighting (IDW) interpolation by inhabited area monitoring module (IAMM) were taken to be the initial outdoor ground (paved area/lawn) surface concentrations at different building locations. The median values were provided in the data package for this modeling exercise (Appendix II) and the values are listed in Table III.5.1.

Table III.5.1. Initial outdoor ground surface concentrations (Bq m^{-2}) used in the Modeling (median values from IDW interpolation by IAMM).

Building 1	Building 2	Building 3	Building 4	Building 5	Building 6
2.89E+06	3.87E+06	7.20E+05	7.50E+05	7.70E+05	1.19E+06

Table III.5.2. Initial partitioning factors.

Paved areas*	Lawn	Exterior walls**	Roofs**	Interior floor	Interior walls	Sloped roofs***
1	1	0.1	0.7	0.1	0.05	0.5

* For calculating the initial concentration on the top floor of the parking garage (i.e., building 2) it is assumed that the partitioning is the same as for paved areas/lawns and the concentration is corrected based on the air concentration data.

** Exterior walls and roof are not contaminated for the 60th floor of building 1 (office building) based on the air concentration data.

*** Buildings 5 (Residential building) and 6 (apartment building) have sloped roofs and other buildings have flat roofs.

Table III.5.3. Weathering coefficients used for hypothetical scenario.

Surface	Mobile fraction (*a*)	Shorter half-life (ln2/*b*), y	Longer half-life (ln2/*c*), y
Street (paved areas)	0.5	0.2	2
Soil (lawn)	0.46	1.5	50
Roof/Sloped roofs	0.5	4	50
Exterior Wall	0.2	0.2	20
Interior Floor	0.5	0.2	2
Interior Wall	0.2	0.2	20

Table III.5.2 lists the partitioning factors assumed for this modeling exercise for the initial retention of radionuclides on different surfaces. The partitioning for roof and outdoor walls are from Andersson et al. [III.5.2]. The initial floor concentration was assumed to be 10% of the initial outdoor concentration. The initial interior wall concentration was assumed to be half (factor of 0.5) of the initial concentration on the floor, which is consistent with indoor deposition patterns [III.5.3]. For this modeling exercise, the initial concentrations of radionuclides on interior floor and interior walls were calculated by multiplying the initial concentration on paved area/lawn with the corresponding partitioning factor.

Air concentrations at different altitudes were provided at the building locations. This information along with the partitioning factors was used in estimating the initial radionuclide concentrations on exterior walls and roof. For the receptor on the 60th floor of the high-rise building (the office building in this exercise), the initial concentrations on the roof and exterior walls were assumed to be 0, judging by the provided air concentration at that altitude. For the receptor on the top floor of the parking lot, the initial concentration on the ground level was adjusted by the ratio of the air concentration at the top floor altitude to the air concentration at the ground level. For all other receptor locations, the air concentration does not change with altitude; therefore, for those receptor locations, the initial concentrations on exterior walls and roof were calculated by multiplying the initial concentration on the paved area/lawn with the partitioning factors for exterior walls and roof, respectively.

Table III.5.3 summarizes the values for the weathering parameters used in this exercise [III.5.2]. The parameters for the interior floor were assumed to be the same as those for the outdoor paved areas to consider the transport of contaminants by human activities (e.g., walking from outdoors to indoors) and air exchange. Therefore, the concentration ratio between these two surfaces would stay the same at any time. The weathering parameters for the interior walls were taken from those for the exterior walls.

In addition to weathering, concentrations on different surfaces were also corrected for radioactive decay. Therefore, the average weathering correction factor (WCF) from time t_1 to t_2, which includes the corrections for both weathering and radioactive decay, can be given by Equation III.5.2:

$$\overline{WCF} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} [a\, e^{-(bt)} + (1-a) e^{-(ct)}] e^{-\lambda t} dt \qquad \text{(III.5.2)}$$

The correction factor at a given time t can be given by Equation III.5.3:

$$WCF = [ae^{-(bt)} + (1-a)\, e^{-(ct)}]\, e^{-\lambda t} \qquad \text{(III.5.3)}$$

Figure III.5.2 shows the effect of weathering on different surfaces as a function of time. The following weathering effects are observed:

— Concentrations on paved surfaces change very fast compared with concentrations on other surfaces due to smaller values of both the short and long half-lives;
— Concentrations on walls initially change faster compared with concentrations on roofs and lawns due to a smaller value of the short half-life but later, concentration changes are faster for lawn and roofs because the lawn and roofs have much higher mobile fractions compared with walls; and
— Concentrations on lawns change faster compared with concentration on roofs due to a smaller value of the short half-life.

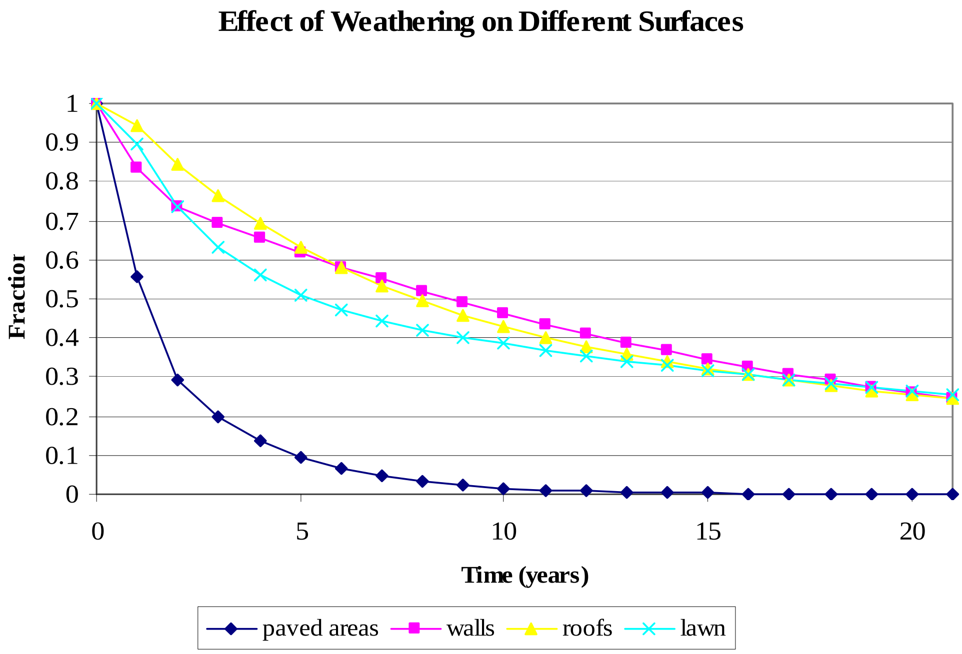

Fig. III.5.2. Effect of weathering on different surfaces.

III.5.3. Exposure

The potential external radiation dose incurred by a receptor is considered to come from multiple contaminated surfaces. The followings are the six components contributing to the external radiation dose:

(1) Exposure (ground shine) to contaminants on paved areas/lawns while staying outdoors;
(2) Exposure to contaminants on exterior walls of a building while staying inside of the building;
(3) Exposure to contaminants on roofs of a building while staying inside of the building;
(4) Exposure to contaminants on interior walls of a building while staying inside of the building;
(5) Exposure to contaminants on interior floors of a building while staying inside of the building; and
(6) Exposure to contaminants on paved areas/lawns outside of a building while staying inside of the building.

Table III.5.4 lists the exposure durations considered for each receptor in the modeling exercise. For all the receptors, it was assumed that they worked or lived at the contaminated location for 50 weeks in a year, and they were away from the contaminated location for the rest of the year.

Table III.5.5 lists the dimensions and characteristics assumed for the six target buildings as well as the dimensions for the outdoor ground source (lawn/paved area).

Table III.5.4. Exposure durations for each receptor and assumptions for outdoor exposures.

Receptor	Receptor description	Indoor exposure duration (h y^{-1})	Outdoor exposure duration (h y^{-1})	Assumption for outdoor exposure
Office Building -1	Adult spending 40 h wk^{-1} indoor on first floor of office building	2000	0	80% from paved areas and 20% from lawn
Parking Garage - 1	Adult spending 40 h wk^{-1} indoor on top floor (8) of parking lot	2000	0	100% from paved areas
School - 1	School children staying 35 h wk^{-1} inside	1750	0	33.3% from paved areas and 66.7% from lawn
Super Market - 1	Worker staying 40 h wk^{-1} inside super market	2000	0	33.3% from paved areas and 66.7% from lawn
Super Market - 2	Adult staying 1 h inside super market	50	0	33.3% from paved areas and 66.7% from lawn
Residential Home -1	Resident staying 120 h wk^{-1} inside & 15 h wk^{-1} outside	6000	750	33.3% from paved areas and 66.7% from lawn
Apartment - 1	Resident staying 120 h wk^{-1} inside on first floor & 15 h wk^{-1} outside	6000	750	33.3% from paved areas and 66.7% from lawn

Table III.5.5. Dimensions and characteristics assumed for the outdoor ground source and different target buildings.

Building/source	Floor length (m)	Floor width (m)	Building/ floor height (m)	Thickness of walls/floor/ roof (cm)	Material of walls/floor/ roof	Density of material (g cm^{-3})
Office building	62	25.6	4.4	10	Concrete	2.4
Parking garage	94	94	17	10	Concrete	2.4
School	35	6.2	5	3.5	Concrete	2.4
Supermarket	30	22.3	8	3.5	Concrete	2.4
Residential Home	15.4	8.4	7	3.5	Concrete	2.4
Apartment	37.3	7.5	7	10	Concrete	2.4
Lawn/paved area	1000	1000	NA	NA	NA	NA

III.5.4. Dose calculations

To calculate the external doses, first the dose-to-source ratios (DSR) for each of the six external dose components resulting from different contaminated surfaces were calculated using the RESRAD-BUILD computer code [III.5.4]. Because the dimensions, building materials, and structures of the six target buildings considered in this modeling exercise [an office building (building 1), a parking garage (building 2), a school (building 3), a supermarket (building 4), a residential home (building 5), and an apartment (building 6)] are different, the DSRs were calculated separately for each building.

For the 1st component pathway (outdoor exposure to lawn/paved area), an infinite homogeneously contaminated concrete area and lawn were considered and the DSR for a receptor located at the center of each area was calculated. The DSR for the component pathway was calculated as the weighted sum of the two DSRs for the paved area and the lawn. The ratio of the contributions from the paved area and the lawn was varied to consider the environment surrounding a specific building (see Column 5 of Table III.5.4 for the assumptions used in the modeling). For component pathways 2–5 (indoor exposures to exterior walls, roofs, interior walls, and floor), the receptor was assumed to be located at the center of the floor of a contaminated building.

For a multiple-story building, the floor area and height were assumed to be the same for different floor levels. Except for the ground floor, the floor for any other floor level was also considered as the roof for the floor beneath it. Concentrations of radionuclides on the floor, exterior walls, and interior walls were assumed independent of the floor level when air concentrations at different altitudes are the same. Shielding between the surface source and the receptor was considered in the calculation of DSR for each component pathway (see Table III.5.5). For the last component pathway (indoor exposure to outside ground source), the DSR was obtained by adjusting the DSR for the first component pathway by a shielding factor. Table III.5.6 provides the shielding factors used for this component for different buildings. RESRAD-BUILD computer code was used in calculating the shielding factors.

Table III.5.6. Average external shielding factors used for the calculation of indoor exposure to an outside ground source.

Building/floor location	**Shielding factor**
Office building (1st floor)	0.05
Office building (5th floor)	0.04
Office building (20th floor)	0.02
Office building (60th floor)	0.01
Parking garage (1st floor)	0.05
Parking garage (4th floor)	0.03
Parking garage (8th floor)	0.02
School	0.2
Supermarket	0.2
Residential home	0.2
Apartment (1st floor)	0.05
Apartment (5th floor)	0.04

Table III.5.7. Countermeasures considered and decontamination factors assumed for dose modeling.

Countermeasure	**Decontamination factor (DF)**	**Time of application**
Cutting and removal of grass	3	at day 7
Washing of roads	5	at day 14
Washing of exterior walls	10	at day 14
Washing of roof	1.4	at day 14
Removal of soil	10	at day 180
Washing of interior walls	5	at day 14
Washing of interior floors	5	at day 14
Vacuuming indoor surfaces	5	at day 14
Relocation of population (temporary)	–	For the first two weeks
Relocation of population (temporary)	–	For the first six weeks
Relocation of population (temporary)	–	For the first six months

Note: The decontamination factors were obtained from Gallay [III.5.5].

The indoor hourly external dose at a specific time for a receptor living or working on a specific floor level in a specific building was calculated as the sum of the doses from component pathways 2 to 5 using Equation III.5.4. For the 60th floor of building 1 and on the top floor of the parking lot, height correction based on the air concentration data was also applied.

$$hourly\ dose_{in,b,f}(t) = \sum_{n=2-5} C_{s,b} \times P_n \times WCF_n(t) \times DSR_{n,f}\ , \qquad \text{(III.5.4)}$$

where:

$hourly\ dose_{in,b,f}\ (t)$ = indoor hourly external dose on the floor level f inside building b (Sv y^{-1});
$C_{s,b}$ = initial outdoor ground surface concentration at the location of building b (Bq m^{-2});
P_n = partitioning factor for the surface source corresponding to component pathway n;
$WCF_n\ (t)$ = weathering and radiological decay correction factor for the initial concentration on the surface source corresponding to component pathway n at a given time t;
n = index for component pathway; and
$DSR_{n,f}$ = dose-to-source ratio for component pathway n at the floor level f (mSv h^{-1} per Bq m^{-2}).

The outdoor hourly external dose was calculated similarly to the indoor hourly dose, except that only the first component pathway was relevant; therefore, summation is not required.

The annual average external dose was calculated by summing the indoor annual average external dose and the outdoor annual average external dose. The indoor annual average external dose was calculated by multiplying the indoor average hourly dose with the average indoor exposure duration using Equation III.5.5. The outdoor annual average external dose was calculated by multiplying the outdoor average hourly dose with the average outdoor exposure duration.

$$annual\ dose_{in,b,f}(t) = \left(\sum_{n=2-5} C_{s,b} \times P_n \times \overline{WCF_n(t)} \times DSR_{n,f} \right) \times ED_{in,b,f} \qquad \text{(III.5.5)}$$

where:

$\overline{WCF_n}\ (t)$ = average weathering and radiological decay correction factor for the initial concentration on the surface source corresponding to component pathway n in a specific year t (see Equation III.5.2 for its calculation); and
$ED_{in,,b,f}\ (t)$ = indoor exposure duration on the floor level f in building b (h y^{-1}).

The external doses are predicted for the case without any countermeasure and for several cases with different countermeasures. The different countermeasures were specified in the data package provided for this modeling exercise (Appendix II). Table III.5.7 lists the decontamination factors assumed for the different countermeasures. Radionuclide concentrations on the surface source involved in a countermeasure were assumed to be reduced by the decontamination factor after the application of the countermeasure. For example, cutting and removing grass at day 7 would result in the reduction of the lawn concentration by a factor of 3 at day 7. When a countermeasure was considered, the first year was divided into two time periods, from t = 0 to the time the countermeasure was applied, and from the time the countermeasure was applied to the end of the first year. External doses incurred during these two time periods were calculated separately, then they were added together to give the total dose for the first year.

III.5.5. Modeling endpoints

There were four modeling end points in this exercise as follows:

(1) External exposure rates (dose rates, mGy h^{-1}) at specified locations, from all relevant surfaces (by surface and total);
(2) Contribution to the dose rates (%) from each surface, for the most important surfaces;
(3) Annual and cumulative external doses (mGy) for specified reference (hypothetical) receptors; and
(4) Radionuclide surface concentrations (Bq m^{-2}) at each outdoor location.

For this exercise, the model calculations started following the initial deposition from the radiological dispersal device event and were carried forward for 20 years. Results were presented as a time series, with the date specified for each predicted dose rate, dose, or radionuclide concentration. Example formats were provided for each phase of modeling.

Since this exercise was designed to allow modeling with and without the effects of various remediation efforts on the changes over time of the radiological situation, all the predictions were done with no remediation and were repeated with different countermeasures. Each calculation was carried forward for 20 years.

III.5.5.1. First modeling endpoint

The external dose rates were predicted for 18 test locations at different times starting from time zero and were carried forward for twenty years in the future using the methodology as described above. Six test locations were just outside the six buildings considered in this exercise. Eleven test locations were inside the buildings and one test location was on the top floor of the parking lot. Building 1 is a 60-story office building and has four inside test locations on the 1^{st} floor, 5^{th} floor, 20^{th} floor, and 60^{th} floor. Building 2 is an 8-story parking lot and has two inside test locations on the 1^{st} floor and 4^{th} floor. Building 3 is a single-story school and has only one inside test location on 1^{st} floor; similarly, building 4 is a supermarket and building 5 is a residential home, and each has only one test location on the 1^{st} floor. Building 6 is an apartment building and has two inside test locations on the 1^{st} floor and 5^{th} floor.

III.5.5.2. Second modeling endpoint

For the 18 test locations, the external dose rates included the dose rates from all contaminated surfaces. The three most important contributing contaminated surfaces and their percent contributions to the total dose rate were listed.

III.5.5.3. Third modeling endpoint

For dose calculations, the following (hypothetical) reference individuals (receptors) were used (see Table III.5.4):

(1) An adult occupational worker spending 40 hours per week, in office work indoors in Building 1 (office building) on the1st floor;
(2) An adult occupational worker spending 40 hours per week, in outdoor work at Building 2 (parking garage) on the top floor of the parking garage with open sides;
(3) An adult occupational worker, spending 40 hours per week, in indoor work in Building 4 (supermarket) on the 1st floor;
(4) A resident spending 120 hours inside on the first floor and 15 hours outside Building 5 (residential home);
(5) A resident spending 120 hours inside on the first floor and 15 hours outside Building 6 (apartment building);
(6) A child staying 35 hours per week inside, attending school (Building 3); and
(7) an adult staying one hour per week inside, in a supermarket (Building 4).

III.5.5.4. Fourth modeling endpoint

For the six outside test locations, average outside contamination densities were predicted at different times starting from time zero and were carried forward for twenty years in the future.

III.5.6. Results and discussions

The accompanying EXCEL spreadsheet (see Appendix IV) includes all the results for the four modeling endpoints with no remediation (no countermeasures) and with different countermeasures.

III.5.6.1. Results of first modeling endpoint

Figure III.5.3 shows the predicted dose rates at outdoor test locations with no countermeasures. The dose rate is the maximum outside the parking lot (building 2) because of the highest outdoor concentration at that location (see Table III.5.1). The dose rate at this outdoor location decreases the fastest because of the weathering (see Figure III.5.2) of the outside paved areas (see Table III.5.4 for outdoor exposure assumptions).

Figure III.5.4 shows the predicted dose rate inside building 1 on different floor levels. Inside dose rates are about an order of magnitude lower compared to outside dose rates because of less indoor contamination and the shielding provided by the building. As expected, the dose rate decreases at higher floor levels. The maximum dose rate is received at the first floor and the minimum is predicted at the 60th floor. Interior contamination on all floors is the same, but the dose contribution from outside decreases with height because shielding increases with height; moreover, there is no exterior walls and roof contamination on the 60th floor.

Figure III.5.5 shows the predicted dose rate inside building 2 on the 1st and 4th floors. The dose rate on the 1st floor is initially higher, but afterward there is not much difference. The observed difference in dose rate is because of the percent contribution from outdoors, but this contribution decreases with time. Initially, inside dose rates are much less compared to outdoor dose rates; but after 15 years, outdoor dose rates are lower because of much faster weathering of the paved areas compared to weathering of the surfaces contributing to indoor exposure.

Figure III.5.6 shows the predicted dose rate inside buildings 3, 4, and 5 on the 1st floor. The main difference in dose rates is because of the difference in initial outdoor contamination. For all three building locations, the inside dose rate is much less compared to the outside dose rate.

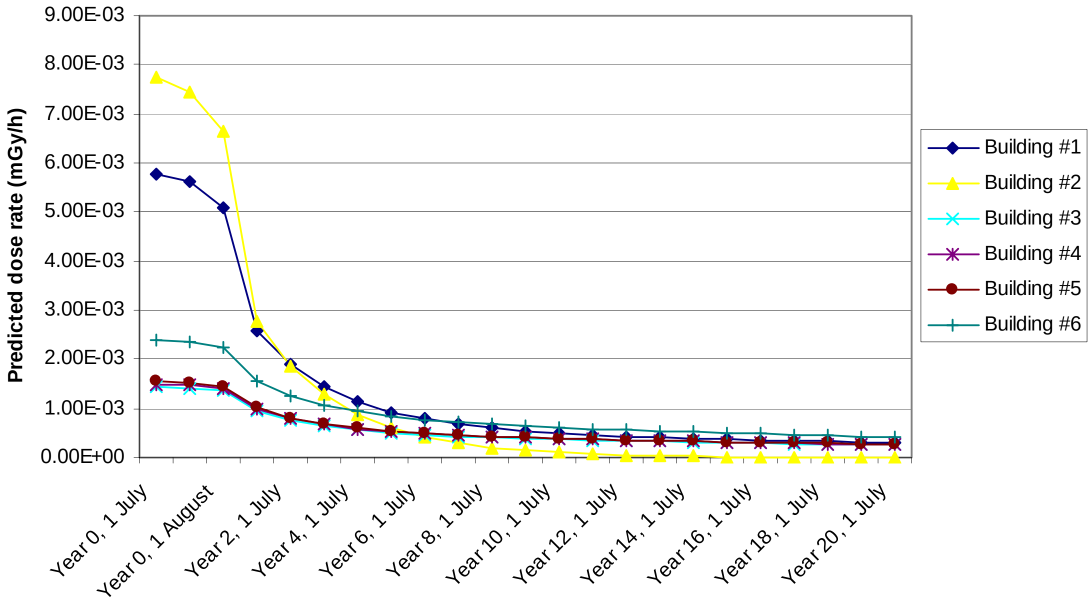

Fig. III.5.3. Predicted dose rates at outdoor test locations with no countermeasures.

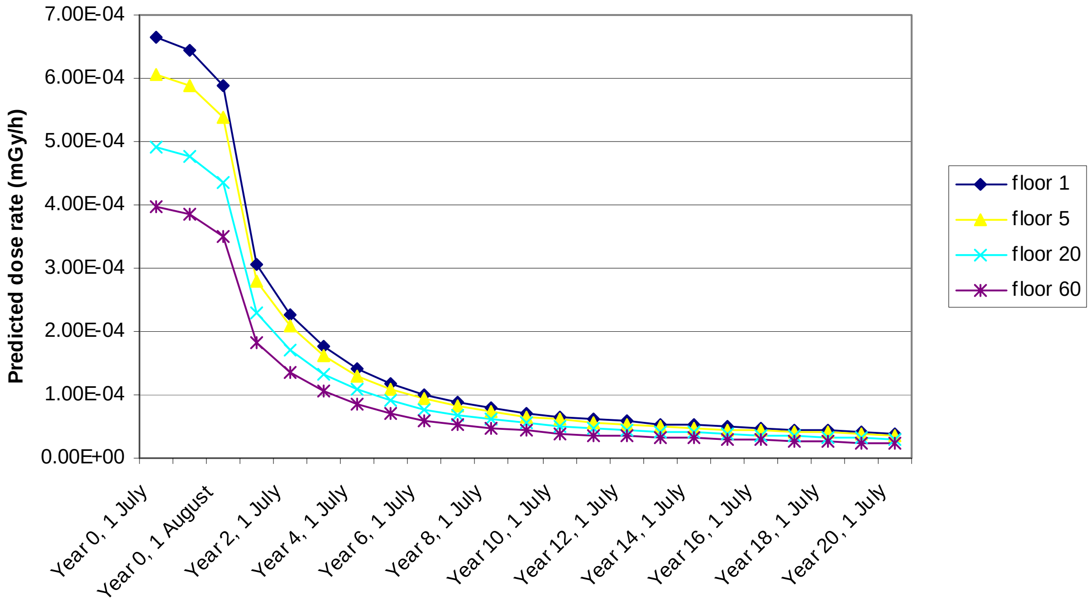

Fig. III.5.4. Predicted dose rates inside building 1 on different floors.

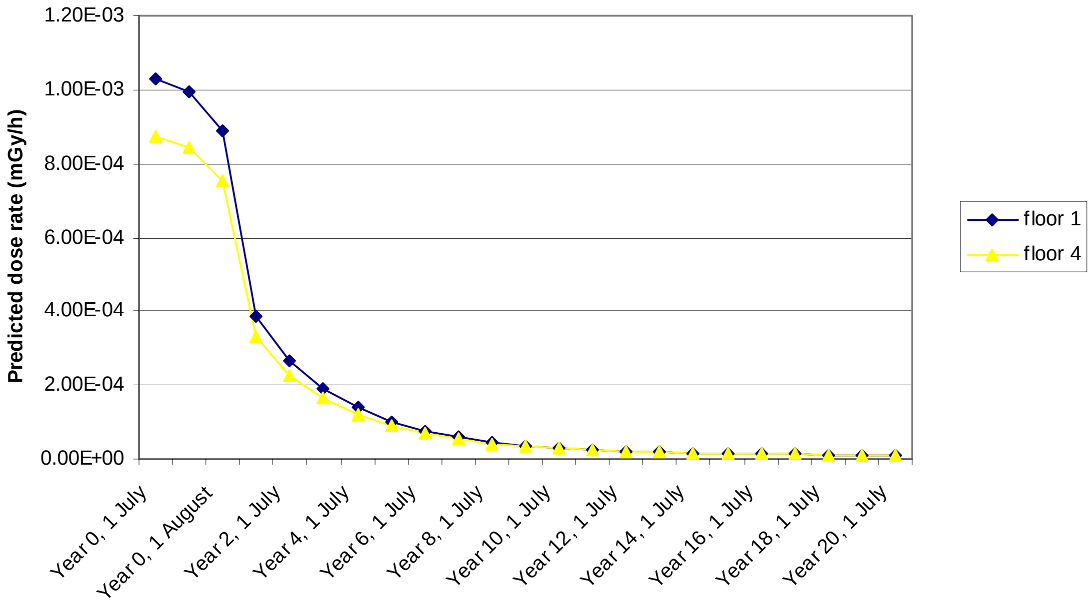

Fig. III.5.5. Predicted dose rates inside building 2 on different floors.

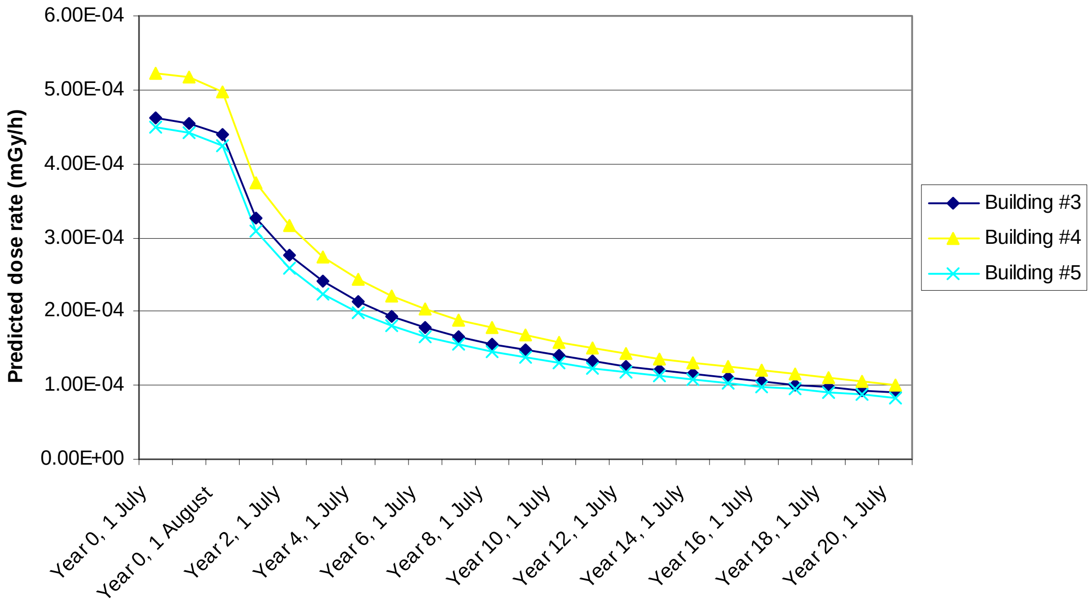

Fig. III.5.6. Predicted dose rates inside buildings 3, 4, and 5 on floor 1.

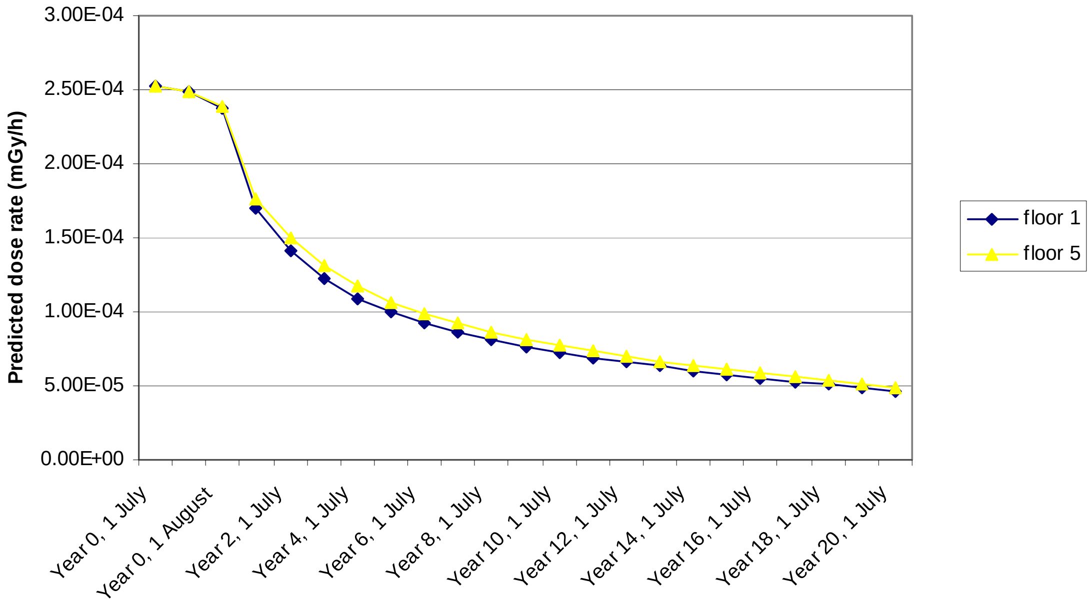

Fig. III.5.7. Predicted dose rates inside building 6 on different floors.

Figure III.5.7 shows the predicted dose rate inside building 6 on the 1st and 5th floors. There is practically no difference in the dose rate on different floors. The higher dose contribution from outside on the 1st floor is compensated by the higher dose concentration from the contamination on the roof for the 5th floor. However, for both the 1st and 5th floors, the inside dose rate is much lower compared to the outside dose rate.

Figures III.5.8 to III.5.25 show the predicted external dose rates for 18 test locations with different countermeasures. The following 9 countermeasures were modeled:

- Washing roofs and exterior walls;
- Washing indoor surfaces;
- Washing roads;
- Grass removal;
- Soil removal;
- Vacuuming indoor surfaces;
- Relocation for first two weeks;
- Relocation for first six weeks; and
- Relocation for first six months.

The decontamination factor used and the time when the countermeasure was applied are provided in Table III.5.7. The countermeasure titled “vacuuming indoor surfaces” did not change indoor concentrations because of model assumptions (i.e., indoor floor concentration is always at 10% of the outside concentration). Therefore, vacuuming indoor surfaces did not change the dose rate and is not shown in Figures III.5.8 to III.5.25.

Figures III.5.8 (outside building 1), III.5.13 (outside building 2), III.5.17 (outside building 3), III.5.19 (outside building 4), III.5.21 (outside building 5), and III.5.23 (outside building 6) show the external dose rates outside six buildings considered in this exercise. For the six outside building locations, the following observations were made:

- Countermeasures that change building surface concentrations do not change outside concentrations (assumption that weathering on different surfaces is independent);
- Countermeasures that were effective outside were: (1) washing roads; (2) grass removal; (3) soil removal; and (4) relocation for first two weeks, for first six weeks, and for first six months;
- Outside building 2 (parking lot), washing roads was the most effective countermeasure and soil or grass removal did not have any affect because the parking lot is surrounded by paved areas (see Table III.5.4, column titled “assumption for outdoor exposure”); and
- Outside building 1, 3, 4, 5, and 6, soil removal and grass removal were the two most effective countermeasures.

Figure III.5.16 shows the dose rate on the top floor of building 2. The only effective countermeasure for this location is washing the roof.

Figures III.5.9 to III.5.12 show the dose rates inside building 1 at floors 1, 5, 20, and 60 with different countermeasures. On the 60th floor, exterior walls and roof are not contaminated. Soil removal, grass removal, and washing roads are the most effective countermeasures in reducing external dose rates because the maximum contribution to the dose rate is from outside contamination. The contribution to the dose rate from exterior and interior walls contamination is small. Therefore, washing exterior walls and washing indoor surfaces are not effective countermeasures.

Figures III.5.14 and III.5.15 show the external dose rates inside building 2 at the 1st and 4th floors, respectively, with different countermeasures. On both floor 1 and floor 4, washing roads is most effective initially, but washing indoor surfaces (interior walls) and washing exterior walls become most effective later.

Figures III.5.18, III.5.20, III.5.22, III.5.24 and III.5.25 show the external dose rates inside building 3 on the 1st floor, inside building 4 on the 1st floor, inside building 5 on the 1st floor, inside building 6 on the 1st floor, and inside building 6 on the 5th floor, respectively. For all these inside locations, soil removal and grass removal are the two most effective countermeasures in reducing inside external dose rates.

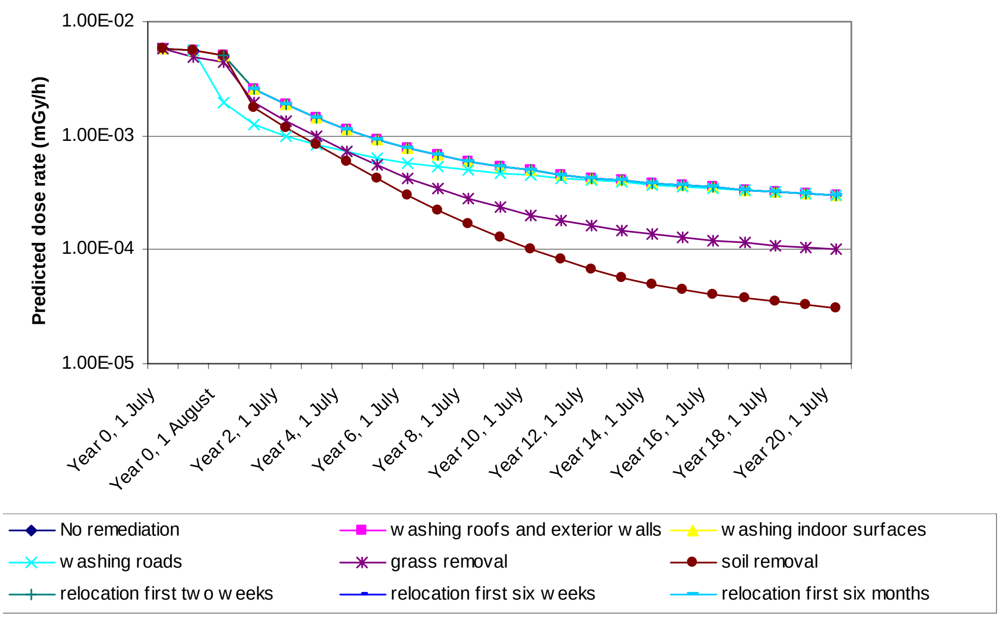

Fig. III.5.8. Predicted dose rates with different countermeasures for location 1 (outside building 1).

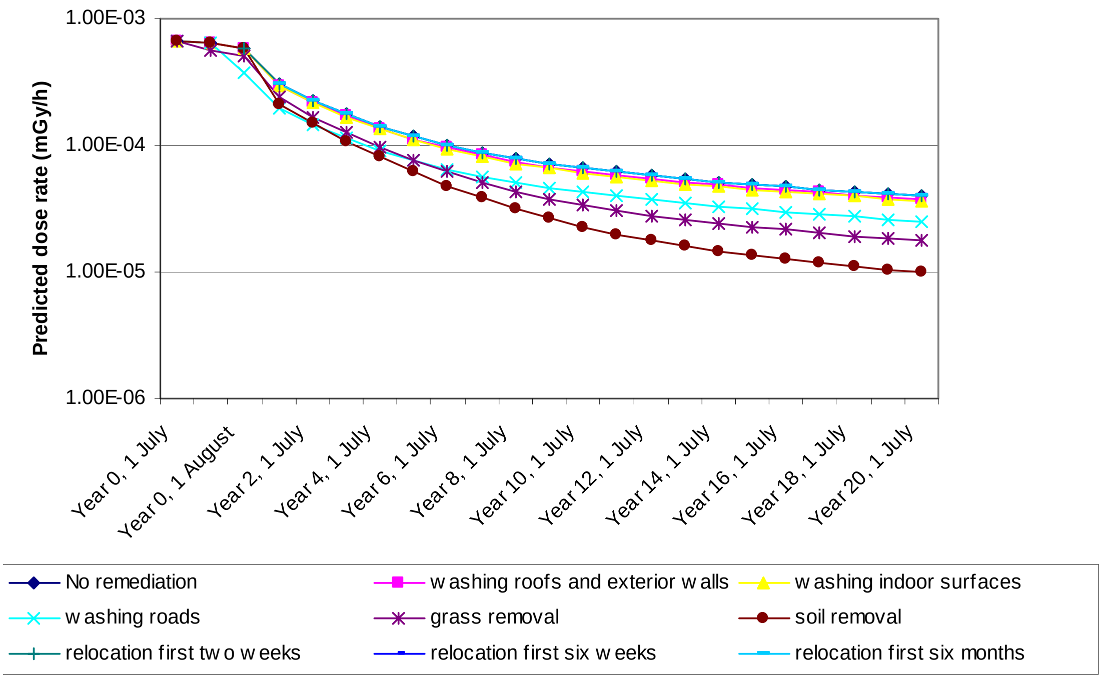

Fig. III.5.9. Predicted dose rates with different countermeasures for location 2 (inside building 1 on floor 1).

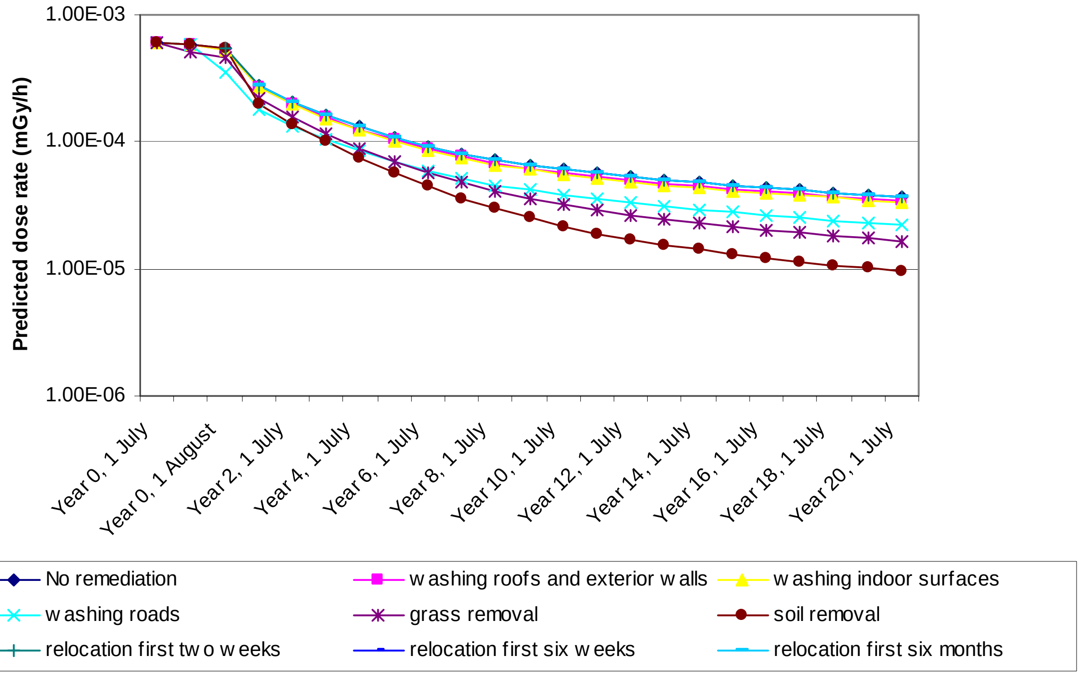

Fig. III.5.10. Predicted dose rates with different countermeasures for location 3 (inside building 1 on floor 5).

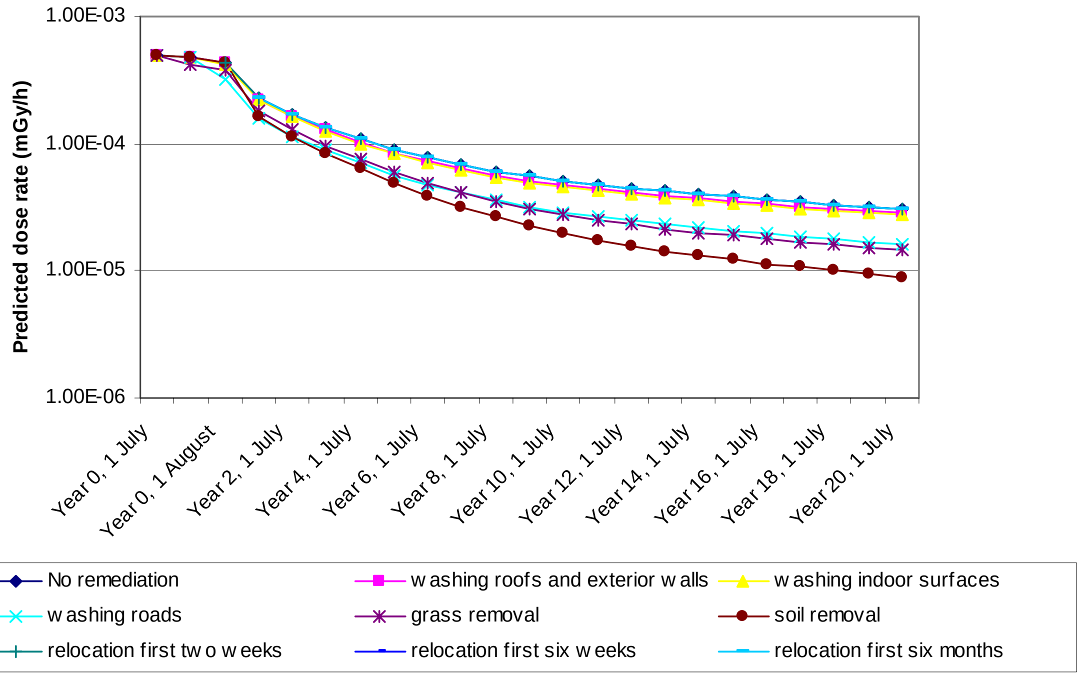

Fig. III.5.11. Predicted dose rates with different countermeasures for location 4 (inside building 1 on floor 20).

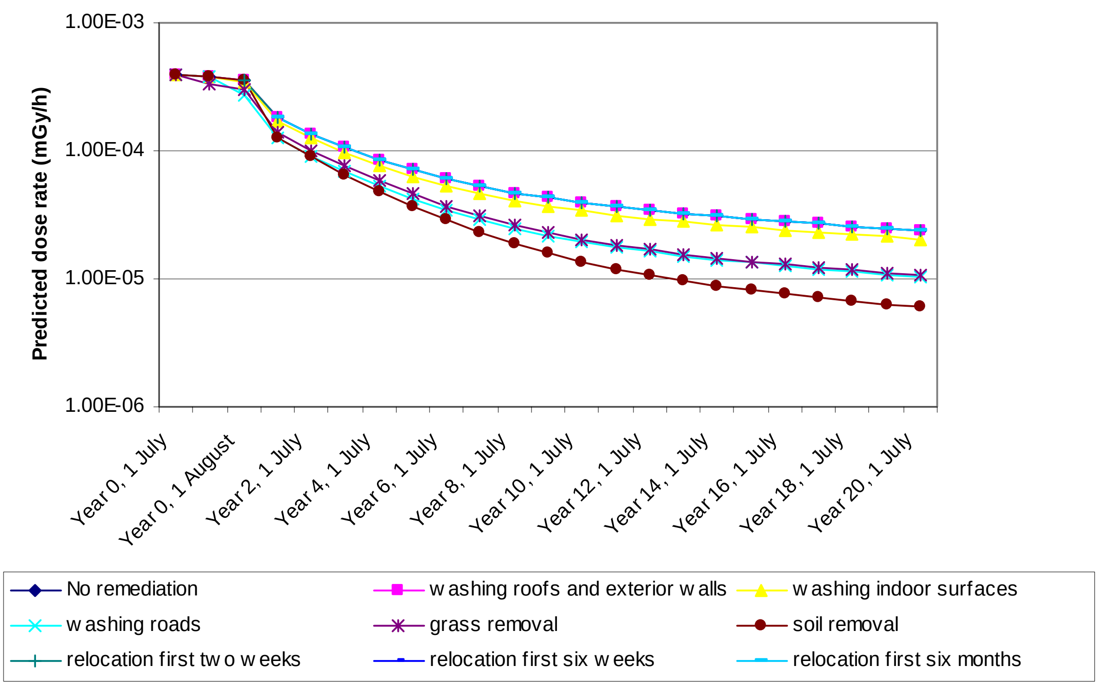

Fig. III.5.12. Predicted dose rates with different countermeasures for location 5 (inside building 1 on floor 60).

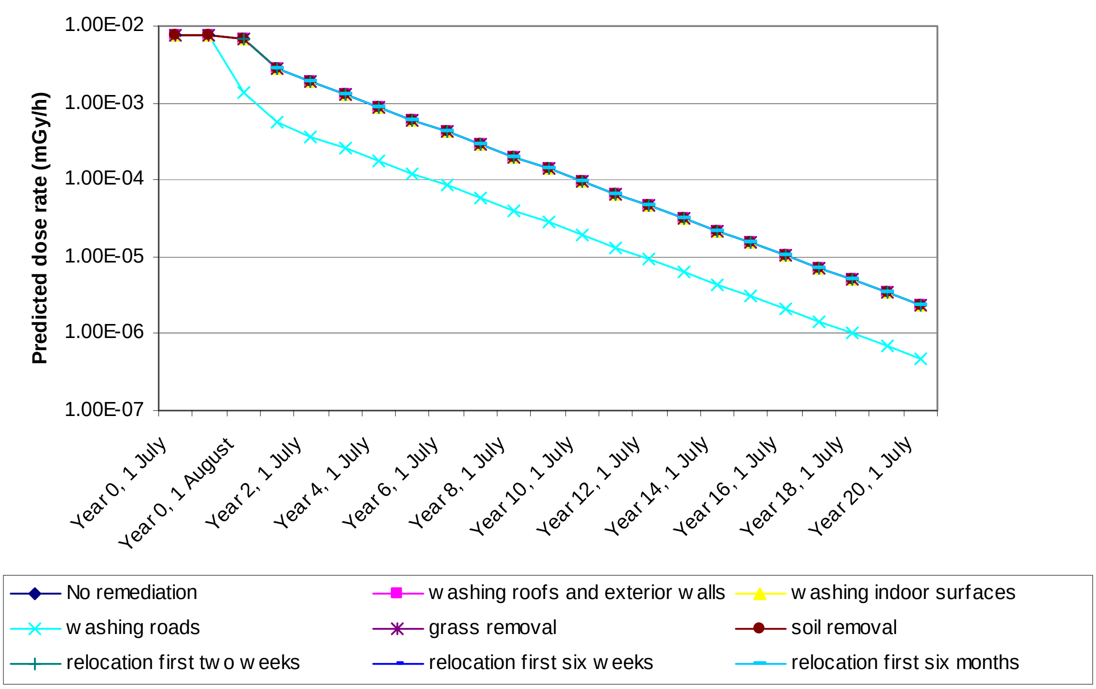

Fig. III.5.13. Predicted dose rates with different countermeasures for location 6 (outside building 2).

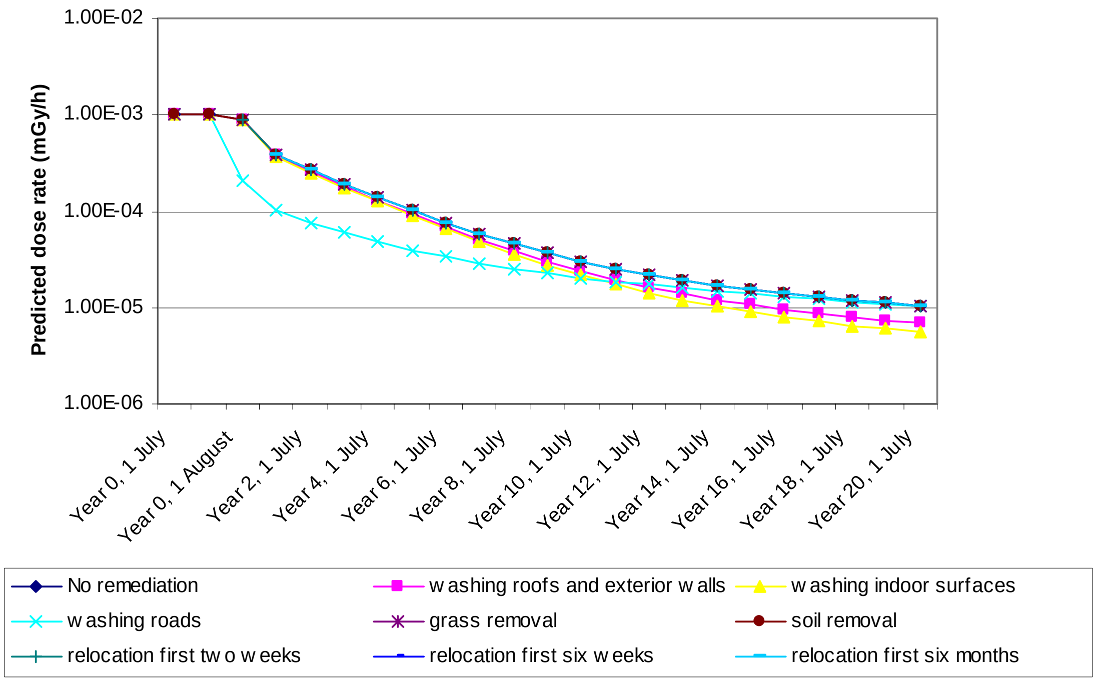

Fig. III.5.14. Predicted dose rates with different countermeasures for location 7 (inside building 2 on floor 1).

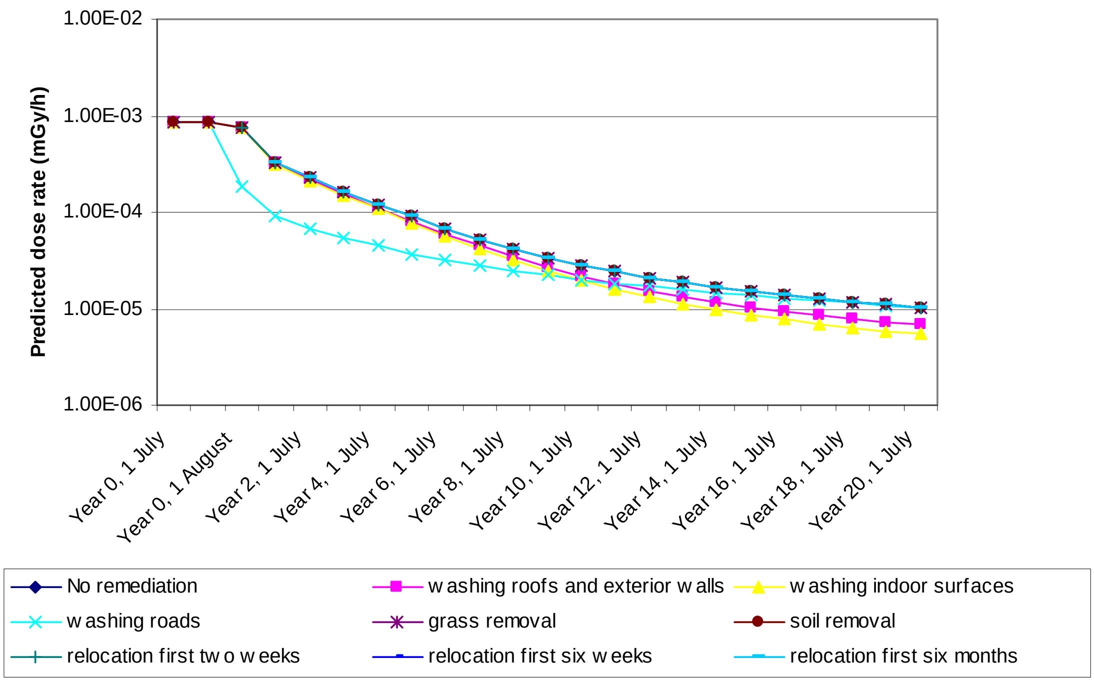

Fig. III.5.15. Predicted dose rates with different countermeasures for location 8 (inside building 2 on floor 4).

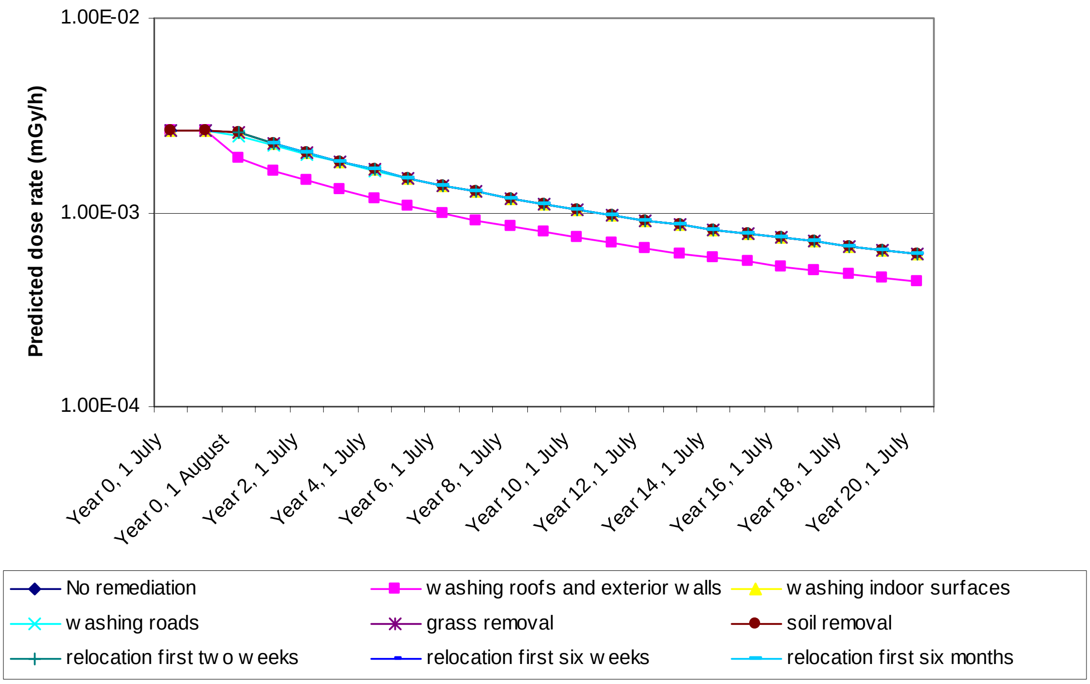

Fig. III.5.16. Predicted dose rates with different countermeasures for location 9 (building 2 on top floor 8).

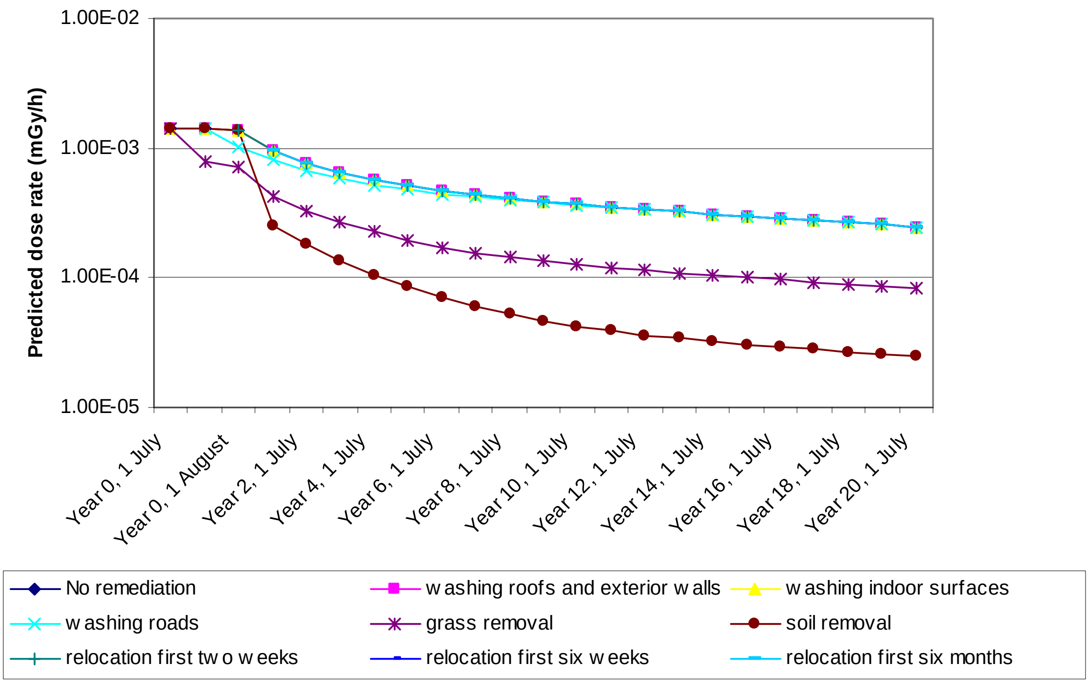

Fig. III.5.17. Predicted dose rates with different countermeasures for location 10 (building 3 outside).

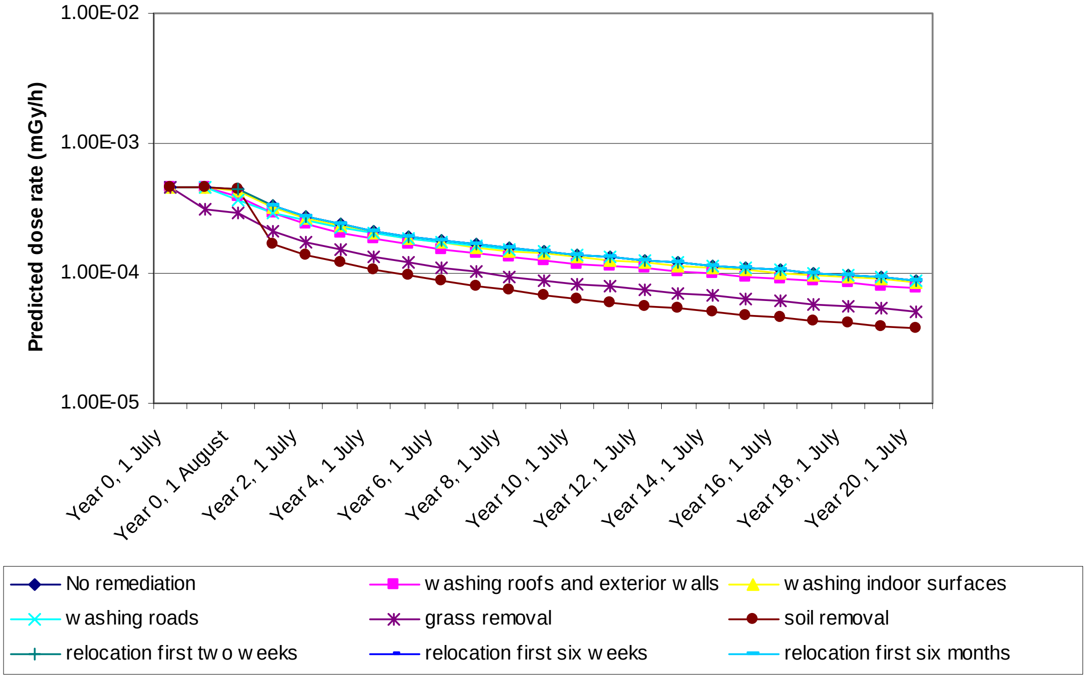

Fig. III.5.18. redicted dose rates with different countermeasures for location 11 (building 3 inside on floor 1).

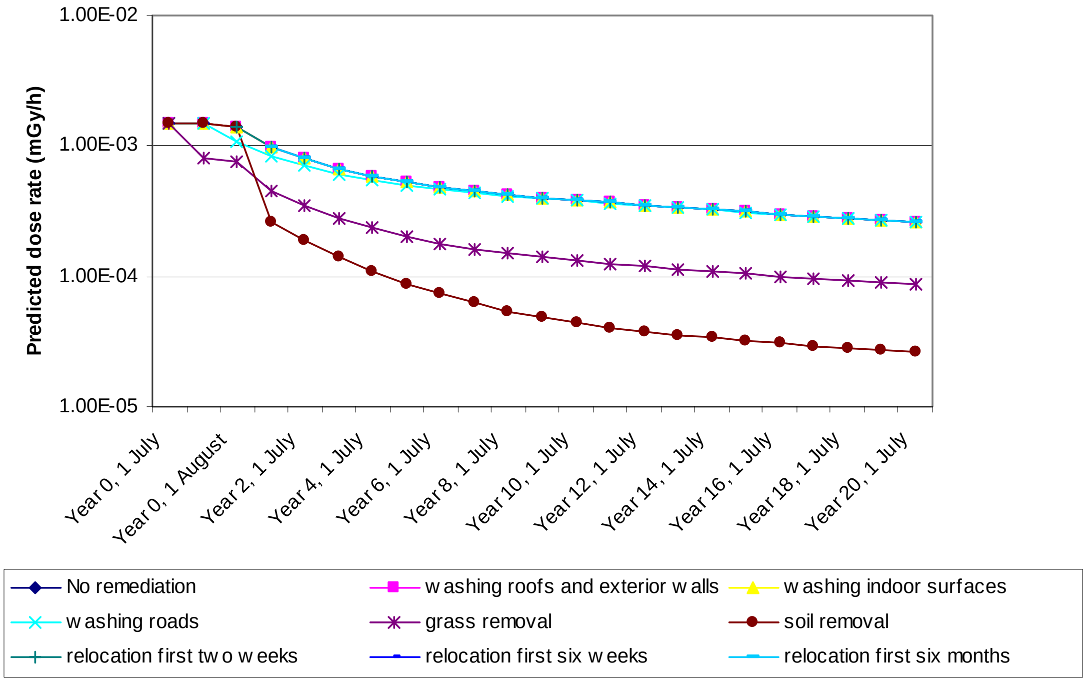

Fig. III.5.19. Predicted dose rates with different countermeasures for location 12 (building 4 outside).

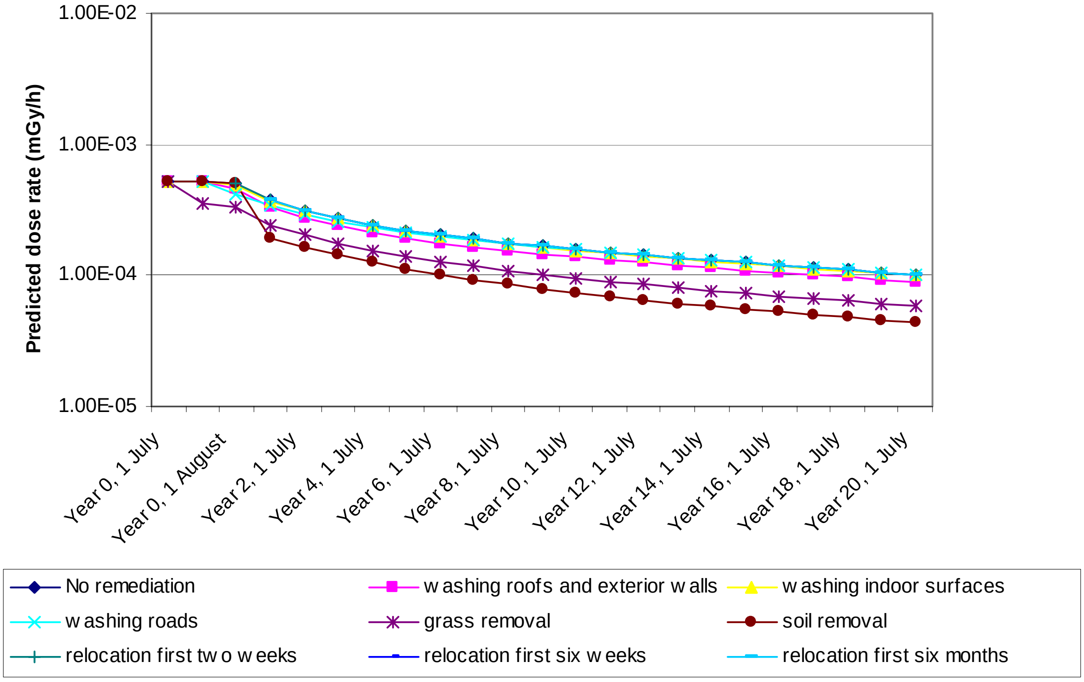

Fig. III.5.20. Predicted dose rates with different countermeasures for location 13 (building 4 inside on floor 1).

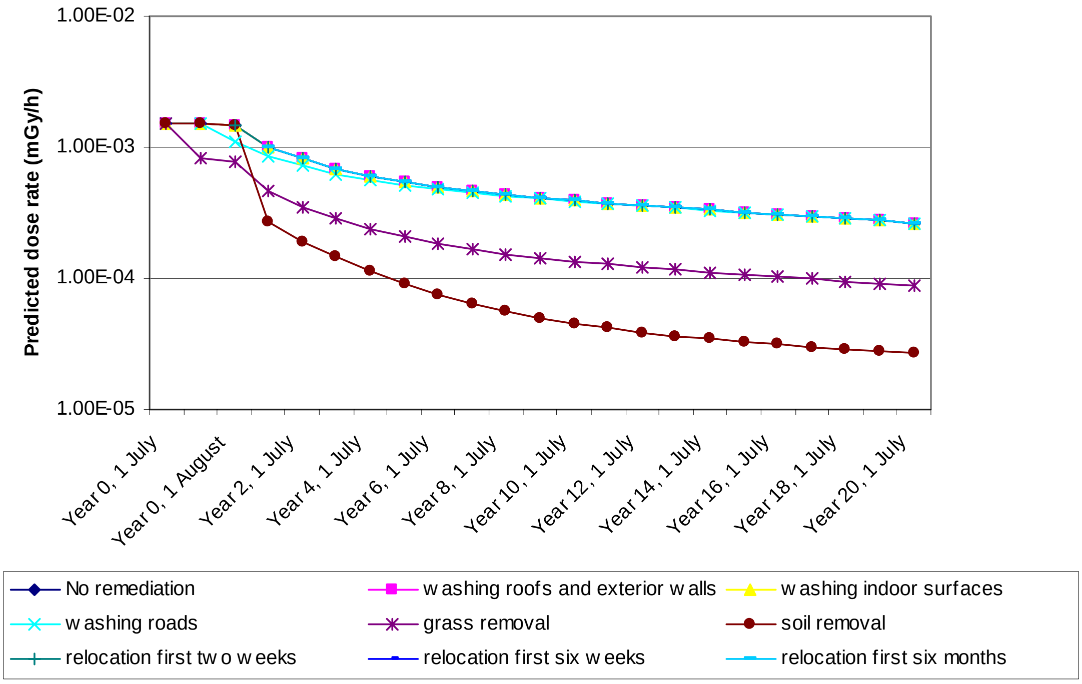

Fig. III.5.21. Predicted dose rates with different countermeasures for location 14 (building 5 outside).

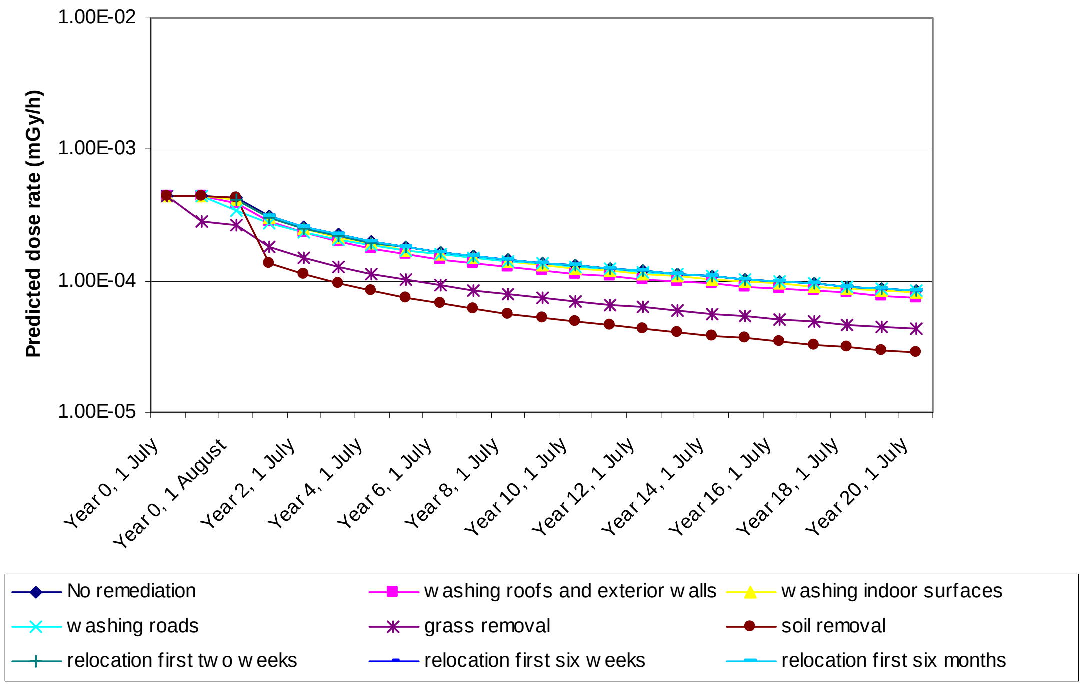

Fig. III.5.22. Predicted dose rates with different countermeasures for location 15 (building 5 inside on floor 1).

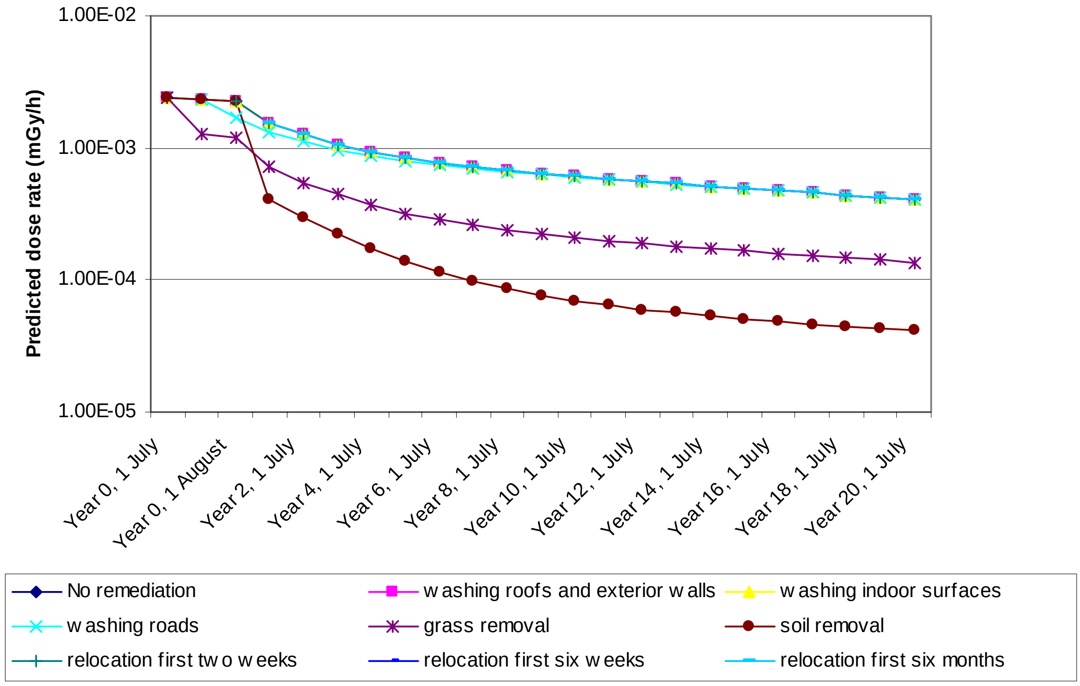

Fig. III.5.23. Predicted dose rates with different countermeasures for location 16 (building 6 outside).

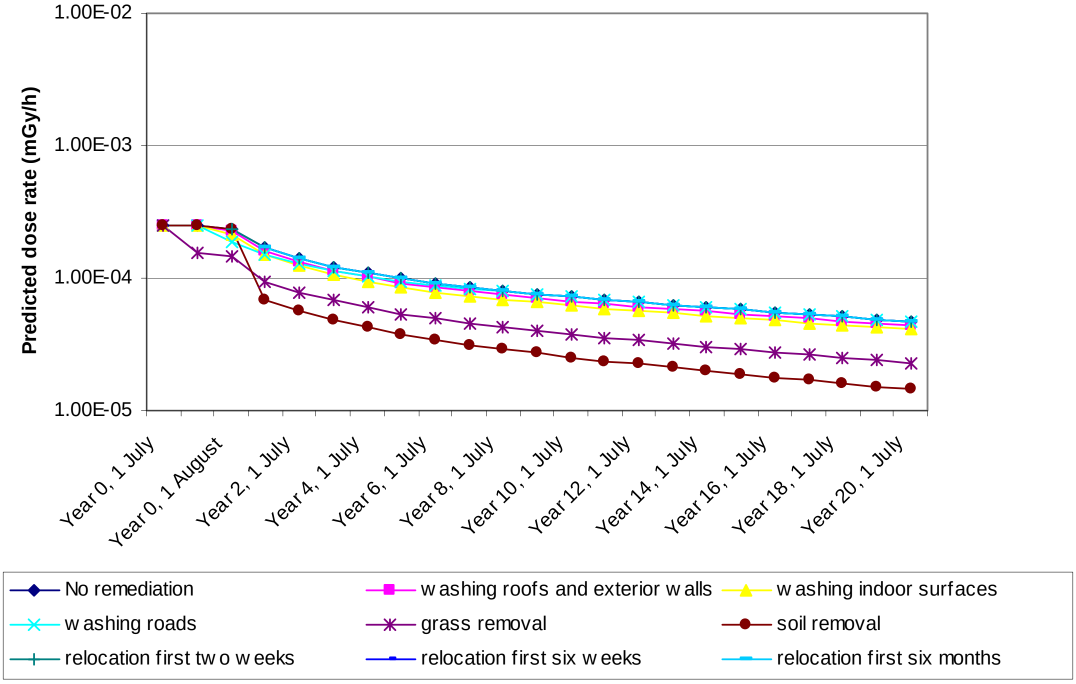

Fig. III.5.24. Predicted dose rates with different countermeasures for location 17 (building 6 inside on floor 1).

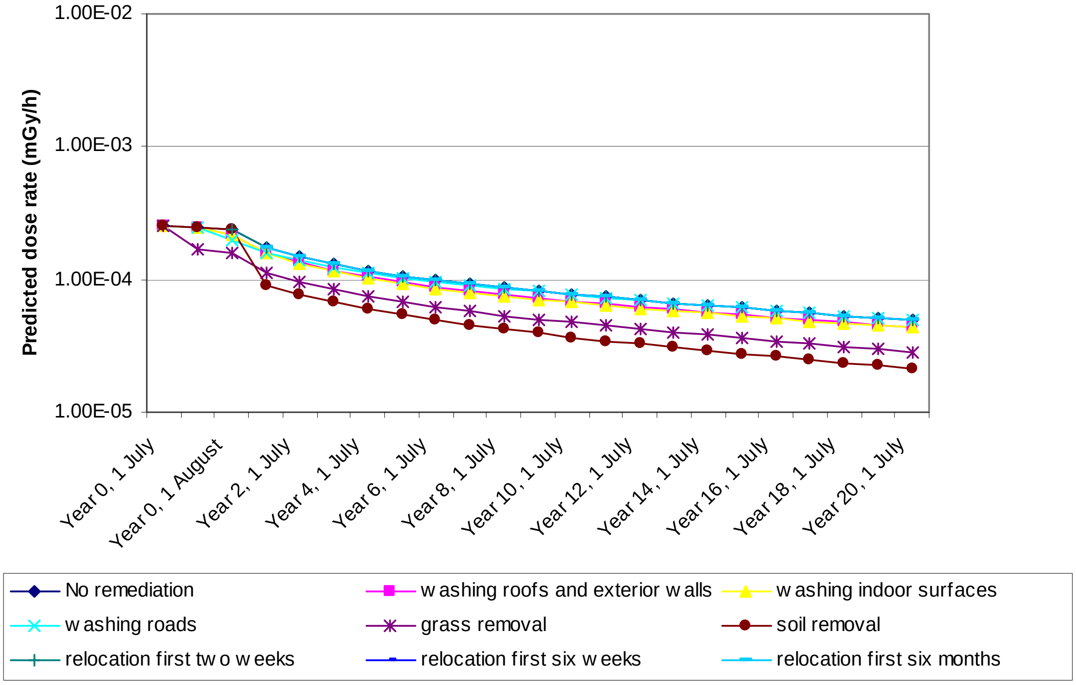

Fig. III.5.25. Predicted dose rates with different countermeasures for location 18 (building 6 inside on floor 5).

Table III.5.8. Three most important contributing surfaces* and their percent contribution to the dose rate outside building 1 with different countermeasures.

Date	**No remediation**		**Washing roads**		**Grass removal**		**Soil removal**	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Paved areas	80%	Paved areas	80%	Paved areas	80%	Paved areas	80%
	Lawn	20%	Lawn	20%	Lawn	20%	Lawn	20%
Year 5, 1 July	Lawn	61%	Lawn	89%	Paved areas	66%	Paved areas	87%
	Paved areas	39%	Paved areas	11%	Lawn	34%	Lawn	13%
Year 10, 1 July	Lawn	88%	Lawn	97%	Lawn	72%	Paved areas	57%
	Paved areas	12%	Paved areas	3%	Paved areas	28%	Lawn	43%
Year 15, 1 July	Lawn	98%	Lawn	99%	Lawn	93%	Lawn	80%
	Paved areas	2%	Paved areas	1%	Paved areas	7%	Paved areas	20%
Year 20, 1 July	Lawn	100%	Lawn	100%	Lawn	99%	Lawn	95%
	Paved areas	0%	Paved areas	0%	Paved areas	1%	Paved areas	5%

* Only two surfaces contribute to dose rate outside building 1.

Table III.5.9. Three most important contributing surfaces and their percent contribution to the dose rate inside building 1 on 1st floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Floor	49%	Floor	49%	Floor	49%	Floor	49%	Floor	49%	Floor	49%
	From outside	44%	From outside	44%	From outside	44%	From outside	44%	From outside	44%	From outside	44%
	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%
Year 5, 1 July	Floor	44%	Floor	46%	Floor	47%	From outside	42%	Floor	40%	Floor	38%
	From outside	39%	From outside	41%	From outside	42%	Floor	35%	From outside	36%	From outside	34%
	Interior walls	8%	Interior walls	8%	Exterior walls	5%	Interior walls	12%	Interior walls	12%	Interior walls	15%
Year 10, 1 July	Floor	42%	Floor	45%	Floor	46%	From outside	53%	Floor	33%	Interior walls	31%
	From outside	37%	From outside	40%	From outside	41%	Floor	19%	From outside	30%	Floor	25%
	Interior walls	11%	Interior walls	11%	Exterior walls	7%	Interior walls	16%	Interior walls	21%	From outside	22%
Year 15, 1 July	Floor	42%	Floor	44%	Floor	46%	From outside	57%	Floor	32%	Interior walls	39%
	From outside	37%	From outside	40%	From outside	41%	Interior walls	17%	From outside	28%	Exterior walls	25%
	Interior walls	11%	Interior walls	11%	9.93E-06	7%	Floor	14%	Interior walls	23%	Floor	19%
Year 20, 1 July	Floor	42%	Floor	45%	Floor	46%	From outside	60%	Floor	32%	Interior walls	40%
	From outside	38%	From outside	40%	From outside	41%	Interior walls	16%	From outside	29%	Exterior walls	25%
	Interior walls	10%	Interior walls	11%	Exterior walls	7%	Floor	14%	Interior walls	22%	Floor	18%

* For inside building 1 on 1st floor the contamination on 2nd floor acts as the roof contamination.

Table III.5.10. Three most important contributing surfaces and their percent contribution to the dose rate inside building 1 on 5th floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Floor	53%	Floor	53%	Floor	53%	Floor	53%	Floor	53%	Floor	53%
	From outside	38%	From outside	38%	From outside	38%	From outside	38%	From outside	38%	From outside	38%
	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%
Year 5, 1 July	Floor	48%	Floor	50%	Floor	51%	Floor	38%	Floor	44%	Floor	41%
	From outside	34%	From outside	36%	From outside	37%	From outside	37%	From outside	31%	From outside	29%
	Interior walls	9%	Interior walls	9%	Exterior walls	6%	Interior walls	13%	Interior walls	13%	Interior walls	16%
Year 10, 1 July	Floor	45%	Floor	48%	Floor	50%	From outside	47%	Floor	36%	Interior walls	32%
	From outside	32%	From outside	35%	From outside	36%	Floor	21%	From outside	25%	Floor	26%
	Interior walls	11%	Interior walls	12%	Exterior walls	8%	Interior walls	18%	Interior walls	22%	Exterior walls	21%
Year 15, 1 July	Floor	45%	Floor	48%	Floor	50%	From outside	52%	Floor	33%	Interior walls	40%
	From outside	32%	From outside	35%	From outside	36%	Interior walls	19%	Interior walls	24%	Exterior walls	26%
	Interior walls	11%	Interior walls	12%	Exterior walls	8%	Floor	16%	From outside	24%	Floor	19%
Year 20, 1 July	Floor	46%	Floor	49%	Floor	50%	From outside	54%	Floor	34%	Interior walls	41%
	From outside	33%	From outside	35%	From outside	36%	Interior walls	18%	From outside	24%	Exterior walls	26%
	Interior walls	11%	Interior walls	11%	Exterior walls	8%	Floor	15%	Interior walls	24%	Floor	18%

* For inside building 1 on 5th floor the contamination on 6th floor acts as the roof contamination.

Table III.5.11. Three most important contributing surfaces and their percent contribution to the dose rate inside building 1 on 20th floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Floor	66%	Floor	66%	Floor	66%	Floor	66%	Floor	66%	Floor	66%
	From outside	24%	From Outside	24%	From outside	24%	From outside	24%	From outside	24%	From outside	24%
	Roof*	5%	Roof*	5%	Roof*	5%	Roof*	5%	Roof*	5%	Roof*	5%
Year 5, 1 July	Floor	58%	Floor	61%	Floor	63%	Floor	47%	Floor	52%	Floor	48%
	From outside	21%	From Outside	22%	From outside	22%	From outside	22%	From outside	19%	Interior walls	19%
	Interior walls	10%	Interior Walls	11%	Exterior walls	7%	Interior walls	16%	Interior walls	16%	From outside	17%
Year 10, 1 July	Floor	54%	Floor	58%	Floor	61%	From outside	31%	Floor	41%	Interior walls	36%
	From outside	19%	From Outside	21%	From outside	22%	Floor	28%	Interior walls	25%	Floor	29%
	Interior walls	14%	Interior Walls	15%	Exterior walls	10%	Interior walls	24%	Exterior walls	16%	Exterior walls	23%
Year 15, 1 July	Floor	54%	Floor	58%	Floor	60%	From outside	35%	Floor	38%	Interior walls	43%
	From outside	19%	From Outside	21%	From outside	22%	Floor	22%	Interior walls	28%	Exterior walls	27%
	Interior walls	14%	Interior Walls	15%	Exterior walls	10%	Floor	22%	Exterior walls	18%	Floor	21%
Year 20, 1 July	Floor	55%	Floor	59%	Floor	61%	From outside	37%	Floor	39%	Interior walls	44%
	From outside	20%	From Outside	21%	From outside	22%	Floor	21%	Interior walls	27%	Exterior walls	28%
	Interior walls	13%	Interior Walls	14%	Exterior walls	9%	Floor	21%	Exterior walls	17%	Floor	20%

* For inside building 1 on 20th floor the contamination on 21st floor acts as the roof contamination.

Table III.5.12. Three most important contributing surfaces and their percent contribution to the dose rate inside building 1 on 60th floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Floor	82%	Floor	82%	Floor	82%	Floor	82%	Floor	82%	Floor	82%
	From outside	15%	From outside	15%	From outside	15%	From outside	15%	From outside	15%	From outside	15%
	Interior walls	4%	Interior walls	4%	Interior walls	4%	Interior walls	4%	Interior walls	4%	Interior walls	4%
Year 5, 1 July	Floor	74%	Floor	74%	Floor	82%	Floor	63%	Floor	68%	Floor	64%
	Interior walls	13%	Interior walls	13%	From outside	15%	Interior walls	22%	Interior walls	20%	Interior walls	25%
	From outside	13%	From outside	13%	Interior walls	3%	From outside	15%	From outside	12%	From outside	11%
Year 10, 1 July	Floor	70%	Floor	70%	Floor	81%	Floor	41%	Floor	56%	Interior walls	51%
	Interior walls	18%	Interior walls	18%	From outside	15%	Interior walls	36%	Interior walls	34%	Floor	41%
	From outside	12%	From outside	12%	Interior walls	4%	From outside	23%	From outside	10%	From outside	7%
Year 15, 1 July	Floor	70%	Floor	70%	Floor	81%	Interior walls	39%	Floor	52%	Interior walls	64%
	Interior walls	18%	Interior walls	18%	From outside	15%	Floor	34%	Interior walls	38%	Floor	31%
	From outside	12%	From outside	12%	Interior walls	4%	From outside	27%	From outside	9%	From outside	5%
Year 20, 1 July	Floor	71%	Floor	71%	Floor	82%	Interior walls	38%	Floor	53%	Interior walls	66%
	Interior walls	17%	Interior walls	17%	From outside	15%	Floor	33%	Interior walls	37%	Floor	29%
	From outside	13%	From outside	13%	Interior walls	4%	From outside	29%	From outside	10%	From outside	5%

Table III.5.13. Three most important contributing surfaces* and their percent contribution to the dose rate outside building 2 with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	%	surface	%	surface	%	surface	%	surface	%	surface	%
Year 0, 1 July	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%
Year 5, 1 July	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%
Year 10, 1 July	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%
Year 15, 1 July	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%
Year 20, 1 July	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%	Paved areas	100%

* Only paved areas contribute to the dose rate outside building 2

Table III.5.14. Three most important contributing surfaces and their percent contribution to the dose rate inside building 2 on 1st floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Floor	55%	Floor	55%	Floor	55%	Floor	55%	Floor	55%	Floor	55%
	From outside	38%	From outside	38%	From outside	38%	From outside	38%	From outside	38%	From outside	38%
	Roof*	3%	Roof*	3%	Roof*	3%	Roof*	3%	Roof*	3%	Roof*	3%
Year 5, 1 July	Floor	44%	Floor	48%	Floor	50%	Interior walls	37%	Floor	44%	Floor	44%
	From outside	30%	From outside	33%	From outside	34%	Exterior walls	24%	From outside	30%	From outside	30%
	Interior walls	14%	Interior walls	16%	Exterior walls	11%	Floor	23%	Interior walls	14%	Interior walls	14%
Year 10, 1 July	Interior walls	36%	Interior walls	46%	Exterior walls	33%	Interior walls	53%	Interior walls	36%	Interior walls	36%
	Exterior walls	23%	Floor	30%	Floor	33%	Exterior walls	35%	Exterior walls	23%	Exterior walls	23%
	Floor	23%	From outside	20%	From outside	22%	Floor	7%	Floor	23%	Floor	23%
Year 15, 1 July	Interior walls	53%	Interior walls	77%	Exterior walls	60%	Interior walls	59%	Interior walls	53%	Interior walls	53%
	Exterior walls	34%	Floor	10%	Interior walls	18%	Exterior walls	38%	Exterior walls	34%	Exterior walls	34%
	Floor	7%	From outside	7%	Floor	13%	Floor	2%	Floor	7%	Floor	7%
Year 20, 1 July	Interior walls	59%	Interior walls	90%	Exterior walls	72%	Interior walls	60%	Interior walls	59%	Interior walls	59%
	Exterior walls	38%	Exterior walls	6%	Interior walls	22%	Exterior walls	39%	Exterior walls	38%	Exterior walls	38%
	Floor	2%	Floor	3%	Floor	3%	Floor	0%	Floor	2%	Floor	2%

* For inside building 2 on 1st floor the contamination on 2nd floor acts as the roof contamination.

Table III.5.15. Three most important contributing surfaces and their percent contribution to the dose rate inside building 2 on 4th floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Floor	65%	Floor	65%	Floor	65%	Floor	65%	Floor	65%	Floor	65%
	From outside	27%	From outside	27%	From outside	27%	From outside	27%	From outside	27%	From outside	27%
	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%	Roof*	4%
Year 5, 1 July	Floor	50%	Floor	55%	Floor	58%	Interior walls	39%	Floor	50%	Floor	50%
	From outside	20%	From outside	23%	From outside	23%	Exterior walls	26%	From outside	20%	From outside	20%
	Interior walls	16%	Interior walls	18%	Exterior walls	12%	Floor	24%	Interior walls	16%	Interior walls	16%
Year 10, 1 July	Interior walls	38%	Interior walls	50%	Exterior walls	36%	Interior walls	54%	Interior walls	38%	Interior walls	38%
	Exterior walls	25%	Floor	32%	Floor	36%	Exterior walls	35%	Exterior walls	25%	Exterior walls	25%
	Floor	25%	From outside	13%	From outside	15%	Floor	7%	Floor	25%	Floor	25%
Year 15, 1 July	Interior walls	54%	Interior walls	79%	Exterior walls	62%	Interior walls	59%	Interior walls	54%	Interior walls	54%
	Exterior walls	35%	Floor	11%	Interior walls	19%	Exterior walls	38%	Exterior walls	35%	Exterior walls	35%
	Floor	7%	Exterior walls	5%	Floor	13%	Floor	2%	Floor	7%	Floor	7%
Year 20, 1 July	Interior walls	59%	Interior walls	90%	Exterior walls	73%	Interior walls	60%	Interior walls	59%	Interior walls	59%
	Exterior walls	38%	Exterior walls	6%	Interior walls	22%	Exterior walls	39%	Exterior walls	38%	Exterior walls	38%
	Floor	2%	Floor	3%	Floor	3%	Floor	0%	Floor	2%	Floor	2%

* For inside building 2 on 4th floor the contamination on 5th floor acts as the roof contamination.

Table III.5.16. Three most important contributing surfaces* and their percent contribution to the dose rate inside building 2 on top floor (8th floor) with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	on Top Floor From outside	94% 6%	on Top Floor From outside	94% 6%	on Top Floor From outside	94% 6%	on Top Floor From outside	94% 6%	on Top Floor From outside	94% 6%	on Top Floor From outside	94% 6%
Year 5, 1 July	on Top Floor From outside	99% 1%	on Top Floor From outside	99% 1%	on Top Floor From outside	99% 1%	on Top Floor From outside	100% 0%	on Top Floor From outside	99% 1%	on Top Floor From outside	99% 1%
Year 10, 1 July	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%
Year 15, 1 July	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%
Year 20, 1 July	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%	on Top Floor From outside	100% 0%

* Only contamination on the top floor and the outside concentration contribute to the toal dose rate on the top floor of building 2.

Table III.5.17. Three most important contributing surfaces and their percent contribution to the dose rate outside building 3 with different measures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%
Year 5, 1 July	Lawn Paved areas	93% 7%	Lawn Paved areas	93% 7%	Lawn Paved areas	93% 7%	Lawn Paved areas	98% 2%	Lawn Paved areas	81% 19%	Lawn Paved areas	55% 45%
Year 10, 1 July	Lawn Paved areas	98% 2%	Lawn Paved areas	98% 2%	Lawn Paved areas	98% 2%	Lawn Paved areas	100% 0%	Lawn Paved areas	95% 5%	Lawn Paved areas	86% 14%
Year 15, 1 July	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	99% 1%	Lawn Paved areas	97% 3%
Year 20, 1 July	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	99% 1%

* Only contamination on the lawn and paved areas contribute to the total dose rate outside of building 3.

Table III.5.18. Three most important contributing surfaces and their percent contribution to the dose rate inside building 3 on 1st floor with different measures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	From outside	62%	From outside	62%	From outside	62%	From outside	62%	From outside	62%	From outside	62%
	Roof	19%	Roof	19%	Roof	19%	Roof	19%	Roof	19%	Roof	19%
	Floor	10%	Floor	10%	Floor	10%	Floor	10%	Floor	10%	Floor	10%
Year 5, 1 July	From outside	52%	From outside	61%	From outside	54%	From outside	51%	Roof	43%	Roof	54%
	Roof	27%	Roof	22%	Roof	28%	Roof	28%	From outside	32%	From outside	18%
	Floor	9%	Floor	10%	Floor	9%	Floor	8%	Exterior walls	12%	Exterior walls	15%
Year 10, 1 July	From outside	53%	From outside	62%	From outside	55%	From outside	52%	Roof	43%	Roof	56%
	Roof	26%	Roof	21%	Roof	27%	Roof	26%	From outside	30%	Exterior walls	17%
	Floor	9%	Floor	10%	Floor	9%	Floor	9%	Exterior walls	13%	From outside	13%
Year 15, 1 July	From outside	54%	From outside	63%	From outside	57%	From outside	54%	Roof	42%	Roof	56%
	Roof	24%	Roof	20%	Roof	25%	Roof	24%	From outside	31%	Exterior walls	17%
	Floor	9%	Floor	10%	Floor	9%	Floor	9%	Exterior walls	13%	From outside	13%
Year 20, 1 July	From outside	55%	From outside	64%	From outside	58%	From outside	55%	Roof	42%	Roof	57%
	Roof	24%	Roof	20%	Roof	25%	Roof	24%	From outside	32%	Exterior walls	16%
	Floor	9%	Floor	10%	Floor	9%	Floor	9%	Exterior walls	12%	From outside	13%

Table III.5.19. Three most important contributing surfaces and their percent contribution to the dose rate outside building 4 with different measures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Lawn	67%	Lawn	67%	Lawn	67%	Lawn	67%	Lawn	67%	Lawn	67%
	Paved areas	33%	Paved areas	33%	Paved areas	33%	Paved areas	33%	Paved areas	33%	Paved areas	33%
Year 5, 1 July	Lawn	93%	Lawn	93%	Lawn	93%	Lawn	98%	Lawn	81%	Lawn	55%
	Paved areas	7%	Paved areas	7%	Paved areas	7%	Paved areas	2%	Paved areas	19%	Paved areas	45%
Year 10, 1 July	Lawn	98%	Lawn	98%	Lawn	98%	Lawn	100%	Lawn	95%	Lawn	86%
	Paved areas	2%	Paved areas	2%	Paved areas	2%	Paved areas	0%	Paved areas	5%	Paved areas	14%
Year 15, 1 July	Lawn	100%	Lawn	100%	Lawn	100%	Lawn	100%	Lawn	99%	Lawn	97%
	Paved areas	0%	Paved areas	0%	Paved areas	0%	Paved areas	0%	Paved areas	1%	Paved areas	3%
Year 20, 1 July	Lawn	100%	Lawn	100%	Lawn	100%	Lawn	100%	Lawn	100%	Lawn	99%
	Paved areas	0%	Paved areas	0%	Paved areas	0%	Paved areas	0%	Paved areas	0%	Paved areas	1%

Table III.5.20. Three most important contributing surfaces and their percent contribution to the dose rate inside building 4 on 1st floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	From outside	57%	From outside	57%	From outside	57%	From outside	57%	From outside	57%	From outside	57%
	Roof	24%	Roof	24%	Roof	24%	Roof	24%	Roof	24%	Roof	24%
	Floor	14%	Floor	14%	Floor	14%	Floor	14%	Floor	14%	Floor	14%
Year 5, 1 July	From outside	48%	From outside	55%	From outside	49%	From outside	47%	Roof	54%	Roof	68%
	Roof	34%	Roof	28%	Roof	35%	Roof	36%	From outside	29%	From outside	16%
	Floor	12%	Floor	14%	Floor	12%	Floor	12%	Floor	7%	Exterior walls	8%
Year 10, 1 July	From outside	48%	From outside	56%	From outside	49%	From outside	48%	Roof	55%	Roof	71%
	Roof	33%	Roof	27%	Roof	34%	Roof	33%	From outside	28%	From outside	12%
	Floor	12%	Floor	14%	Floor	12%	Floor	12%	Floor	7%	Exterior walls	9%
Year 15, 1 July	From outside	50%	From outside	57%	From outside	51%	From outside	50%	Roof	54%	Roof	72%
	Roof	32%	Roof	26%	Roof	32%	Roof	32%	From outside	29%	From outside	12%
	Floor	12%	Floor	14%	Floor	13%	Floor	12%	Floor	7%	Exterior walls	9%
Year 20, 1 July	From outside	51%	From outside	58%	From outside	52%	From outside	51%	Roof	54%	Roof	72%
	Roof	31%	Roof	25%	Roof	31%	Roof	31%	From outside	29%	From outside	12%
	Floor	13%	Floor	14%	Floor	13%	Floor	13%	Floor	7%	Exterior walls	8%

Table III.5.21. Three most important contributing surfaces and their percent contribution to the dose rate outside building 5 with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%
Year 5, 1 July	Lawn Paved areas	93% 7%	Lawn Paved areas	93% 7%	Lawn Paved areas	93% 7%	Lawn Paved areas	98% 2%	Lawn Paved areas	81% 19%	Lawn Paved areas	55% 45%
Year 10, 1 July	Lawn Paved areas	98% 2%	Lawn Paved areas	98% 2%	Lawn Paved areas	98% 2%	Lawn Paved areas	100% 0%	Lawn Paved areas	95% 5%	Lawn Paved areas	86% 14%
Year 15, 1 July	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	99% 1%	Lawn Paved areas	97% 3%
Year 20, 1 July	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	99% 1%

Table III.5.22. Three most important contributing surfaces and their percent contribution to the dose rate inside building 5 on 1st floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	%	surface	%	surface	%	surface	%	surface	%	surface	%
Year 0, 1 July	From outside	69%	From outside	69%	From outside	69%	From outside	69%	From outside	69%	From outside	69%
	Floor	12%	Floor	12%	Floor	12%	Floor	12%	Floor	12%	Floor	12%
	Roof	10%	Roof	10%	Roof	10%	Roof	10%	Roof	10%	Roof	10%
Year 5, 1 July	From outside	60%	From outside	69%	From outside	63%	From outside	59%	From outside	41%	Roof	36%
	Roof	15%	Roof	12%	Roof	16%	Roof	16%	Roof	27%	From outside	24%
	Floor	10%	Floor	12%	Floor	11%	Floor	10%	Exterior walls	16%	Exterior walls	22%
Year 10, 1 July	From outside	60%	From outside	69%	From outside	63%	From outside	60%	From outside	39%	Roof	38%
	Roof	14%	Floor	12%	Roof	15%	Roof	14%	Roof	27%	Exterior walls	25%
	Floor	10%	Roof	12%	Floor	11%	Floor	10%	Exterior walls	18%	From outside	18%
Year 15, 1 July	From outside	62%	From outside	70%	From outside	65%	From outside	62%	From outside	40%	Roof	39%
	Roof	14%	Floor	12%	Roof	14%	Roof	14%	Roof	26%	Exterior walls	25%
	Floor	10%	Roof	11%	Floor	11%	Floor	10%	Exterior walls	17%	From outside	18%
Year 20, 1 July	From outside	63%	From outside	71%	From outside	66%	From outside	63%	From outside	41%	Roof	39%
	Roof	13%	Floor	12%	Roof	14%	Roof	13%	Roof	26%	Exterior walls	24%
	Floor	11%	Roof	11%	Floor	11%	Floor	11%	Exterior walls	16%	From outside	19%

Table III.5.23. Three most important contributing surfaces and their percent contribution to the dose rate outside building 6 with different countermeasures.

Date	**No remediation**		**Washing roofs and exterior walls**		**Washing indoor surfaces**		**Washing roads**		**Grass removal**		**Soil removal**	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%	Lawn Paved areas	67% 33%
Year 5, 1 July	Lawn Paved areas	93% 7%	Lawn Paved areas	93% 7%	Lawn Paved areas	93% 7%	Lawn Paved areas	98% 2%	Lawn Paved areas	81% 19%	Lawn Paved areas	55% 45%
Year 10, 1 July	Lawn Paved areas	98% 2%	Lawn Paved areas	98% 2%	Lawn Paved areas	98% 2%	Lawn Paved areas	100% 0%	Lawn Paved areas	95% 5%	Lawn Paved areas	86% 14%
Year 15, 1 July	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	99% 1%	Lawn Paved areas	97% 3%
Year 20, 1 July	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	100% 0%	Lawn Paved areas	99% 1%

Table III.5.24. Three most important contributing surfaces and their percent contribution to the dose rate inside building 6 on 1st floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	From outside	47%	From outside	47%	From outside	47%	From outside	47%	From outside	47%	From outside	47%
	Floor	34%	Floor	34%	Floor	34%	Floor	34%	Floor	34%	Floor	34%
	Interior walls	12%	Interior walls	12%	Interior walls	12%	Interior walls	12%	Interior walls	12%	Interior walls	12%
Year 5, 1 July	From outside	42%	From outside	45%	From outside	49%	From outside	41%	Interior walls	33%	Interior walls	46%
	Floor	30%	Floor	32%	Floor	35%	Floor	29%	From outside	30%	Exterior walls	21%
	Interior walls	18%	Interior walls	19%	Exterior walls	9%	Interior walls	18%	Floor	21%	From outside	18%
Year 10, 1 July	From outside	42%	From outside	45%	From outside	49%	From outside	42%	Interior walls	35%	Interior walls	52%
	Floor	30%	Floor	32%	Floor	35%	Floor	30%	From outside	28%	Exterior walls	24%
	Interior walls	18%	Interior walls	20%	Exterior walls	10%	Interior walls	18%	Floor	20%	From outside	14%
Year 15, 1 July	From outside	43%	From outside	46%	From outside	49%	From outside	43%	Interior walls	34%	Interior walls	52%
	Floor	30%	Floor	33%	Floor	35%	Floor	30%	From outside	29%	Exterior walls	24%
	Interior walls	17%	Interior walls	18%	Exterior walls	9%	Interior walls	17%	Floor	20%	From outside	13%
Year 20, 1 July	From outside	44%	From outside	47%	From outside	50%	From outside	44%	Interior walls	32%	Interior walls	51%
	Floor	31%	Floor	33%	Floor	36%	Floor	31%	From outside	30%	Exterior walls	24%
	Interior walls	16%	Interior walls	17%	Exterior walls	8%	Interior walls	16%	Floor	21%	From outside	14%

Table III.5.25. Three most important contributing surfaces and their percent contribution to the dose rate inside building 6 on 5th floor with different countermeasures.

Date	No remediation		Washing roofs and exterior walls		Washing indoor surfaces		Washing roads		Grass removal		Soil removal	
	surface	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**	**surface**	**%**
Year 0, 1 July	From outside	38%	From outside	38%	From outside	38%	From outside	38%	From outside	38%	From outside	38%
	Floor	34%	Floor	34%	Floor	34%	Floor	34%	Floor	34%	Floor	34%
	Roof	12%	Roof	12%	Roof	12%	Roof	12%	Roof	12%	Roof	12%
Year 5, 1 July	From outside	31%	From outside	36%	From outside	36%	From outside	31%	Roof	26%	Roof	33%
	Floor	28%	Floor	32%	Floor	32%	Floor	27%	Interior walls	26%	Interior walls	32%
	Roof	17%	Interior walls	19%	Roof	19%	Roof	17%	From outside	19%	Exterior walls	15%
Year 10, 1 July	From outside	31%	From outside	36%	From outside	36%	From outside	31%	Interior walls	28%	Interior walls	36%
	Floor	28%	Floor	32%	Floor	32%	Floor	28%	Roof	26%	Roof	33%
	Interior walls	17%	Interior walls	19%	Roof	18%	Interior walls	17%	From outside	18%	Exterior walls	17%
Year 15, 1 July	From outside	32%	From outside	36%	From outside	37%	From outside	32%	Interior walls	27%	Interior walls	36%
	Floor	29%	Floor	32%	Floor	33%	Floor	29%	Roof	26%	Roof	34%
	Interior walls	16%	Interior walls	18%	Roof	17%	Interior walls	16%	From outside	18%	Exterior walls	17%
Year 20, 1 July	From outside	33%	From outside	37%	From outside	38%	From outside	33%	Interior walls	26%	Interior walls	35%
	Floor	30%	Floor	33%	Floor	34%	Floor	30%	Roof	26%	Roof	35%
	Interior walls	15%	Interior walls	17%	Roof	17%	Interior walls	15%	From outside	19%	Exterior walls	16%

III.5.6.2. Results of second modeling endpoint

For the second modeling endpoint, the three most important contributing contaminated surfaces and their percent contributions to the total instantaneous dose rate (mGy h^{-1}) were listed for five times (year 0, year 5, year 10, year 15, and year 20) for the 18 test locations, both with no countermeasures and with different countermeasures. Relocation would not change the surface concentration. Therefore, the dose rate at test locations would not change with relocation. Since all the countermeasures would be after the incident, therefore, the dose rate for year 0 would be the same in all countermeasures. Tables III.5.8 to III.5.25 show the percent contribution of the three most important surfaces for 18 test locations with different countermeasures. The following observations were made:

- The percent contribution of different surfaces to the dose rate changes with countermeasure and with time due to weathering and initial assumptions for outdoor exposure; and
- The percent contribution of different surfaces to the dose rate is dependent on the test locations (the outside setting, building characteristics, initial surface concentration of the contributing surfaces at a given test location, etc.).

III.5.6.3. Results of third modeling endpoint

For the third modeling endpoint, annual and cumulative doses were calculated for seven reference individuals, both with no countermeasures and with different countermeasures. Figure III.5.26 shows the annual average dose for seven reference individuals with no countermeasures, and Figure III.5.27 shows the cumulative dose for six reference individuals with no countermeasures. The cumulative dose was not calculated for a child that attends school because the child would not stay in the same school for 20 some years. Doses are maximum for an adult occupational worker spending 40 hours per week in outdoor work at Building 2 (parking garage) on the top floor of the parking garage with open sides, due to high initial surface concentration. The doses are minimum for an adult staying one hour per week inside, in a supermarket (Building 4) due to low exposure duration. The only difference in the occupational (Building 4) and occasional (Building 4) reference individuals' exposures is the difference in exposure duration. Therefore, only occupational reference individual doses are shown in the figures that show the effect of countermeasures.

It was observed that the differences in dose (annual and cumulative) for seven reference individuals with no countermeasures were mostly due to differences in the following elements:

- Initial reference concentration;
- Occupancy factor;
- Assumptions for outdoor exposure;
- Building characteristics; and
- Weathering of contributing contaminated surfaces

Figures III.5.28 to III.5.33 show the annual dose with and without different countermeasures for each reference individual considered in this exercise. Figures III.5.34 to III.5.38 show the cumulative dose with and without different countermeasures for each reference individual considered. To find out which countermeasure is most effective for a given reference individual, countermeasure effectiveness (CE), defined as the percentage change in dose, was calculated for each countermeasure. CE was calculated for both annual and cumulative dose. Tables III.5.26 to III.5.31 show the CE based on annual dose and Tables III.5.32 to III.5.36 show the CE based on cumulative dose for each reference individual considered in this exercise. The tables also include the annual or cumulative dose with no countermeasure. The following observations were made:

- Countermeasure effectiveness depends on the decontamination factor and the contribution of the contaminated surfaces to the total dose;
- Countermeasure effectiveness changes with time;
- Relocation for the first six months is the most effective countermeasure in reducing the annual or cumulative dose for first year for all reference individuals;
- Relocation effectiveness decreases after the first year for cumulative dose, and the effectiveness is zero after the first year for annual dose (i.e., annual dose does not change after first year) for all reference individuals;
- Soil removal and grass removal are the two most effective countermeasures in reducing the annual and cumulative dose after the first year for all reference individuals except for the occupant on the top floor of the parking lot. The effectiveness of both countermeasures increases with time as the contribution from outside contamination on the lawn to the total dose increases with time due to less weathering of the lawn contamination compared to the contamination on other surfaces;
- Washing the roof is the most effective countermeasure for the occupant on the top floor of the parking lot;
- Washing of roads is most effective immediately after the incident but its effectiveness decreases with time because of the natural fast weathering of the contamination on the paved areas; and
- Washing outdoor surfaces (roof and exterior walls) and indoor surfaces (interior walls) are less effective countermeasures immediately after the incident, but their effectiveness increases with time as the contribution from roof, exterior walls, interior walls to the total dose increases.

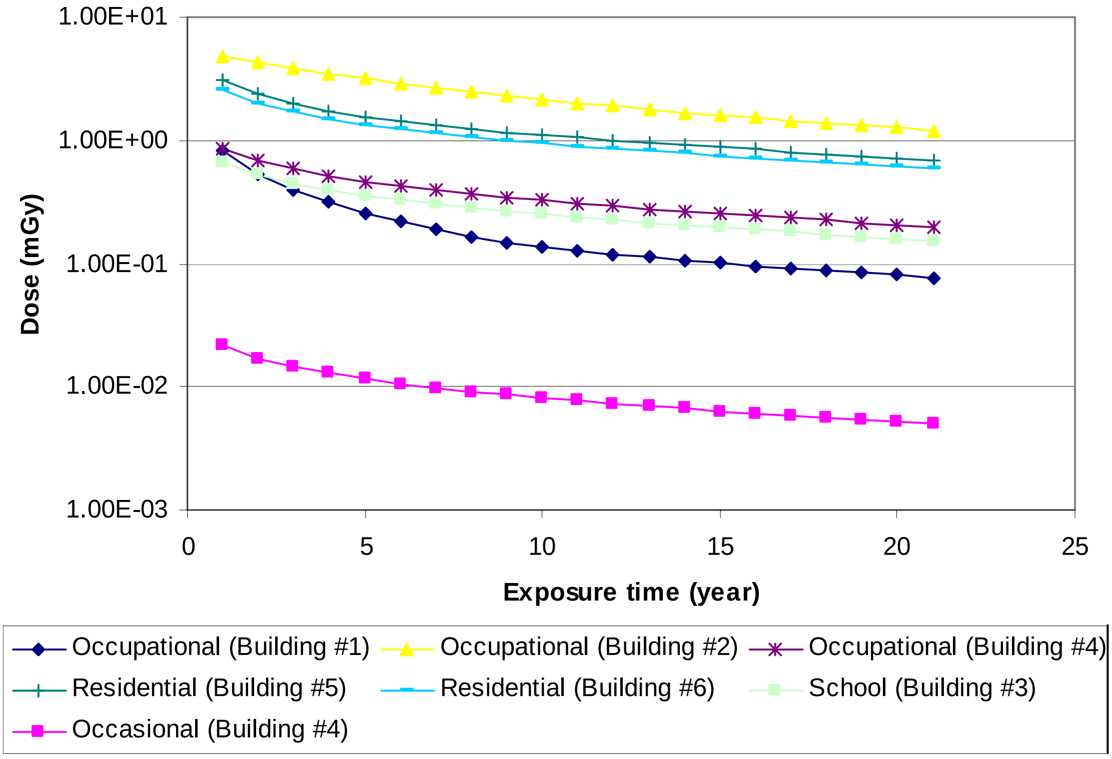

Fig. III.5.26. Annual dose for reference individuals with no remediation.

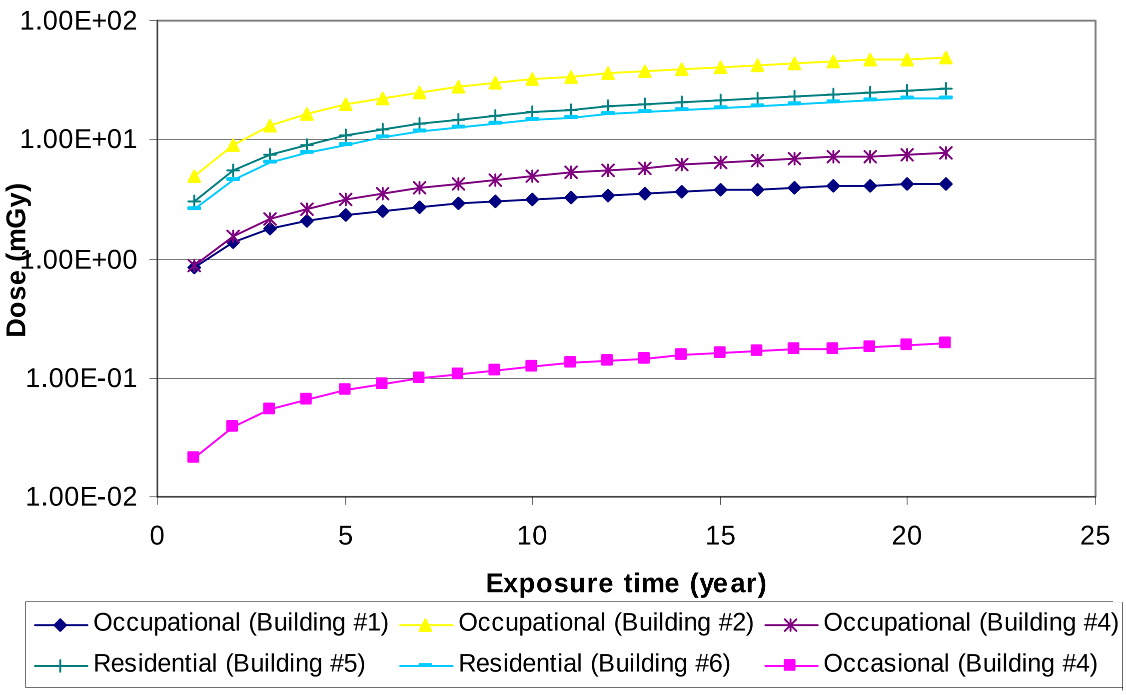

Fig. III.5.27. Cumulative doses for reference individuals with no remediation.

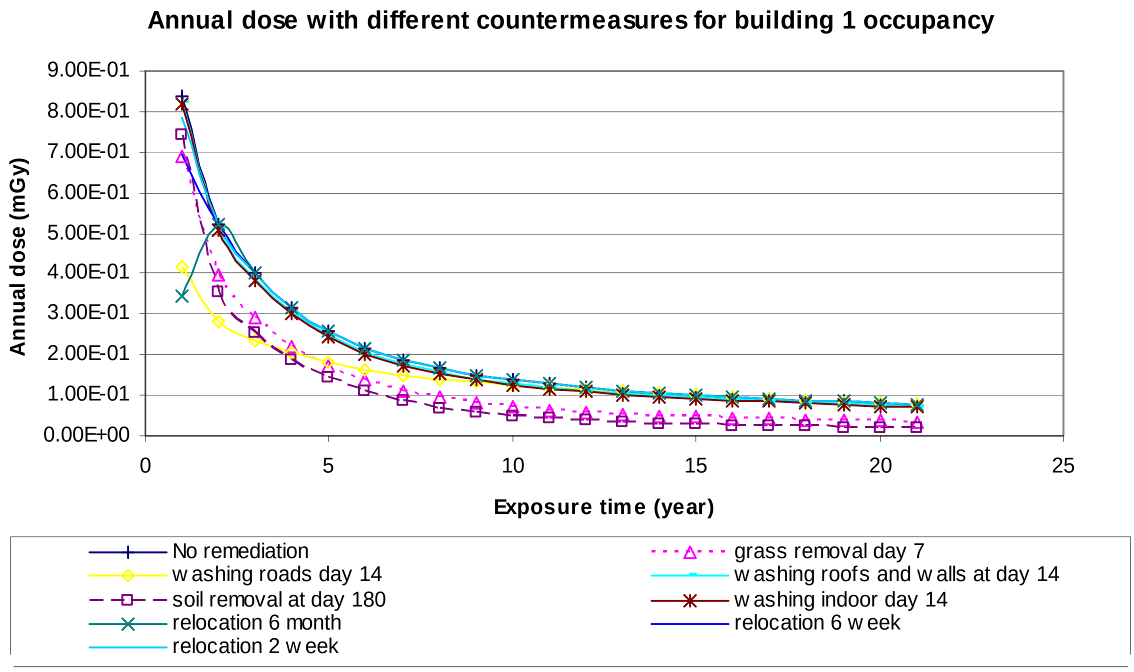

Fig. III.5.28. Annual doses with different countermeasures for a building 1 occupancy for an adult occupational worker spending 40 hours per week, in office work indoors on the1st floor.

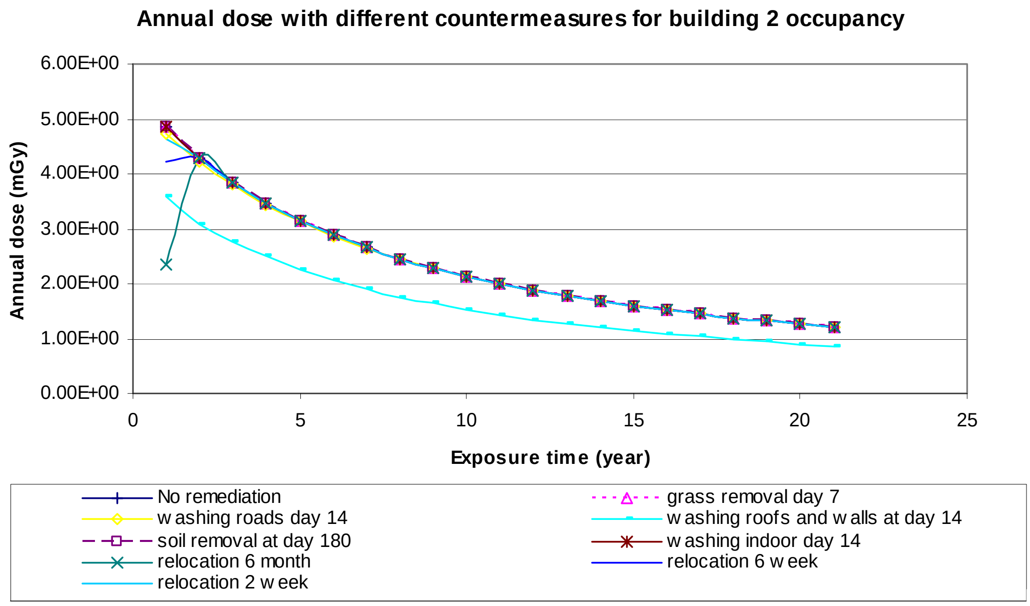

Fig. III.5.29. Annual doses with different countermeasures for a building 2 occupancy for an adult occupational worker spending 40 hours per week on the top floor of the parking garage.

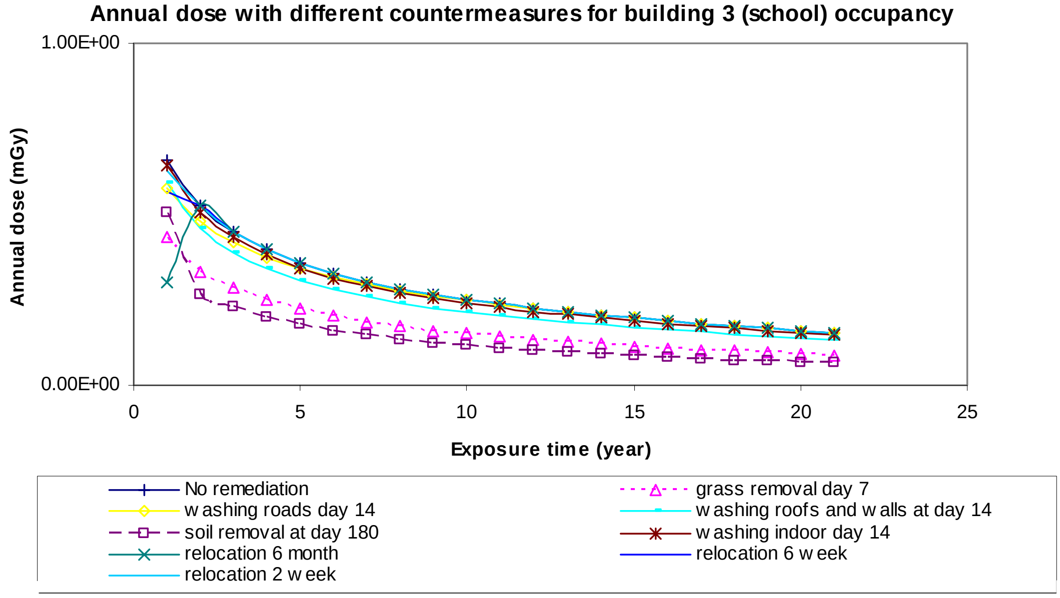

Fig. III.5.30. Annual doses with different countermeasures for a building 3 occupancy for a child staying 35 hours per week inside, attending school.

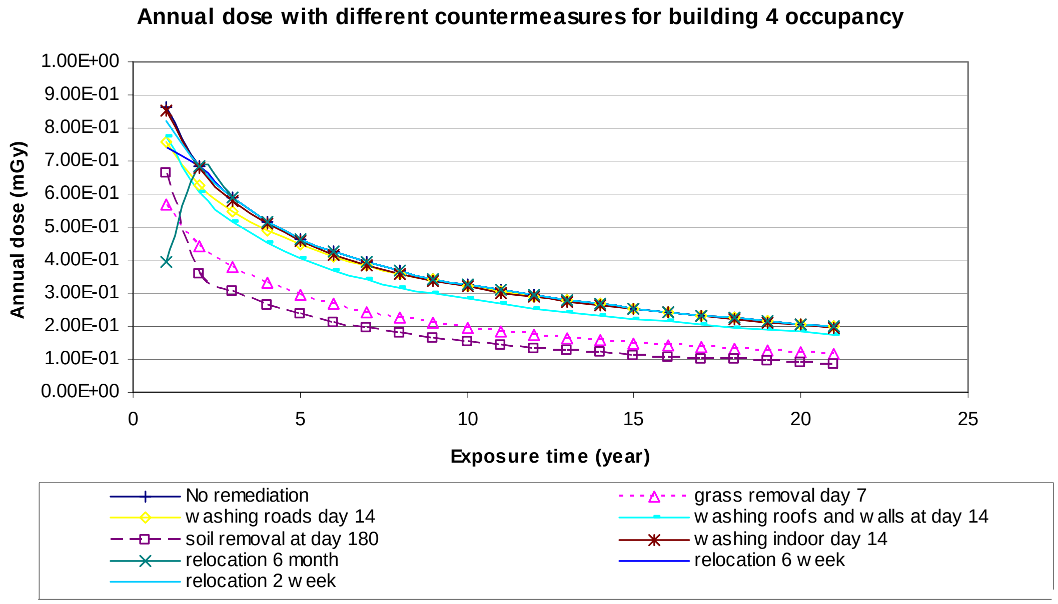

Fig. III.5.31. Annual doses with different countermeasures for a building 4 occupancy for an adult occupational worker spending 40 hours per week, indoors on the 1st floor.

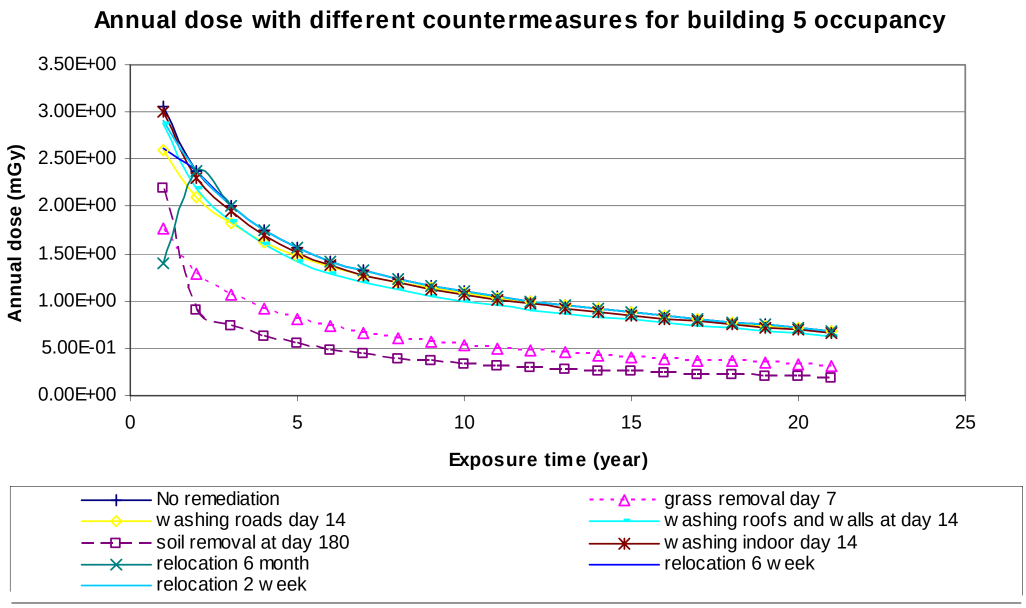

Fig. III.5.32. Annual doses with different countermeasures for building 5 occupancy for a resident spending 120 hours inside on first floor and 15 hours outside a residential home.

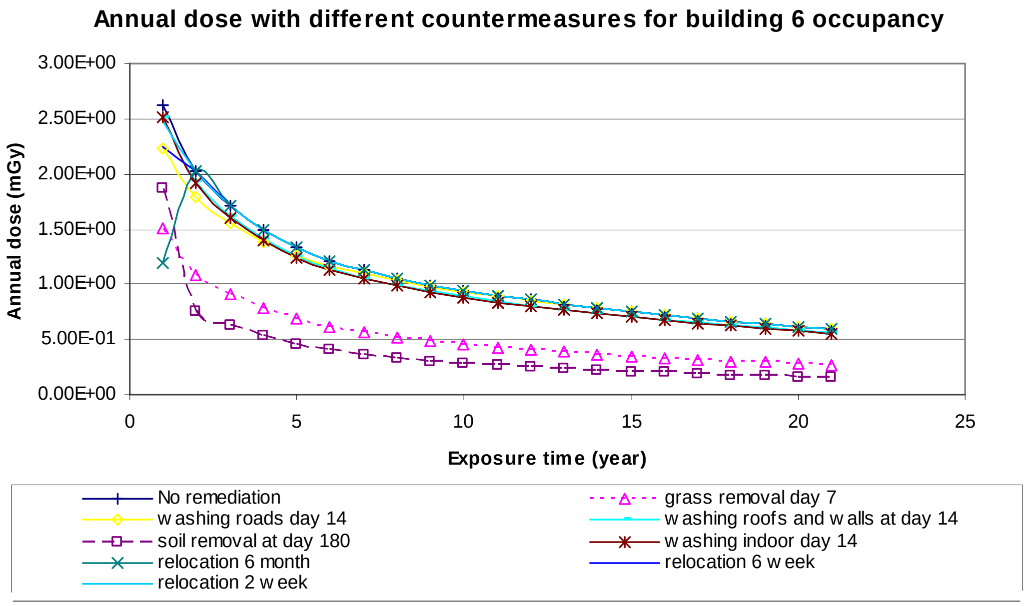

Fig. III.5.33. Annual doses with different countermeasures for a building 6 occupancy for a resident spending 120 hours inside on first floor and 15 hours outside an apartment building.

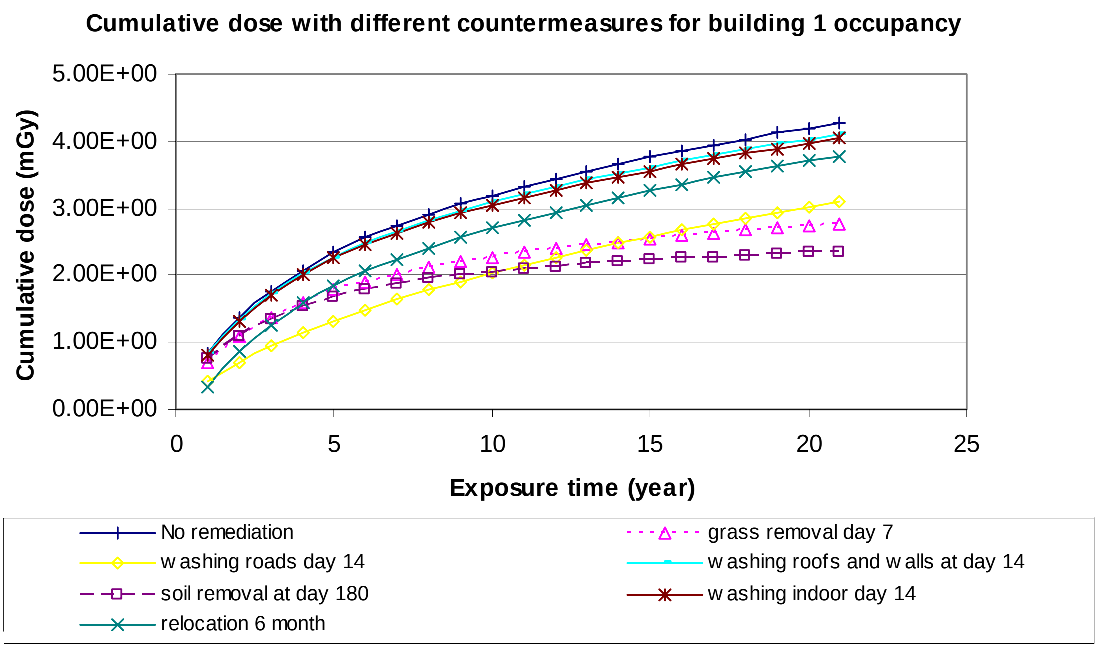

Fig. III.5.34. Cumulative doses with different countermeasures for a building 1 occupancy for an adult occupational worker spending 40 hours per week, in office work indoors on the 1st floor.

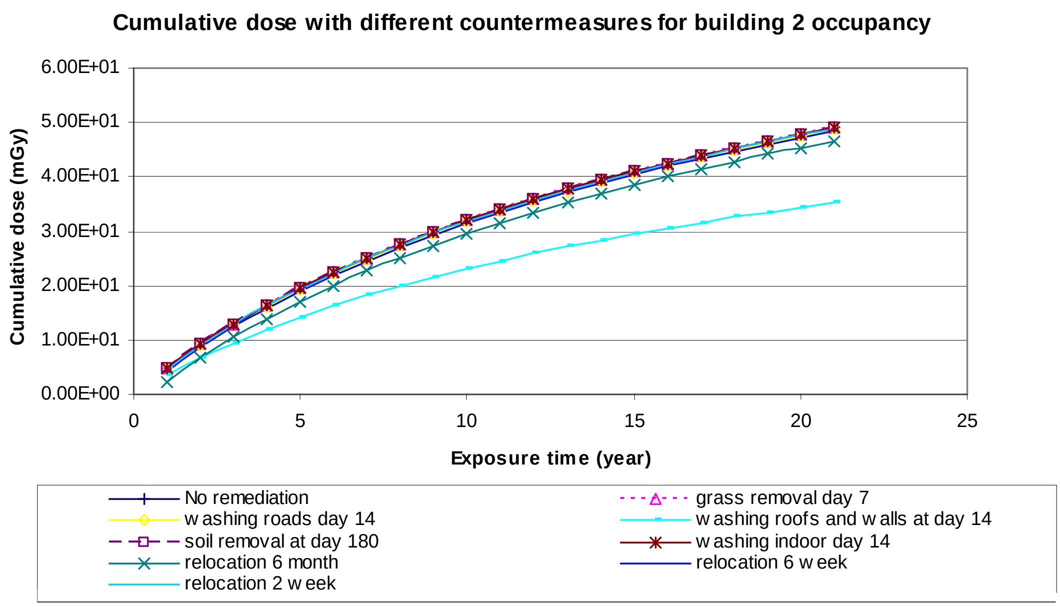

Fig. III.5.35. Cumulative doses with different countermeasures for a building 2 occupancy for an adult occupational worker spending 40 hours per week on the top floor of the parking garage.

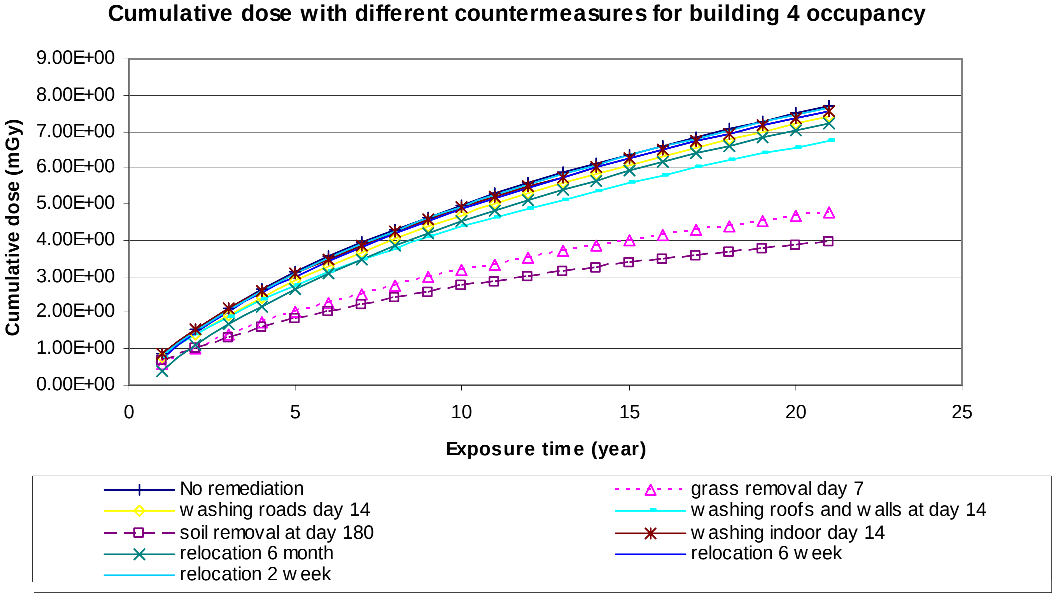

Fig. III.5.36. Cumulative doses with different countermeasures for building 4 occupancy for an adult occupational worker spending 40 hours per week, indoors on the 1st floor.

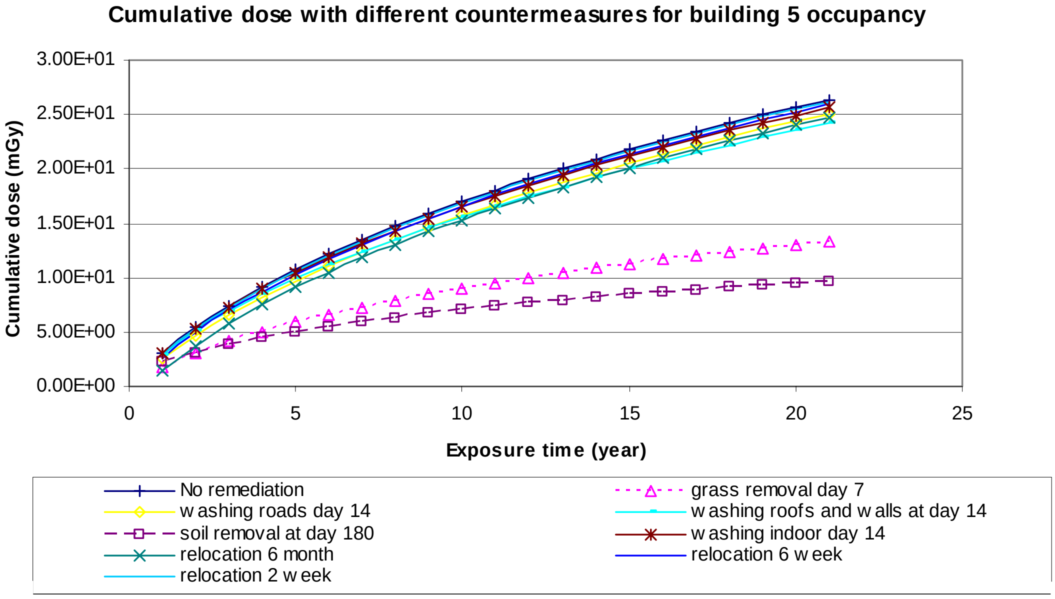

Fig. III.5.37. Cumulative doses with different countermeasures for building 5 occupancy for a resident spending 120 hours inside on first floor and 15 hours outside a residential home.

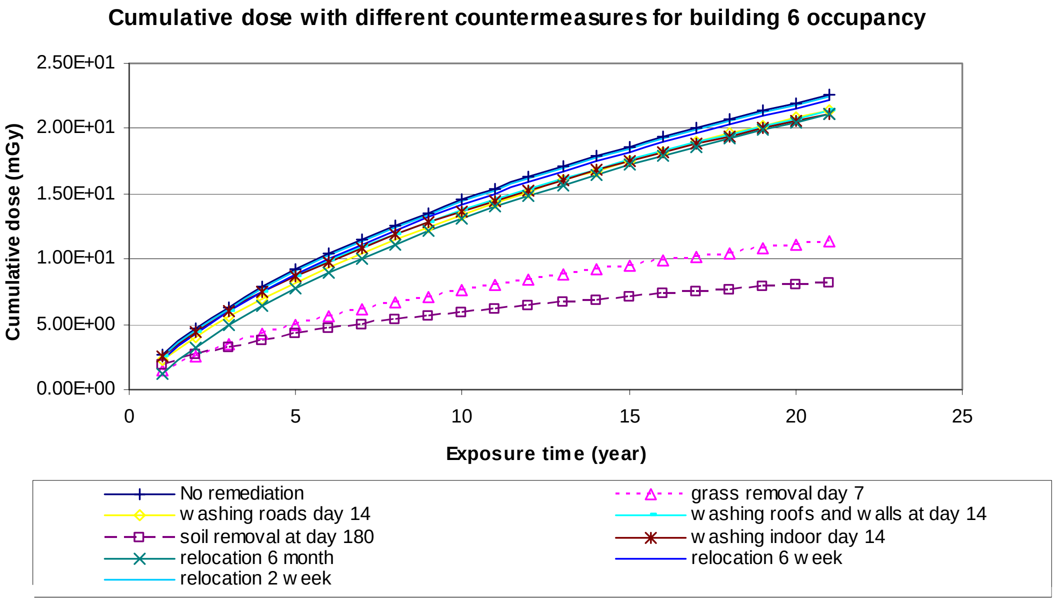

Fig. III.5.38. Cumulative doses with different countermeasures for building 6 occupancy for a resident spending 120 hours inside on first floor and 15 hours outside an apartment building.

Table III.5.26. Annual dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 1 occupancy based on annual dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	8.39E-01	17.8	50.5	1.7	11.6	2.3	59.2	17.3	6.2
2	5.24E-01	23.9	45.7	2.5	32.2	3.5	0.0	0.0	0.0
3	4.00E-01	26.8	40.8	3.1	36.2	4.3	0.0	0.0	0.0
4	3.17E-01	30.0	35.5	3.7	40.6	5.1	0.0	0.0	0.0
5	2.59E-01	33.5	30.1	4.3	45.2	5.9	0.0	0.0	0.0
6	2.17E-01	37.0	24.7	4.8	49.9	6.6	0.0	0.0	0.0
7	1.88E-01	40.3	19.8	5.2	54.4	7.3	0.0	0.0	0.0
8	1.66E-01	43.2	15.5	5.6	58.3	7.8	0.0	0.0	0.0
9	1.50E-01	45.7	11.8	5.8	61.7	8.1	0.0	0.0	0.0
10	1.37E-01	47.8	8.9	6.0	64.5	8.4	0.0	0.0	0.0
11	1.27E-01	49.5	6.7	6.1	66.8	8.5	0.0	0.0	0.0
12	1.19E-01	50.8	4.9	6.2	68.6	8.6	0.0	0.0	0.0
13	1.12E-01	51.9	3.6	6.2	70.0	8.6	0.0	0.0	0.0
14	1.06E-01	52.7	2.6	6.2	71.2	8.6	0.0	0.0	0.0
15	1.01E-01	53.4	1.9	6.1	72.1	8.5	0.0	0.0	0.0
16	9.60E-02	54.0	1.4	6.1	72.9	8.4	0.0	0.0	0.0
17	9.18E-02	54.4	1.0	6.0	73.5	8.3	0.0	0.0	0.0
18	8.78E-02	54.8	0.7	5.9	74.0	8.2	0.0	0.0	0.0
19	8.41E-02	55.1	0.5	5.8	74.4	8.1	0.0	0.0	0.0
20	8.06E-02	55.4	0.4	5.8	74.8	8.0	0.0	0.0	0.0
21	7.73E-02	55.7	0.3	5.7	75.2	7.9	0.0	0.0	0.0

Relocation for the first six months is the most effective countermeasure in reducing the annual dose for the first year, but the effectiveness of relocation is zero in later years. Soil removal and grass removal are effective countermeasures after the first year in reducing annual dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal and grass removal increases with time.

Table III.5.27. Annual dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 2 occupancy based on annual dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	4.86E+00	0.0	2.6	26.4	0.0	0.0	51.8	12.8	4.3
2	4.29E+00	0.0	1.7	28.0	0.0	0.0	0.0	0.0	0.0
3	3.84E+00	0.0	1.3	28.1	0.0	0.0	0.0	0.0	0.0
4	3.47E+00	0.0	1.0	28.2	0.0	0.0	0.0	0.0	0.0
5	3.16E+00	0.0	0.7	28.3	0.0	0.0	0.0	0.0	0.0
6	2.89E+00	0.0	0.6	28.4	0.0	0.0	0.0	0.0	0.0
7	2.66E+00	0.0	0.4	28.4	0.0	0.0	0.0	0.0	0.0
8	2.46E+00	0.0	0.3	28.5	0.0	0.0	0.0	0.0	0.0
9	2.29E+00	0.0	0.2	28.5	0.0	0.0	0.0	0.0	0.0
10	2.14E+00	0.0	0.2	28.5	0.0	0.0	0.0	0.0	0.0
11	2.00E+00	0.0	0.1	28.5	0.0	0.0	0.0	0.0	0.0
12	1.88E+00	0.0	0.1	28.5	0.0	0.0	0.0	0.0	0.0
13	1.78E+00	0.0	0.1	28.5	0.0	0.0	0.0	0.0	0.0
14	1.68E+00	0.0	0.1	28.6	0.0	0.0	0.0	0.0	0.0
15	1.60E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0
16	1.52E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0
17	1.45E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0
18	1.38E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0
19	1.32E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0
20	1.26E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0
21	1.21E+00	0.0	0.0	28.6	0.0	0.0	0.0	0.0	0.0

Relocation for the first six months is the most effective countermeasure in reducing the annual dose for the first year, but the effectiveness of relocation is zero in later years. Soil removal, grass removal, and washing indoor surfaces are not effective countermeasures. Effectiveness of washing roads decreases with time. Effectiveness of soil removal and grass removal increases with time.

Table III.5.28. Annual dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 3 occupancy based on annual dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	6.60E-01	34.6	12.3	10.5	23.5	2.8	54.0	14.1	4.9
2	5.24E-01	36.5	8.7	12.3	49.3	3.3	0.0	0.0	0.0
3	4.49E-01	36.5	6.9	13.2	49.3	3.6	0.0	0.0	0.0
4	3.96E-01	36.8	5.4	13.8	49.7	3.8	0.0	0.0	0.0
5	3.56E-01	37.2	4.2	14.2	50.3	4.0	0.0	0.0	0.0
6	3.26E-01	37.8	3.1	14.5	51.0	4.2	0.0	0.0	0.0
7	3.02E-01	38.3	2.4	14.6	51.8	4.2	0.0	0.0	0.0
8	2.82E-01	38.9	1.7	14.6	52.5	4.3	0.0	0.0	0.0
9	2.65E-01	39.4	1.3	14.5	53.3	4.3	0.0	0.0	0.0
10	2.51E-01	39.9	0.9	14.4	53.9	4.3	0.0	0.0	0.0
11	2.38E-01	40.4	0.7	14.3	54.5	4.3	0.0	0.0	0.0
12	2.26E-01	40.8	0.5	14.2	55.1	4.2	0.0	0.0	0.0
13	2.16E-01	41.2	0.4	14.0	55.6	4.2	0.0	0.0	0.0
14	2.06E-01	41.5	0.3	13.9	56.0	4.1	0.0	0.0	0.0
15	1.97E-01	41.8	0.2	13.7	56.4	4.1	0.0	0.0	0.0
16	1.89E-01	42.1	0.1	13.6	56.8	4.0	0.0	0.0	0.0
17	1.81E-01	42.3	0.1	13.5	57.1	4.0	0.0	0.0	0.0
18	1.73E-01	42.5	0.1	13.3	57.4	3.9	0.0	0.0	0.0
19	1.66E-01	42.7	0.1	13.2	57.7	3.8	0.0	0.0	0.0
20	1.59E-01	42.9	0.0	13.1	57.9	3.8	0.0	0.0	0.0
21	1.53E-01	43.1	0.0	13.0	58.2	3.7	0.0	0.0	0.0

Relocation for the first six months is the most effective countermeasure in reducing the annual dose for the first year, but the effectiveness of relocation is zero in later years. Soil removal and grass removal are effective countermeasures after first year in reducing annual dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal and grass removal increases with time.

Table III.5.29. Annual dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 4 occupancy based on annual dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	8.61E-01	33.8	12.0	9.9	23.0	1.2	53.9	14.0	4.8
2	6.86E-01	35.7	8.5	11.6	48.1	1.4	0.0	0.0	0.0
3	5.88E-01	35.7	6.8	12.3	48.2	1.6	0.0	0.0	0.0
4	5.17E-01	36.0	5.3	12.8	48.6	1.7	0.0	0.0	0.0
5	4.65E-01	36.5	4.1	13.2	49.3	1.8	0.0	0.0	0.0
6	4.24E-01	37.1	3.1	13.3	50.1	1.8	0.0	0.0	0.0
7	3.92E-01	37.7	2.3	13.4	50.9	1.9	0.0	0.0	0.0
8	3.66E-01	38.3	1.7	13.3	51.8	1.9	0.0	0.0	0.0
9	3.44E-01	38.9	1.3	13.3	52.5	1.9	0.0	0.0	0.0
10	3.25E-01	39.4	0.9	13.1	53.2	1.9	0.0	0.0	0.0
11	3.08E-01	39.9	0.7	13.0	53.9	1.9	0.0	0.0	0.0
12	2.93E-01	40.3	0.5	12.9	54.4	1.9	0.0	0.0	0.0
13	2.79E-01	40.7	0.4	12.8	54.9	1.9	0.0	0.0	0.0
14	2.67E-01	41.0	0.3	12.7	55.3	1.8	0.0	0.0	0.0
15	2.55E-01	41.3	0.2	12.5	55.7	1.8	0.0	0.0	0.0
16	2.44E-01	41.5	0.1	12.4	56.1	1.8	0.0	0.0	0.0
17	2.34E-01	41.7	0.1	12.3	56.4	1.8	0.0	0.0	0.0
18	2.25E-01	41.9	0.1	12.2	56.6	1.7	0.0	0.0	0.0
19	2.15E-01	42.1	0.0	12.1	56.8	1.7	0.0	0.0	0.0
20	2.07E-01	42.3	0.0	12.0	57.1	1.7	0.0	0.0	0.0
21	1.99E-01	42.4	0.0	12.0	57.2	1.6	0.0	0.0	0.0

Relocation for the first six months is the most effective countermeasure in reducing the annual dose for the first year, but the effectiveness of relocation is zero in later years. Soil removal and grass removal are effective countermeasures after first year in reducing annual dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal and grass removal increases with time.

Table III.5.30. Annual dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 5 occupancy based on annual dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	3.06E+00	42.1	14.9	6.1	28.7	2.0	54.6	14.4	5.0
2	2.37E+00	45.7	10.9	7.3	61.8	2.4	0.0	0.0	0.0
3	2.00E+00	46.5	8.8	8.0	62.7	2.7	0.0	0.0	0.0
4	1.74E+00	47.2	7.0	8.6	63.8	2.9	0.0	0.0	0.0
5	1.56E+00	48.1	5.4	8.9	64.9	3.1	0.0	0.0	0.0
6	1.43E+00	48.9	4.1	9.1	66.0	3.2	0.0	0.0	0.0
7	1.32E+00	49.6	3.0	9.2	67.0	3.3	0.0	0.0	0.0
8	1.23E+00	50.3	2.2	9.3	67.9	3.3	0.0	0.0	0.0
9	1.16E+00	50.9	1.6	9.2	68.7	3.3	0.0	0.0	0.0
10	1.10E+00	51.4	1.2	9.2	69.4	3.3	0.0	0.0	0.0
11	1.05E+00	51.8	0.9	9.1	70.0	3.2	0.0	0.0	0.0
12	1.00E+00	52.2	0.6	9.0	70.5	3.2	0.0	0.0	0.0
13	9.57E-01	52.5	0.5	8.8	70.9	3.2	0.0	0.0	0.0
14	9.17E-01	52.8	0.3	8.7	71.3	3.1	0.0	0.0	0.0
15	8.79E-01	53.0	0.2	8.6	71.6	3.1	0.0	0.0	0.0
16	8.43E-01	53.3	0.2	8.5	71.9	3.0	0.0	0.0	0.0
17	8.09E-01	53.5	0.1	8.4	72.2	3.0	0.0	0.0	0.0
18	7.77E-01	53.7	0.1	8.3	72.4	2.9	0.0	0.0	0.0
19	7.46E-01	53.8	0.1	8.2	72.7	2.9	0.0	0.0	0.0
20	7.17E-01	54.0	0.0	8.0	72.9	2.8	0.0	0.0	0.0
21	6.89E-01	54.1	0.0	7.9	73.1	2.8	0.0	0.0	0.0

Relocation for the first six months is the most effective countermeasure in reducing the annual dose for the first year, but the effectiveness of relocation is zero in later years. Soil removal and grass removal are effective countermeasures after first year in reducing annual dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal and grass removal increases with time.

Table III.5.31. Annual dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 6 occupancy based on annual dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	2.62E+00	42.5	15.1	4.0	28.9	4.3	54.6	14.4	5.0
2	2.02E+00	46.3	11.0	4.8	62.5	5.1	0.0	0.0	0.0
3	1.71E+00	47.0	8.9	5.2	63.4	5.7	0.0	0.0	0.0
4	1.49E+00	47.8	7.1	5.6	64.5	6.2	0.0	0.0	0.0
5	1.33E+00	48.6	5.4	5.8	65.6	6.5	0.0	0.0	0.0
6	1.22E+00	49.4	4.1	5.9	66.7	6.7	0.0	0.0	0.0
7	1.13E+00	50.2	3.1	6.0	67.7	6.9	0.0	0.0	0.0
8	1.06E+00	50.8	2.3	6.0	68.6	6.9	0.0	0.0	0.0
9	9.95E-01	51.4	1.7	5.9	69.4	6.9	0.0	0.0	0.0
10	9.43E-01	51.9	1.2	5.9	70.0	6.9	0.0	0.0	0.0
11	8.98E-01	52.3	0.9	5.8	70.6	6.8	0.0	0.0	0.0
12	8.57E-01	52.7	0.6	5.8	71.1	6.8	0.0	0.0	0.0
13	8.19E-01	53.0	0.5	5.7	71.5	6.7	0.0	0.0	0.0
14	7.85E-01	53.3	0.3	5.6	71.9	6.6	0.0	0.0	0.0
15	7.52E-01	53.5	0.2	5.5	72.2	6.5	0.0	0.0	0.0
16	7.21E-01	53.7	0.2	5.5	72.5	6.4	0.0	0.0	0.0
17	6.92E-01	53.9	0.1	5.4	72.8	6.3	0.0	0.0	0.0
18	6.65E-01	54.1	0.1	5.3	73.1	6.2	0.0	0.0	0.0
19	6.38E-01	54.3	0.1	5.3	73.3	6.0	0.0	0.0	0.0
20	6.13E-01	54.5	0.0	5.2	73.5	5.9	0.0	0.0	0.0
21	5.89E-01	54.6	0.0	5.1	73.8	5.8	0.0	0.0	0.0

Relocation for the first six months is the most effective countermeasure in reducing the annual dose for the first year, but the effectiveness of relocation is zero in later years. Soil removal and grass removal are effective countermeasures after first year in reducing annual dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal and grass removal increases in later years.

Table III.5.32. Cumulative dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 1 occupancy based on cumulative dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	8.39E-01	17.8	50.5	1.7	11.6	2.3	59.2	17.3	6.2
2	1.36E+00	20.1	48.6	2.0	19.5	2.8	36.4	10.7	3.8
3	1.76E+00	21.7	46.8	2.3	23.3	3.1	28.2	8.2	2.9
4	2.08E+00	22.9	45.1	2.5	25.9	3.4	23.9	7.0	2.5
5	2.34E+00	24.1	43.4	2.7	28.1	3.7	21.2	6.2	2.2
6	2.56E+00	25.2	41.9	2.8	29.9	4.0	19.4	5.7	2.0
7	2.74E+00	26.2	40.3	3.0	31.6	4.2	18.1	5.3	1.9
8	2.91E+00	27.2	38.9	3.2	33.1	4.4	17.1	5.0	1.8
9	3.06E+00	28.1	37.6	3.3	34.5	4.6	16.2	4.7	1.7
10	3.20E+00	28.9	36.4	3.4	35.8	4.7	15.5	4.5	1.6
11	3.32E+00	29.7	35.2	3.5	37.0	4.9	14.9	4.4	1.6
12	3.44E+00	30.5	34.2	3.6	38.1	5.0	14.4	4.2	1.5
13	3.55E+00	31.1	33.2	3.7	39.1	5.1	14.0	4.1	1.5
14	3.66E+00	31.8	32.3	3.8	40.0	5.2	13.6	4.0	1.4
15	3.76E+00	32.3	31.5	3.8	40.9	5.3	13.2	3.9	1.4
16	3.86E+00	32.9	30.8	3.9	41.7	5.4	12.9	3.8	1.3
17	3.95E+00	33.4	30.1	3.9	42.4	5.5	12.6	3.7	1.3
18	4.04E+00	33.8	29.4	4.0	43.1	5.5	12.3	3.6	1.3
19	4.12E+00	34.3	28.9	4.0	43.7	5.6	12.1	3.5	1.3
20	4.20E+00	34.7	28.3	4.0	44.3	5.6	11.8	3.5	1.2
21	4.28E+00	35.1	27.8	4.1	44.9	5.7	11.6	3.4	1.2

Relocation for the first six months is the most effective countermeasure in reducing the cumulative dose for the first year, but the effectiveness of relocation decreases in later years. Soil removal, washing roads, and grass removal are effective countermeasures after first year in reducing cumulative dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal, grass removal, washing roofs, and washing indoor surfaces increases in later years.

Table III.5.33. Cumulative dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 2 occupancy based on cumulative dose.

Exposure year	No remediation	grass removal day 7	washing roads day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor day 14	relocation 6 month	relocation 6 week	relocation 2 week
1	4.86E+00	0.0	2.6	26.4	0.0	0.0	51.8	12.8	4.3
2	9.15E+00	0.0	2.2	27.1	0.0	0.0	27.5	6.8	2.3
3	1.30E+01	0.0	1.9	27.4	0.0	0.0	19.4	4.8	1.6
4	1.65E+01	0.0	1.7	27.6	0.0	0.0	15.3	3.8	1.3
5	1.96E+01	0.0	1.6	27.7	0.0	0.0	12.8	3.2	1.1
6	2.25E+01	0.0	1.4	27.8	0.0	0.0	11.2	2.8	0.9
7	2.52E+01	0.0	1.3	27.9	0.0	0.0	10.0	2.5	0.8
8	2.76E+01	0.0	1.2	27.9	0.0	0.0	9.1	2.3	0.8
9	2.99E+01	0.0	1.2	28.0	0.0	0.0	8.4	2.1	0.7
10	3.20E+01	0.0	1.1	28.0	0.0	0.0	7.9	1.9	0.7
11	3.41E+01	0.0	1.0	28.0	0.0	0.0	7.4	1.8	0.6
12	3.59E+01	0.0	1.0	28.1	0.0	0.0	7.0	1.7	0.6
13	3.77E+01	0.0	0.9	28.1	0.0	0.0	6.7	1.7	0.6
14	3.94E+01	0.0	0.9	28.1	0.0	0.0	6.4	1.6	0.5
15	4.10E+01	0.0	0.9	28.1	0.0	0.0	6.1	1.5	0.5
16	4.25E+01	0.0	0.8	28.1	0.0	0.0	5.9	1.5	0.5
17	4.40E+01	0.0	0.8	28.1	0.0	0.0	5.7	1.4	0.5
18	4.53E+01	0.0	0.8	28.2	0.0	0.0	5.6	1.4	0.5
19	4.67E+01	0.0	0.8	28.2	0.0	0.0	5.4	1.3	0.5
20	4.79E+01	0.0	0.8	28.2	0.0	0.0	5.3	1.3	0.4
21	4.91E+01	0.0	0.7	28.2	0.0	0.0	5.1	1.3	0.4

Relocation for the first six months is the most effective countermeasure in reducing the cumulative dose for the first year, but the effectiveness of relocation decreases in later years. Soil removal, grass removal, and washing indoors do not change cumulative dose. Effectiveness of washing roads decreases with time. Washing roofs is the most effective countermeasure and its effectiveness increases in later years.

Table III.5.34. Cumulative dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 4 occupancy based on cumulative dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	8.61E-01	33.8	12.0	9.9	23.0	1.2	53.9	14.0	4.8
2	1.55E+00	34.7	10.5	10.7	34.2	1.3	30.0	7.8	2.7
3	2.14E+00	34.9	9.4	11.1	38.0	1.4	21.7	5.7	1.9
4	2.65E+00	35.2	8.6	11.5	40.1	1.4	17.5	4.6	1.6
5	3.12E+00	35.4	8.0	11.7	41.5	1.5	14.9	3.9	1.3
6	3.54E+00	35.6	7.4	11.9	42.5	1.5	13.1	3.4	1.2
7	3.93E+00	35.8	6.9	12.1	43.3	1.6	11.8	3.1	1.1
8	4.30E+00	36.0	6.4	12.2	44.1	1.6	10.8	2.8	1.0
9	4.64E+00	36.2	6.1	12.2	44.7	1.6	10.0	2.6	0.9
10	4.97E+00	36.4	5.7	12.3	45.2	1.6	9.3	2.4	0.8
11	5.28E+00	36.6	5.4	12.3	45.7	1.7	8.8	2.3	0.8
12	5.57E+00	36.8	5.2	12.4	46.2	1.7	8.3	2.2	0.7
13	5.85E+00	37.0	4.9	12.4	46.6	1.7	7.9	2.1	0.7
14	6.12E+00	37.2	4.7	12.4	47.0	1.7	7.6	2.0	0.7
15	6.37E+00	37.3	4.5	12.4	47.3	1.7	7.3	1.9	0.7
16	6.61E+00	37.5	4.4	12.4	47.7	1.7	7.0	1.8	0.6
17	6.85E+00	37.6	4.2	12.4	48.0	1.7	6.8	1.8	0.6
18	7.07E+00	37.8	4.1	12.4	48.2	1.7	6.6	1.7	0.6
19	7.29E+00	37.9	4.0	12.4	48.5	1.7	6.4	1.7	0.6
20	7.50E+00	38.0	3.9	12.4	48.7	1.7	6.2	1.6	0.6
21	7.69E+00	38.1	3.8	12.4	49.0	1.7	6.0	1.6	0.5

Relocation for the first six months is the most effective countermeasure in reducing the cumulative dose for the first year, but the effectiveness of relocation decreases in later years. Soil removal and grass removal are effective countermeasures after first year in reducing cumulative dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal, grass removal, washing roofs, and washing indoor surfaces increases in later years.

Table III.5.35. Cumulative dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 5 occupancy based on cumulative dose.

Exposure year	**No remediation**	**grass removal at day 7**	**washing roads at day 14**	**washing roofs and walls at day 14**	**soil removal at day 180**	**washing indoor surfaces at day 14**	**relocation for first 6 months**	**relocation for first 6 weeks**	**relocation for first 2 weeks**
1	3.06E+00	42.1	14.9	6.1	28.7	2.0	54.6	14.4	5.0
2	5.43E+00	43.7	13.2	6.6	43.1	2.2	30.8	8.1	2.8
3	7.43E+00	44.4	12.0	7.0	48.4	2.3	22.5	5.9	2.0
4	9.17E+00	45.0	11.1	7.3	51.3	2.4	18.2	4.8	1.7
5	1.07E+01	45.4	10.2	7.5	53.3	2.5	15.6	4.1	1.4
6	1.22E+01	45.8	9.5	7.7	54.8	2.6	13.7	3.6	1.3
7	1.35E+01	46.2	8.9	7.9	56.0	2.7	12.4	3.3	1.1
8	1.47E+01	46.5	8.3	8.0	57.0	2.7	11.4	3.0	1.0
9	1.59E+01	46.9	7.8	8.1	57.8	2.8	10.5	2.8	1.0
10	1.70E+01	47.2	7.4	8.1	58.6	2.8	9.8	2.6	0.9
11	1.80E+01	47.4	7.0	8.2	59.2	2.8	9.3	2.4	0.8
12	1.90E+01	47.7	6.7	8.2	59.8	2.8	8.8	2.3	0.8
13	2.00E+01	47.9	6.4	8.3	60.4	2.9	8.4	2.2	0.8
14	2.09E+01	48.1	6.1	8.3	60.8	2.9	8.0	2.1	0.7
15	2.18E+01	48.3	5.9	8.3	61.3	2.9	7.7	2.0	0.7
16	2.26E+01	48.5	5.7	8.3	61.7	2.9	7.4	1.9	0.7
17	2.34E+01	48.7	5.5	8.3	62.0	2.9	7.1	1.9	0.6
18	2.42E+01	48.8	5.3	8.3	62.4	2.9	6.9	1.8	0.6
19	2.50E+01	49.0	5.1	8.3	62.7	2.9	6.7	1.8	0.6
20	2.57E+01	49.1	5.0	8.3	63.0	2.9	6.5	1.7	0.6
21	2.64E+01	49.3	4.9	8.3	63.2	2.9	6.3	1.7	0.6

Relocation for the first six months is the most effective countermeasure in reducing the cumulative dose for the first year, but the effectiveness of relocation decreases in later years. Soil removal and grass removal are effective countermeasures after first year in reducing cumulative dose. Effectiveness of washing roads decreases with time. Effectiveness of soil removal, grass removal, washing roofs, and washing indoor surfaces increases in later years.

Table III.5.36. Cumulative dose (mGy) with no remediation and countermeasure effectiveness of different countermeasures for Building 6 occupancy based on cumulative dose.

Exposure year	No remediation	grass removal at day 7	washing roads at day 14	washing roofs and walls at day 14	soil removal at day 180	washing indoor surfaces at day 14	relocation for first 6 months	relocation for first 6 weeks	relocation for first 2 weeks
1	2.62E+00	42.5	15.1	4.0	28.9	4.3	54.6	14.4	5.0
2	4.64E+00	44.1	13.3	4.3	43.5	4.6	30.8	8.1	2.8
3	6.35E+00	44.9	12.1	4.6	48.9	4.9	22.5	6.0	2.1
4	7.84E+00	45.5	11.2	4.8	51.9	5.2	18.2	4.8	1.7
5	9.17E+00	45.9	10.3	4.9	53.9	5.4	15.6	4.1	1.4
6	1.04E+01	46.3	9.6	5.0	55.4	5.5	13.8	3.6	1.3
7	1.15E+01	46.7	9.0	5.1	56.6	5.6	12.4	3.3	1.1
8	1.26E+01	47.0	8.4	5.2	57.6	5.7	11.4	3.0	1.0
9	1.36E+01	47.4	7.9	5.2	58.4	5.8	10.5	2.8	1.0
10	1.45E+01	47.7	7.5	5.3	59.2	5.9	9.9	2.6	0.9
11	1.54E+01	47.9	7.1	5.3	59.9	6.0	9.3	2.5	0.8
12	1.63E+01	48.2	6.8	5.3	60.5	6.0	8.8	2.3	0.8
13	1.71E+01	48.4	6.5	5.4	61.0	6.0	8.4	2.2	0.8
14	1.79E+01	48.6	6.2	5.4	61.5	6.1	8.0	2.1	0.7
15	1.86E+01	48.8	5.9	5.4	61.9	6.1	7.7	2.0	0.7
16	1.93E+01	49.0	5.7	5.4	62.3	6.1	7.4	2.0	0.7
17	2.00E+01	49.2	5.5	5.4	62.7	6.1	7.1	1.9	0.7
18	2.07E+01	49.3	5.4	5.4	63.0	6.1	6.9	1.8	0.6
19	2.13E+01	49.5	5.2	5.4	63.3	6.1	6.7	1.8	0.6
20	2.19E+01	49.6	5.1	5.4	63.6	6.1	6.5	1.7	0.6
21	2.25E+01	49.7	4.9	5.4	63.9	6.1	6.3	1.7	0.6

Relocation for the first six months is the most effective countermeasure in reducing the cumulative dose for the first year, but the effectiveness of relocation decreases in later years. Soil removal and grass removal are effective countermeasures after first year in reducing cumulative dose. Effectiveness of washing roads also decreases with time. Effectiveness of soil removal, grass removal, washing roofs, and washing indoor surfaces increases in later years.

III.5.6.4. Results of fourth modeling endpoint

Figure III.5.39 shows the predicted contamination density at six outdoor locations (1 – outside building 1, 2 – outside building 2, 3 – outside building 3, 4 – outside building 4, 5 – outside building 5, 6 – outside building 6). The contamination density is the effective surface concentration that the receptor would experience when staying outdoors at that location. For example, outside building 1, 20% of the area is covered by lawn and 80% of the area is covered by paved concrete (see Table III.5.4). The contamination density outside building 1 is the sum of the 20% lawn surface concentration and 80% paved area surface concentration. The sharpest decrease in contamination density with time is observed for the area outside the parking lot. This is because the outside area of the parking lot was assumed to be 100% paved (see Table III.5.4), and on the paved areas, contamination decreases the most over time because of weathering (see Figure III.5.2).

The following countermeasures would change the outdoor contamination density:

(1) Cutting and removal of grass;
(2) Removal of soil; and
(3) Washing of roads.

Figures III.5.40 to III.5.45 show the predicted contamination density without any countermeasures and with the effective countermeasures that would change the outdoor contamination density at each outdoor location. For the area outside the office building (Building 1), soil removal is most effective in decreasing the contamination density. For the area outside the parking lot (Building 2), grass removal or soil removal does not change contamination density because the parking lot was assumed to be surrounded by paved areas, and only washing roads would decrease the contamination density. For the areas outside the school (Building 3), supermarket (Building 4), residential home (Building 5), and apartment building (Building 6), different countermeasures have a similar effect on contamination density because the assumptions for outdoor setting were similar (see Table III.5.4). For these four outdoor locations, soil removal is the most effective countermeasure, followed by grass removal. Washing roads is the least effective countermeasure.

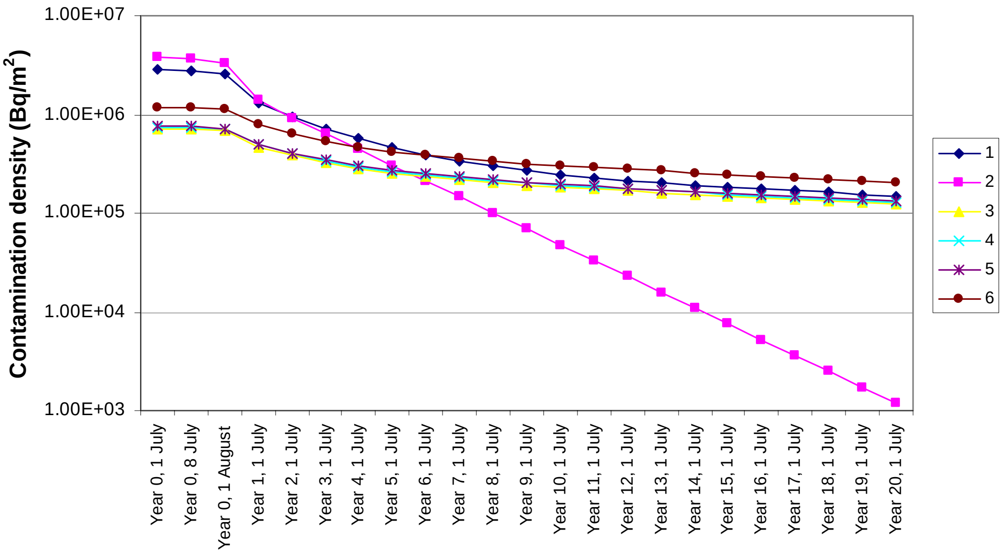

Fig. III.5.39. Predicted contamination density at six outdoor locations without any countermeasures.

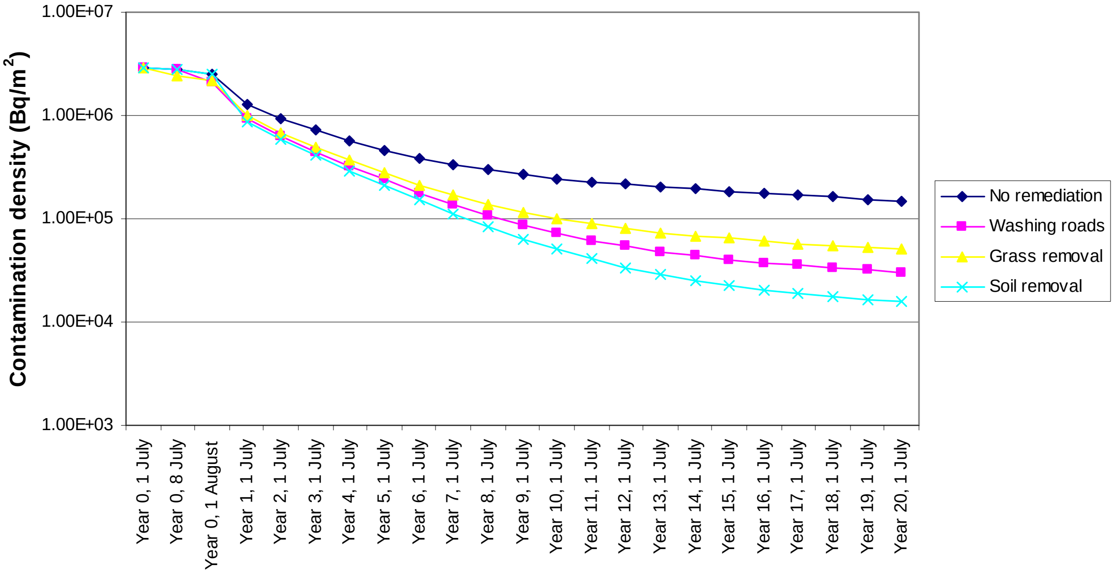

Fig. III.5.40. Predicted contamination density outside office building (Building 1) with different countermeasures.

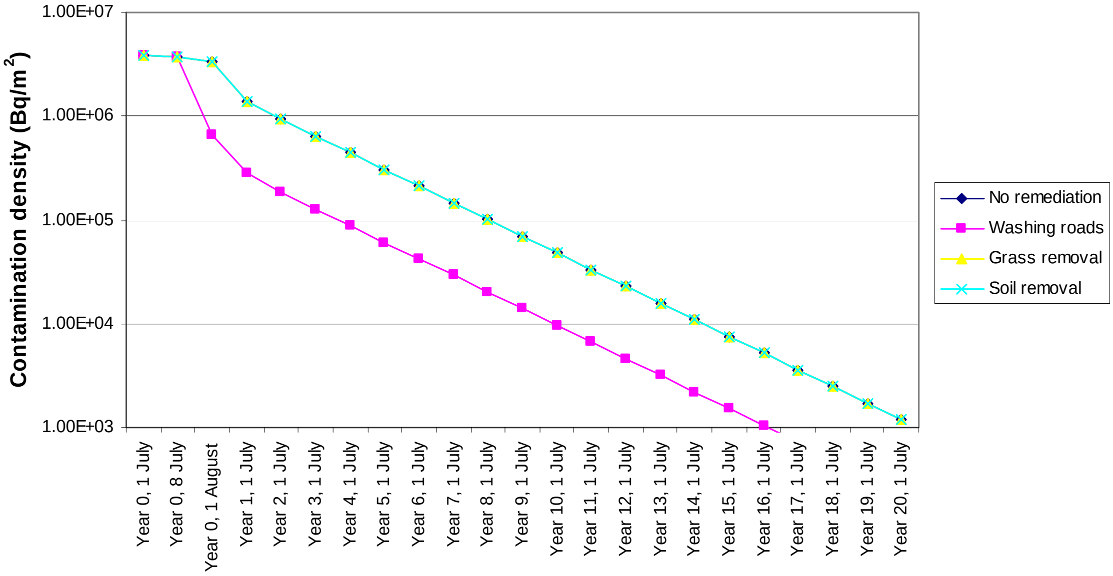

Fig. III.5.41. Predicted contamination density outside parking lot (Building 2) with different countermeasures.

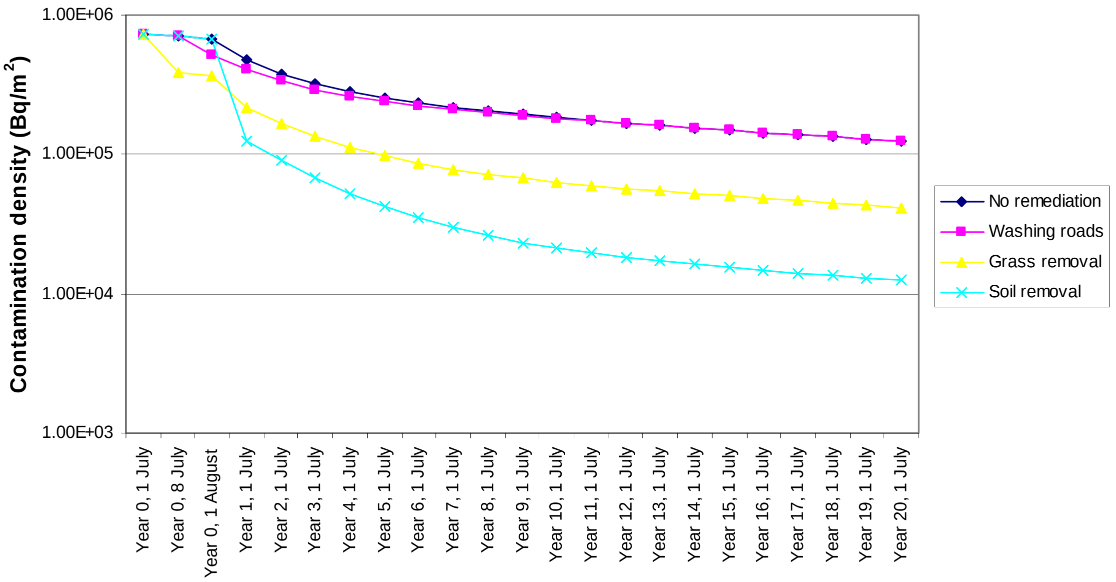

Fig. III.5.42. Predicted contamination density outside school (Building 3) with different countermeasures.

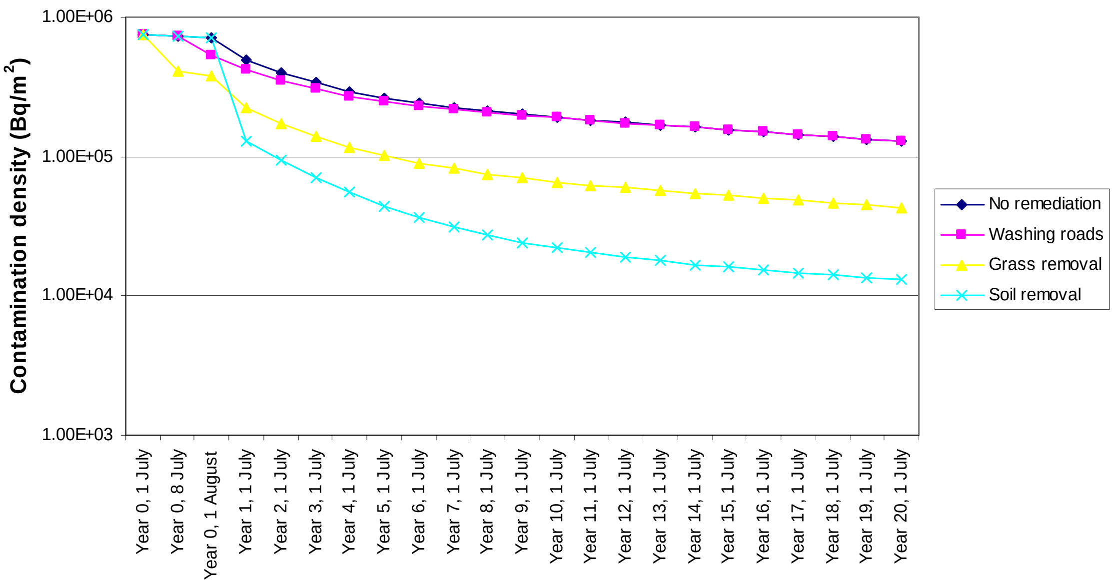

Fig. III.5.43. Predicted contamination density outside supermarket (Building 4) with different countermeasures.

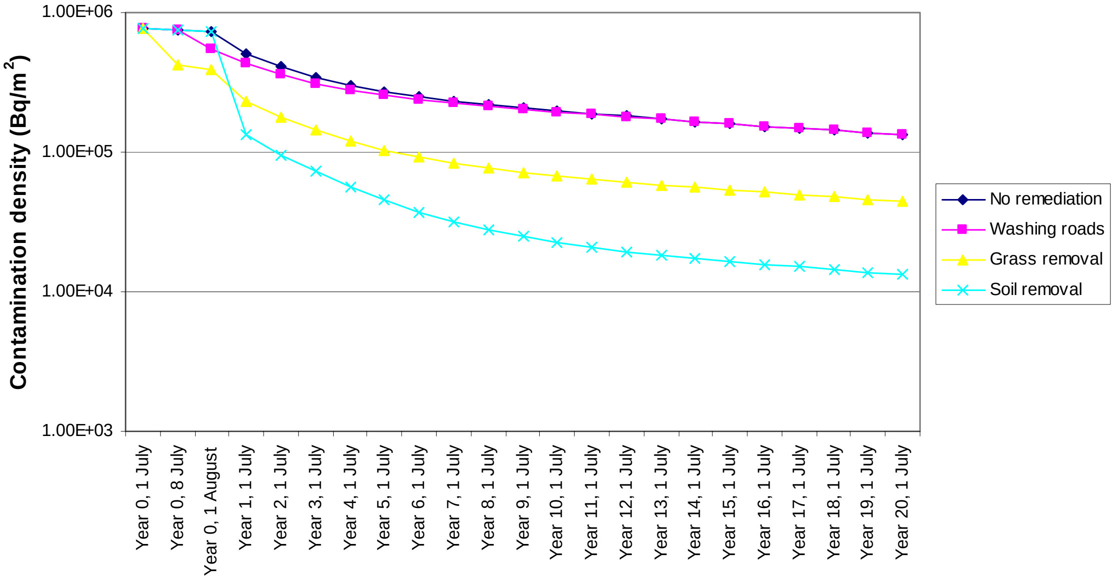

Fig. III.5.44. Predicted contamination density outside residential home (Building 5) with different countermeasures.

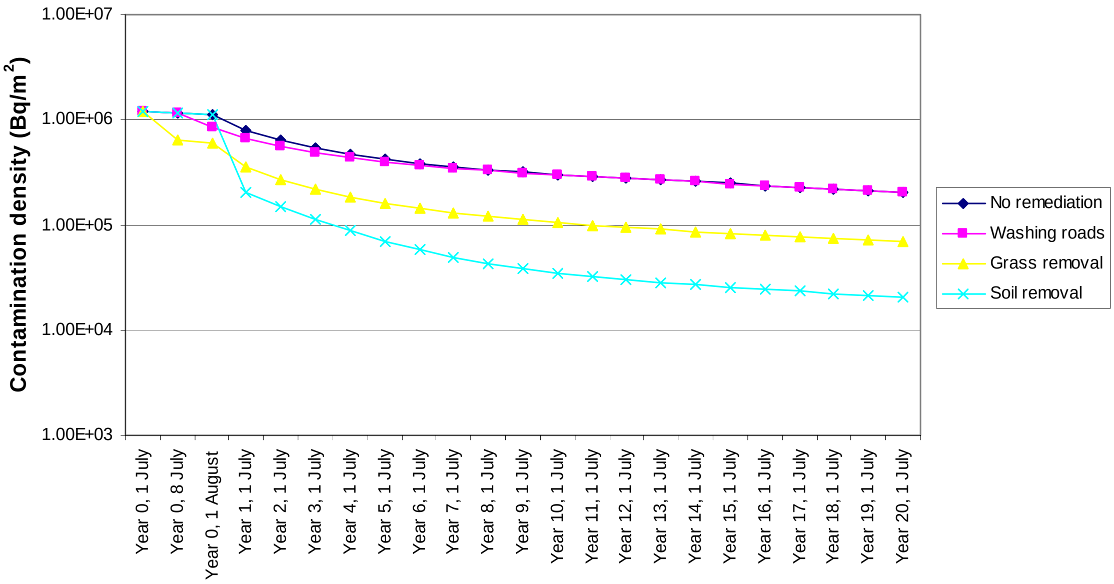

Fig. III.5.45. Predicted contamination density outside apartment building (Building 6) with different countermeasures.

III.5.7. Conclusions and recommendations

The calculated annual and cumulative doses for different buildings depend on initial reference concentrations (including partitioning factors used for different surfaces), occupancy factors, assumptions for outdoor exposure, building characteristics, weathering coefficients, a reference individual's location, and decontamination factors. There is a need to compile representative building characteristics and representative characteristics, including habits of the individuals that may be exposed. The initial partitioning factors and weathering coefficients used are based on Chernobyl data for Cs and may not be appropriate in different environments and for different radionuclides. Therefore, there is a need to compile partitioning factors and weathering coefficients for other environments and radionuclides.

For this exercise, only external doses were calculated; other exposure pathways (inhalation, air submersion, and ingestion) may be important for other radionuclides. Therefore, there is a need to model radiation exposures from other pathways in order to make the dose assessment more complete.

Initially, external dose incurred inside a building is much lower compared with external dose incurred outside a building because of the shielding provided by the building. As time progresses, depending on the outside setting, external dose inside the building may become higher than the external dose outside the building. If all the countermeasures were implemented simultaneously, radiation dose and surface concentrations can be reduced to the greatest extent. If one has to set priorities on the countermeasures to be implemented immediately after the incident, it is observed that countermeasures that reduce the outside surface concentrations (grass removal, soil removal, and washing roads) need to be given higher priority. Washing outdoor surfaces (roof and exterior walls) and indoor surfaces (interior walls) are less effective countermeasures immediately after the incident and need to be given lower priorities; however, their effectiveness increases with time as the dose contribution to the total from roof, exterior walls, and interior walls increases over time.

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APPENDIX IV. SUMMARY OF MODEL PREDICTIONS

IV.1. Model predictions for the Pripyat scenario

Appendix IV.1 provides graphical comparisons of model predictions from four models for the various endpoints in the Pripyat scenario. Figures IV.1 to IV.22 show model predictions for District 1 endpoints, including dose rates, % contributions from different radioisotopes or surfaces, and contamination densities. Figures IV.23 to IV.48 show model predictions for District 4 endpoints, including dose rates, % contributions from different radioisotopes or surfaces, contamination densities, and doses for specified reference individuals. Figures IV.49 to IV.55 show comparisons of predicted and measured dose rates for 1996, 1999, and 2006, by location.

Measured dose rates when shown are corrected for an estimated contribution of 0.1 μGy h^{-1} from background (non-Chernobyl) sources of radiation. (Some figures include both the corrected and uncorrected measurements.) Corrected values below zero (negative values) were obtained for Locations 17 and 18 in District 4 (both indoors); these values are not shown in the graphs.

Unless otherwise indicated, results for EDEM and CPHR are those submitted in Spring 2007. For EXPURT, results include revisions submitted in Summer 2007. For METRO-K, results include revisions submitted in November 2007. METRO-K's predictions for Locations 3, 12, and 19 were not revised, and the revisions for % contributions by radioisotope were very close to the initial predictions and are not shown. Where appropriate, comparisons are made between initial and revised predictions for EXPURT (Spring 2007 vs. Summer 2007) and METRO-K (Spring 2007 vs. November 2007).

When several plots are shown in the same figure, the scales are comparable unless otherwise indicated. In other words, the y-axis (logarithmic scale) represents the same number of orders of magnitude, so that the graphs may be directly compared, although the actual limits may vary from one graph to another.

Model predictions are also available in Excel workbooks, by model (as submitted) and by endpoint (comparisons of results). Available files are listed below:

— Results submitted by Spring 2007:
  - CPHR (Tomás),
  - EDEM (Golikov),
  - EXPURT (Charnock, separate files for Districts 1 and 4),
  - METRO-K (Hwang);

— Results submitted by Summer 2007 (revised results):
  - EXPURT (Charnock, separate files for Districts 1 and 4),
  - METRO-K (Hwang);

— Results submitted in November 2007 (revised results):
  - METRO-K (Hwang);

— District 1 results:
  - Contamination densities,
  - Isotopes (radionuclide contributions),
  - Surfaces (contributions),

- EXPURT (dose rates and countermeasures),
- METRO-K (dose rates and surfaces, with revisions);

— District 4 results:
  - Contamination densities,
  - Isotopes (radionuclide contributions),
  - Surfaces (contributions),
  - Doses and countermeasures, by model,
  - Doses and countermeasures, comparisons among models,
  - METRO-K (dose rates and surfaces, with revisions);

— District 1 and 4 results:
  - Dose rates, comparisons with measurements,
  - EXPURT revised results for 1986.

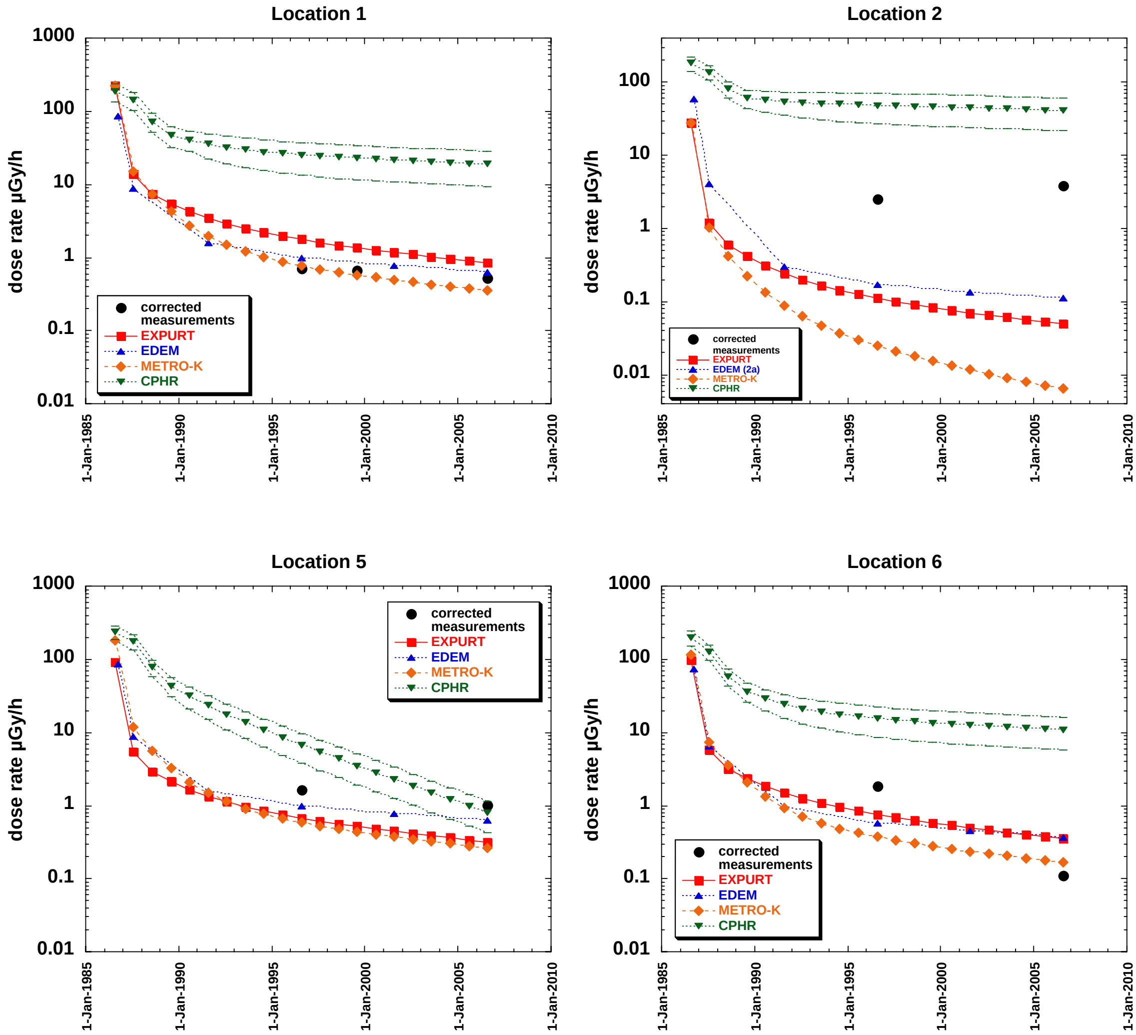


Fig. IV.1. Predicted and measured dose rates for outdoor locations in District 1 of Pripyat.

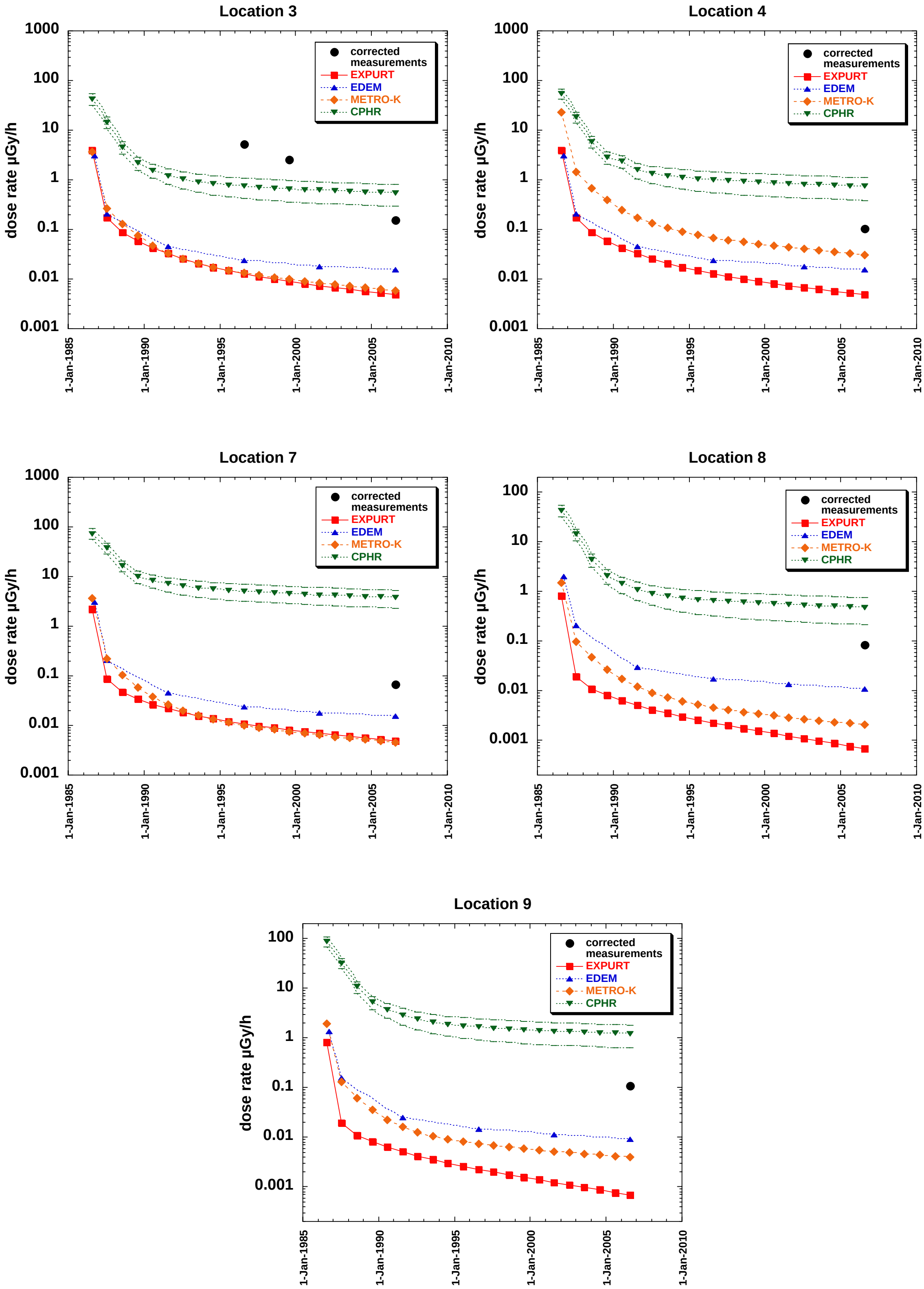
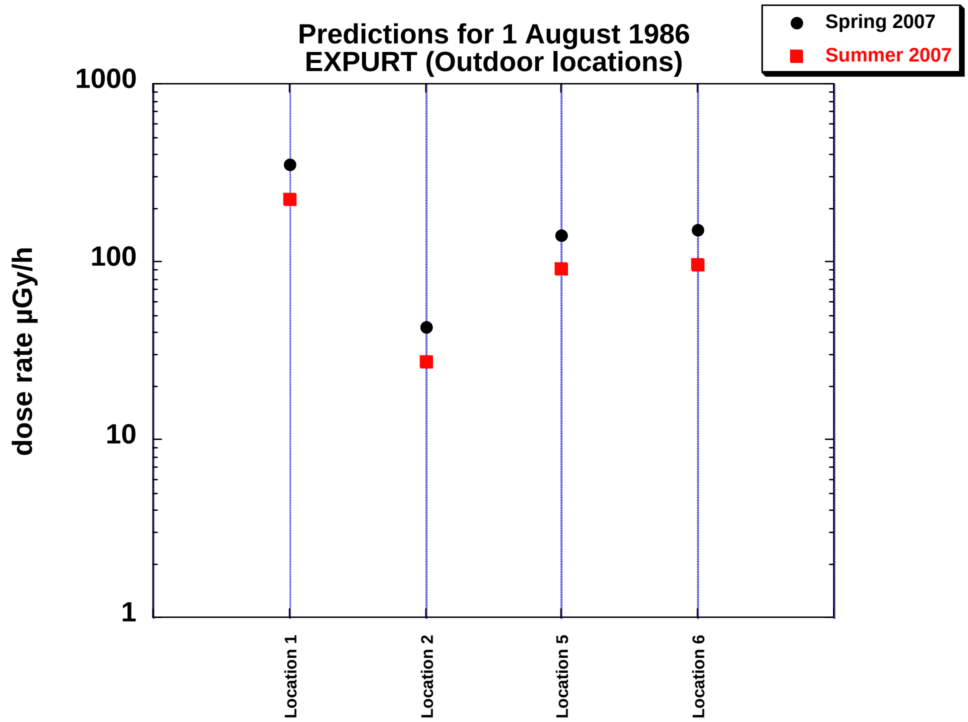


Fig. IV.2. Predicted and measured dose rates for indoor locations in District 1 of Pripyat.



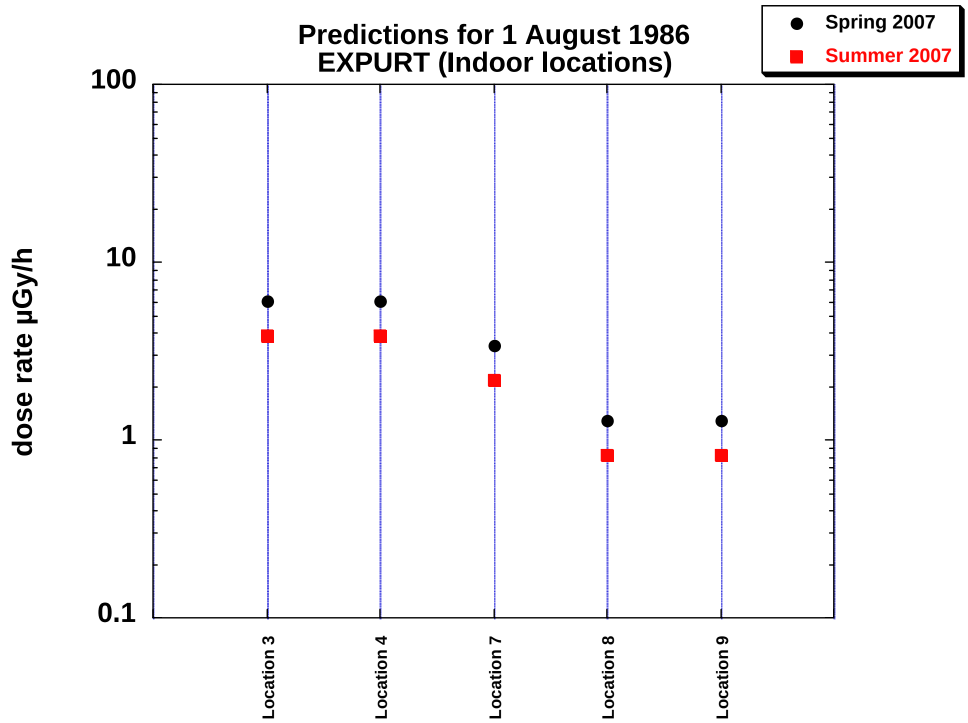


Fig. IV.3. Predicted dose rates on 1 August 1986 for outdoor (top) and indoor (bottom) locations in District 1 for EXPURT, showing predictions of Spring 2007 and revised predictions of Summer 2007.

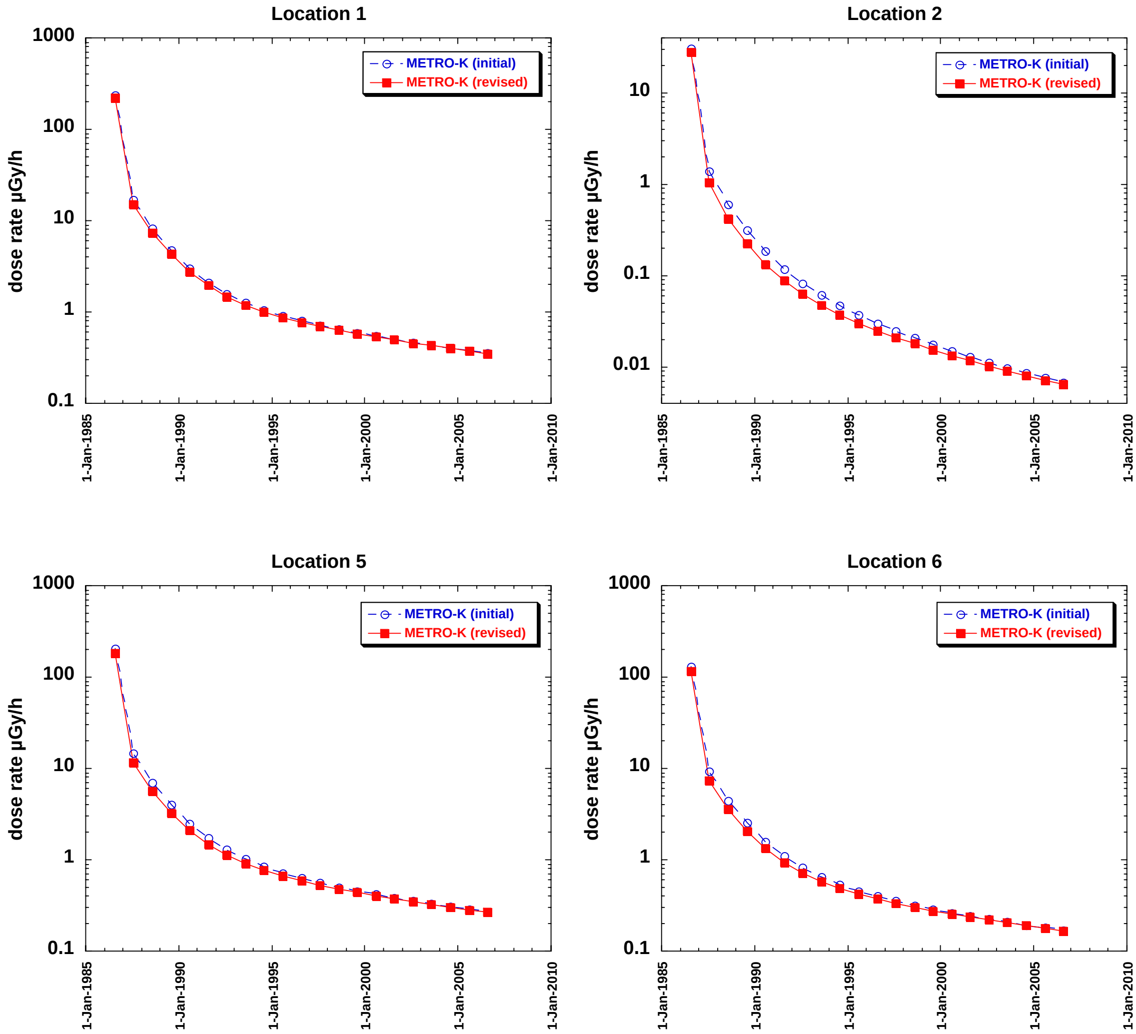


Fig. IV.4. Predicted dose rates for outdoor locations in District 1 of Pripyat for METRO-K, showing predictions of Spring 2007 and revised predictions of November 2007.

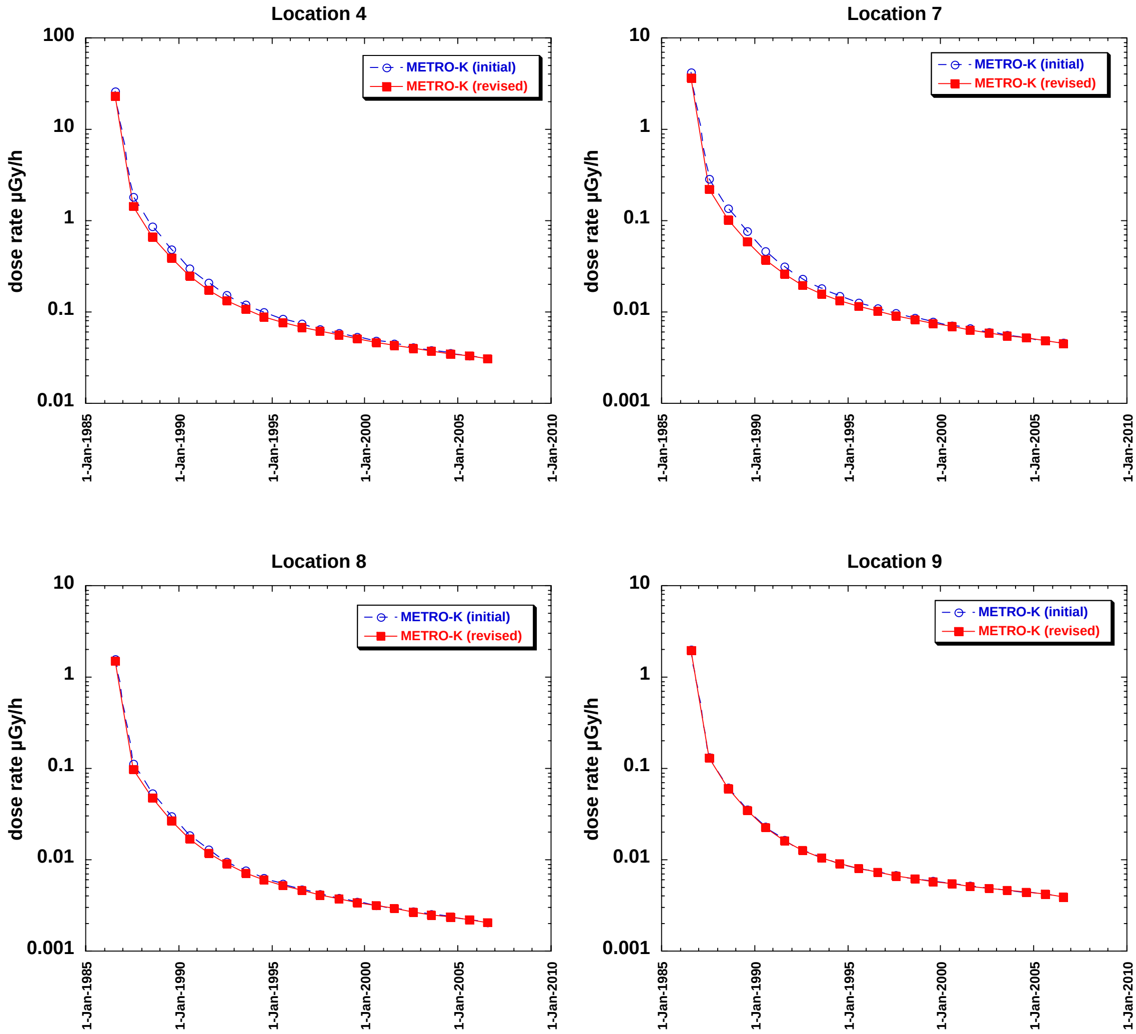


Fig. IV.5. Predicted dose rates for indoor locations in District 1 of Pripyat for METRO-K, showing predictions of Spring 2007 and revised predictions of November 2007. No revisions were made for Location 3. Initial and revised predictions for Location 9 are not distinguishable on the graph.

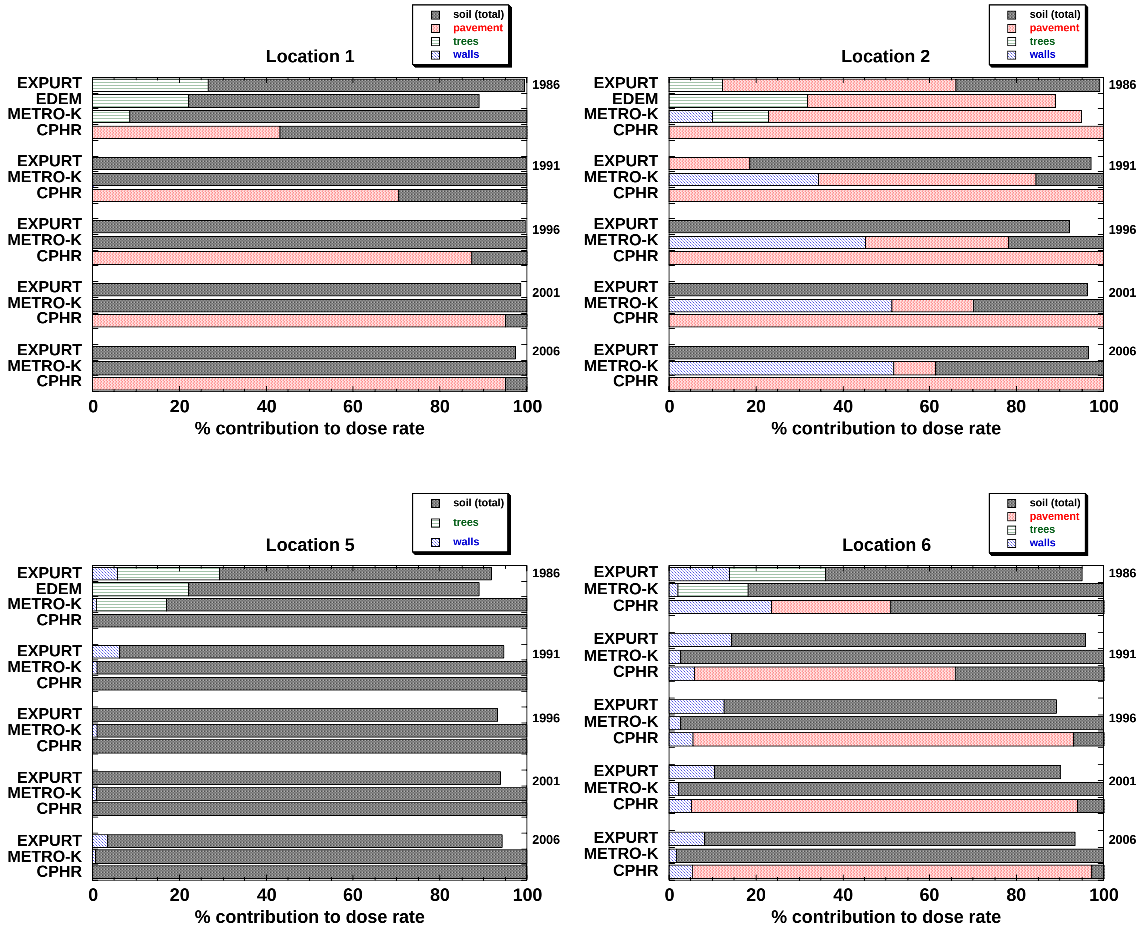


Fig. IV.6. Predicted contributions to dose rate over time from the most important surfaces for outdoor locations in District 1 of Pripyat.

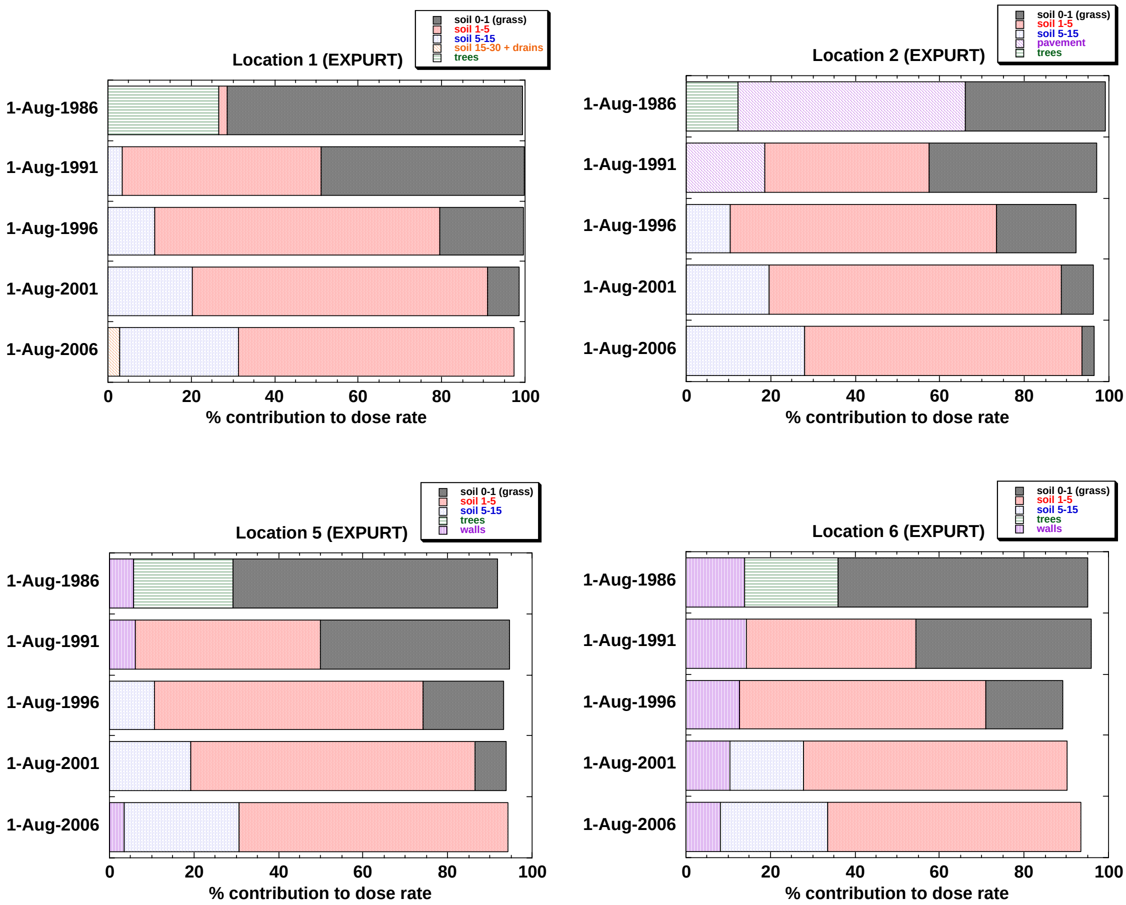


Fig. IV.7. Predicted contributions to dose rate over time from the most important surfaces for outdoor locations in District 1 of Pripyat. Results of Spring 2007 for EXPURT, showing the changes in importance of the soil layers.

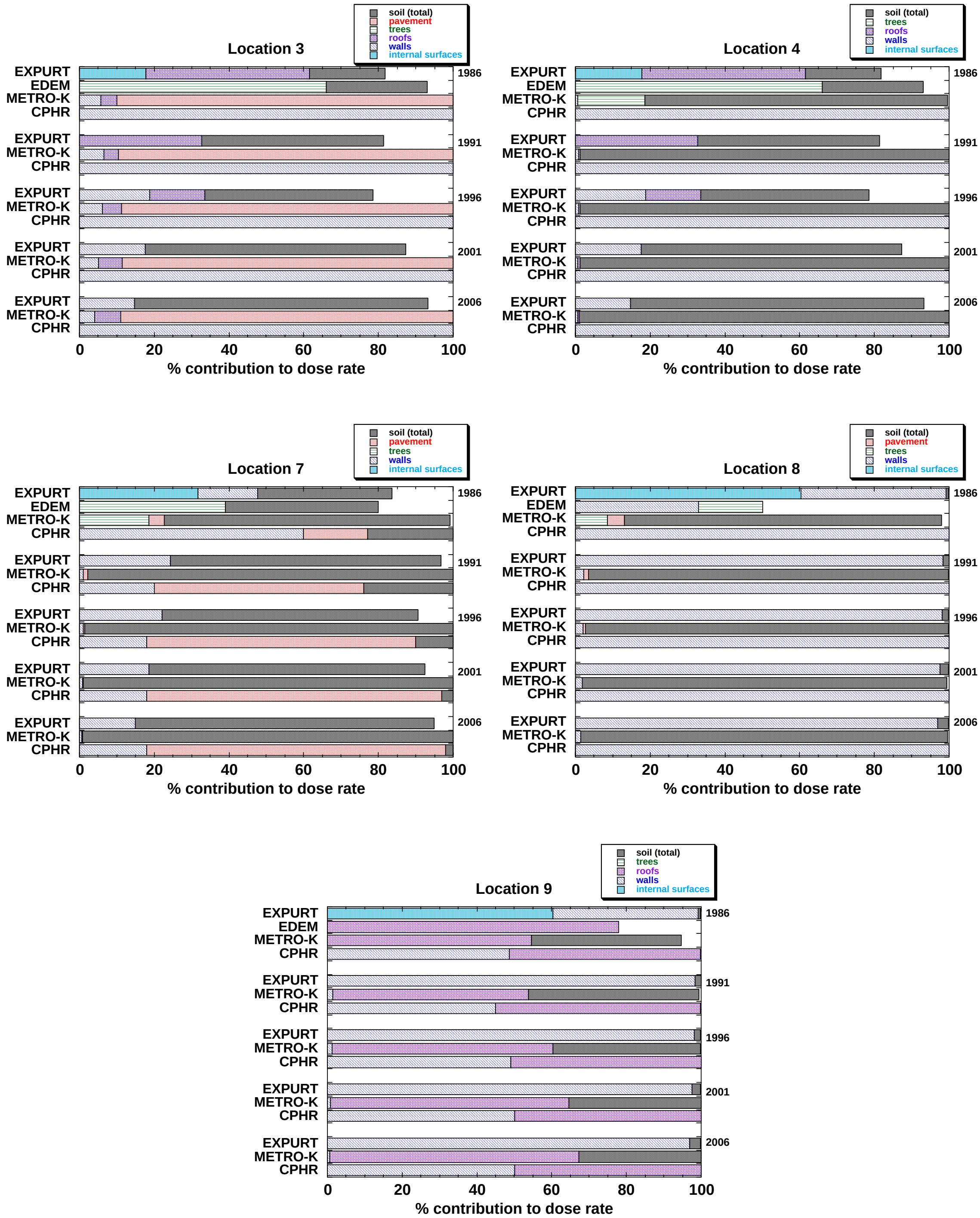


Fig. IV.8. Predicted contributions to dose rate over time from the most important surfaces for indoor locations in District 1 of Pripyat.

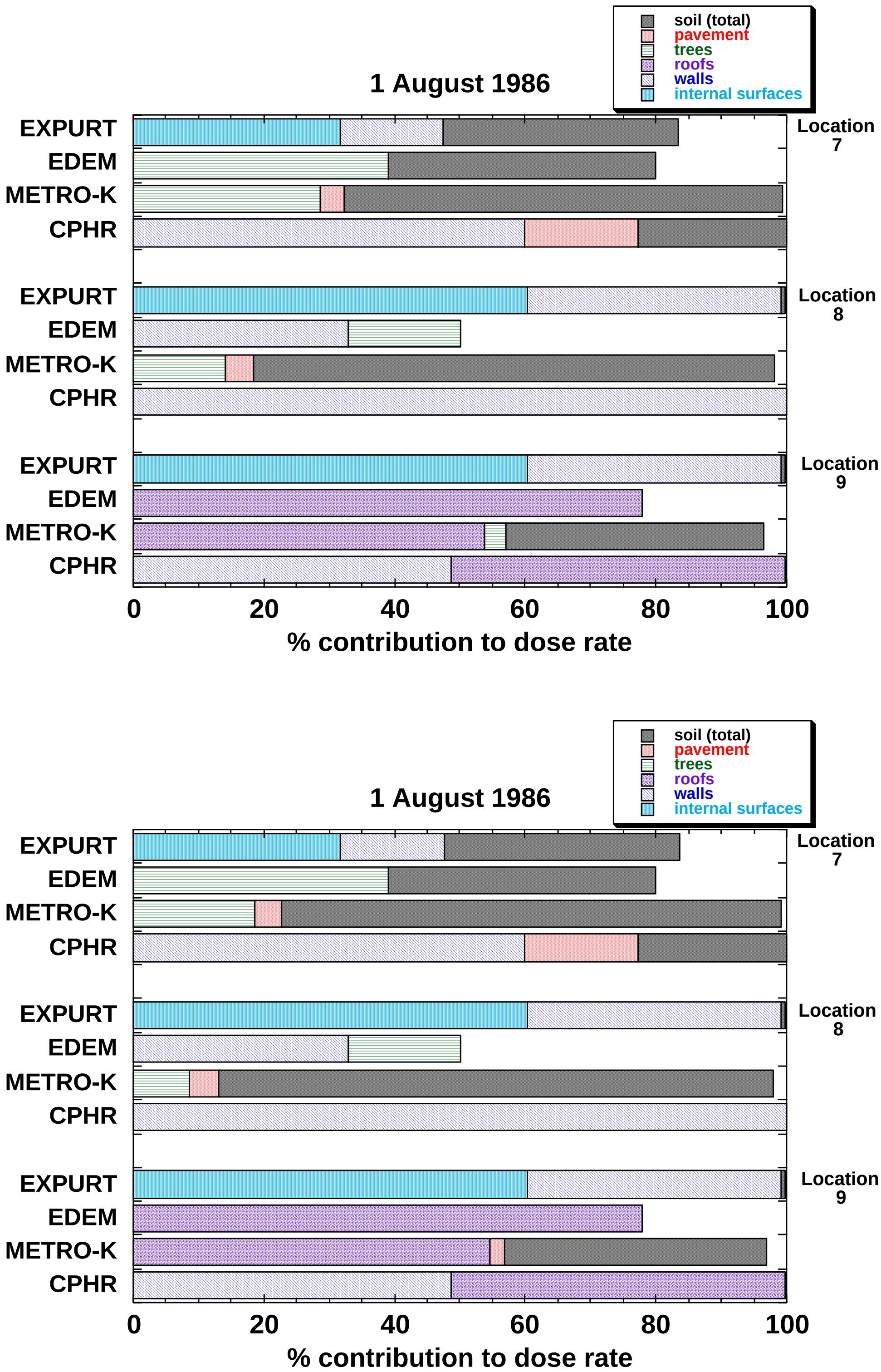
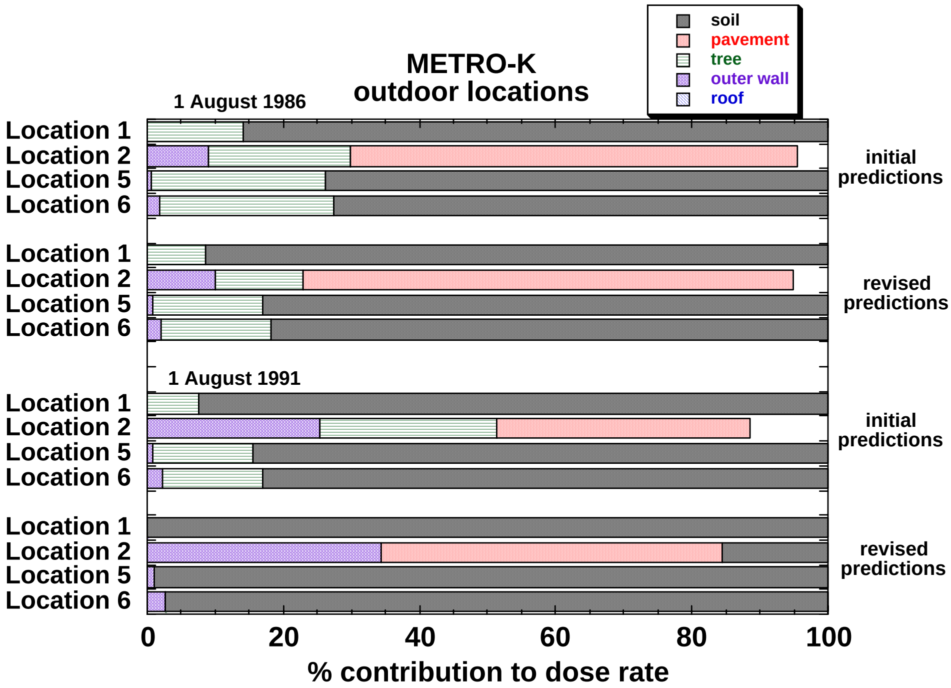


Fig. IV.9. Predicted contributions to dose rate on 1 August 1986 from the most important surfaces for three indoor locations in District 1 of Pripyat. Locations 7, 8, and 9 are on the 1^{st}, 3^{rd}, and 5^{th} (top) floors, respectively, of the same building. Results of Spring 2007 (top) and including revised results (November 2007) from METRO-K (bottom).



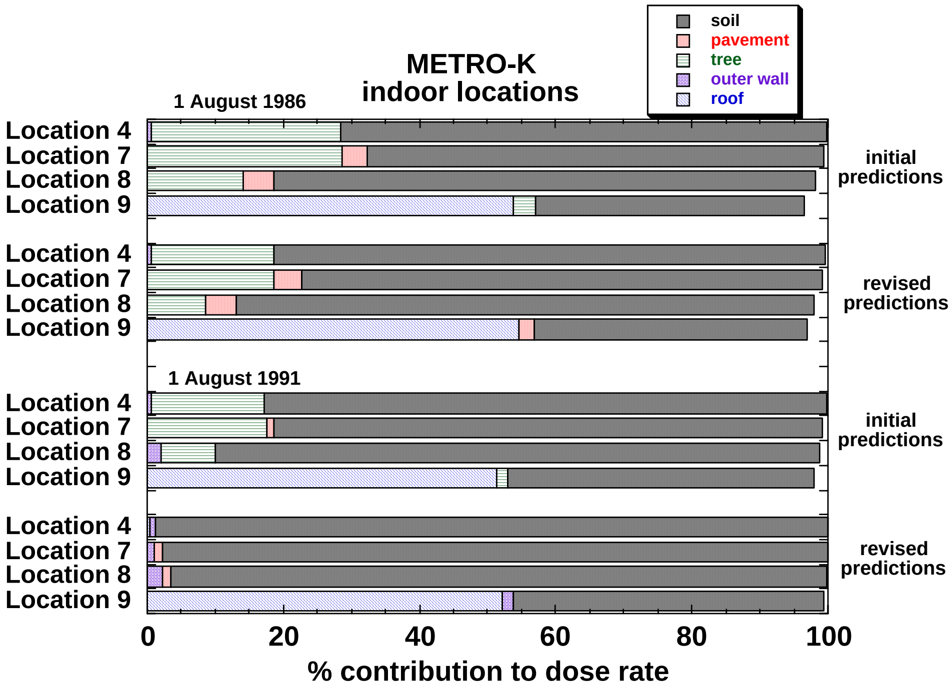


Fig. IV.10. For METRO-K, predicted contributions to dose rate on 1 August 1986 and 1 August 1991 from the most important surfaces for outdoor (top) and indoor (bottom) locations in District 1 of Pripyat, showing predictions of Spring 2007 and revised predictions of November 2007. Note especially the changes to the predicted contributions to dose rate from trees. No revisions were made for Location 3.

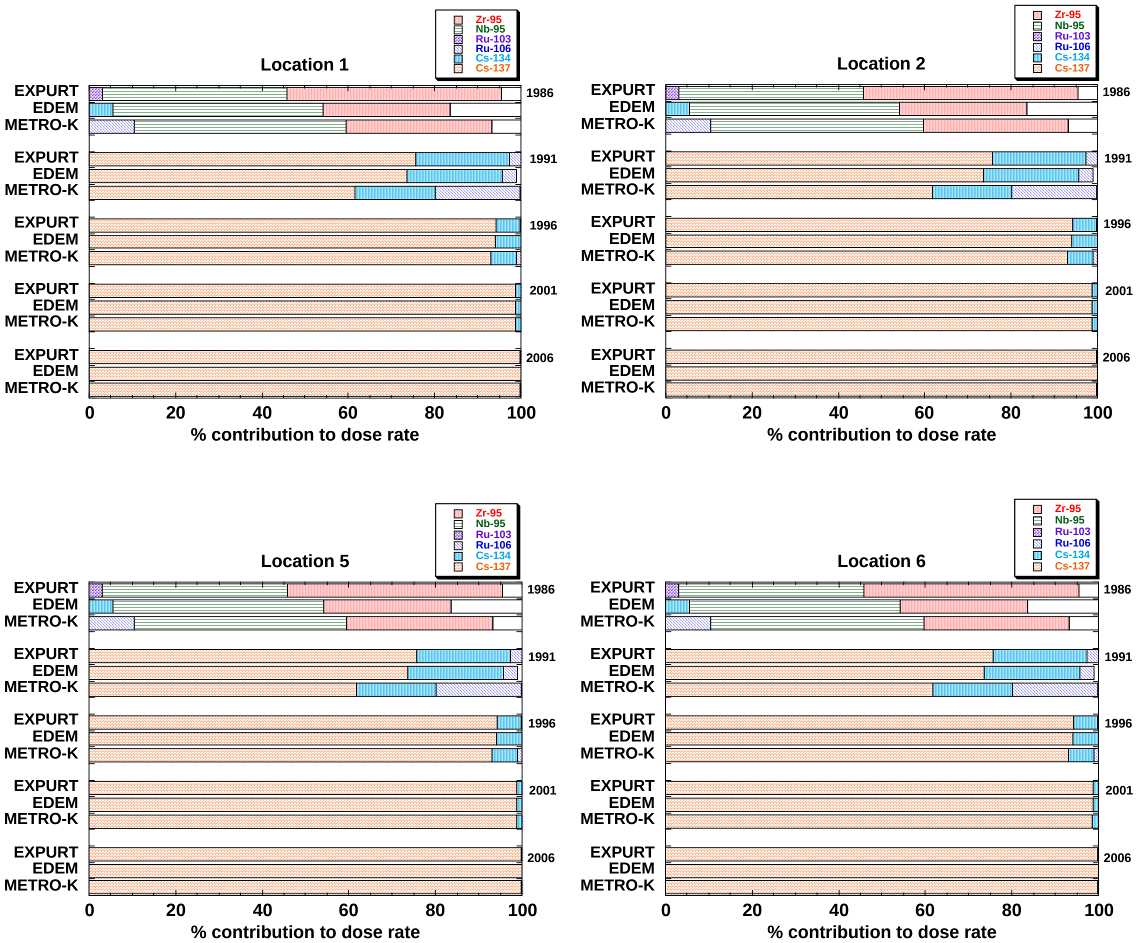


Fig. IV.11. Predicted contributions to dose rate over time from the most important radioisotopes for outdoor locations in District 1 of Pripyat.

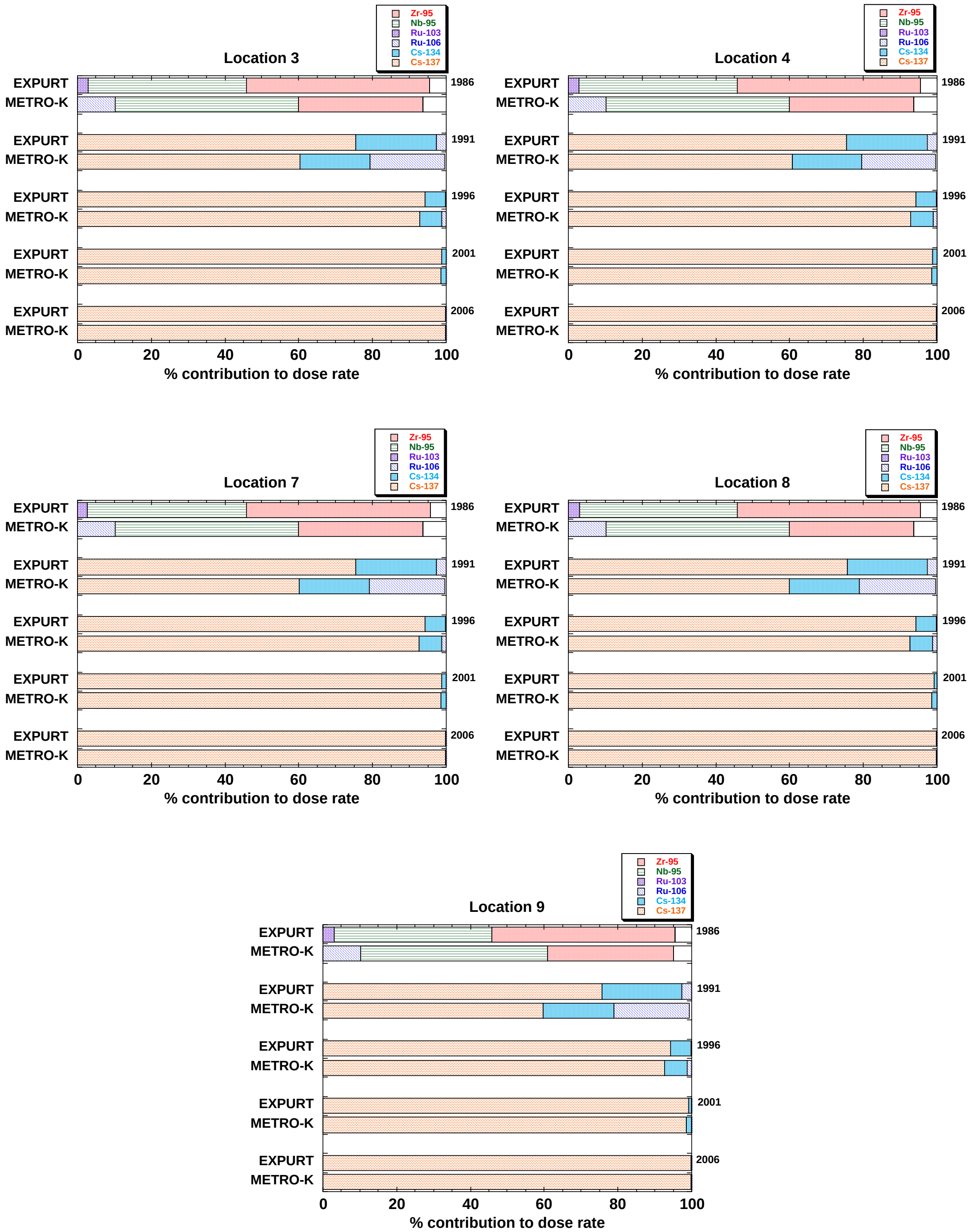
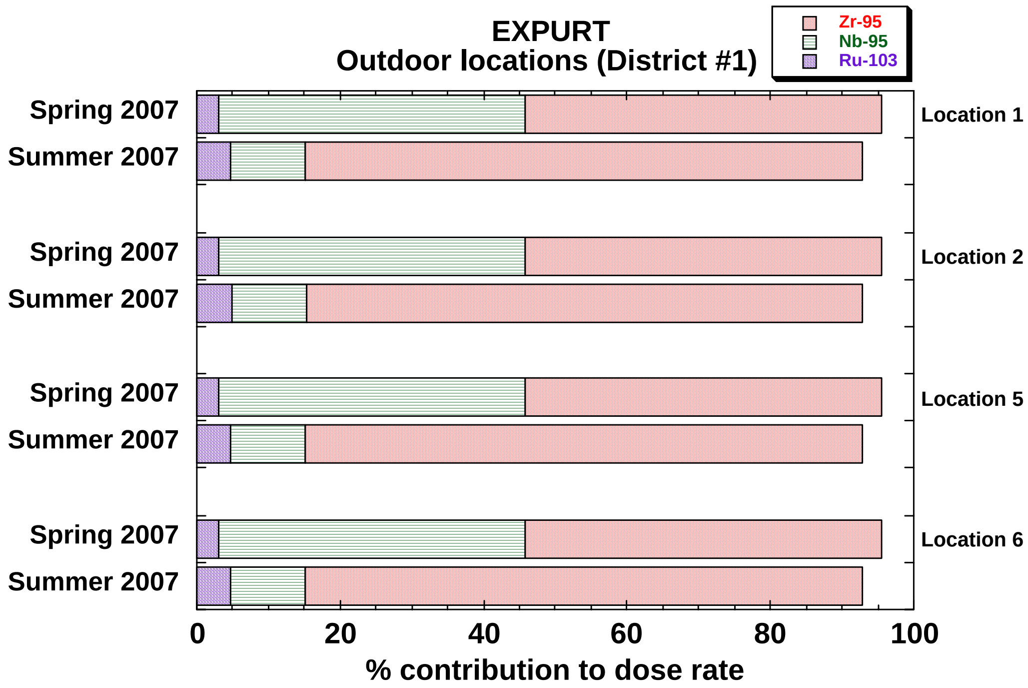


Fig. IV.12. Predicted contributions to dose rate over time from the most important radioisotopes for indoor locations in District 1 of Pripyat.



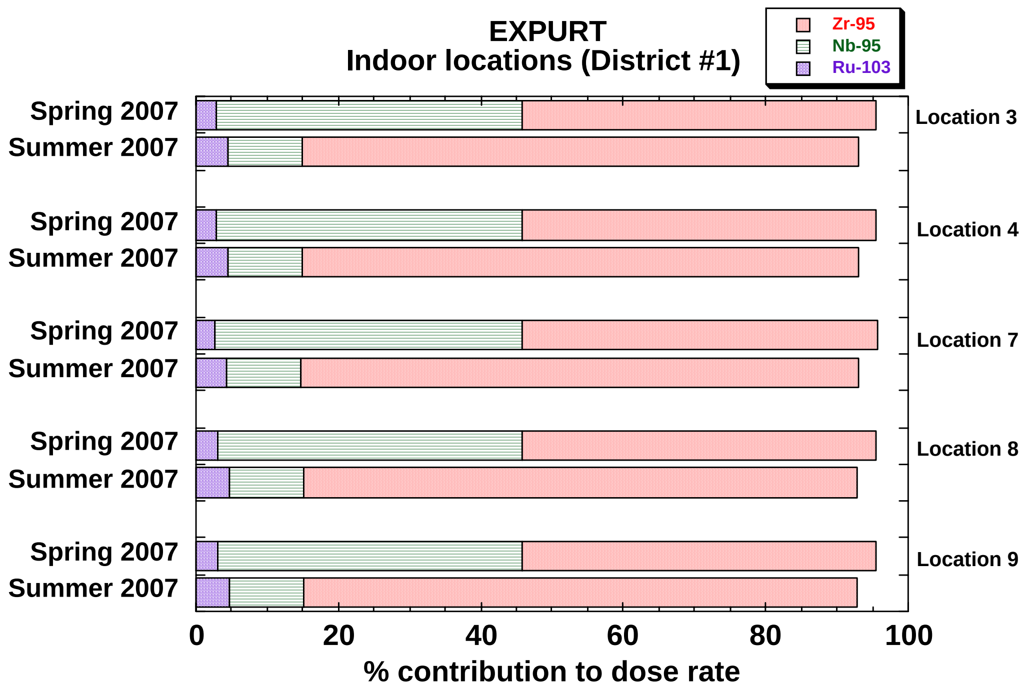


Fig. IV.13. For EXPURT, predicted contributions to dose rate on 1 August 1986 from the three most important radioisotopes for outdoor (top) and indoor (bottom) locations in District 1 of Pripyat, showing predictions of Spring 2007 and revised predictions of Summer 2007.

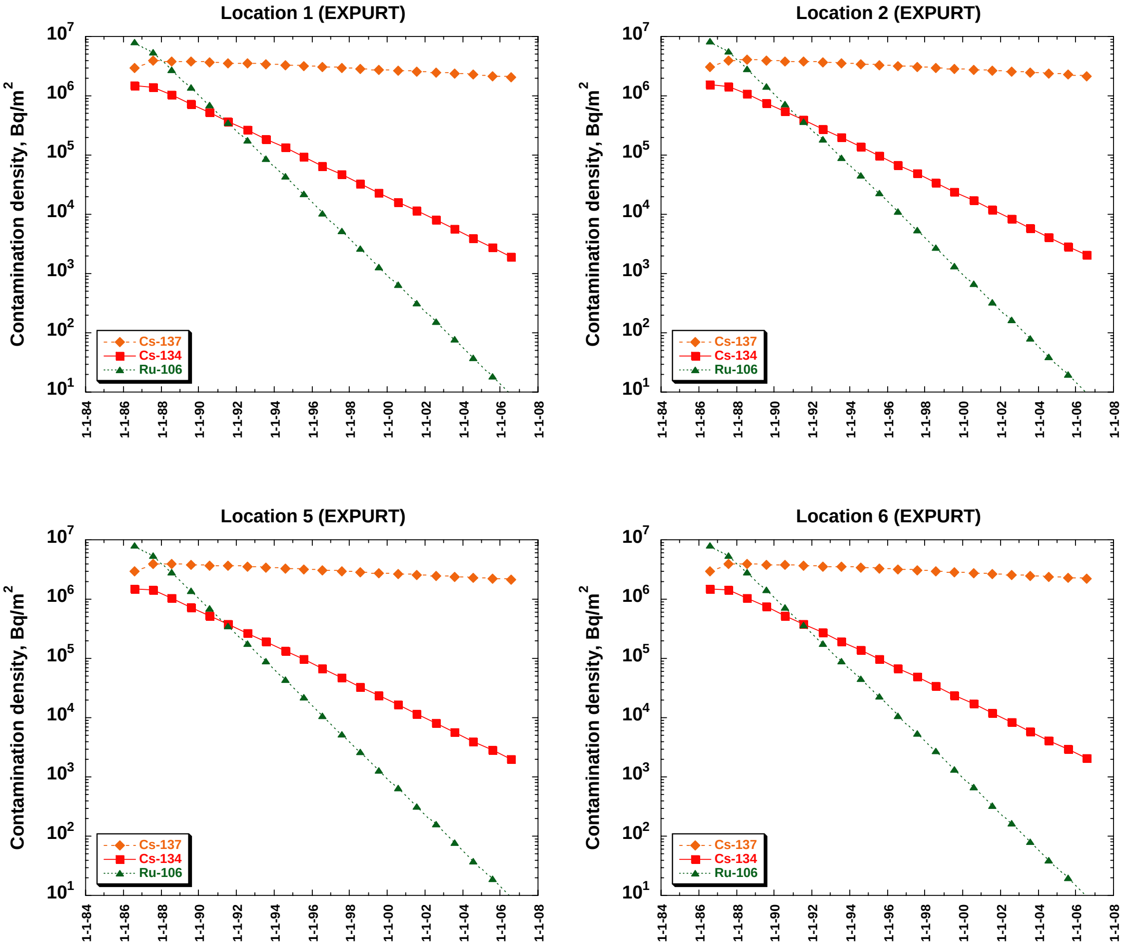


Fig. IV.14. Predicted contamination densities over time at the four outdoor locations in District 1. Predictions from EXPURT, Spring 2007.

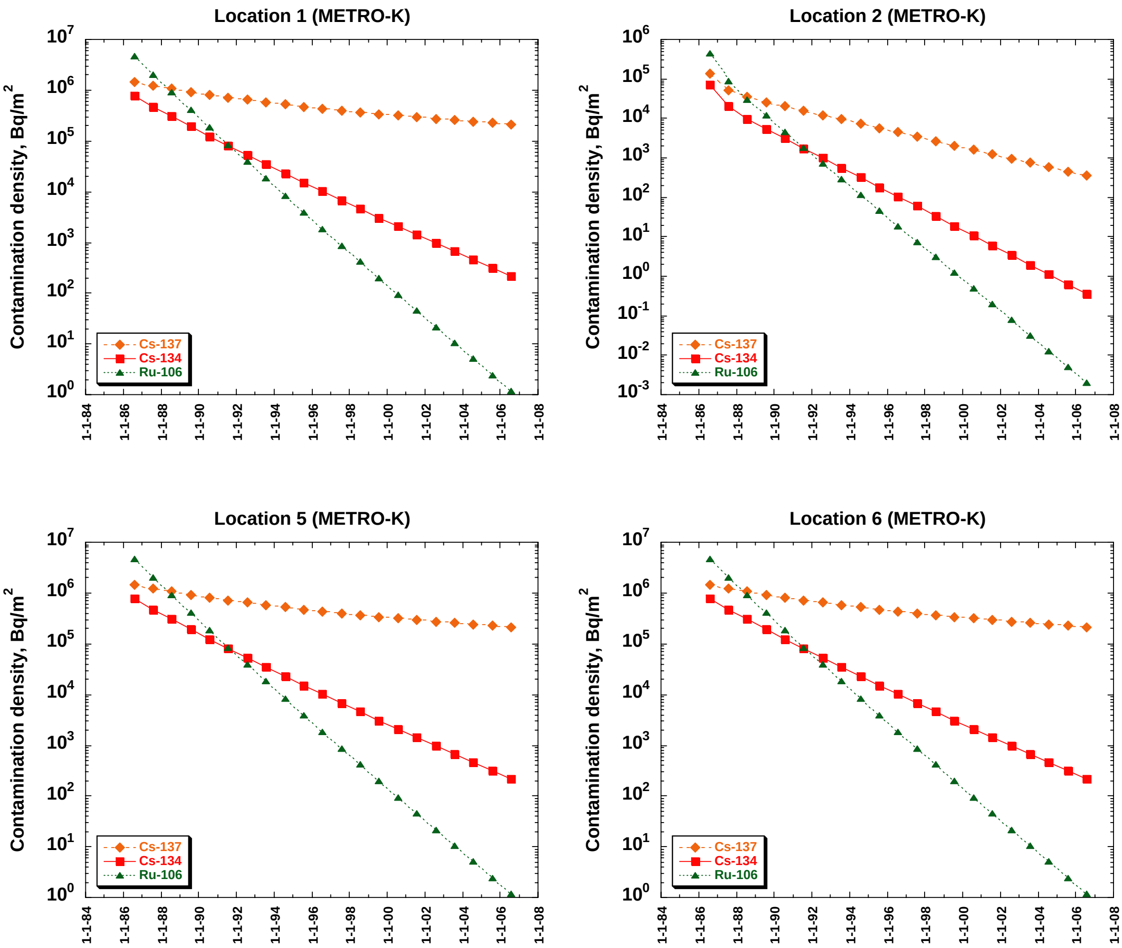


Fig. IV.15. Predicted contamination densities over time at the four outdoor locations in District 1. Predictions from METRO-K, Spring 2007. (Scales are comparable, except for Location 2.)

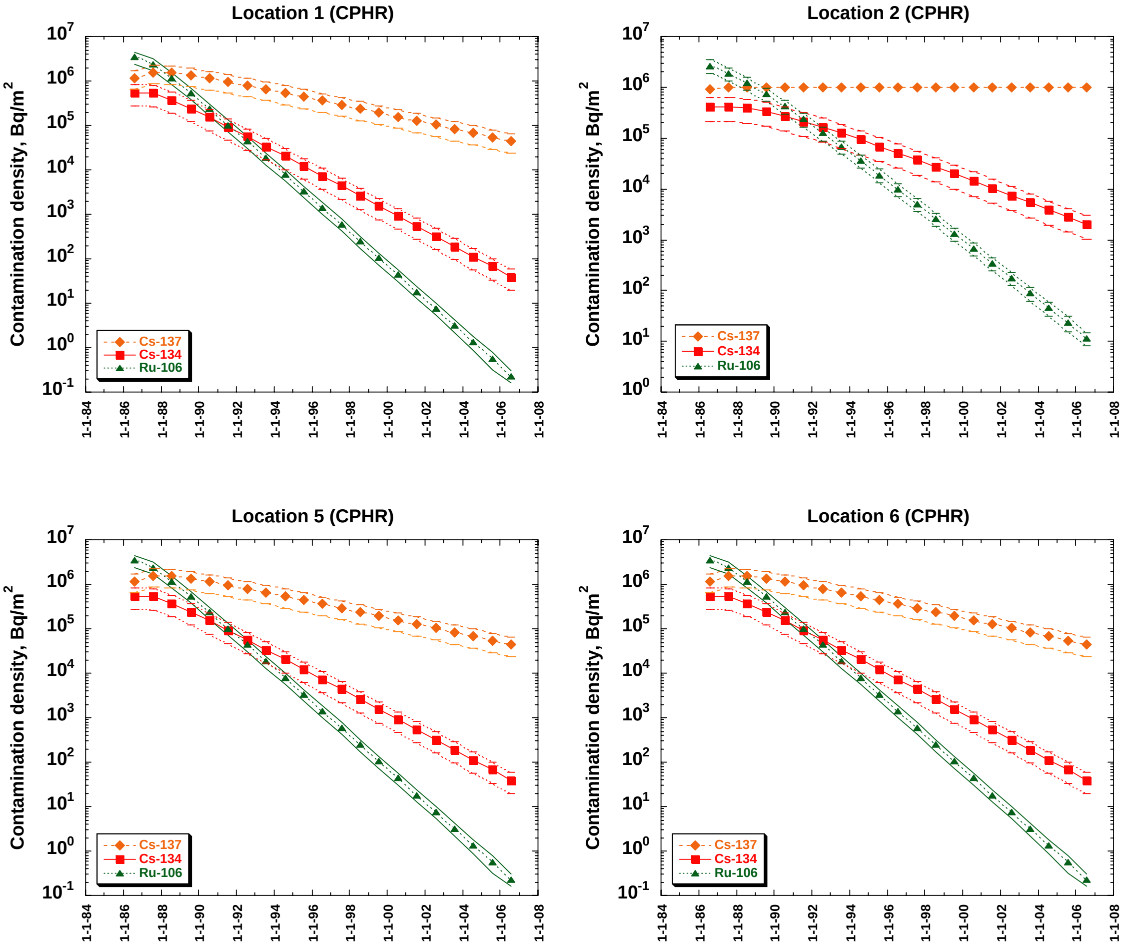


Fig. IV.16. Predicted contamination densities over time at the four outdoor locations in District 1. Predictions from CPHR, Spring 2007. (Scales are comparable, except for Location 2.)

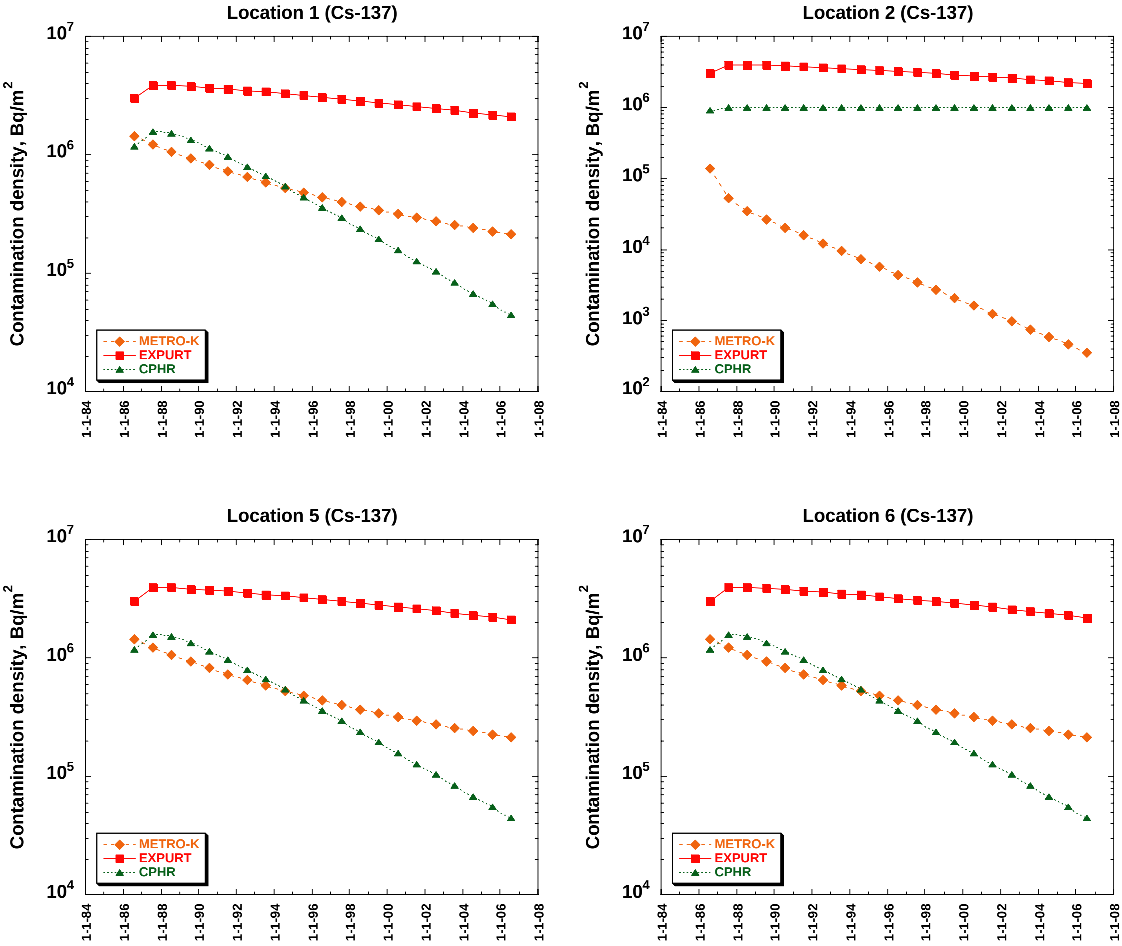


Fig. IV.17. Predicted ^{137}Cs contamination densities over time at the four outdoor locations in District 1. (Scales are comparable, except for Location 2.)

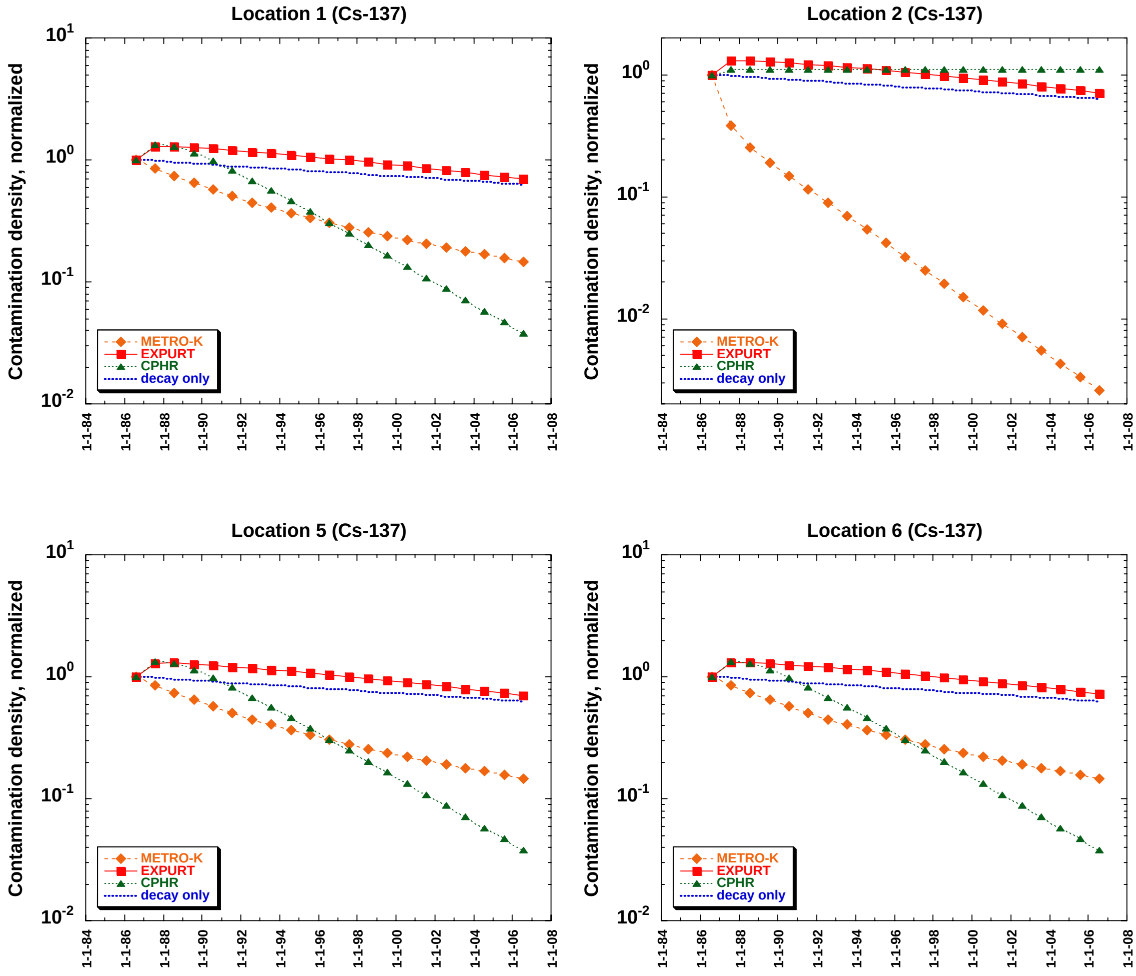


Fig. IV.18. Predicted ^{137}Cs contamination densities over time at the four outdoor locations in District 1, normalized to the predicted value for 1 August 1986. The change in contamination density over time due solely to radioactive decay is also shown. (Scales are comparable.)

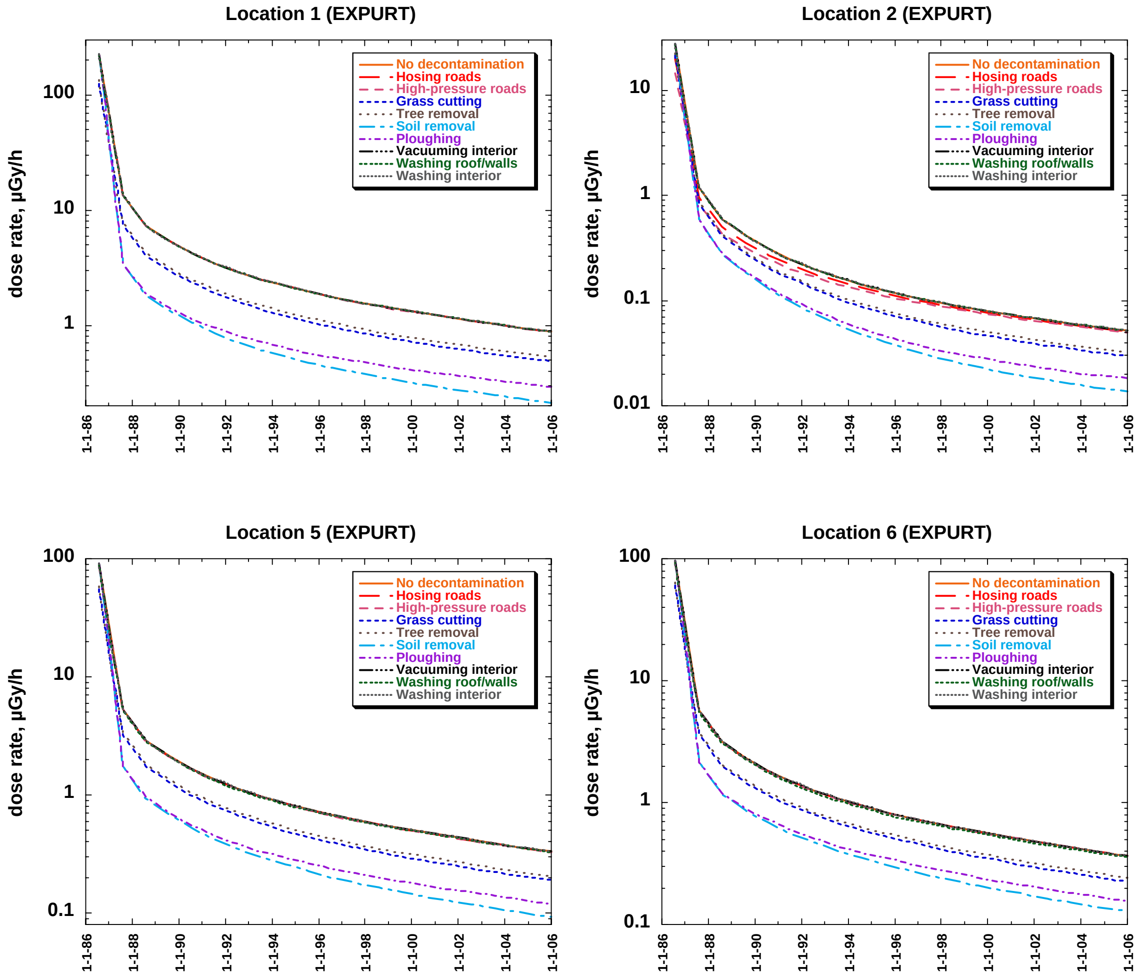


Fig. IV.19. Predicted effects of countermeasures on dose rates over time at outdoor locations in District 1. Predictions from EXPURT. (Scales are similar but not quite comparable.)

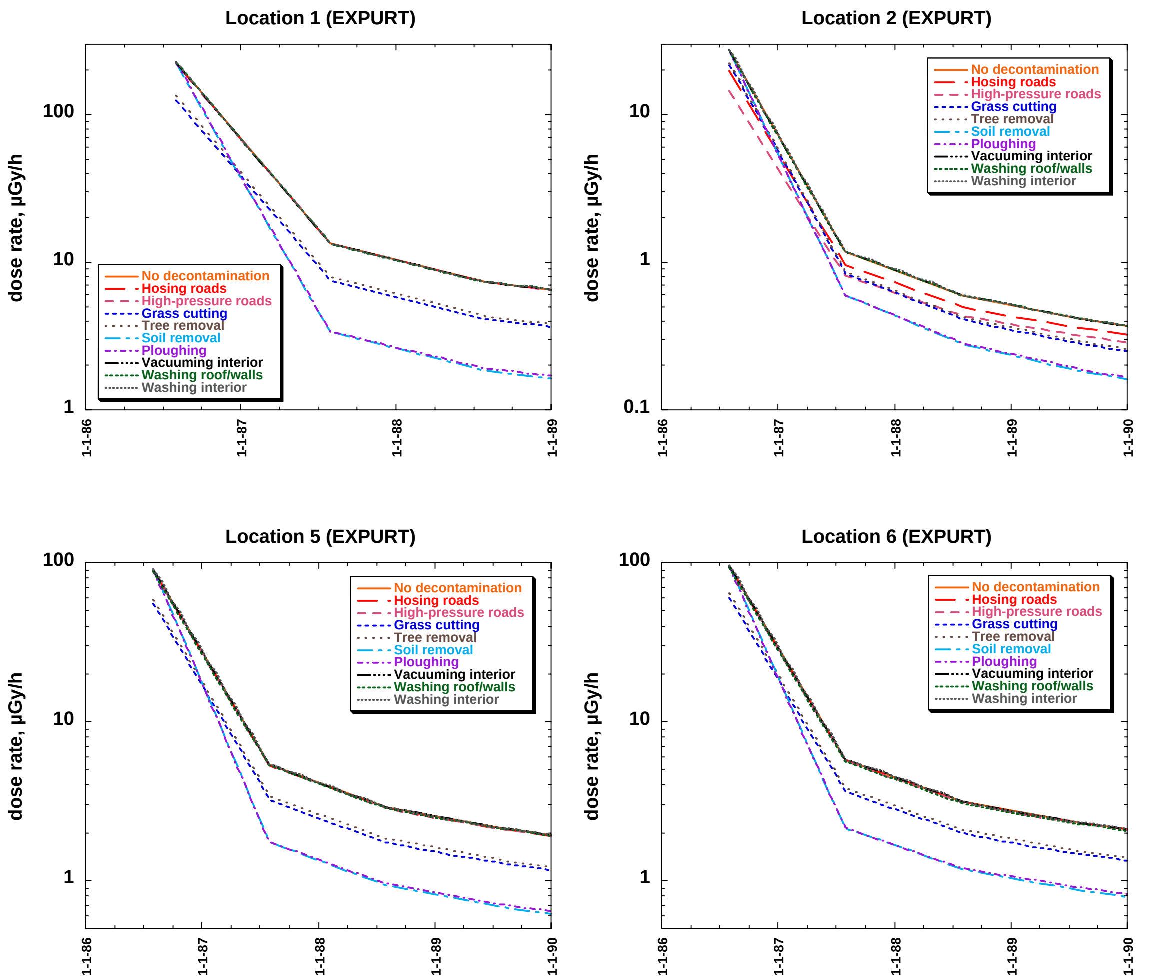


Fig. IV.20. Same information as in Figure IV.19, but showing only 1986–1990. (Scales are similar but not quite comparable.)

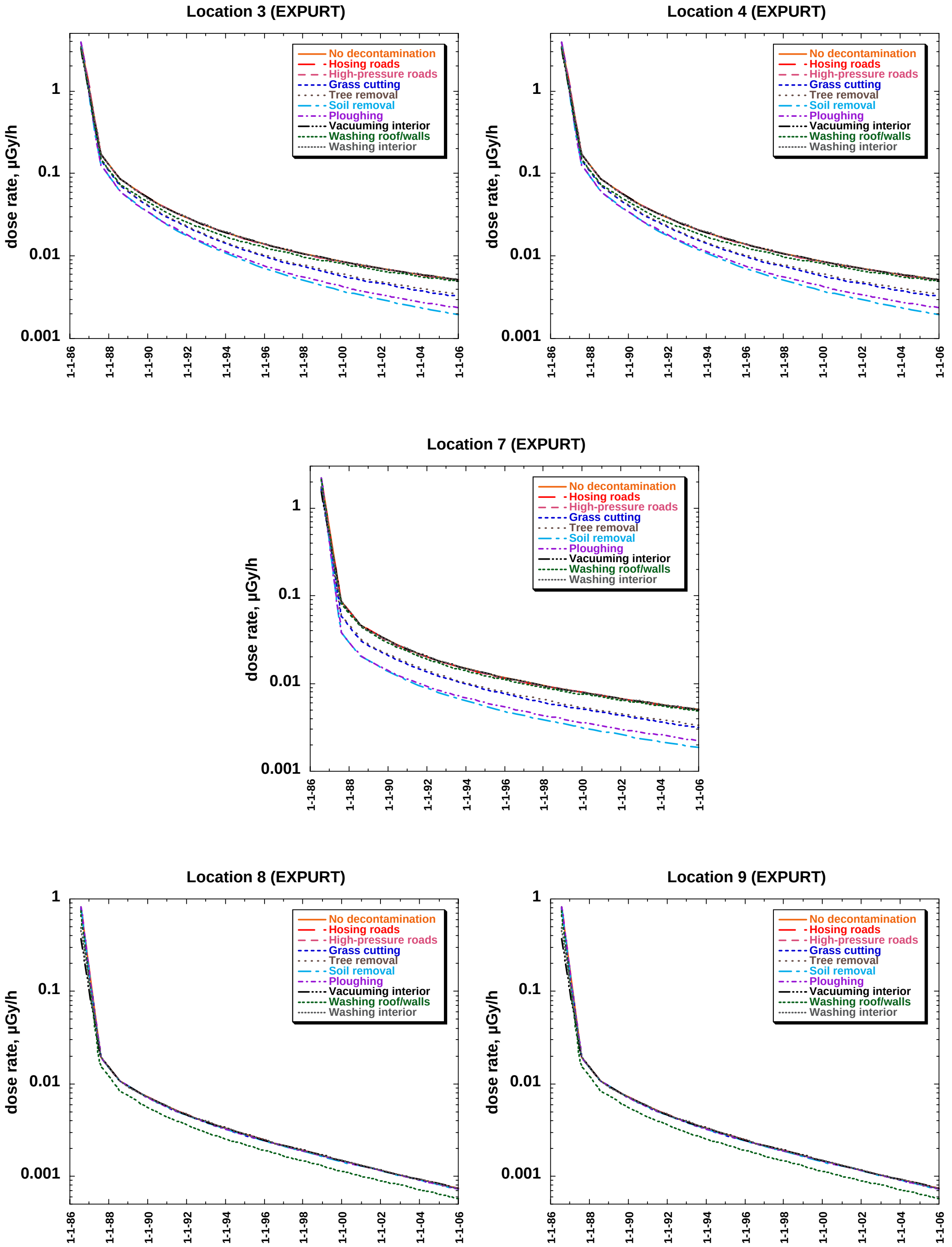


Fig. IV.21. Predicted effects of countermeasures on dose rates over time at indoor locations in District 1. Predictions from EXPURT. (Scales are similar but not quite comparable.)

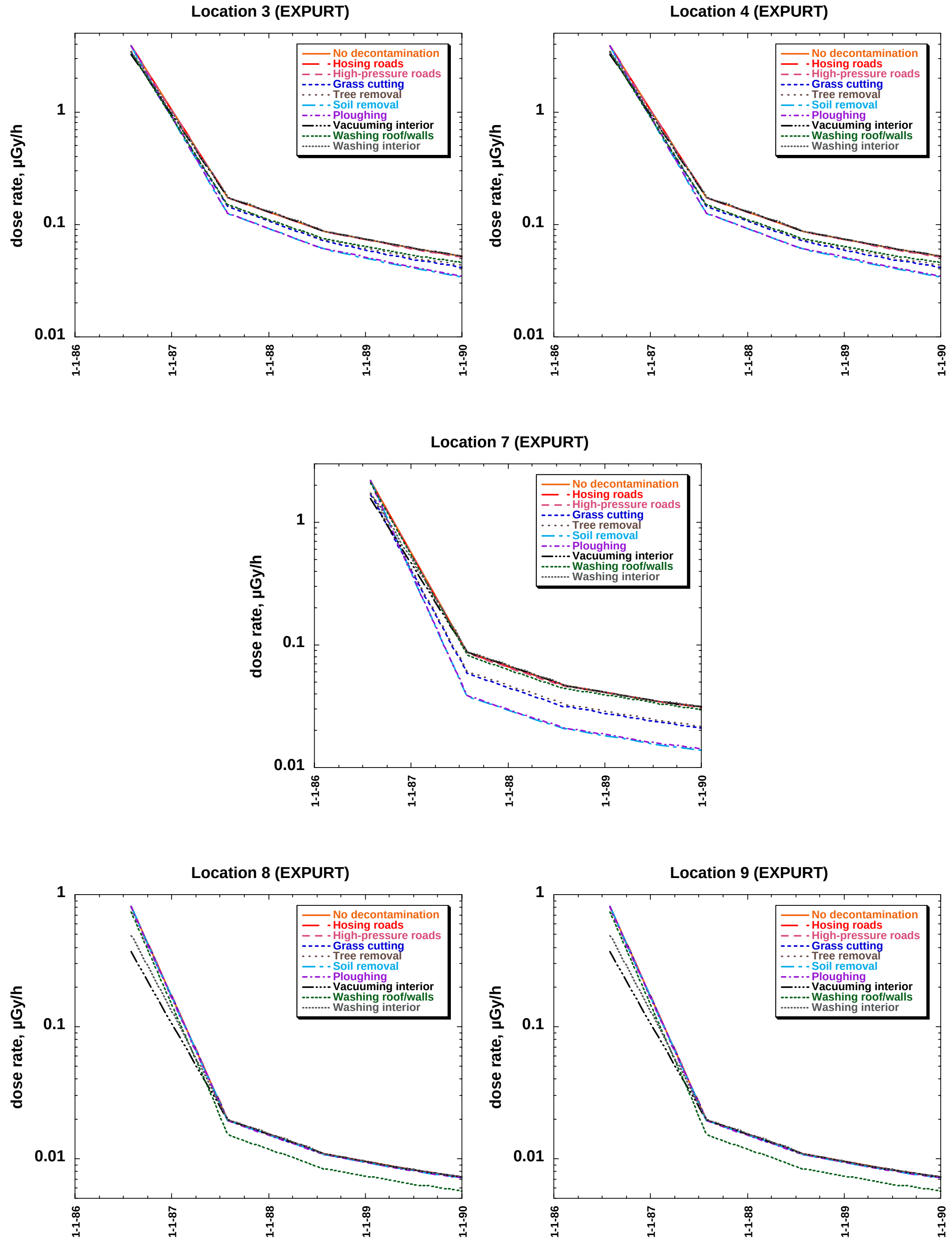


Fig. IV.22. Same information as in Figure IV.21, but showing only 1986–1990. (Scales are similar but not quite comparable.)

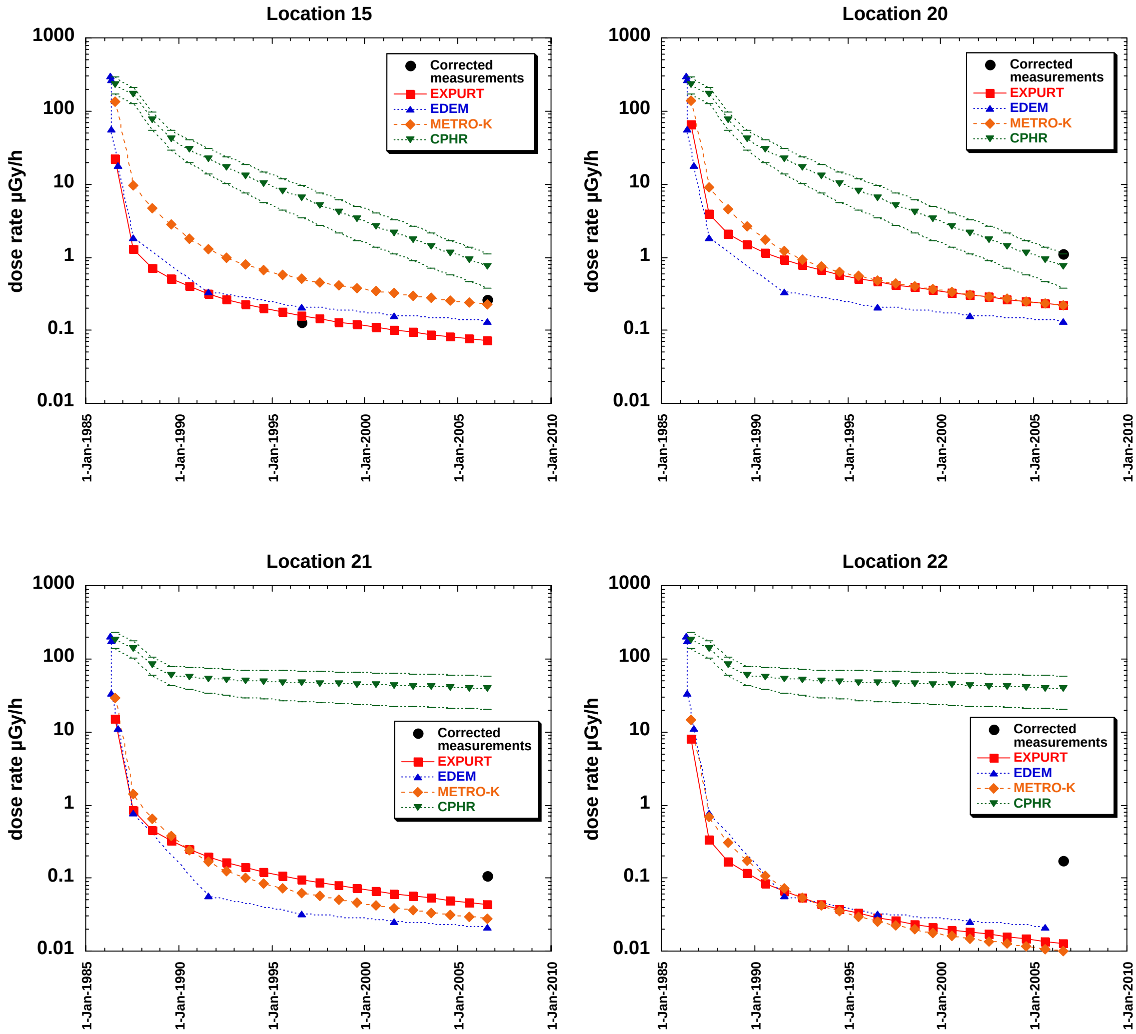


Fig. IV.23. Predicted and measured dose rates for outdoor locations in District 4 of Pripyat.

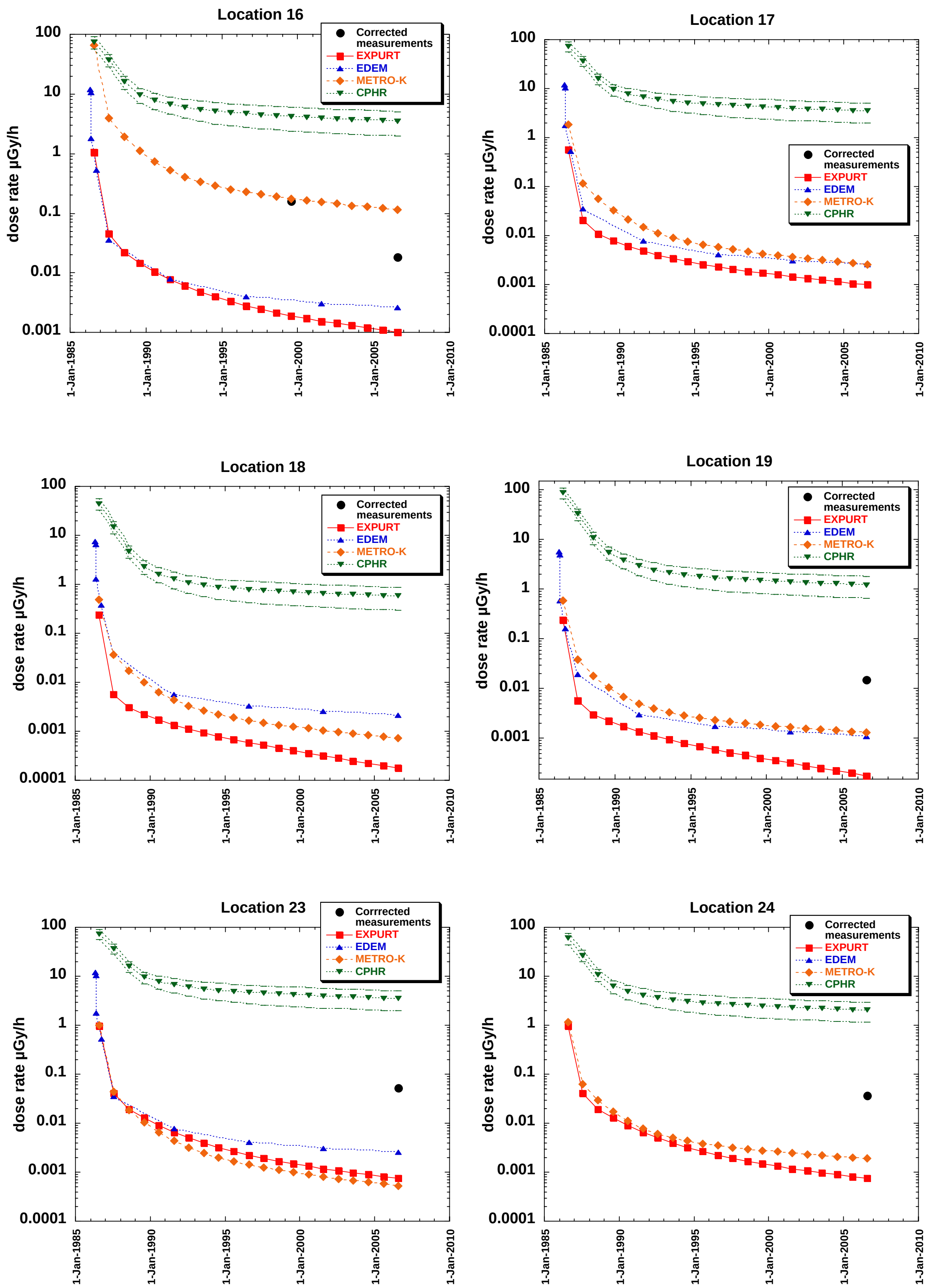
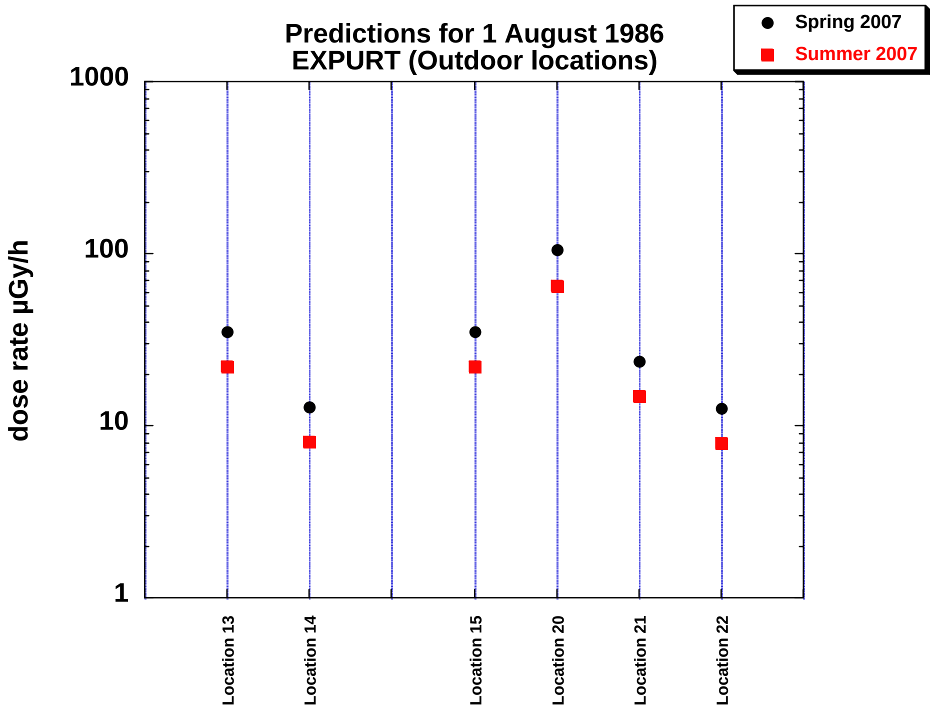


Fig. IV.24. Predicted and measured dose rates for indoor locations in District 4 of Pripyat. For Locations 17 and 18, correction of the measurements for background resulted in values below zero (negative values); these values are not shown.



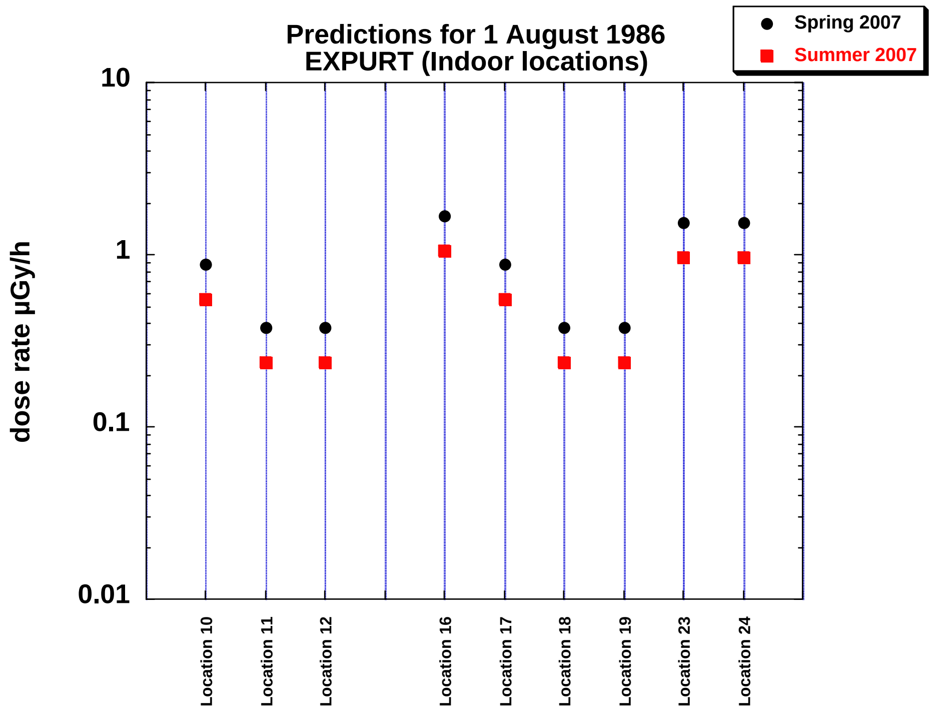


Fig. IV.25. Predicted dose rates on 1 August 1986 for outdoor (top) and indoor (bottom) locations in District 4 for EXPURT, showing predictions of Spring 2007 and revised predictions of Summer 2007.

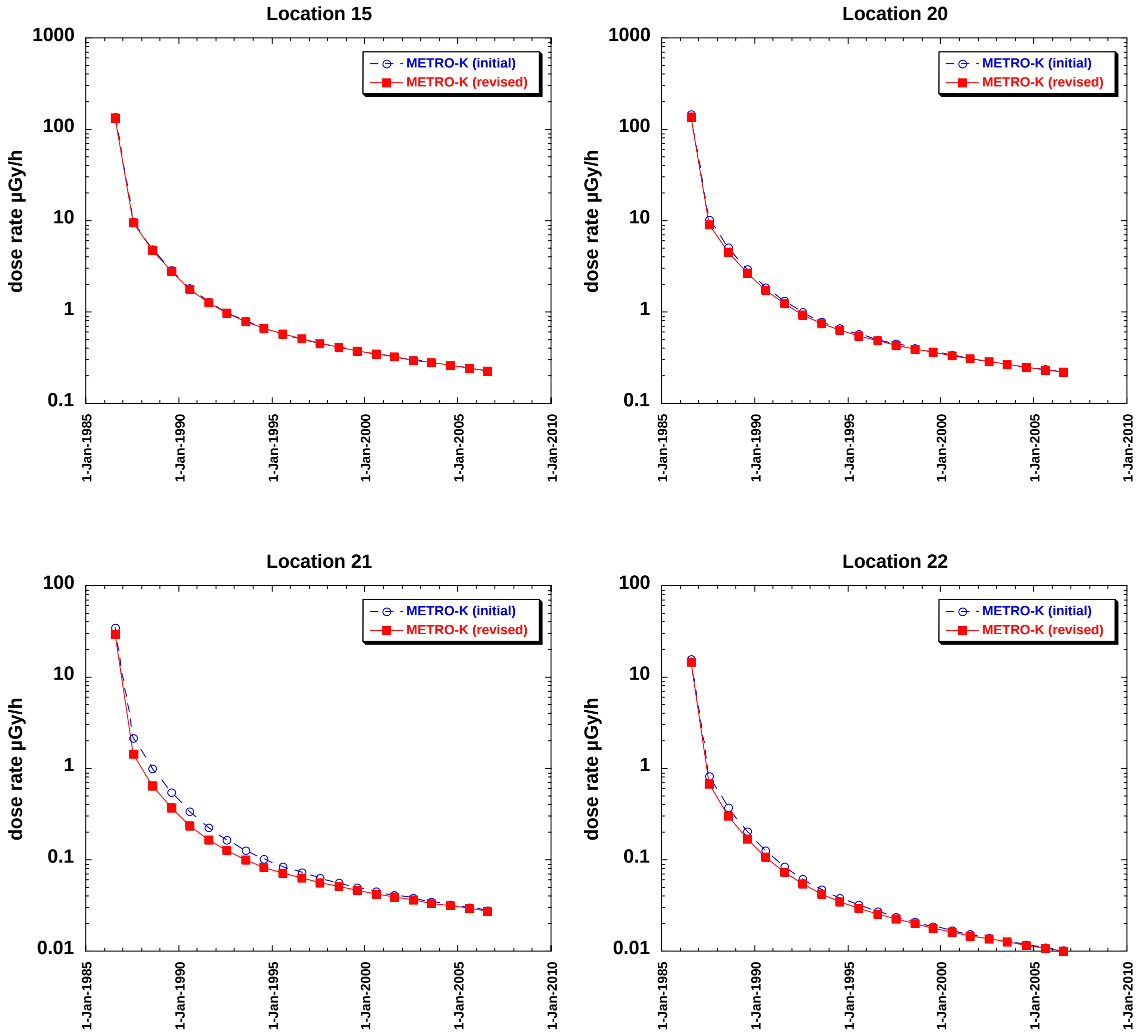


Fig. IV.26. Predicted dose rates for outdoor locations in District 4 of Pripyat for METRO-K, showing predictions of Spring 2007 and revised predictions of November 2007.

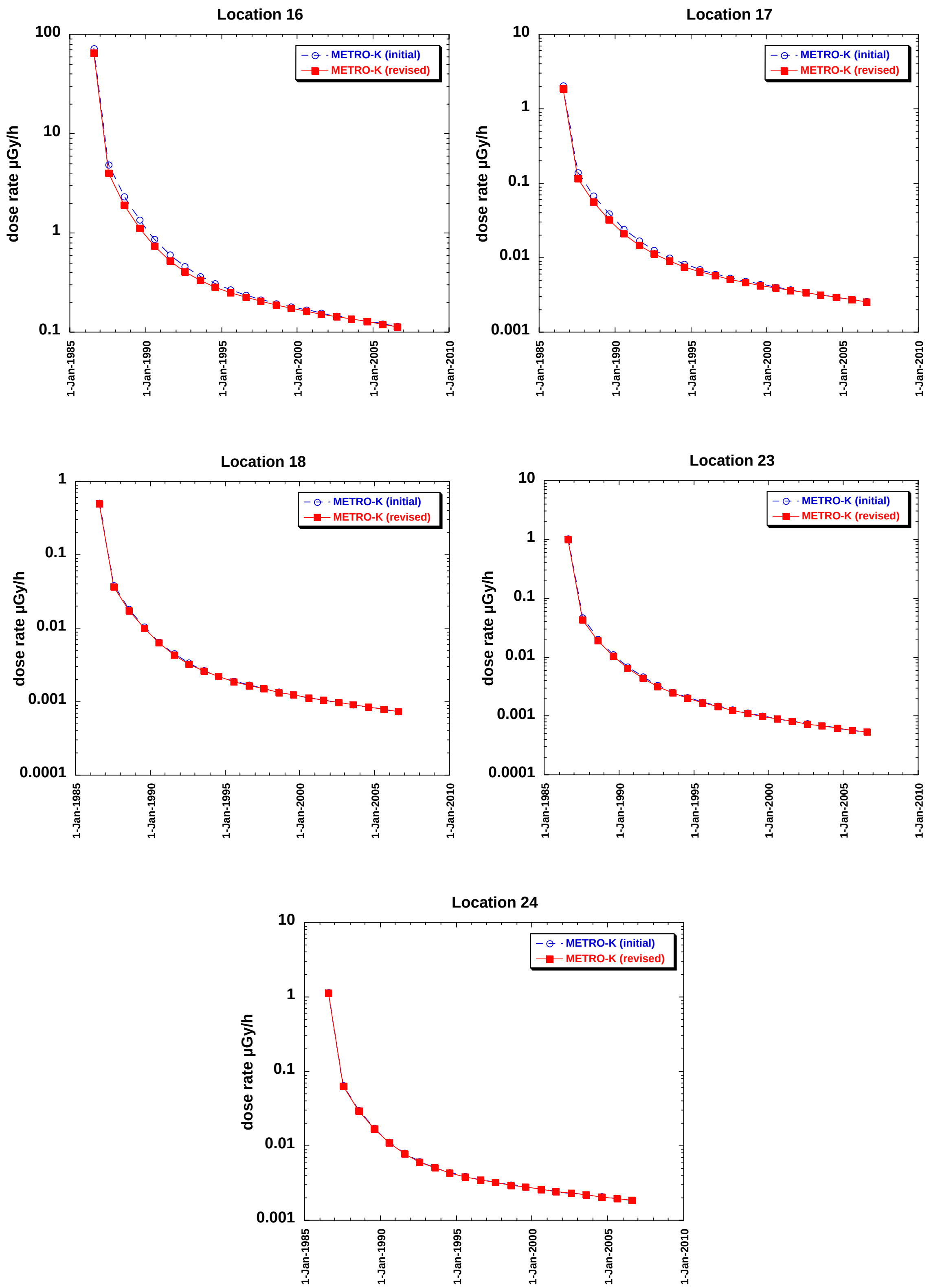


Fig. IV.27. Predicted dose rates for indoor locations in District 4 of Pripyat for METRO-K, showing predictions of Spring 2007 and revised predictions of November 2007. No revisions were made for Location 19. Initial and revised predictions for Location 24 are not distinguishable on the graph.

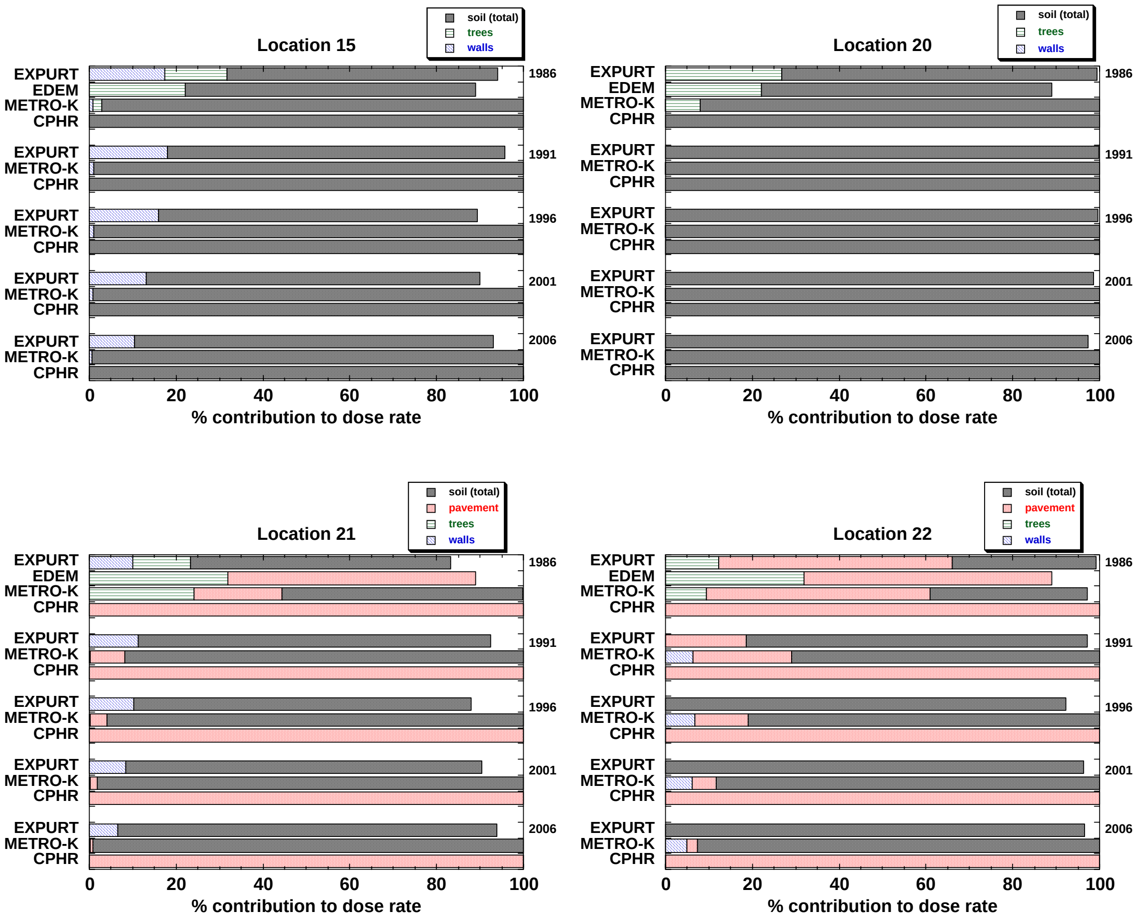


Fig. IV.28. Predicted contributions to dose rate over time from the most important surfaces for outdoor locations in District 4 of Pripyat.

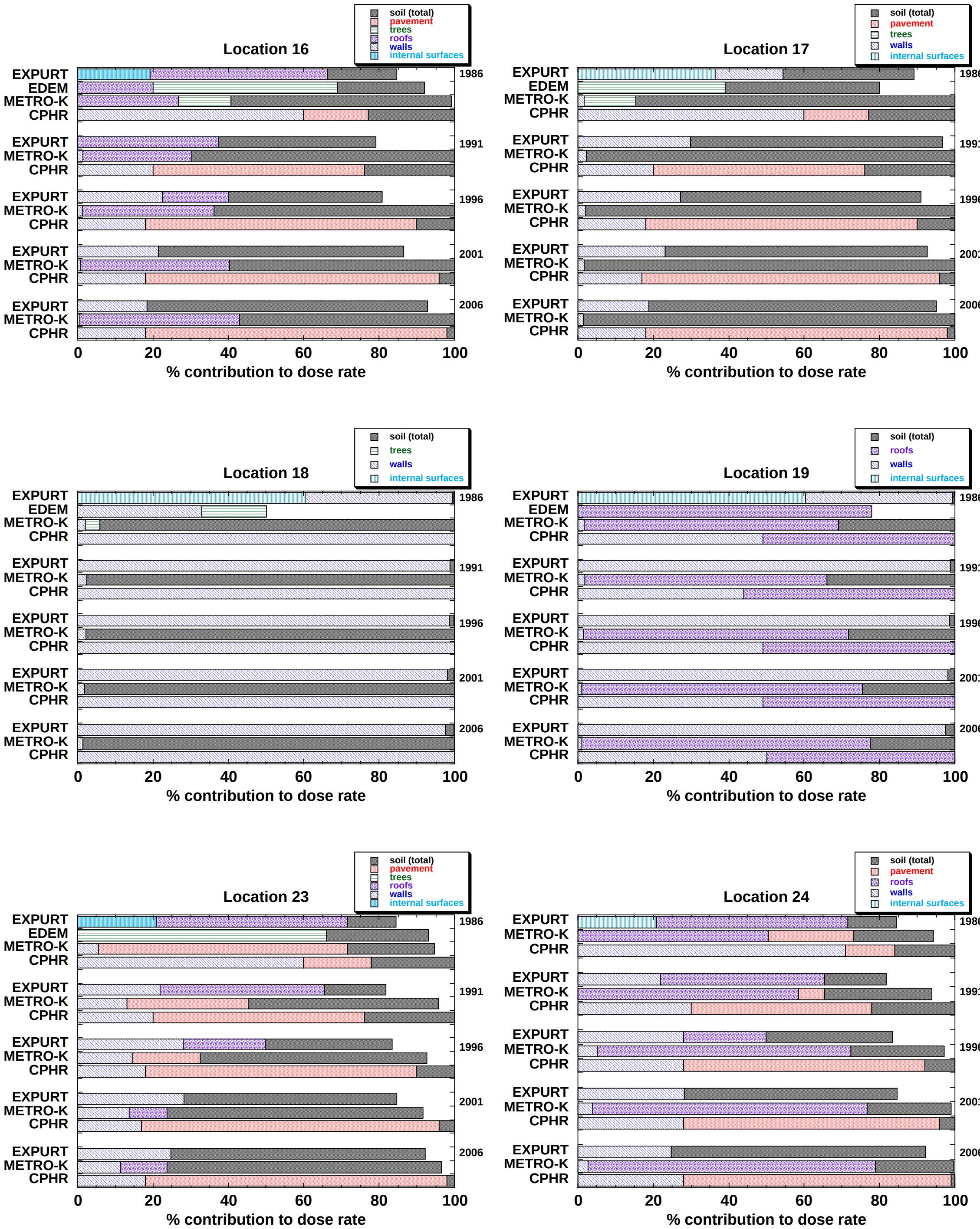
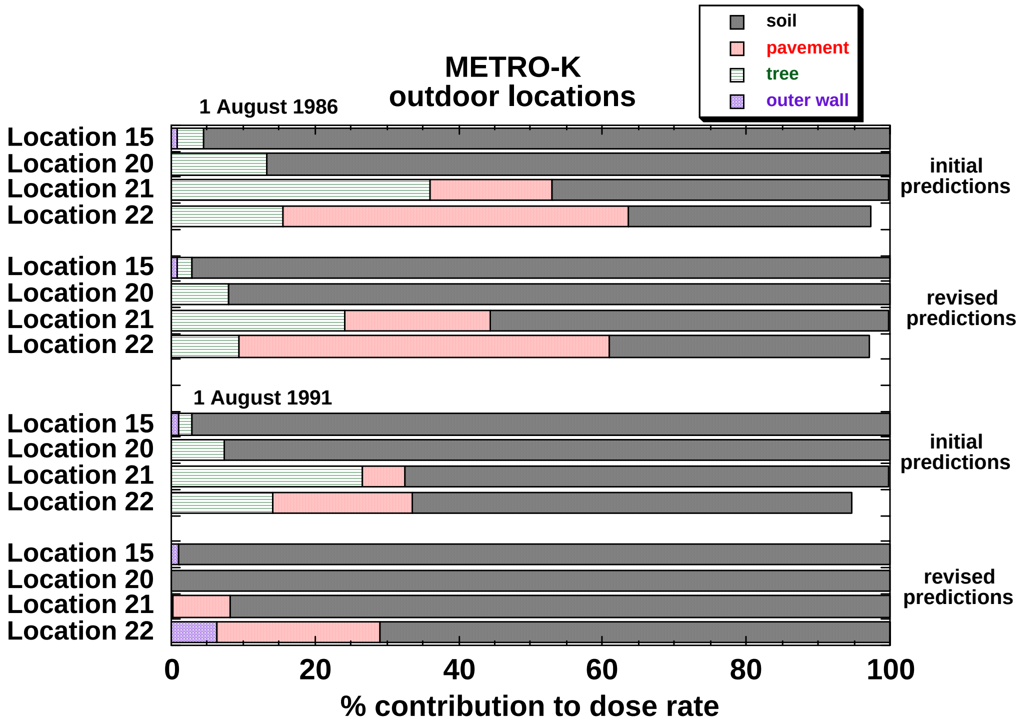


Fig. IV.29. Predicted contributions to dose rate over time from the most important surfaces for indoor locations in District 4 of Pripyat.



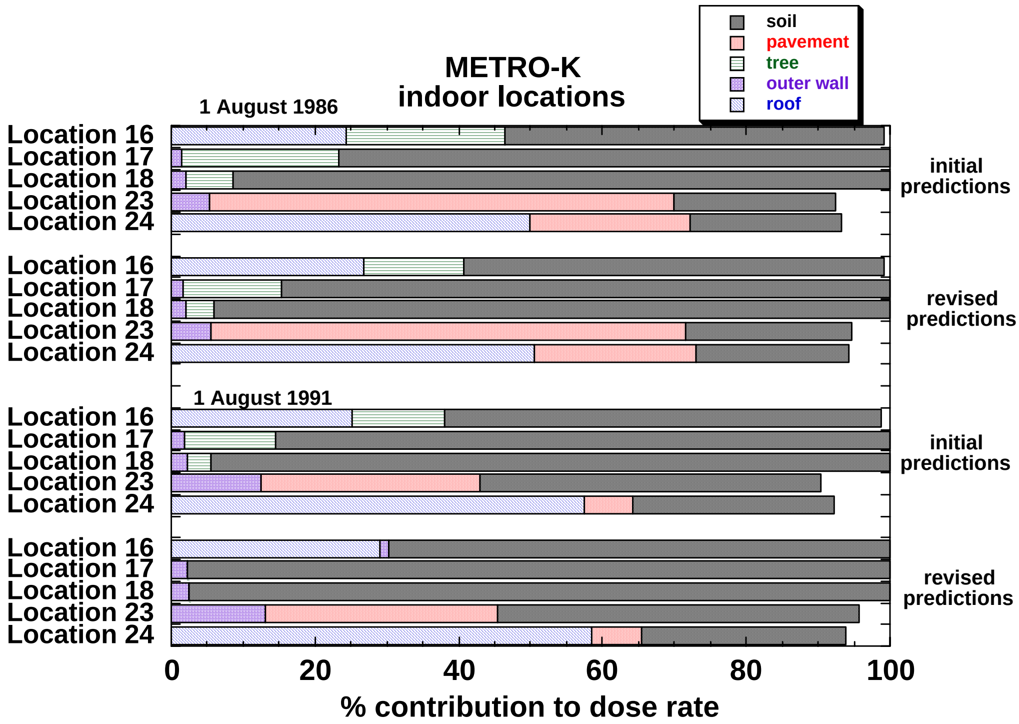


Fig. IV.30. For METRO-K, predicted contributions to dose rate on 1 August 1986 and 1 August 1991 from the most important surfaces for outdoor (top) and indoor (bottom) locations in District 4 of Pripyat, showing predictions of Spring 2007 and revised predictions of November 2007. Note especially the changes to the predicted contributions to dose rate from trees.

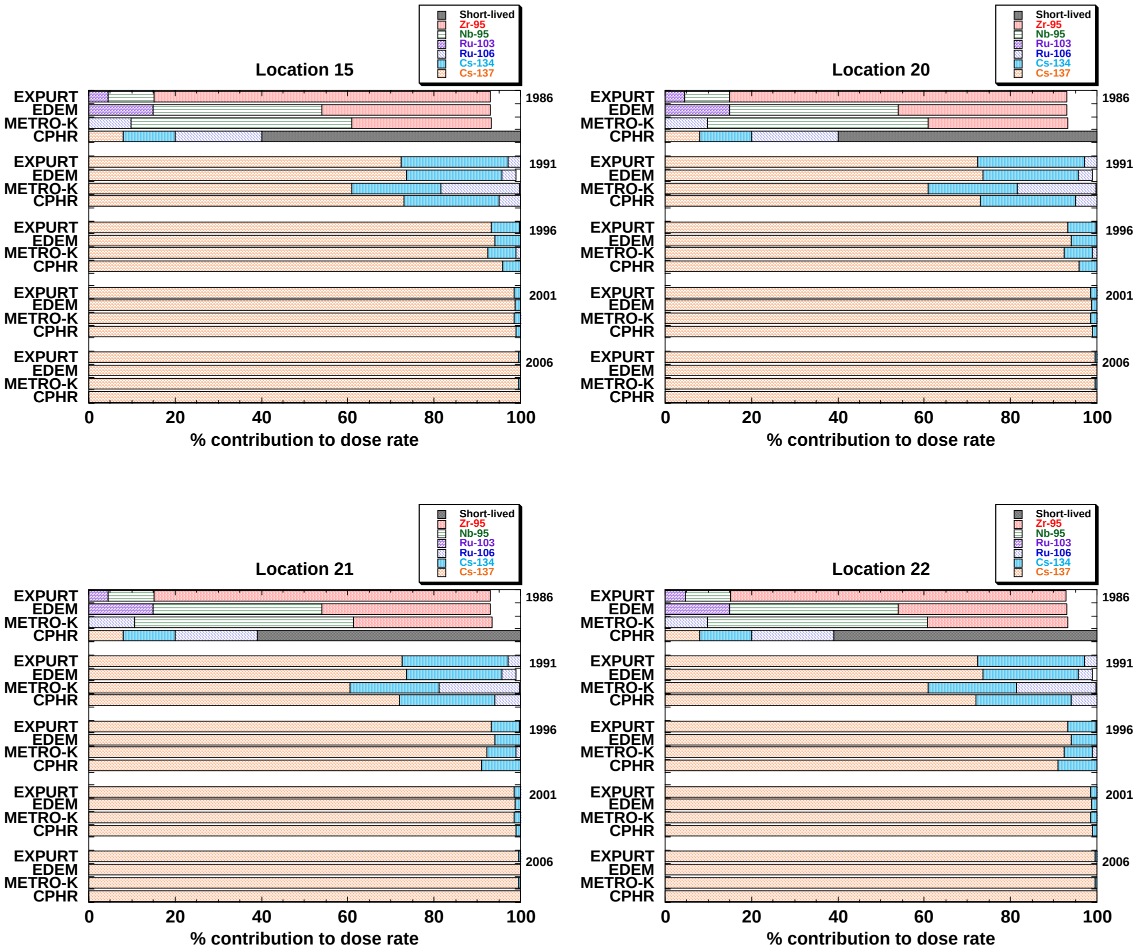


Fig. IV.31. Predicted contributions to dose rate over time from the most important radioisotopes for outdoor locations in District 4 of Pripyat.

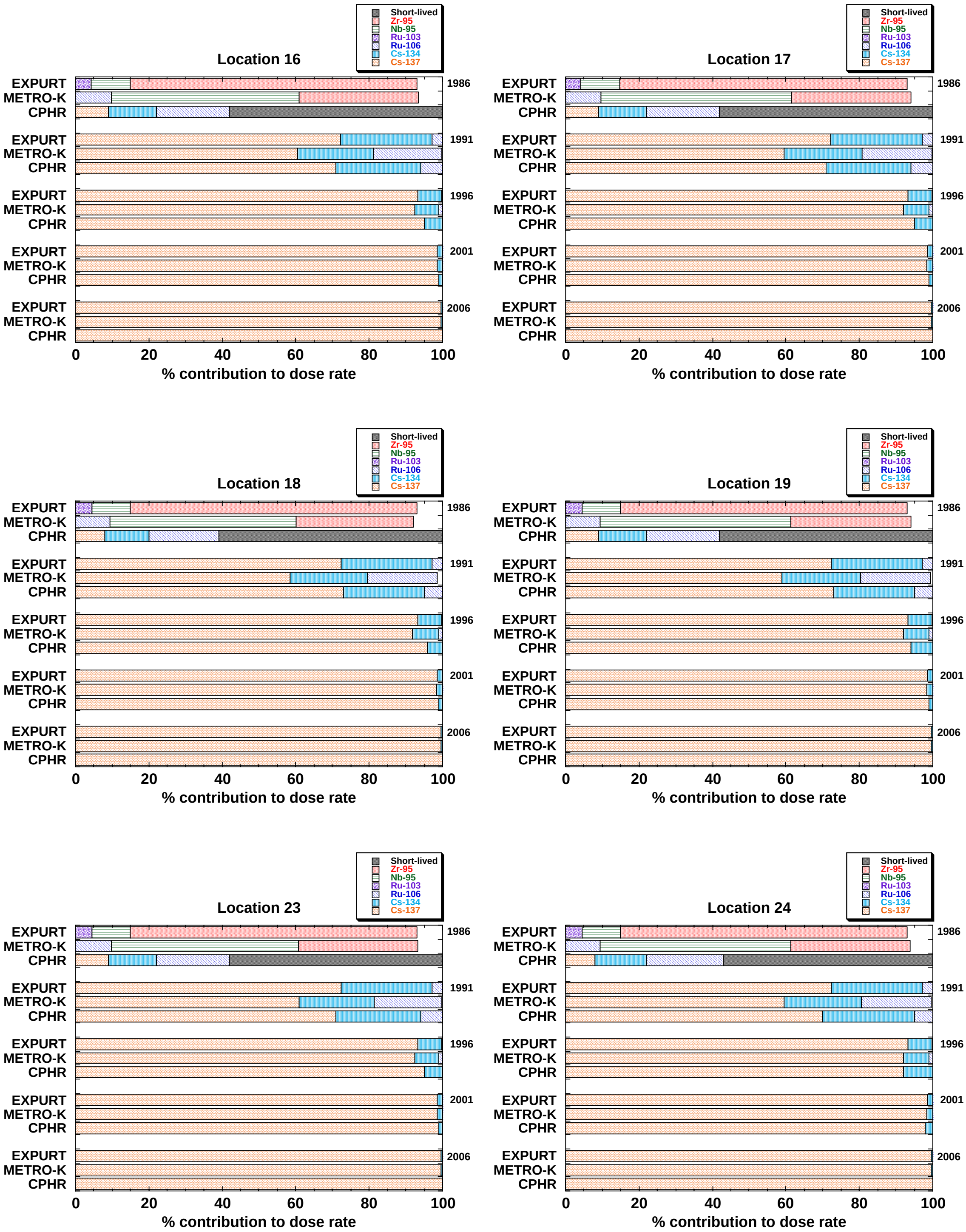


Fig. IV.32. Predicted contributions to dose rate over time from the most important radioisotopes for indoor locations in District 4 of Pripyat.

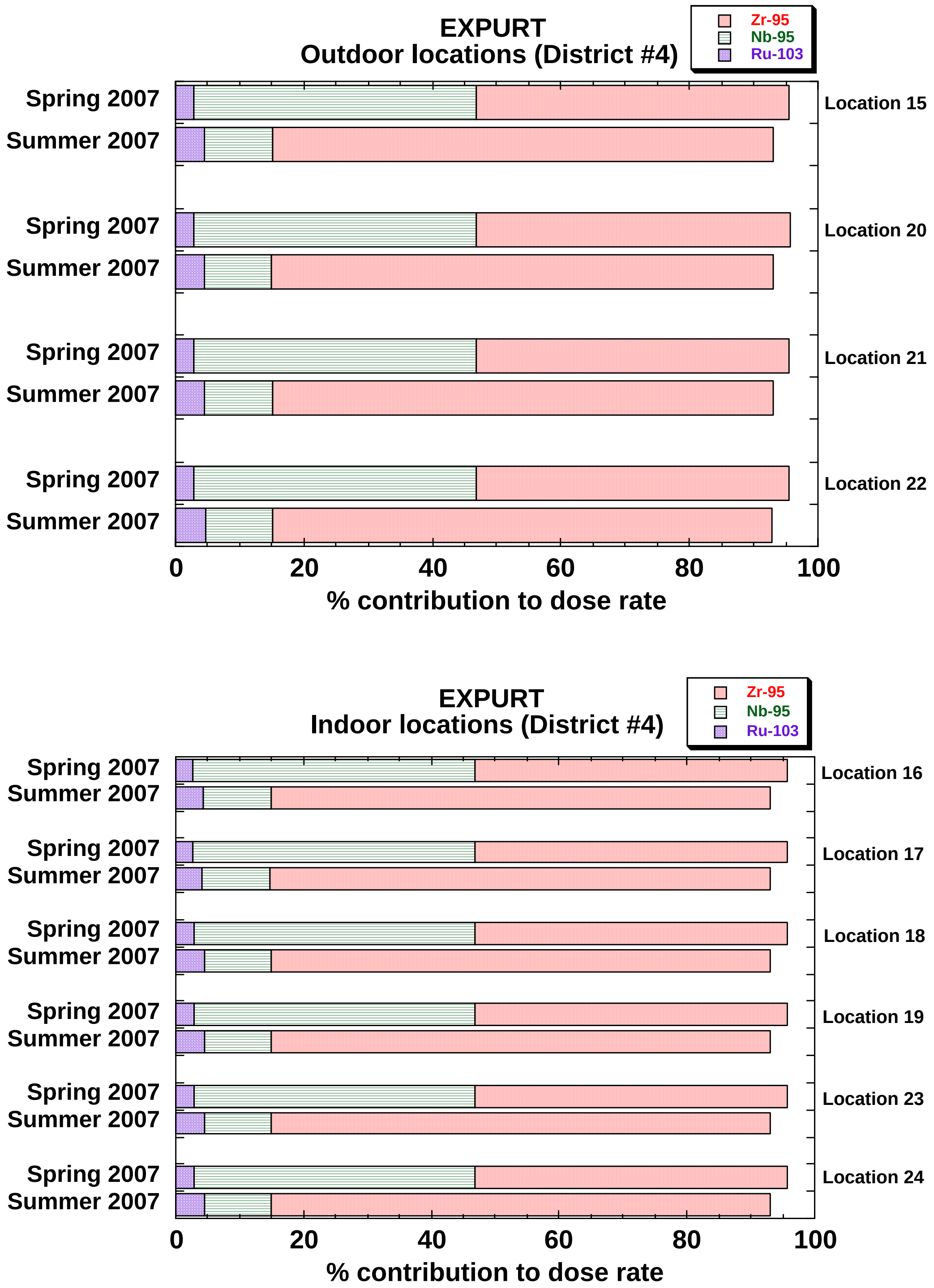


Fig. IV.33. For EXPURT, predicted contributions to dose rate on 1 August 1986 from the three most important radioisotopes for outdoor (top) and indoor (bottom) locations in District 4 of Pripyat, showing predictions of Spring 2007 and revised predictions of Summer 2007.

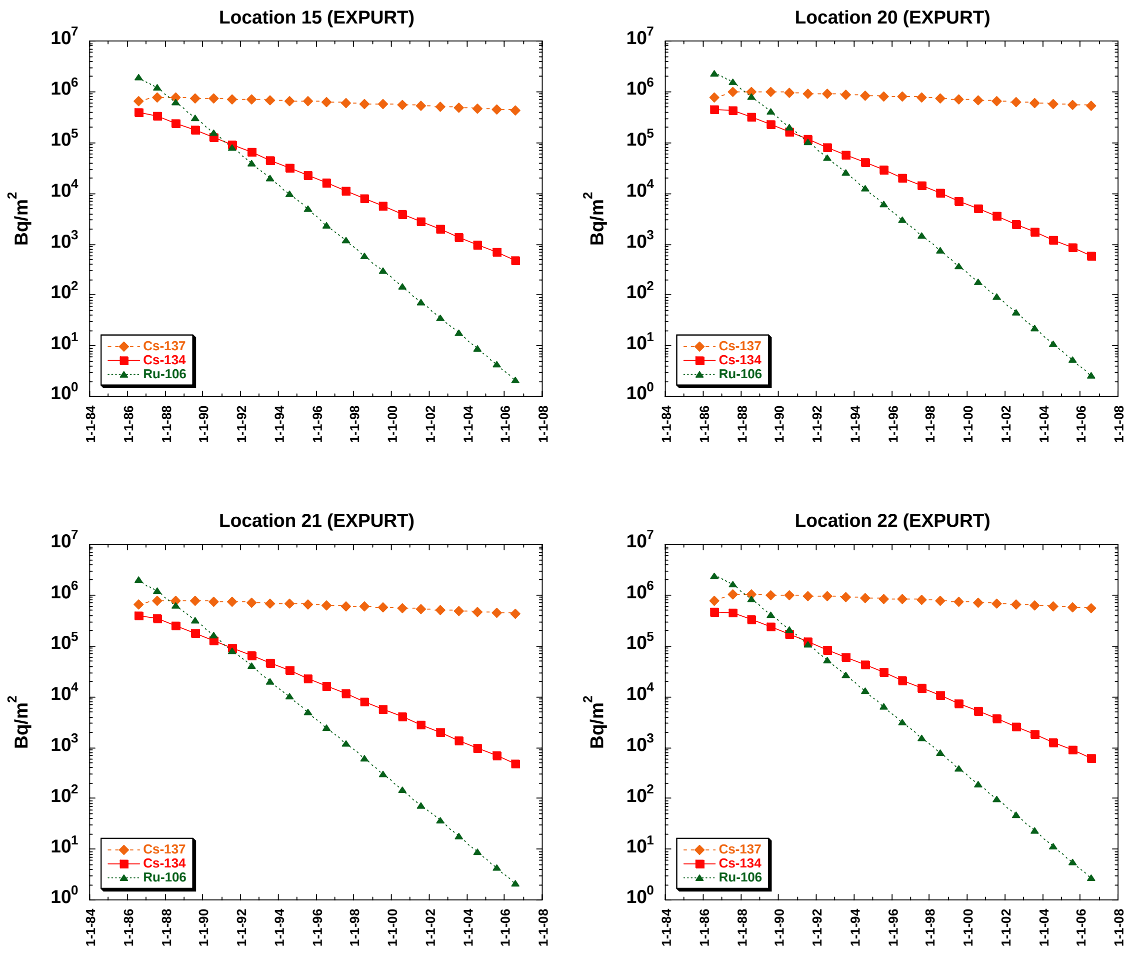


Fig. IV.34. Predicted contamination densities over time at the four outdoor locations in District 4. Predictions from EXPURT.

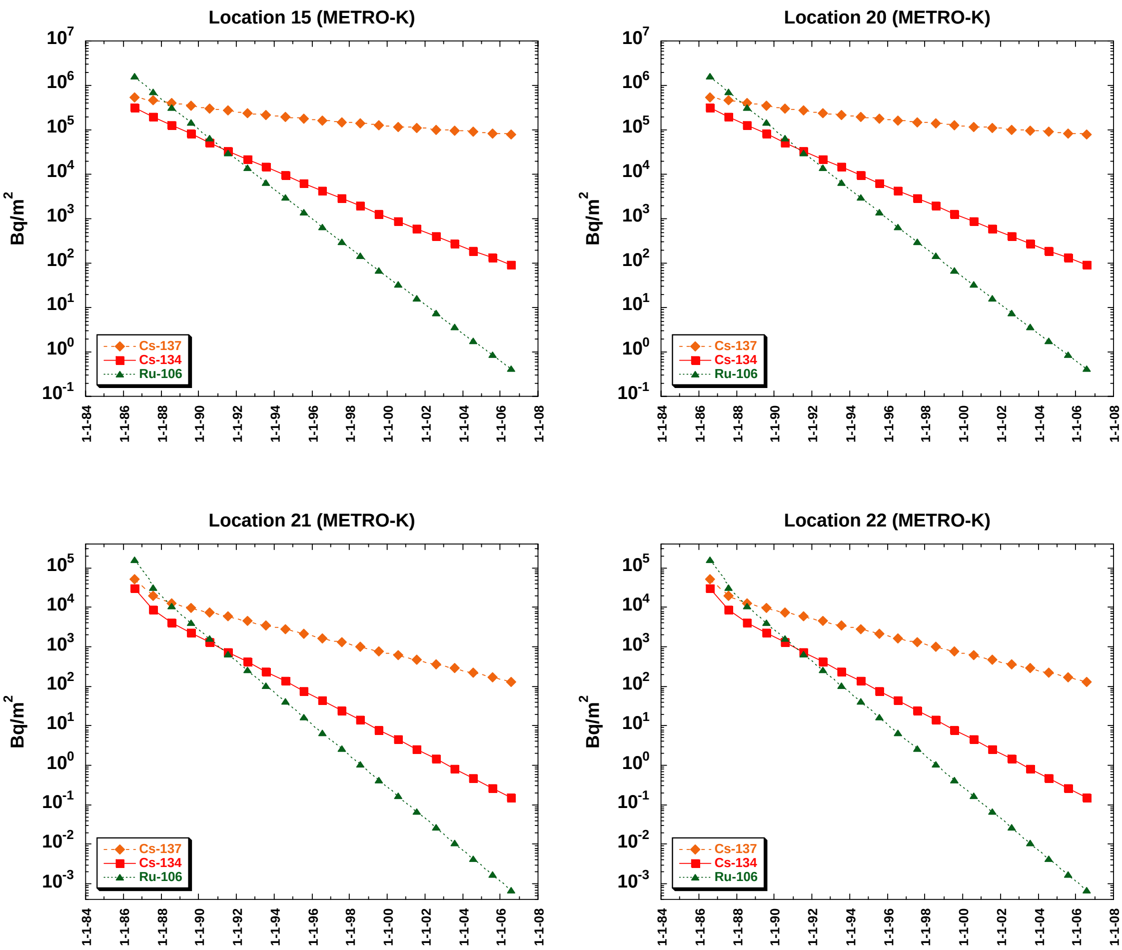


Fig. IV.35. Predicted contamination densities over time at the four outdoor locations in District 4. Predictions from METRO-K. (Scales are comparable for Locations 15 and 20 and for Locations 21 and 22.)

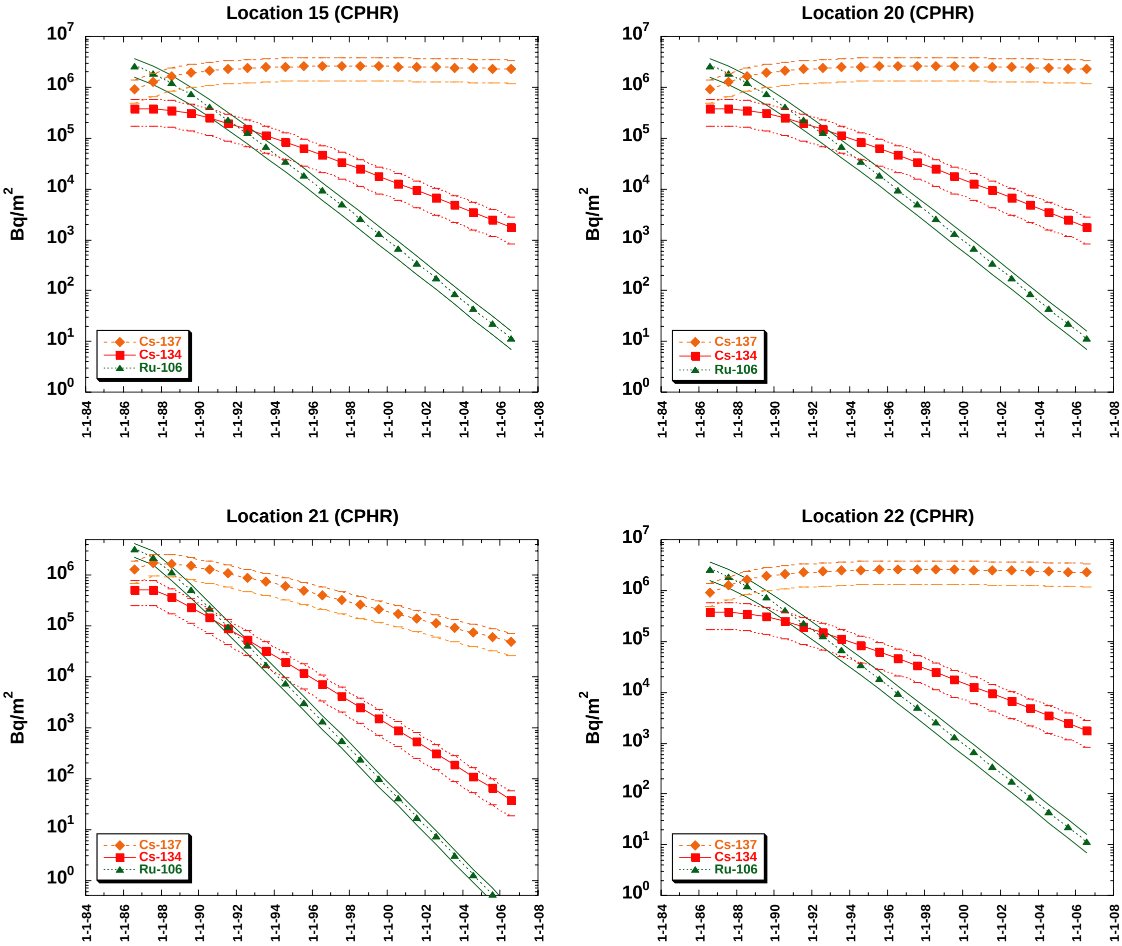


Fig. IV.36. Predicted contamination densities over time at the four outdoor locations in District 4. Predictions from CPHR.

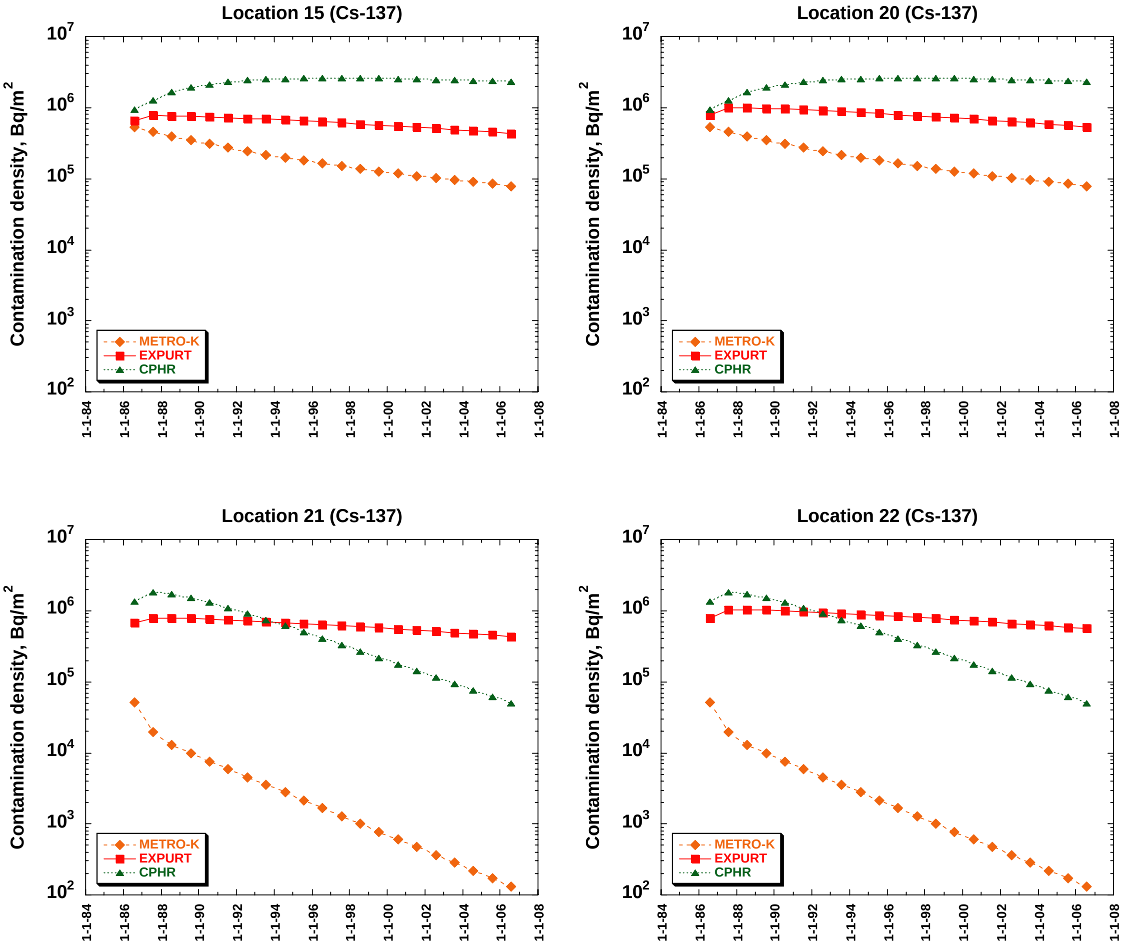


Fig. IV.37. Predicted ^{137}Cs contamination densities over time at the four outdoor locations in District 4.

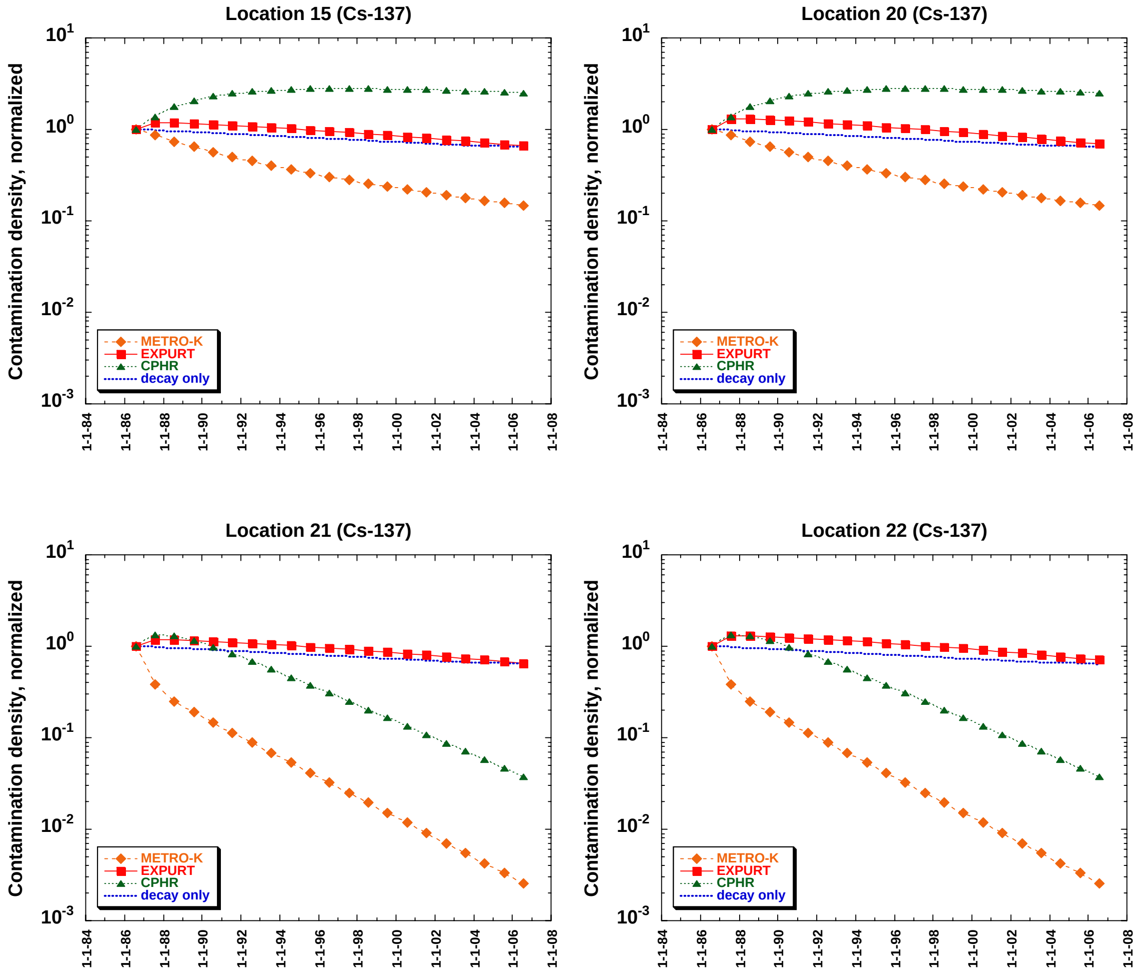


Fig. IV.38. Predicted ^{137}Cs contamination densities over time at the four outdoor locations in District 4, normalized to the predicted value for 1 August 1986. The change in contamination density over time due solely to radioactive decay is also shown.

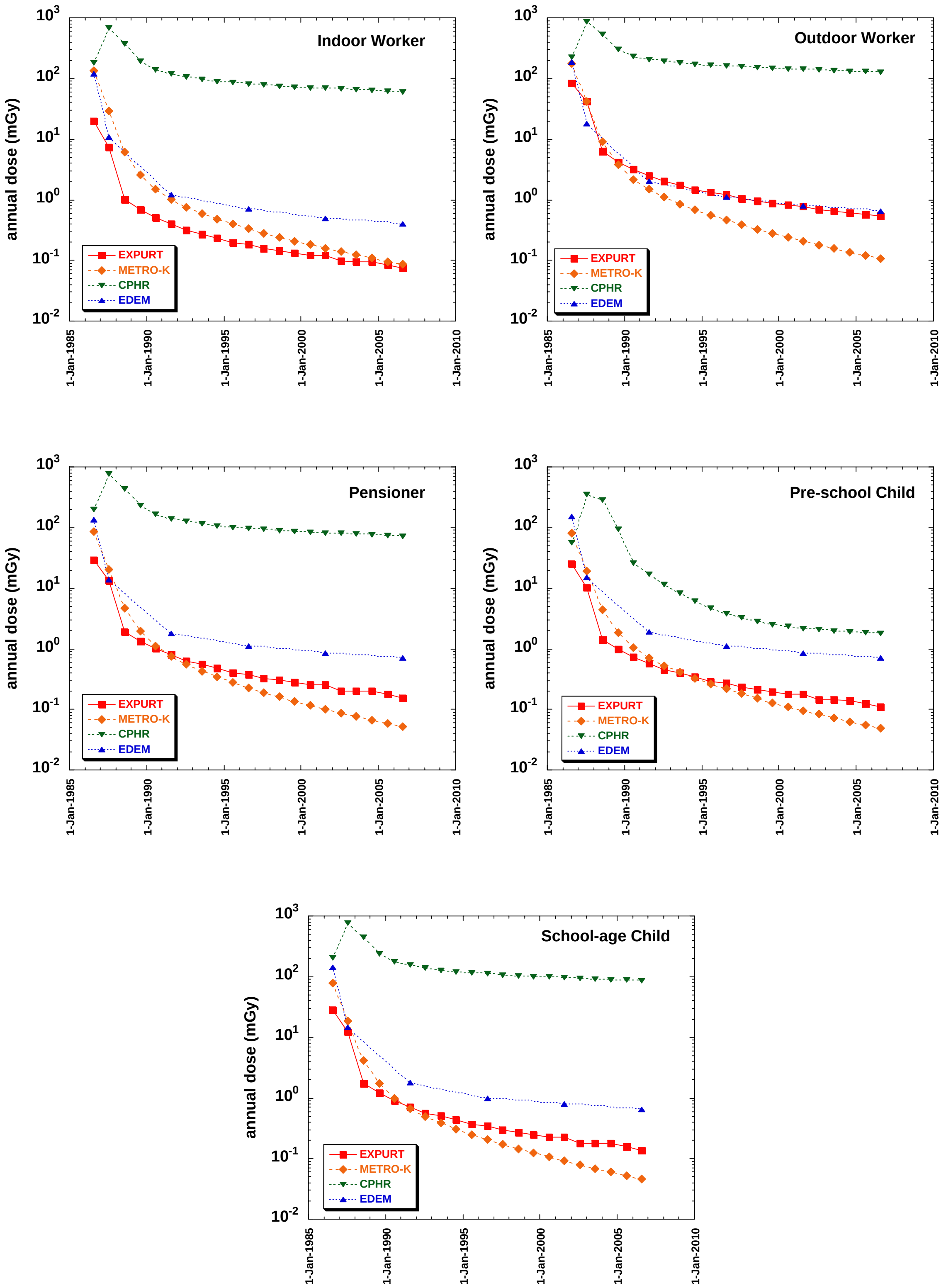


Fig. IV.39. Predicted annual doses to specified reference individuals, assuming no countermeasures.

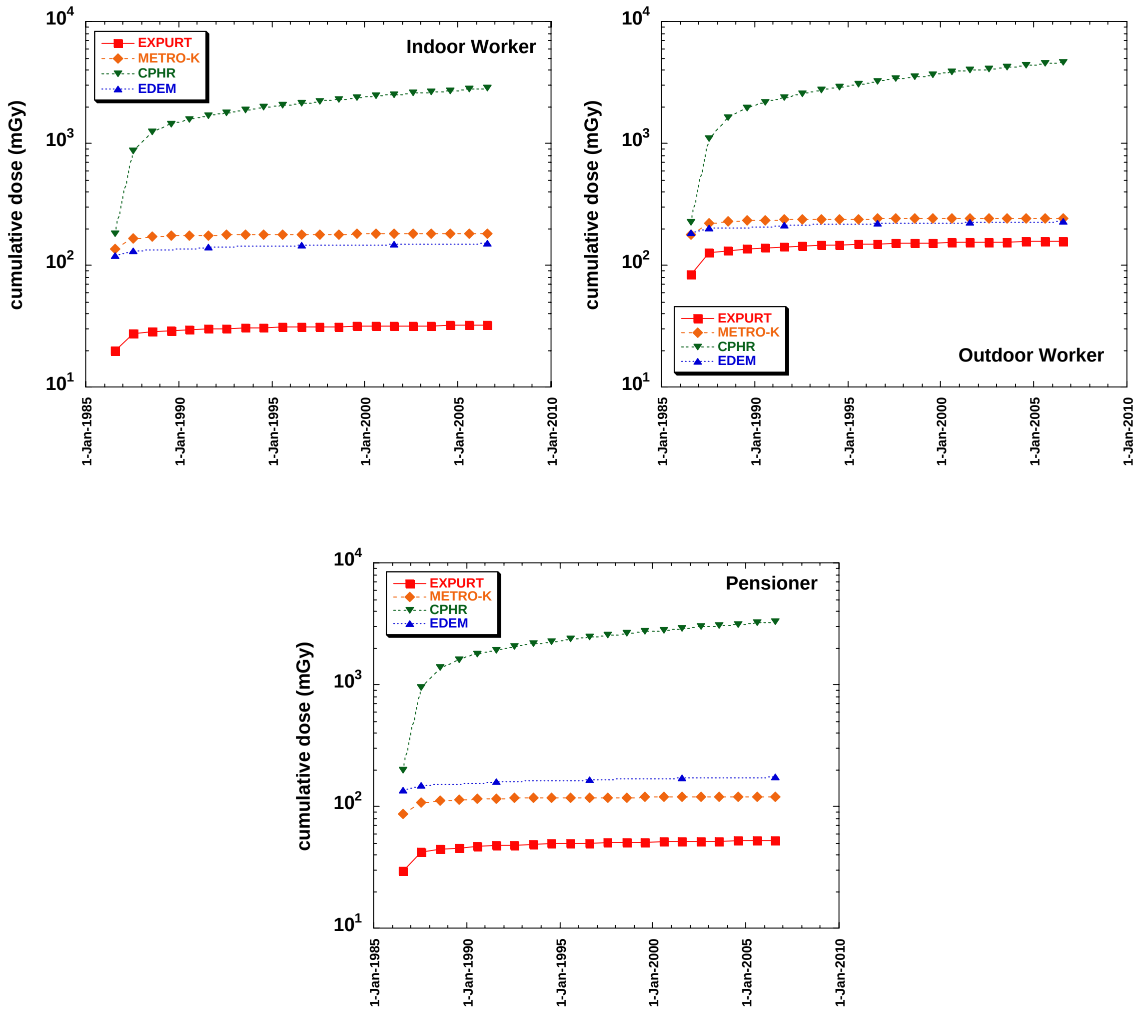


Fig. IV.40. Predicted cumulative doses to specified reference individuals, assuming no countermeasures.

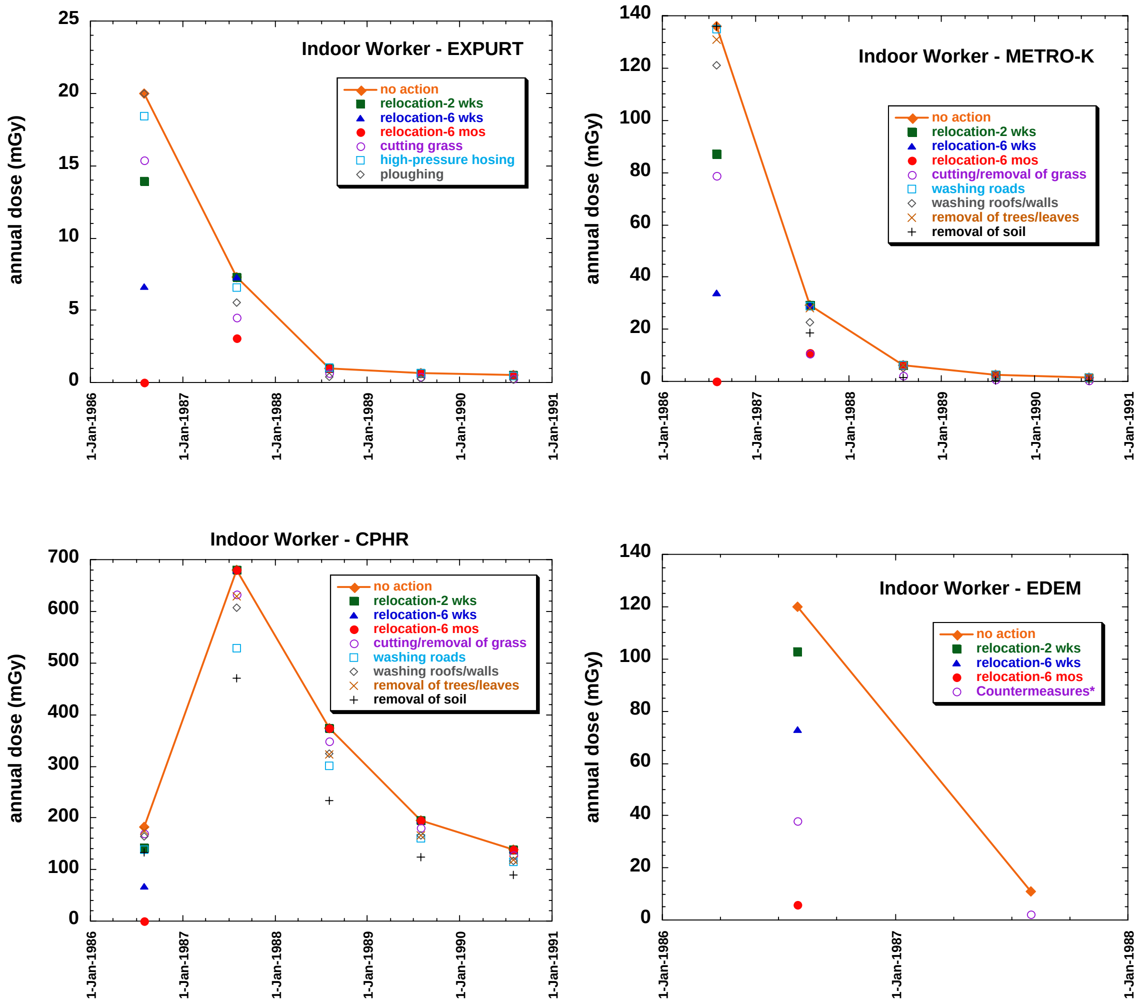


Fig. IV.41. Predicted annual doses (mGy) to a reference indoor worker for the first 5 years (2 years for EDEM), showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

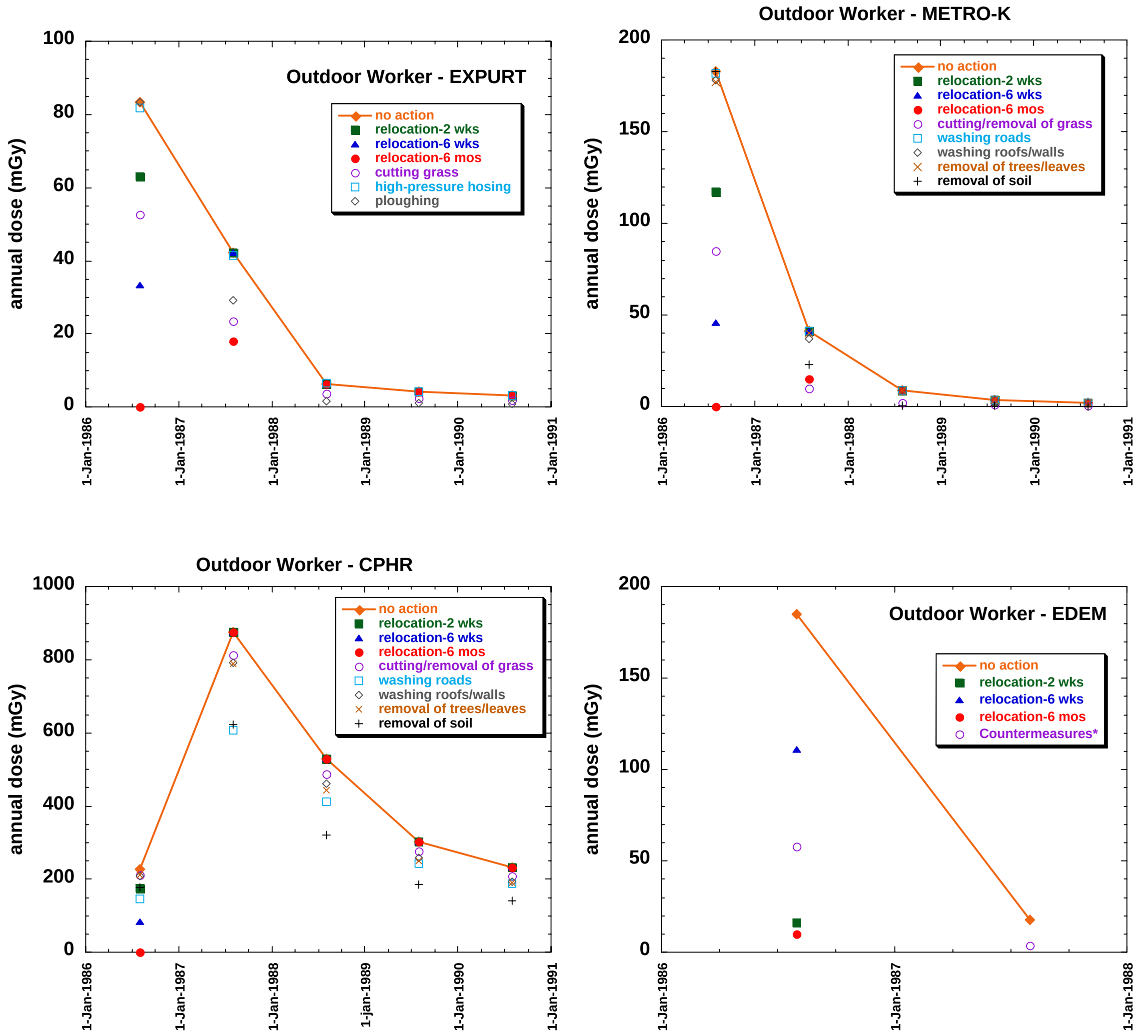


Fig. IV.42. Predicted annual doses (mGy) to a reference outdoor worker for the first 5 years (2 years for EDEM), showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

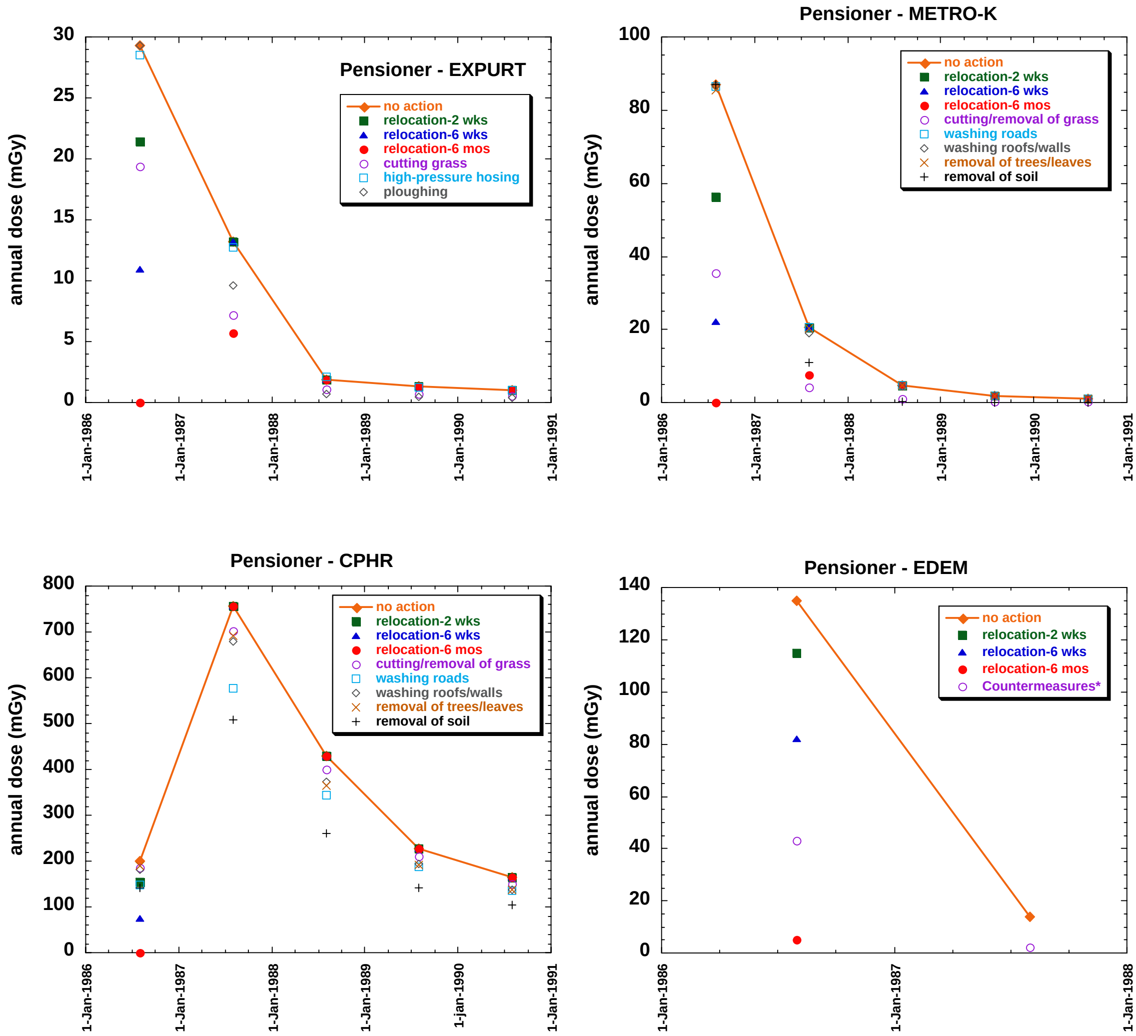


Fig. IV.43. Predicted annual doses (mGy) to a reference pensioner for the first 5 years (2 years for EDEM), showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

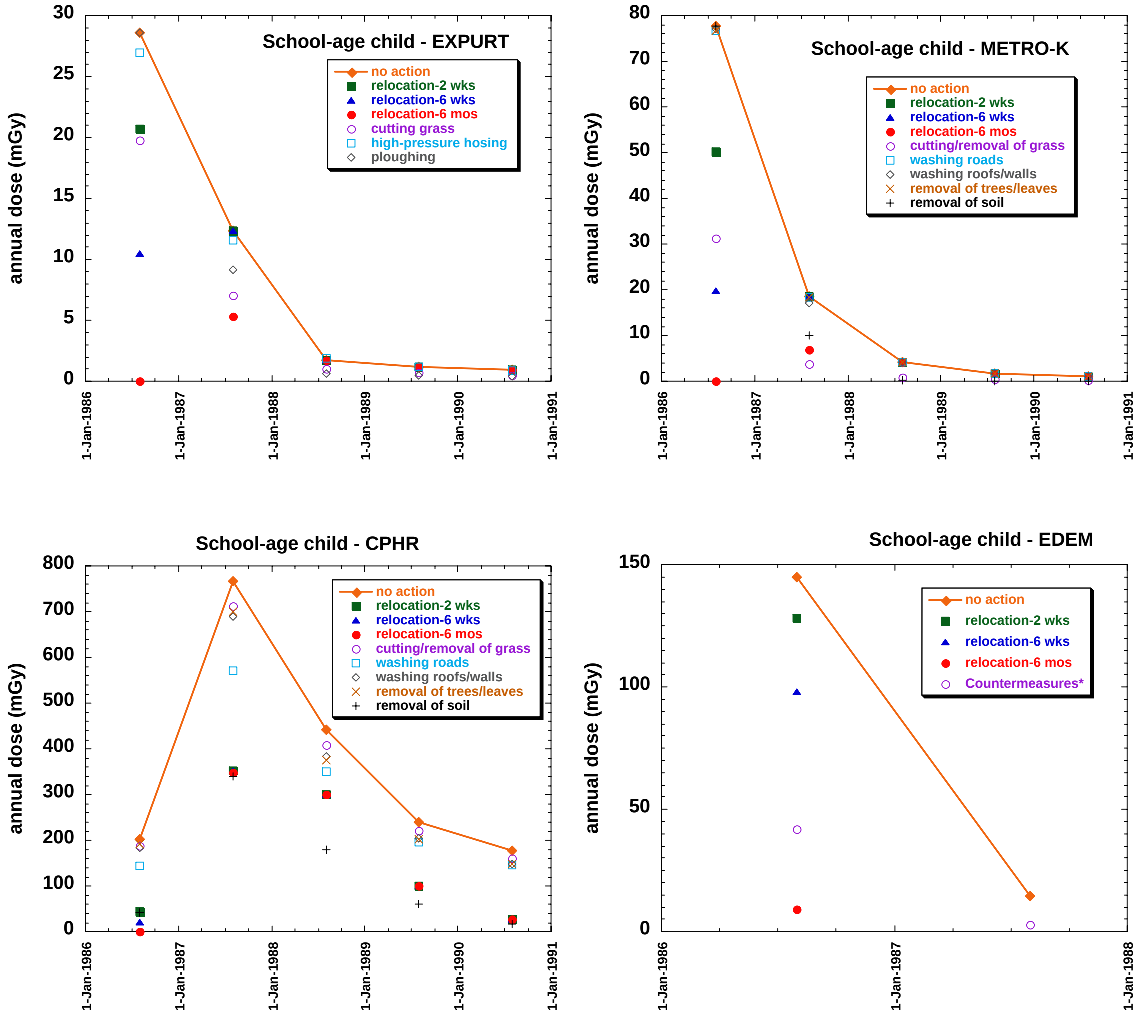


Fig. IV.44. Predicted annual doses (mGy) to a reference school-age child for the first 5 years (2 years for EDEM), showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

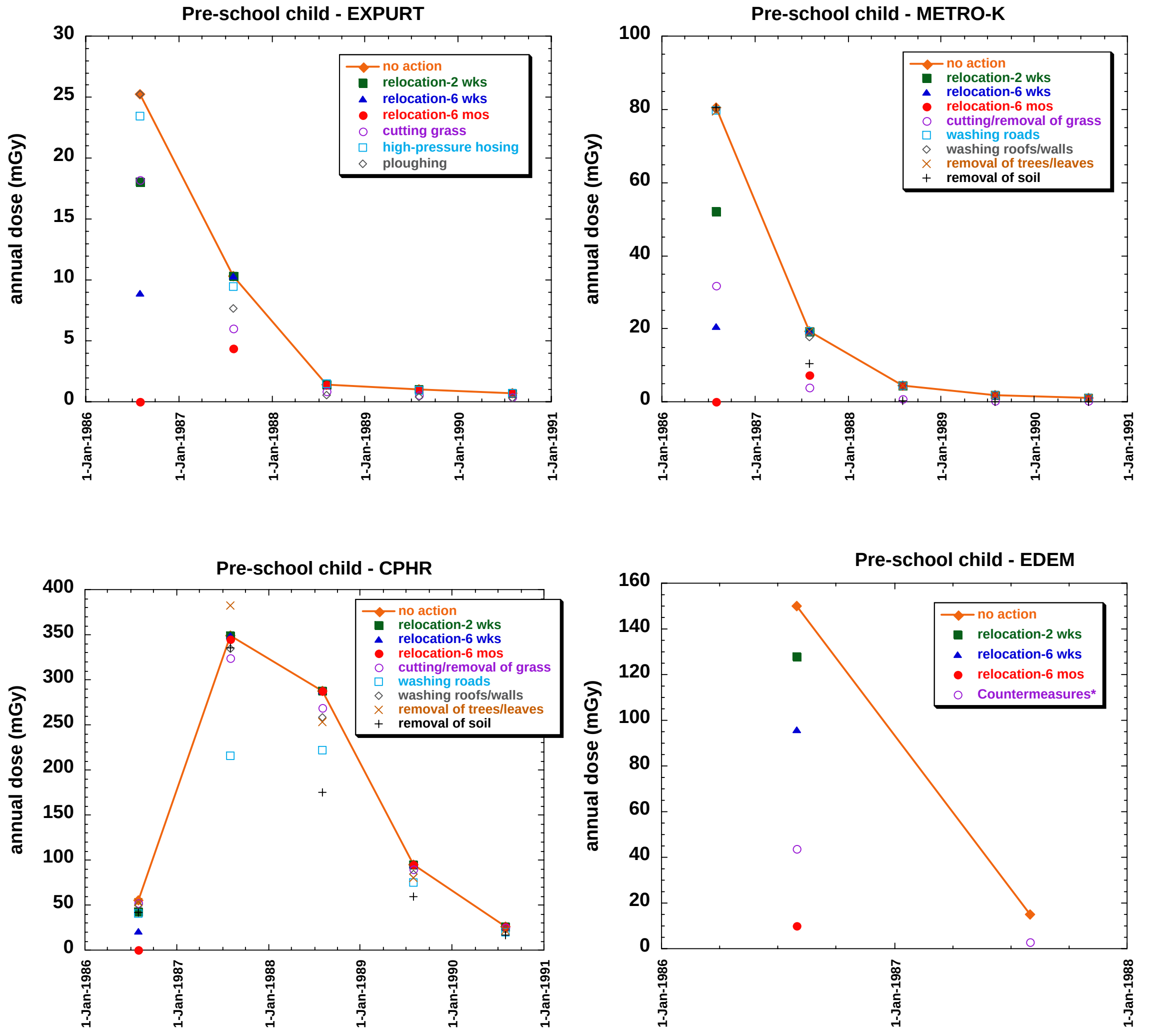


Fig. IV.45. Predicted annual doses (mGy) to a reference preschool-age child for the first 5 years (2 years for EDEM), showing the predicted effects on the annual dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

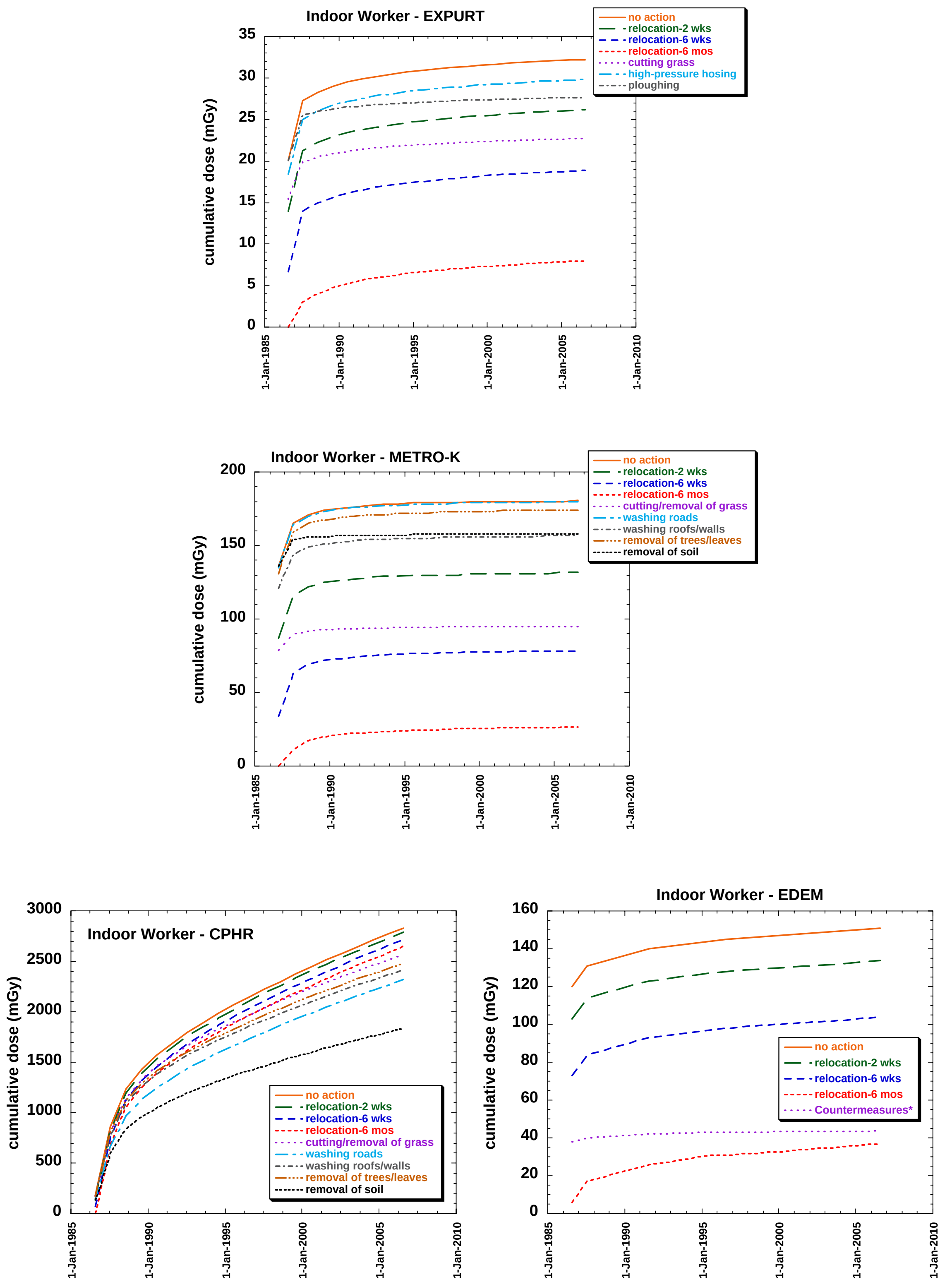


Fig. IV.46. Predicted cumulative doses (mGy) to a reference indoor worker, showing the predicted effects on the cumulative dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

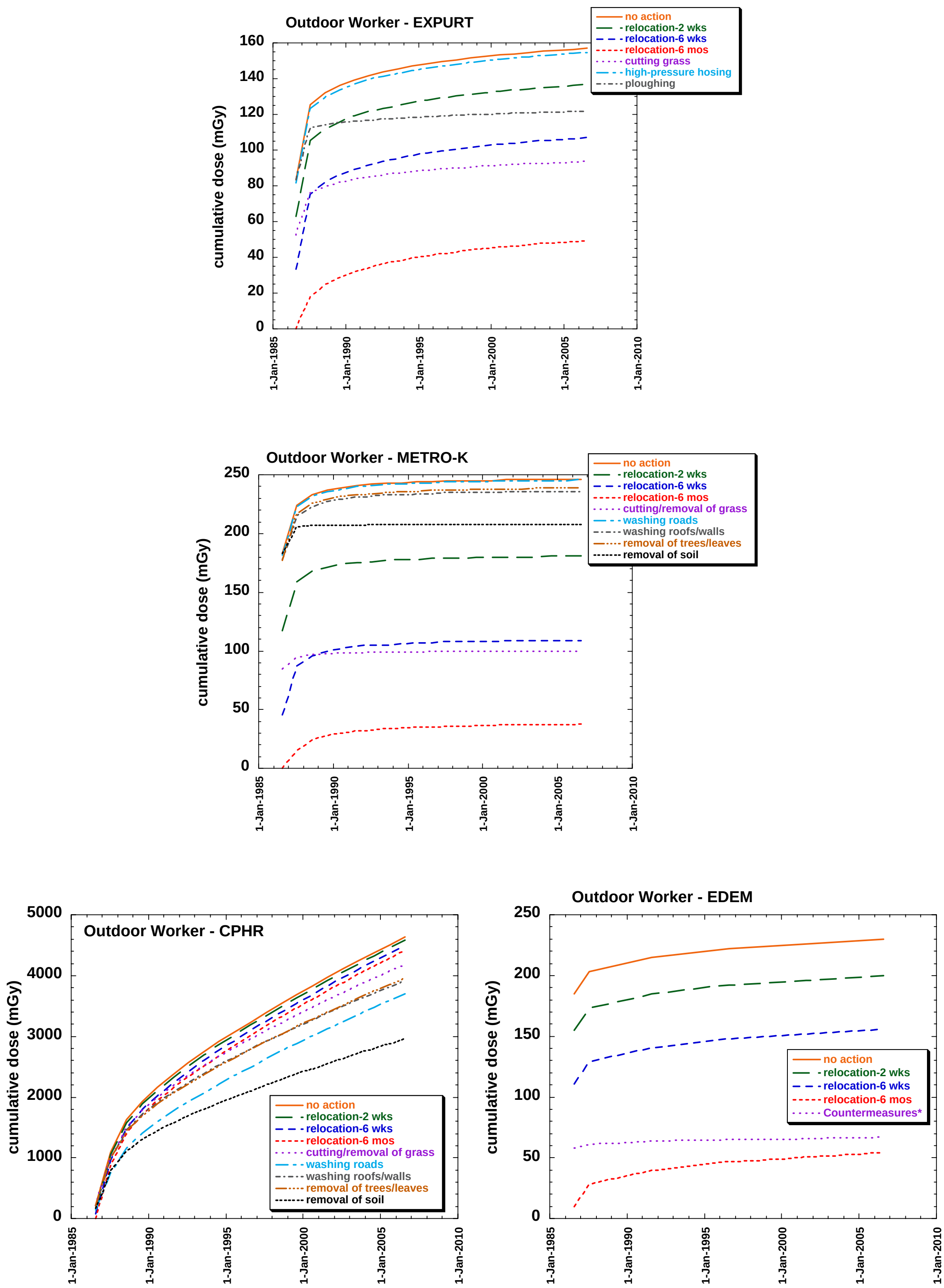


Fig. IV.47. Predicted cumulative doses (mGy) to a reference outdoor worker, showing the predicted effects on the cumulative dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

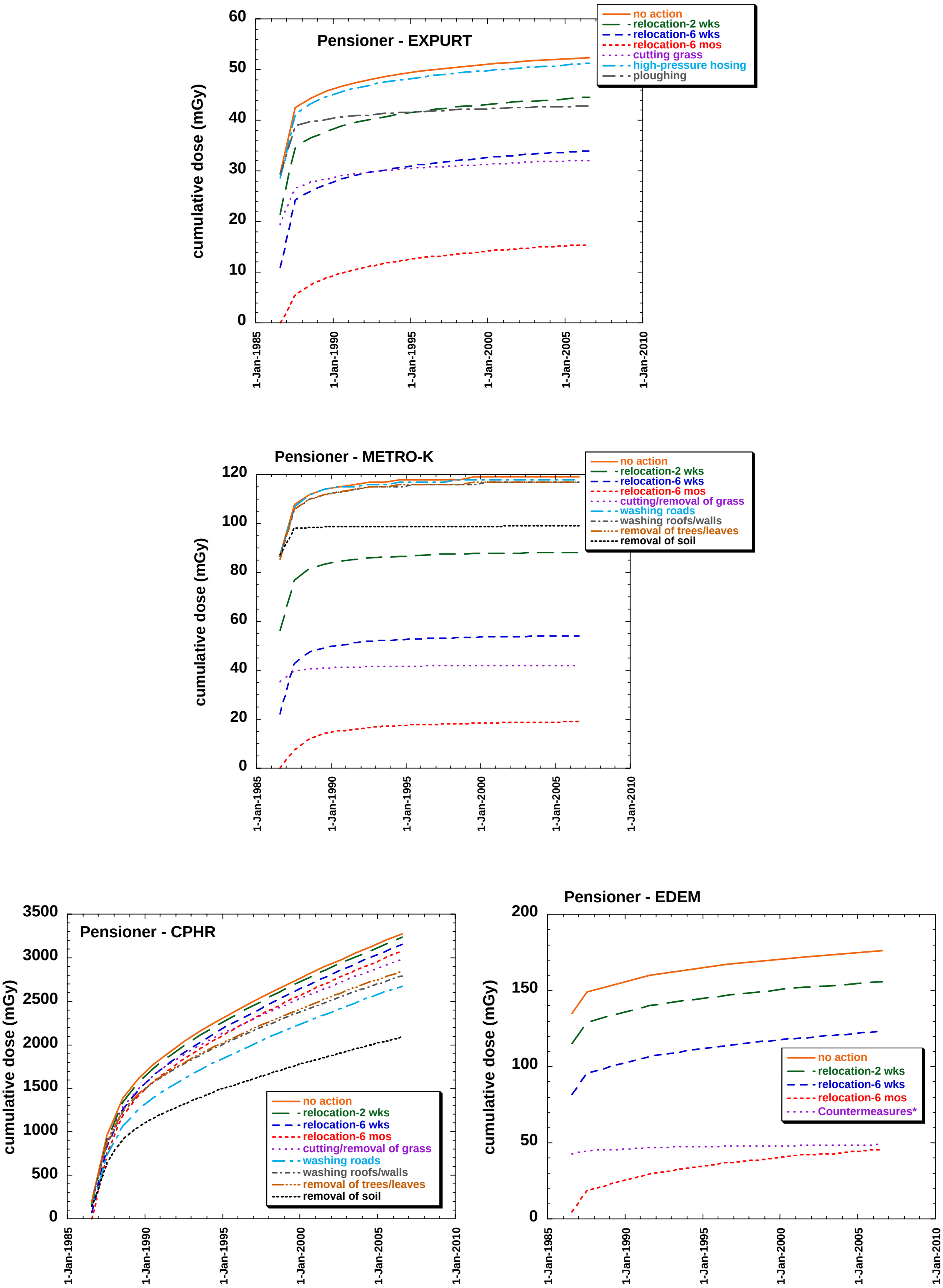


Fig. IV.48. Predicted cumulative doses (mGy) to a reference pensioner, showing the predicted effects on the cumulative dose of several different countermeasures. "Countermeasures" for EDEM includes removal of grass, trees, and soil plus washing of roads, roofs, and walls. (Vertical scales are linear and are not necessarily comparable.)

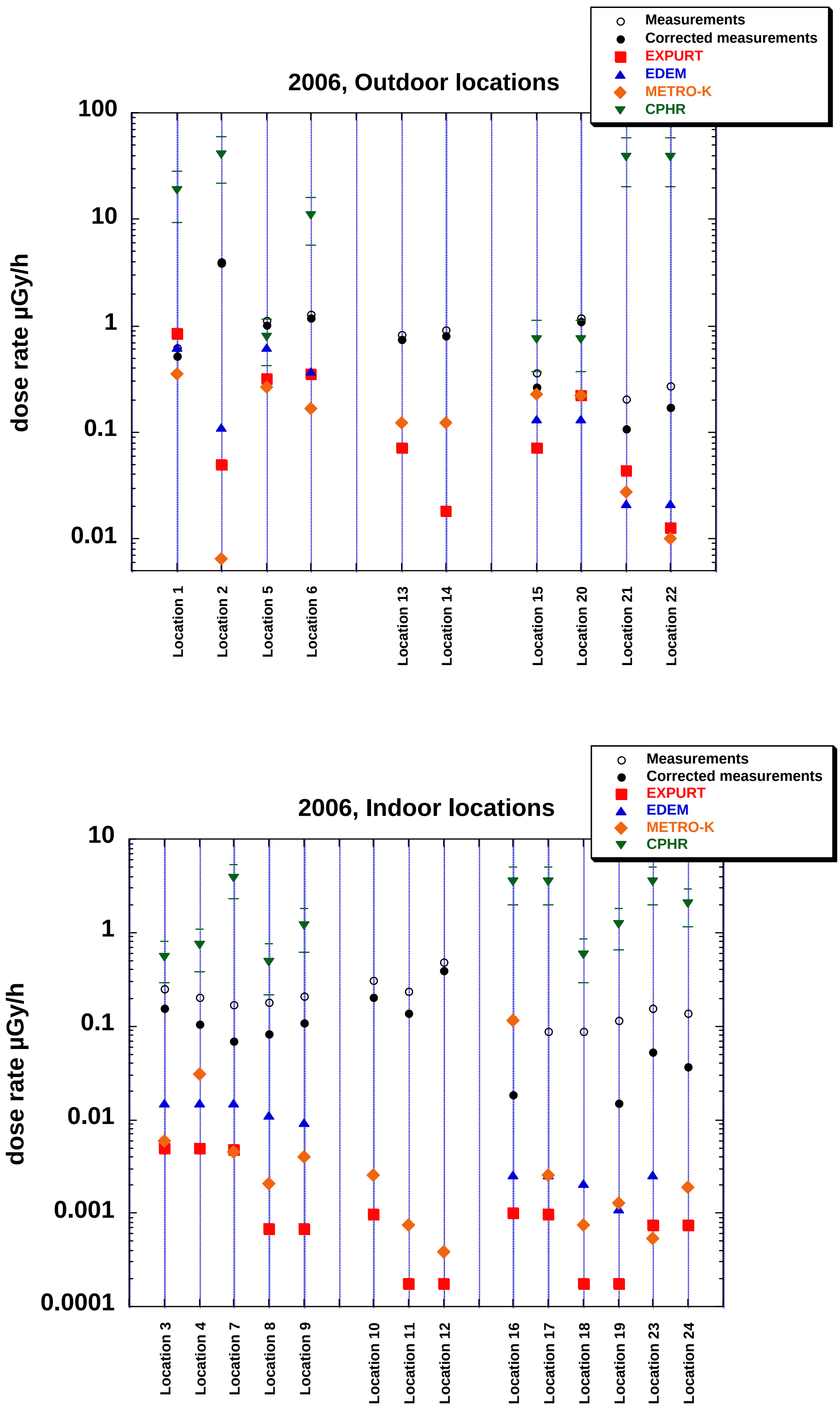


Fig. IV.49. Predicted and measured dose rates at outdoor (top) and indoor (bottom) locations in Districts 1 and 4 of Pripyat, for 1 August 2006. Locations 1–9 are in District 1. Locations 10–14 are in the unremediated part of District 4. Locations 15–24 are in the remediated part of District 4.

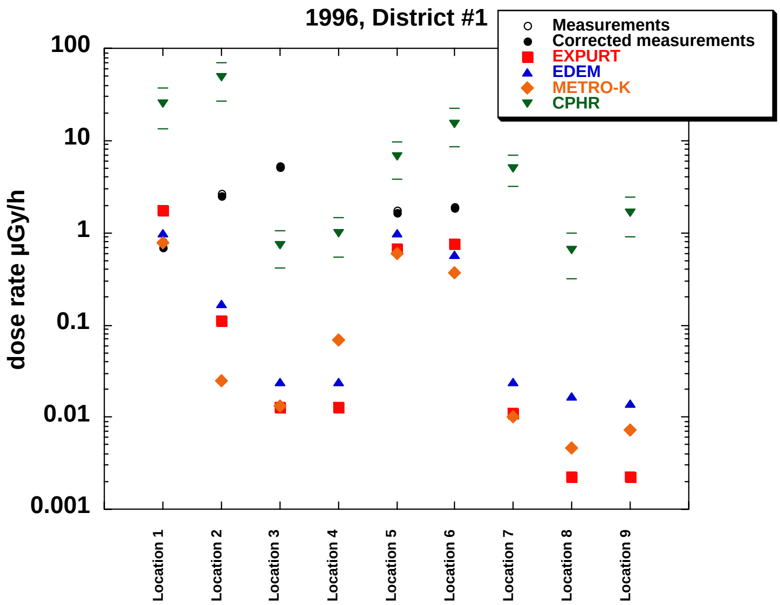


Fig. IV.50. Comparison of model predictions and test data (measurements) by location for District 1 of Pripyat for 1 August 1996. Locations 1, 2, 5, and 6 are outdoors; the rest are indoors.

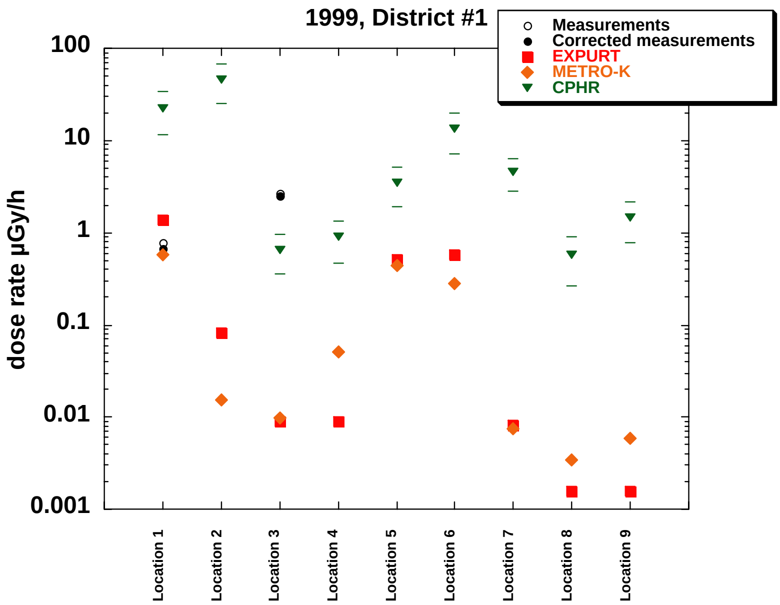


Fig. IV.51. Comparison of model predictions and test data (measurements) by location for District 1 of Pripyat for 1 August 1999. Locations 1, 2, 5, and 6 are outdoors; the rest are indoors.

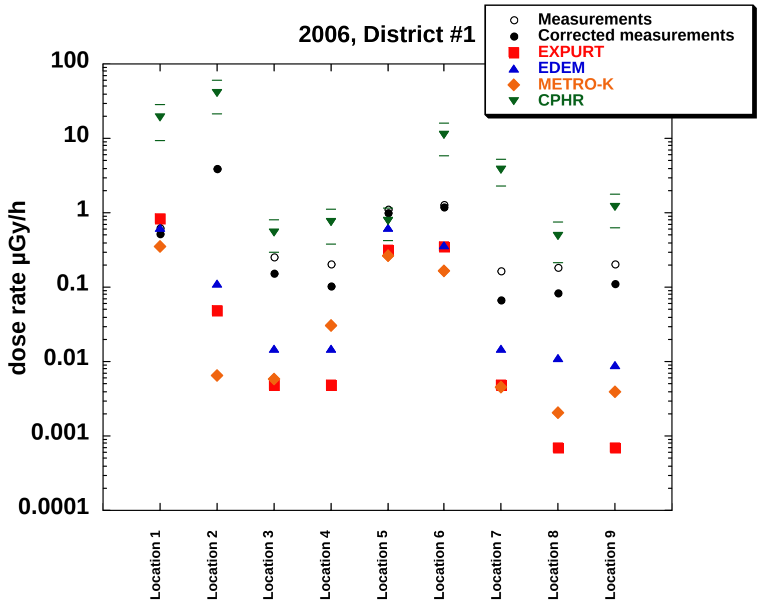


Fig. IV.52. Comparison of model predictions and test data (measurements) by location for District 1 of Pripyat for 1 August 2006. Locations 1, 2, 5, and 6 are outdoors; the rest are indoors.

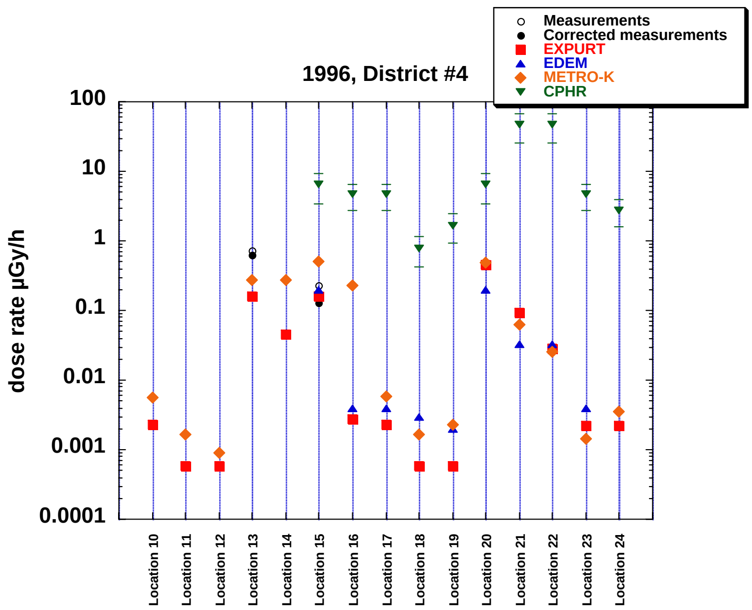


Fig. IV.53. Comparison of model predictions and test data (measurements) by location for District 4 of Pripyat for 1 August 1996. Locations 13, 14, 15, 20, 21, and 22 are outdoors; the rest are indoors.

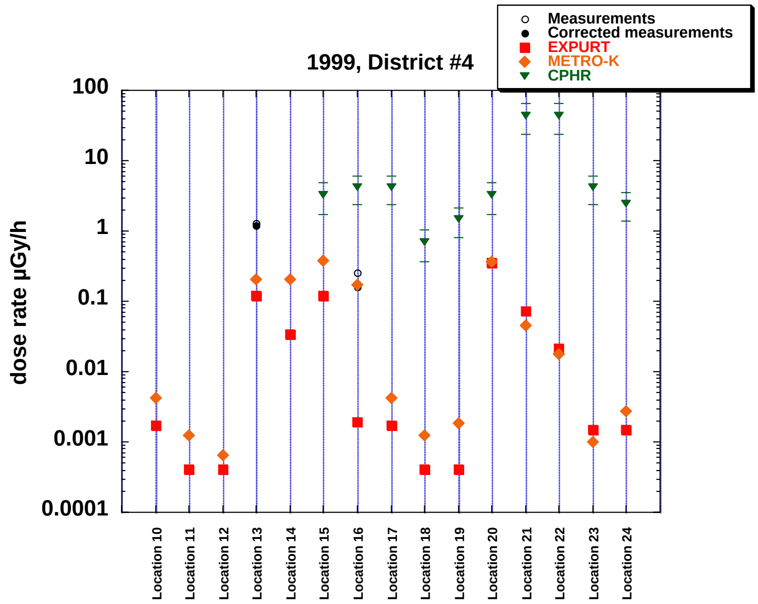


Fig. IV.54. Comparison of model predictions and test data (measurements) by location for District 4 of Pripyat for 1 August 1999. Locations 13, 14, 15, 20, 21, and 22 are outdoors; the rest are indoors.

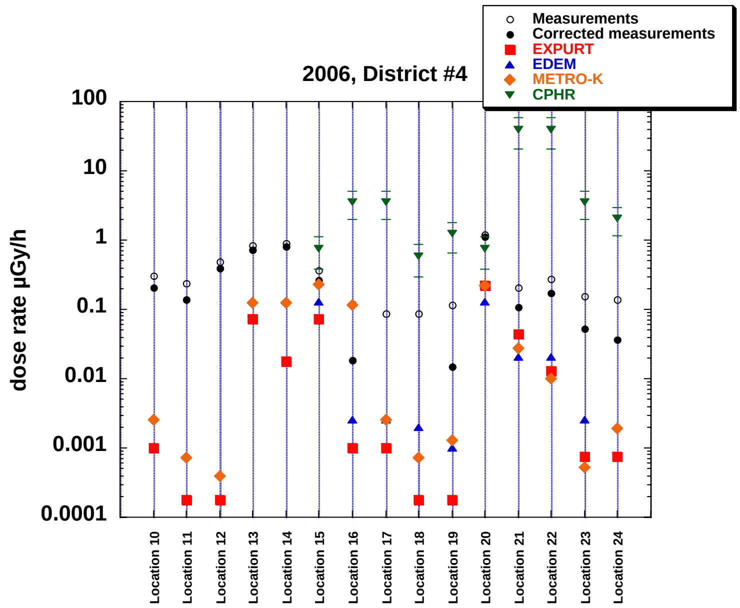


Fig. IV.55. Comparison of model predictions and test data (measurements) by location for District 4 of Pripyat for 1 August 2006. Locations 13, 14, 15, 20, 21, and 22 are outdoors; the rest are indoors.

IV.2. Model predictions for the Hypothetical scenario

Appendix IV.2 provides graphical comparisons of model predictions from three models for the various endpoints in the hypothetical scenario. Figures IV.56 to IV.58 show predicted contamination densities at outdoor locations. Figures IV.59 to IV.60 show the predicted effects of various countermeasures on contamination densities (CPHR and RESRAD-RDD only; countermeasures such as relocation that have no effect on contamination density are not shown). Figures IV.61 to IV.66 show predicted dose rates at specified indoor and outdoor locations. Figures IV.67 to IV.69 show predicted contributions to dose rates from various surfaces. Figures IV.70 to IV.76 show predicted annual and cumulative doses for defined exposures (occupational, residential, school, occasional) at specified locations, assuming no countermeasures. Figures IV.77 to IV.93 show the predicted effects of various countermeasures on the annual or cumulative doses.

Unless otherwise indicated, the figures show the model predictions submitted by September 2007, including any revisions made since Spring 2007. The nature and scope of the revisions are described in individual summaries for each model in Appendix III. Examples of initial and revised predictions are provided for several endpoints to illustrate some of the more significant revisions.

When several log-scale plots are shown in the same figure, the scales are comparable unless otherwise indicated. In other words, the y-axis represents the same number of orders of magnitude, so that the graphs may be directly compared, although the actual limits may vary from one graph to another. The figures showing the effects of countermeasures on predicted contamination densities or doses (Figures IV.59 to IV.60 and IV.77 to IV.93) use linear scales so as to better show the effect of the countermeasures in terms of reducing the contamination density or dose. When several linear scale plots are shown in the same figure, the scales are usually not comparable.

Model predictions are also available in Excel workbooks, by model (as submitted) and by endpoint (comparisons of results). Available files are listed below:

- Results submitted by April 2007:
  - CPHR (Tomás);
  - METRO-K (Hwang);
  - RESRAD-RDD (Kamboj);
- Results submitted by September 2007 (revised results):
  - CPHR (Tomás);
  - METRO-K (Hwang);
  - RESRAD-RDD (Kamboj);
- Results by endpoint:
  - Contamination densities;
  - Contamination densities and countermeasures;
  - Dose rates;
  - Surfaces (% contributions);
  - Doses and countermeasures.

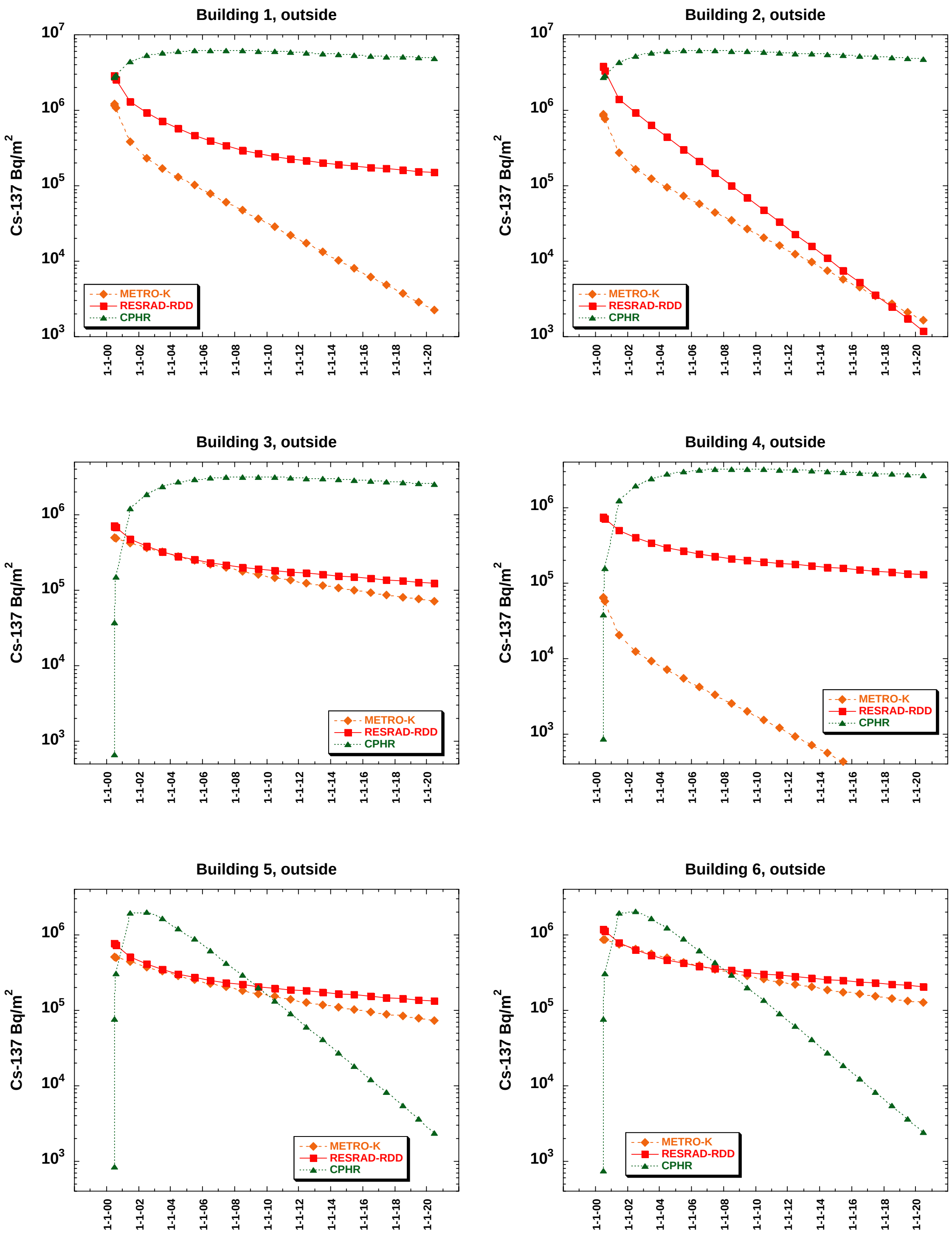


Fig. IV.56. Predicted contamination density (Bq m^{-2}) at outdoor locations.

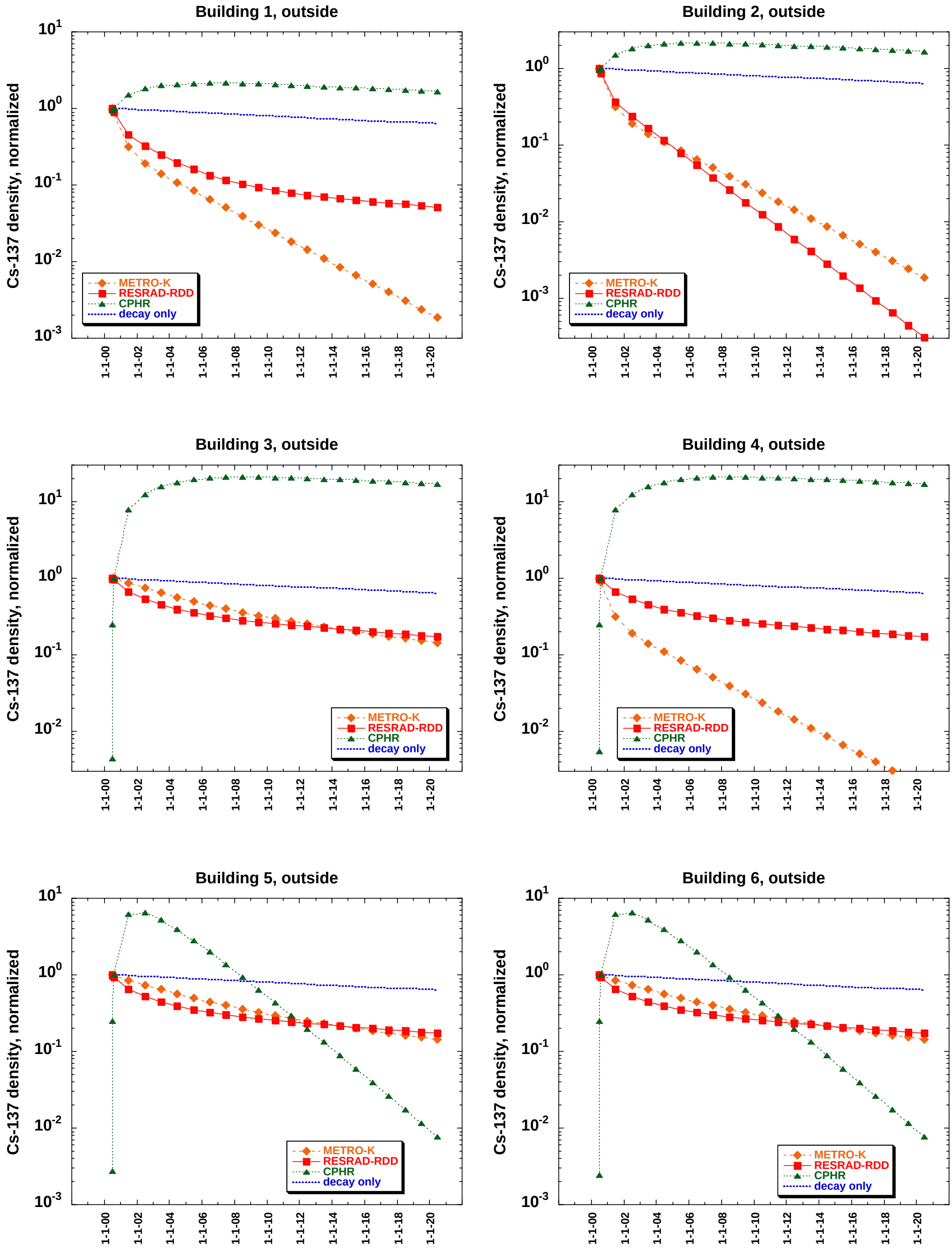


Fig. IV.57. Predicted contamination densities at outdoor locations, normalized for initial value (METRO-K, RESRAD-RDD) or value at one month (CPHR). The expected change in contamination density due only to radioactive decay of ^{137}Cs is also shown.

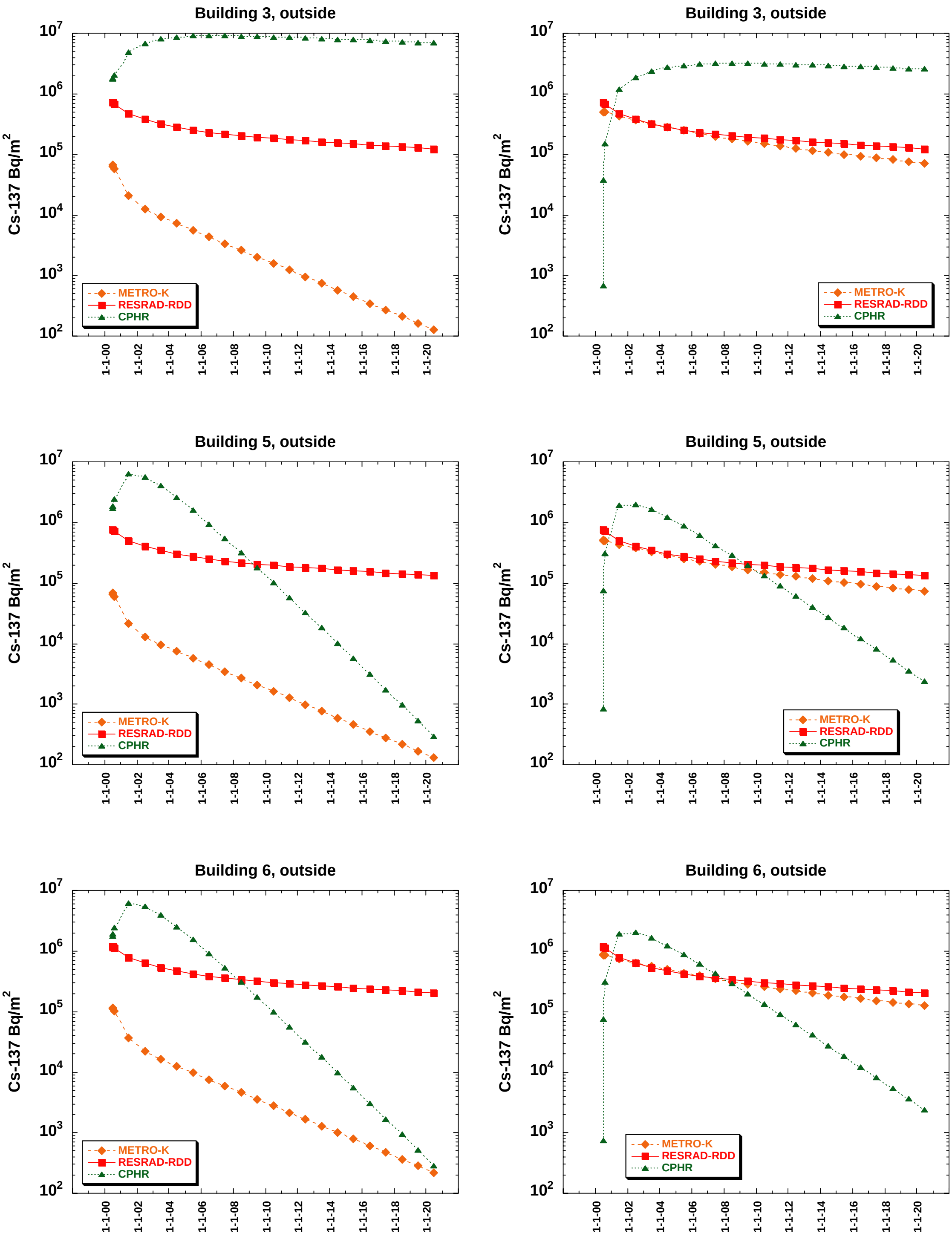


Fig. IV.58. Examples of initial (left) and revised (right) predictions for the contamination density (Bq m^{-2}) at outdoor locations, from METRO-K and CPHR (RESRAD-RDD predictions were not revised).

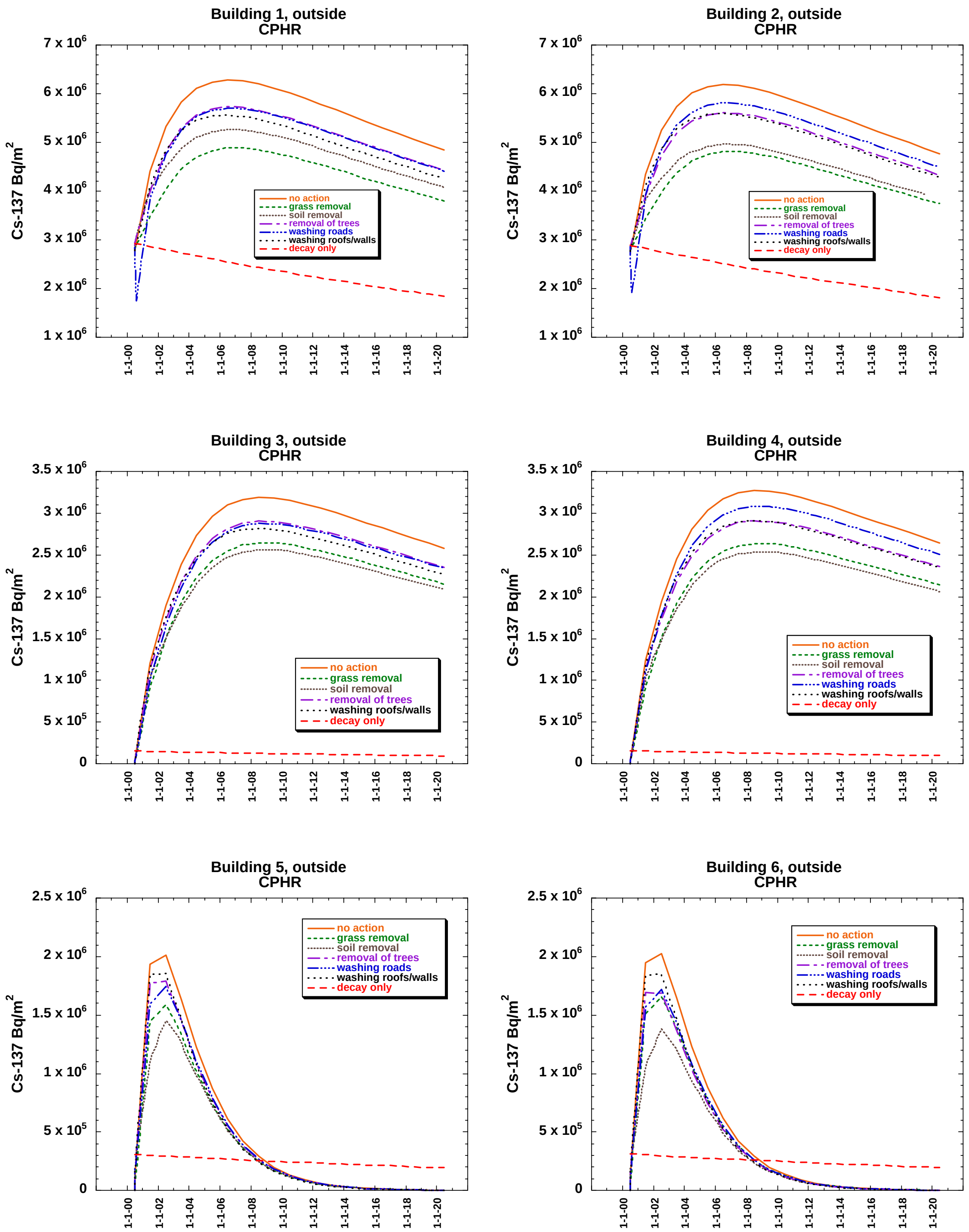


Fig. IV.59. Predicted contamination densities at outdoor locations from CPHR, showing expected effects of countermeasures. The expected change in contamination density due only to radioactive decay of ^{137}Cs is also shown (starting with predicted concentration at 1 month). (Vertical scales are linear and are not necessarily comparable.)

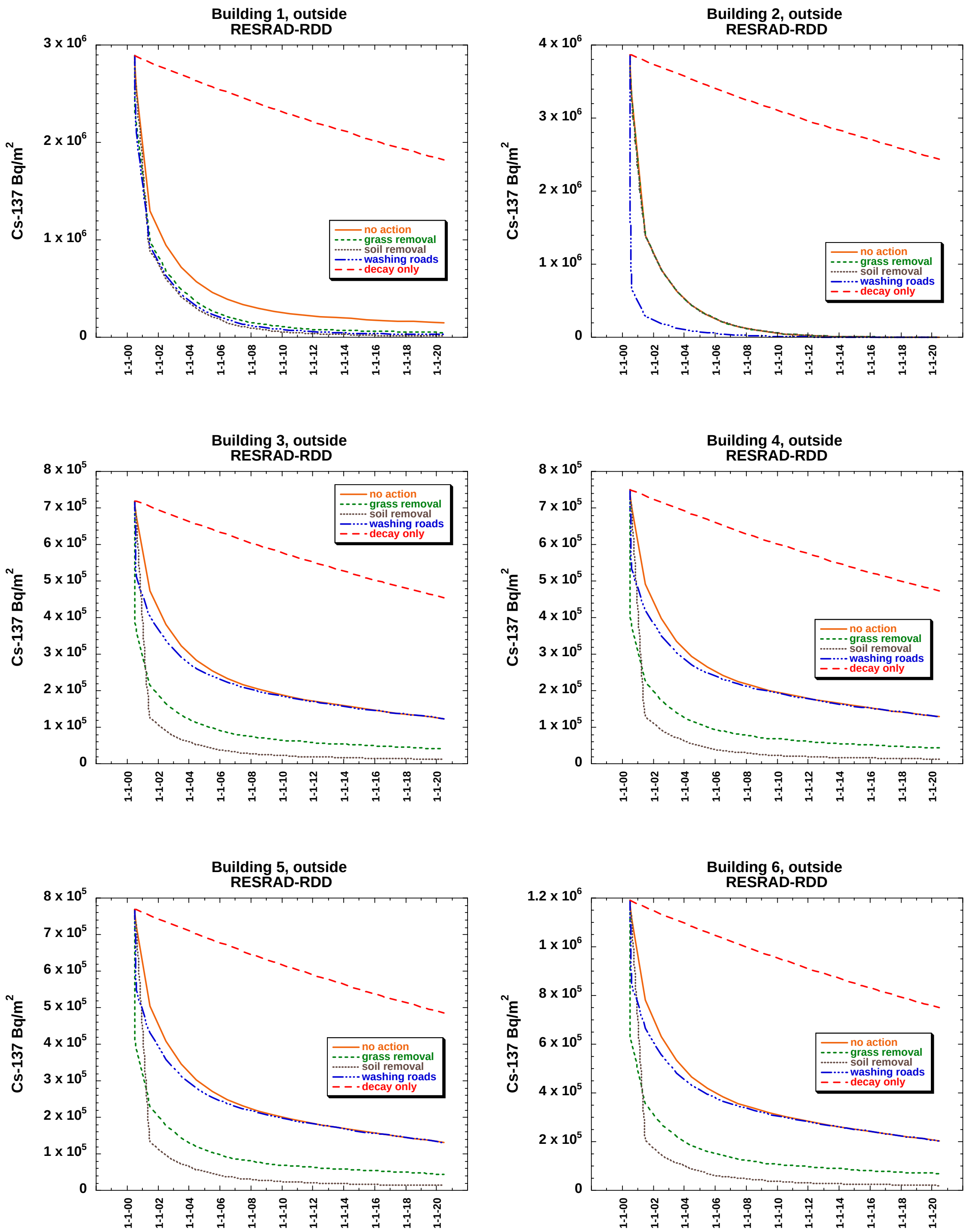


Fig. IV.60. Predicted contamination densities at outdoor locations from RESRAD-RDD, showing expected effects of countermeasures. The expected change in contamination density due only to radioactive decay of ^{137}Cs is also shown. (Vertical scales are linear and are not necessarily comparable.)

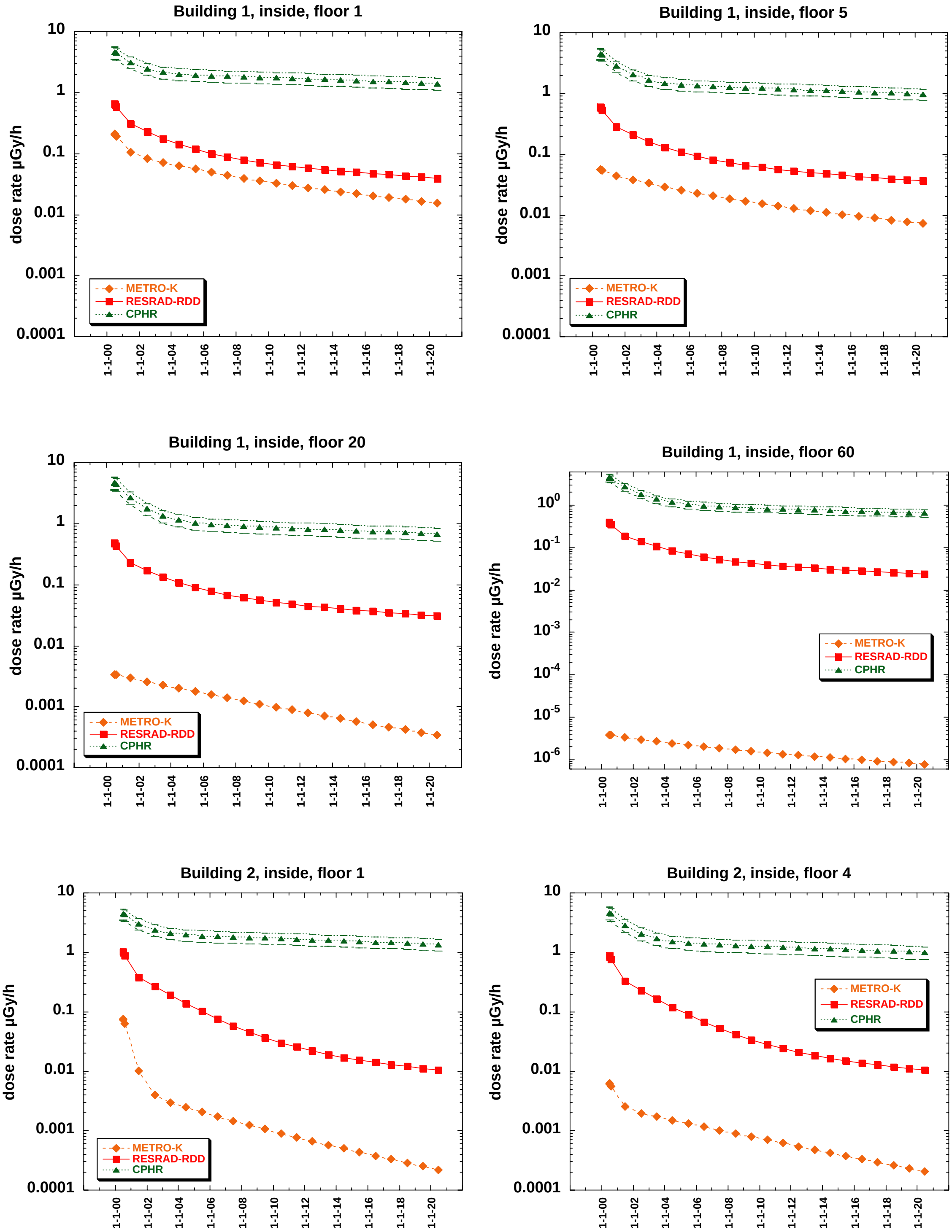


Fig. IV.61. Predicted dose rates (µGy h^{-1}) at indoor locations and the top of Building 2. (Scales are comparable, except for Building 1, Floor 60).

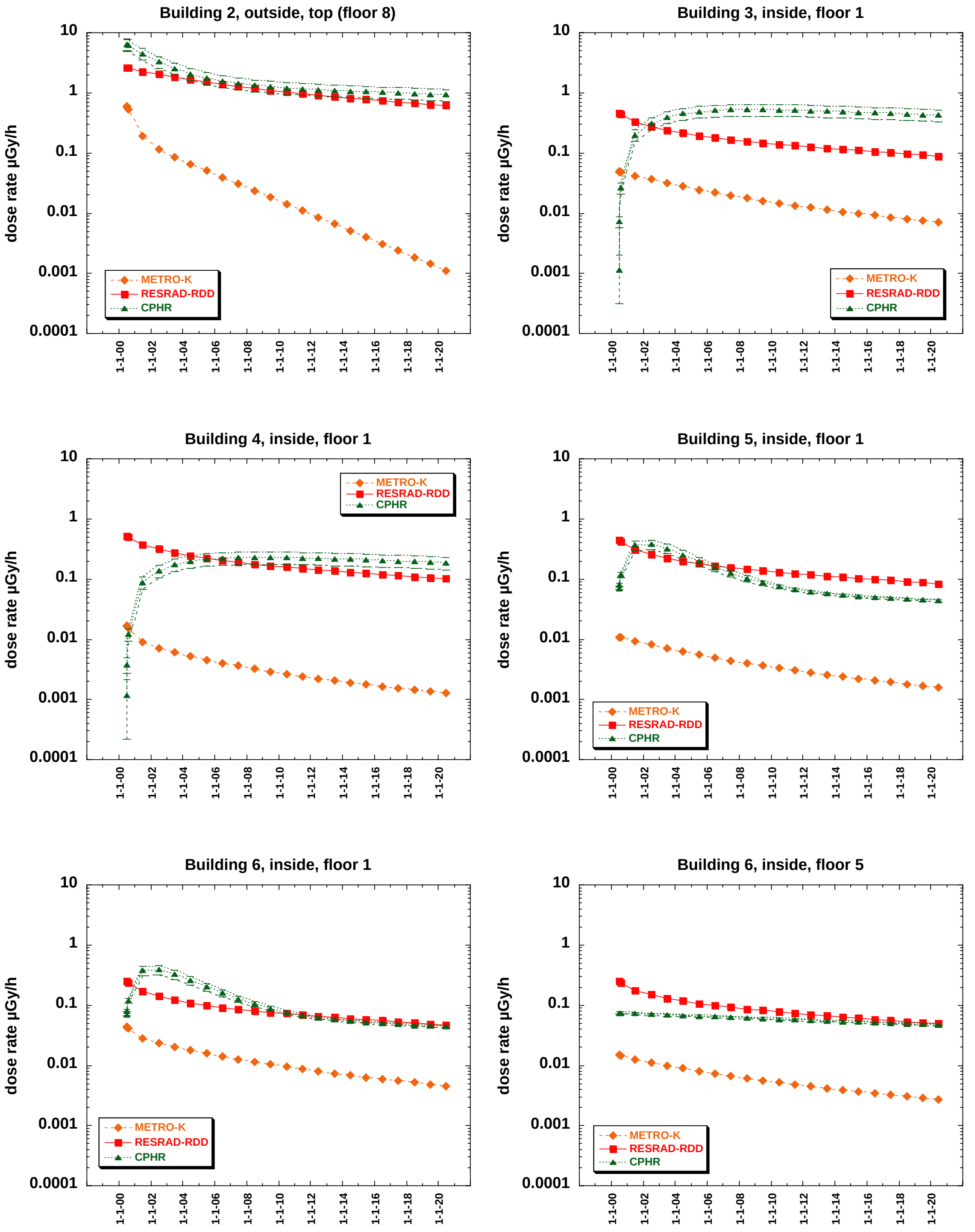


Fig. IV.61. Predicted dose rates (µGy h^{-1}) at indoor locations and the top of Building 2. (Scales are comparable, except for Building 1, Floor 60) (cont.).

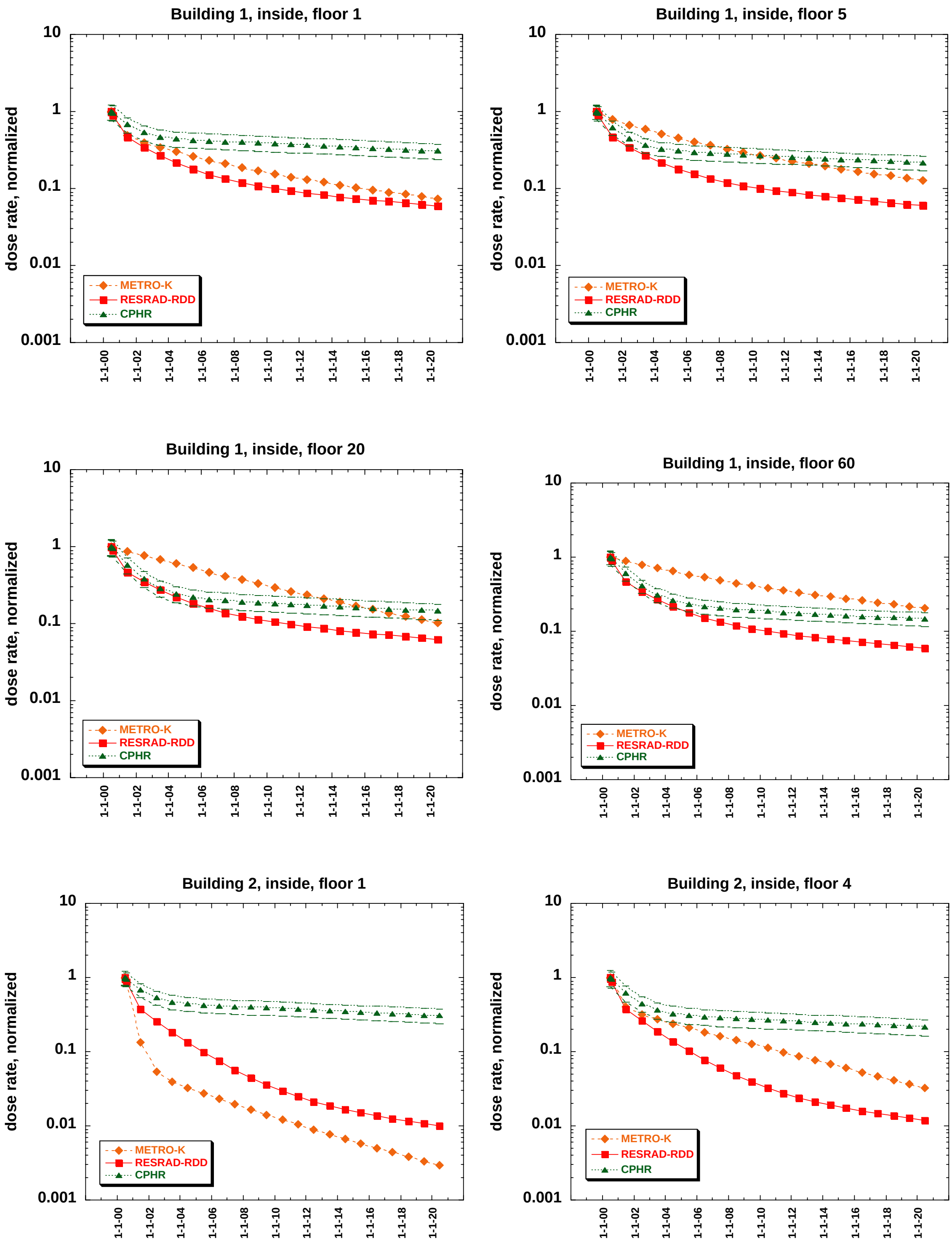


Fig. IV.62. Predicted dose rates (μGy h^{-1}) at indoor locations and the top of Building 2, normalized for initial value (value at 1 month for CPHR, Buildings 3 and 4).

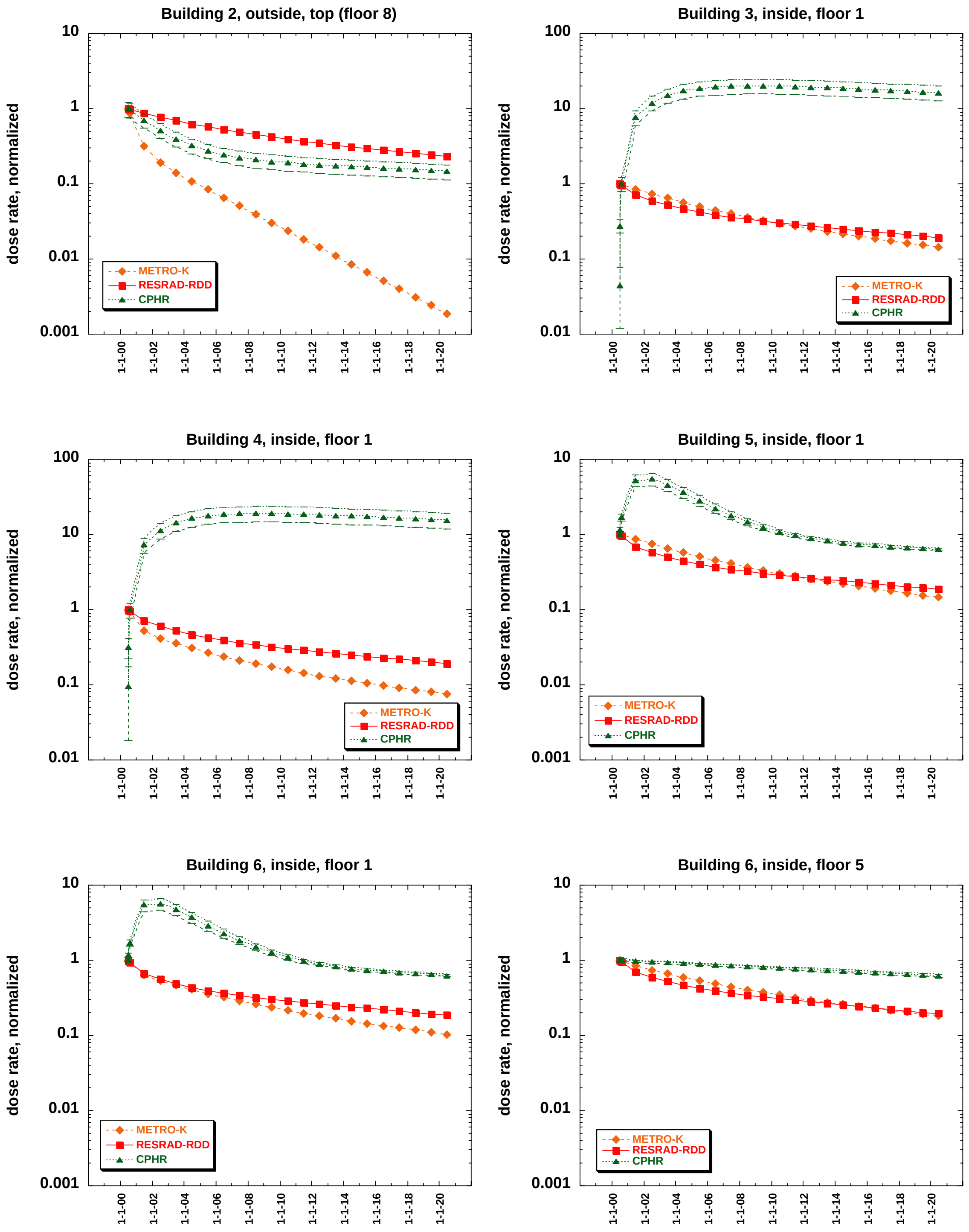


Fig.IV.62. Predicted dose rates (μGy h^{-1}) at indoor locations and the top of Building 2, normalized for initial value (value at 1 month for CPHR, Buildings 3 and 4) (cont.).

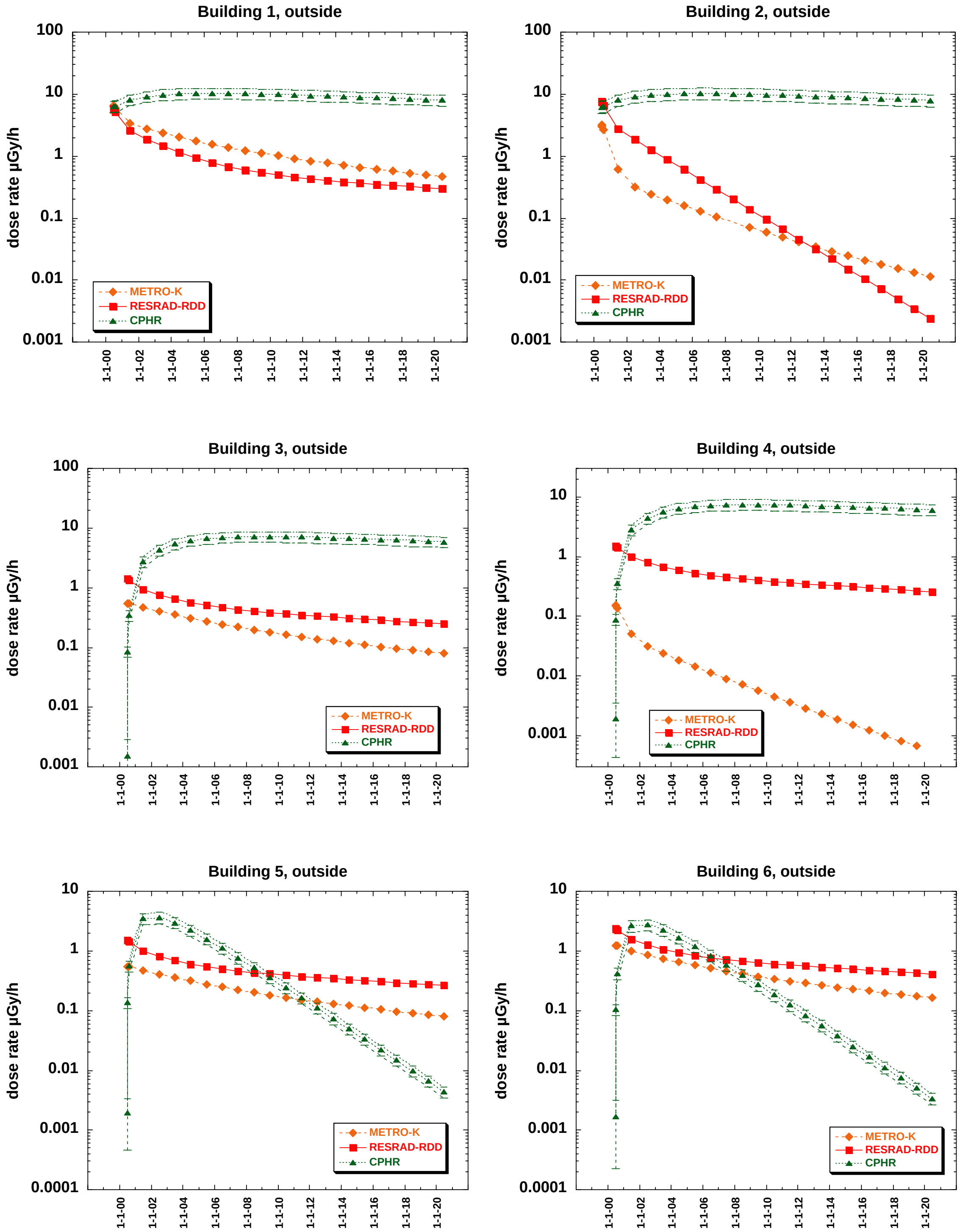


Fig. IV.63. Predicted dose rates (µGy h^{-1}) at outdoor locations.

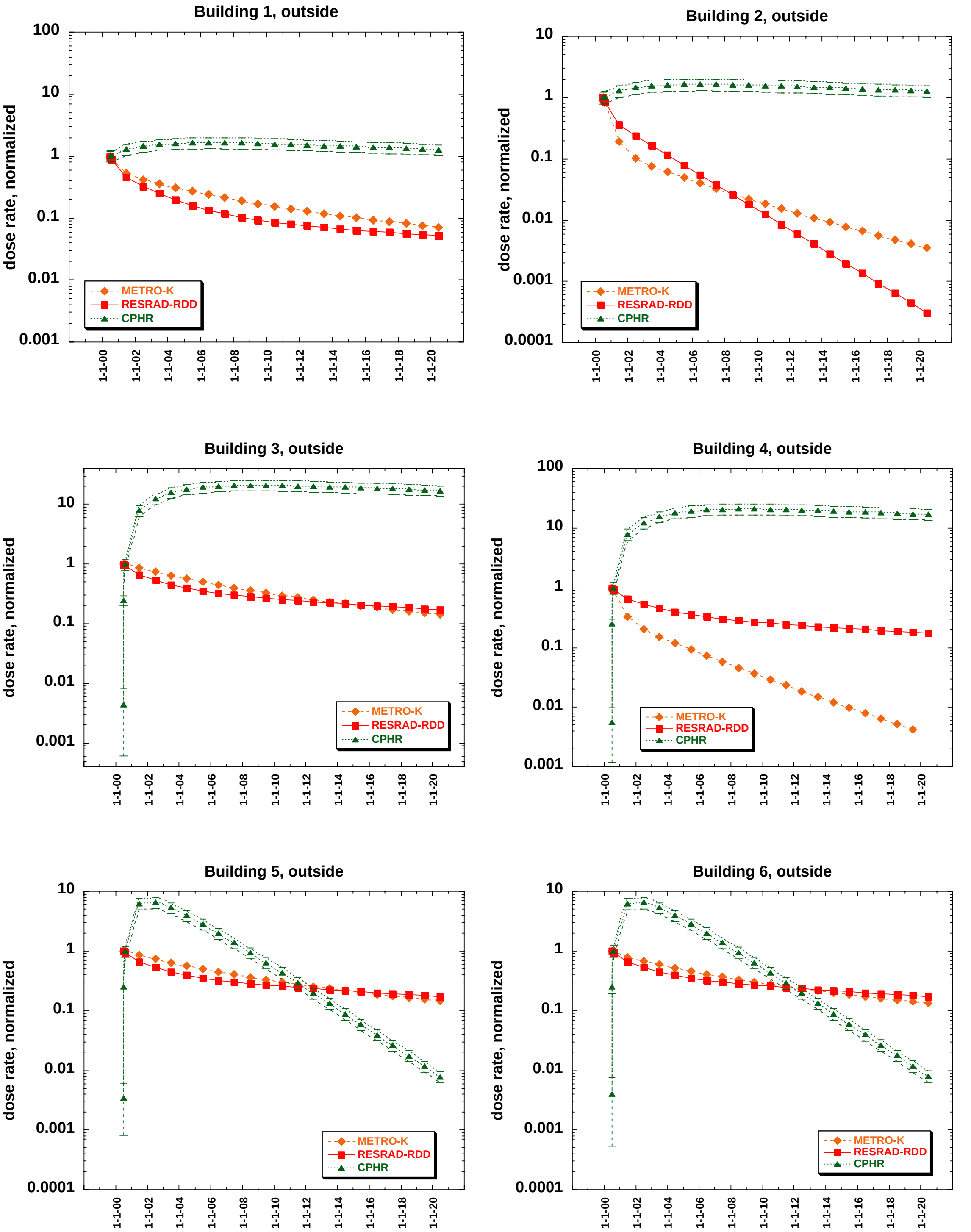


Fig. IV.64. Predicted dose rates (μGy h^{-1}) at outdoor locations, normalized for the initial value (value at 1 month for CPHR, Buildings 3–6).

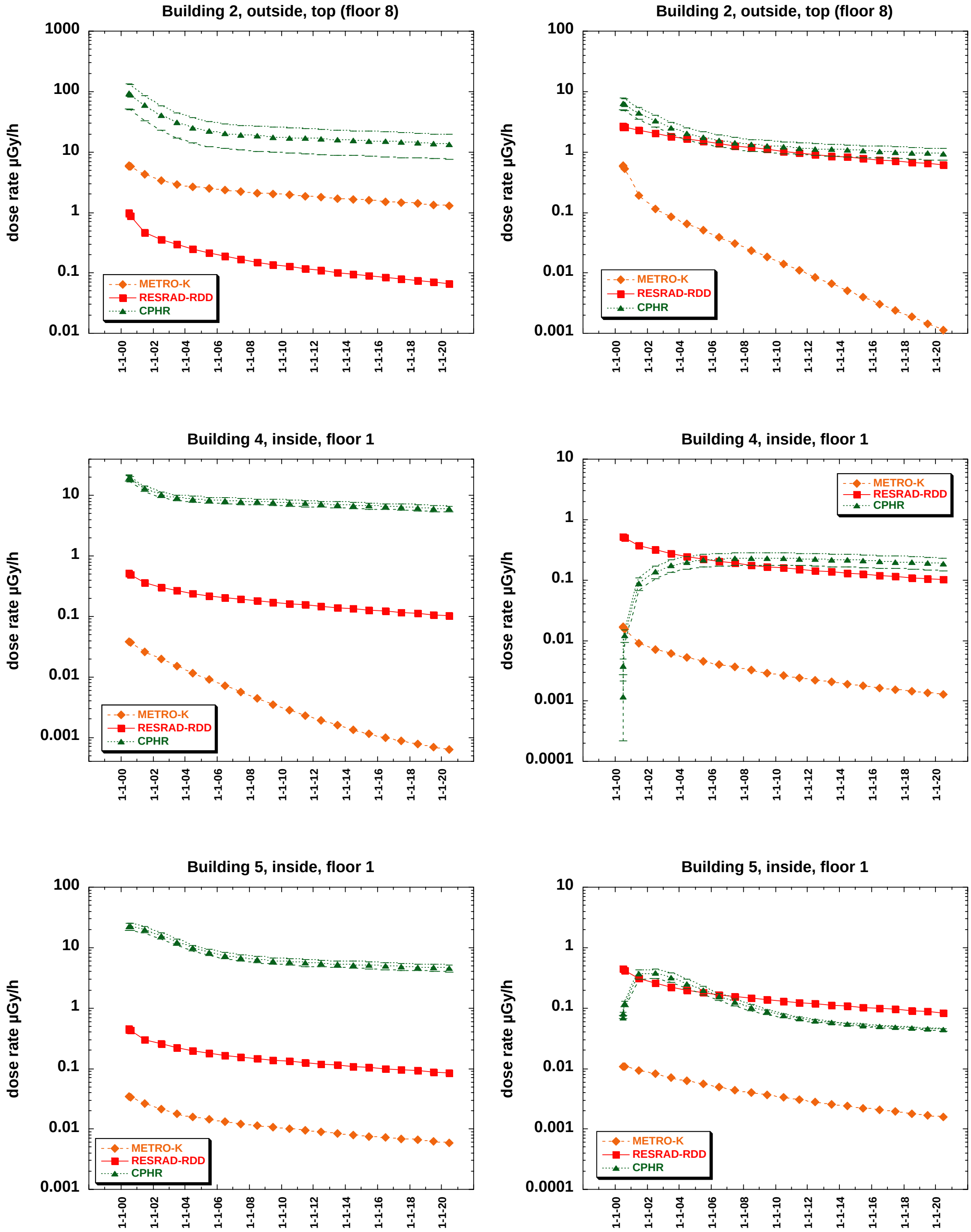


Fig. IV.65. Examples of initial (left) and revised (right) predictions for the dose rate (μGy h^{-1}) at the top of Building 2 and two indoor locations. Revisions are shown for RESRAD-RDD (top of Building 2), METRO-K (all three locations) and CPHR (all three locations).

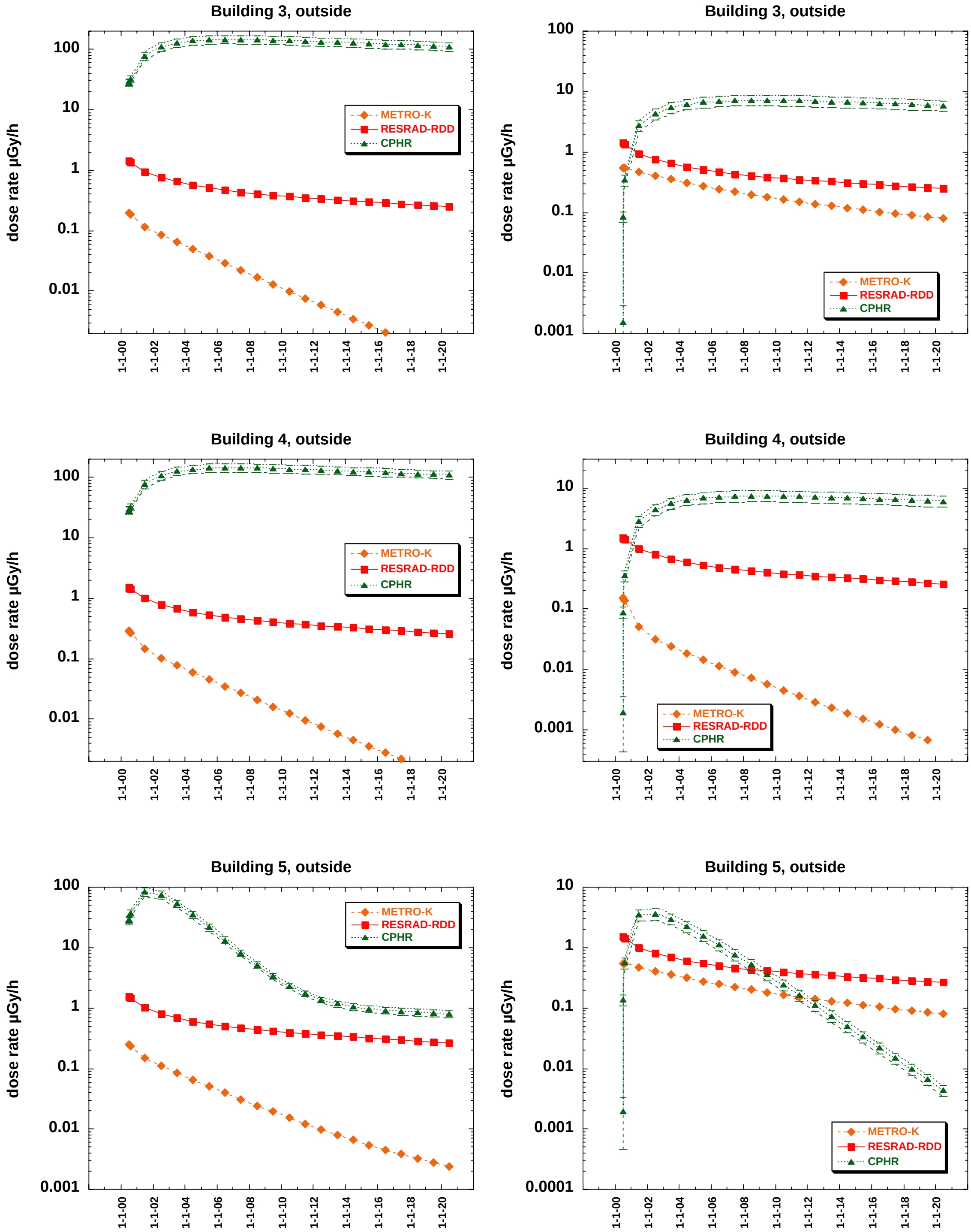


Fig. IV.66. Examples of initial (left) and revised (right) predictions for the dose rate (µGy h^{-1}) at three outdoor locations, from METRO-K and CPHR (RESRAD-RDD predictions were not revised).

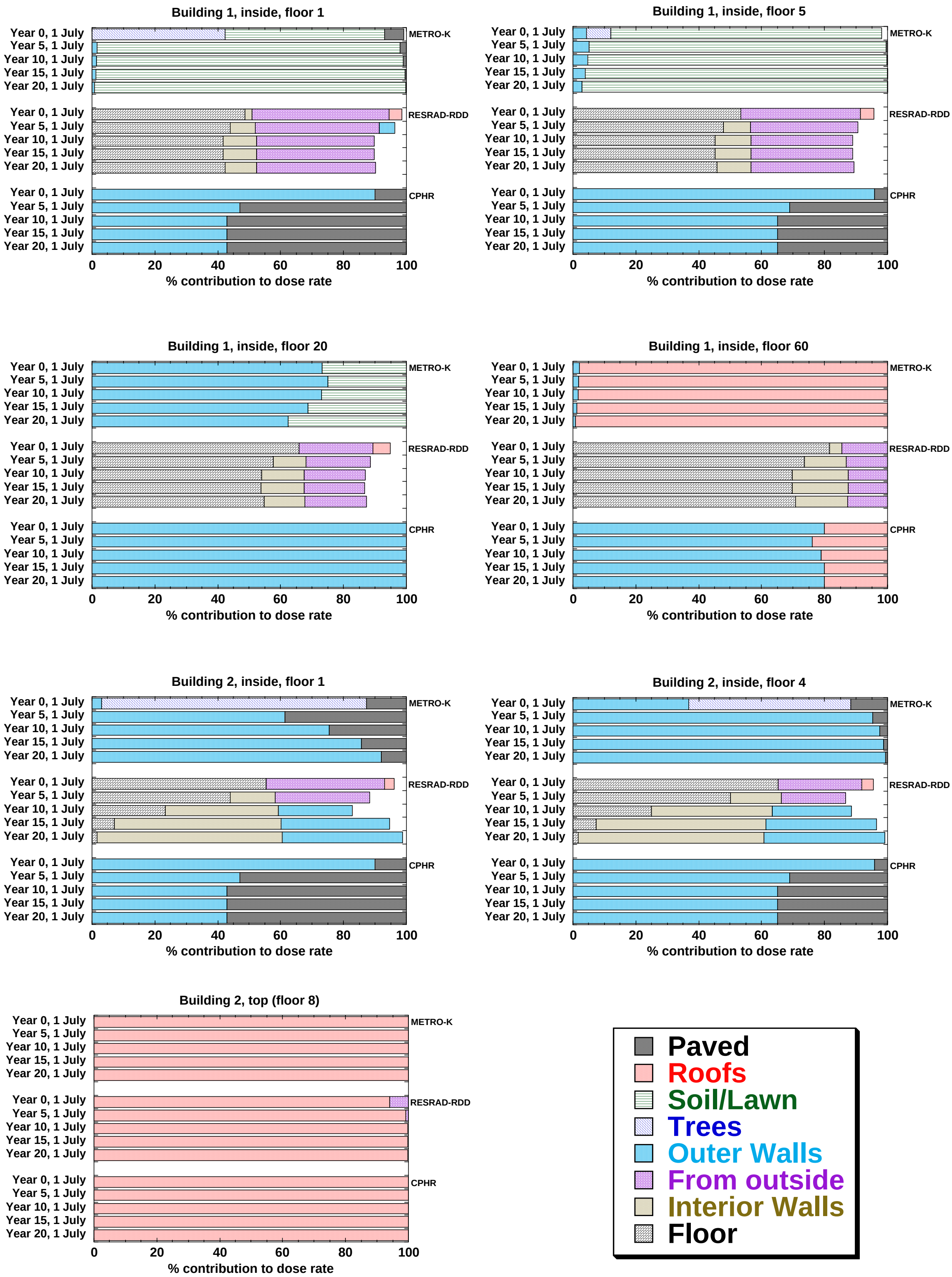


Fig. IV.67. Predicted contributions to dose rates (%) from different surfaces, for indoor locations and top of Building 2.

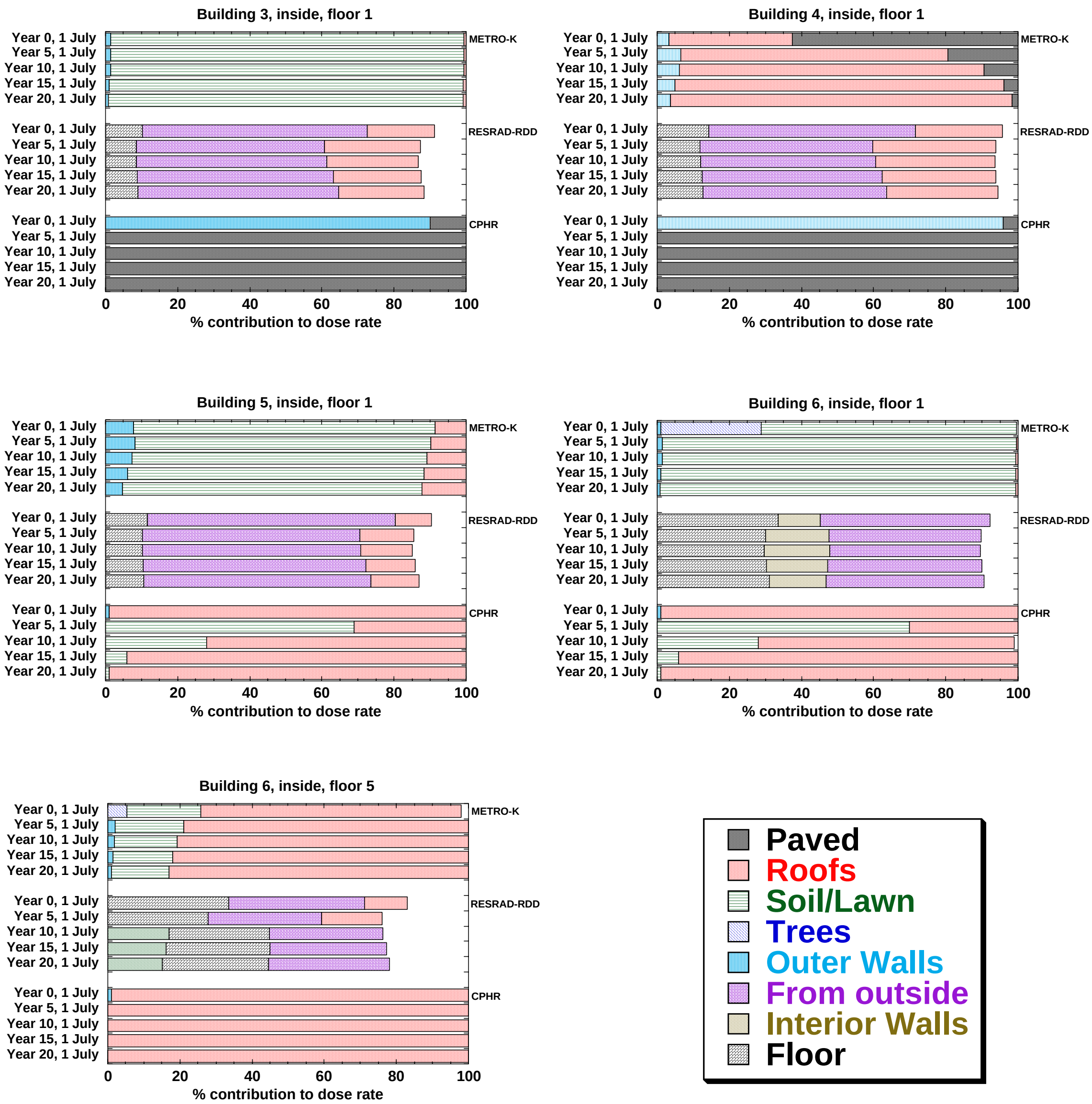


Fig.IV.67. Predicted contributions to dose rates (%) from different surfaces, for indoor locations and top of Building 2 (cont.).

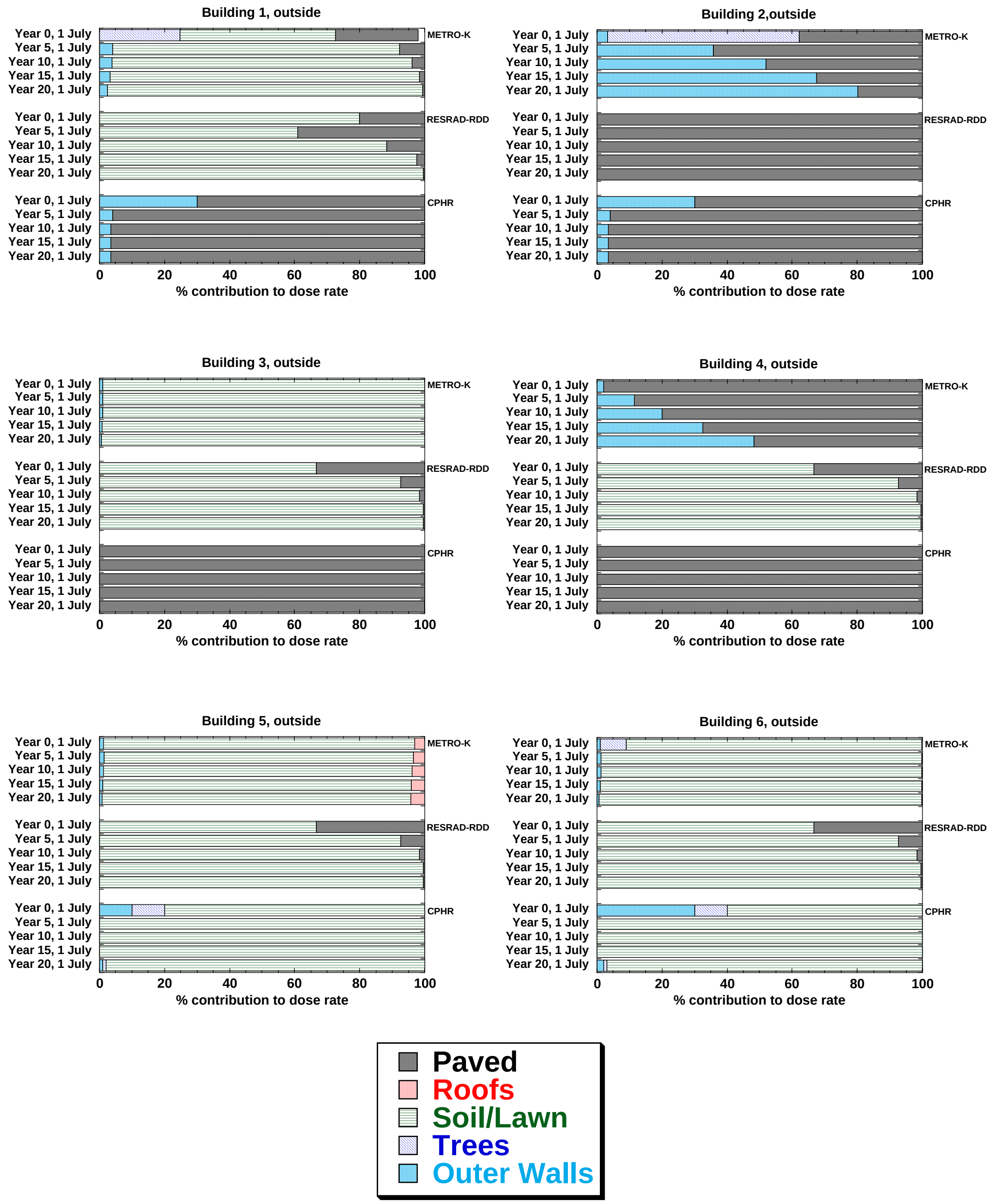


Fig. IV.68. Predicted contributions to dose rates (%) from different surfaces, for outdoor locations.

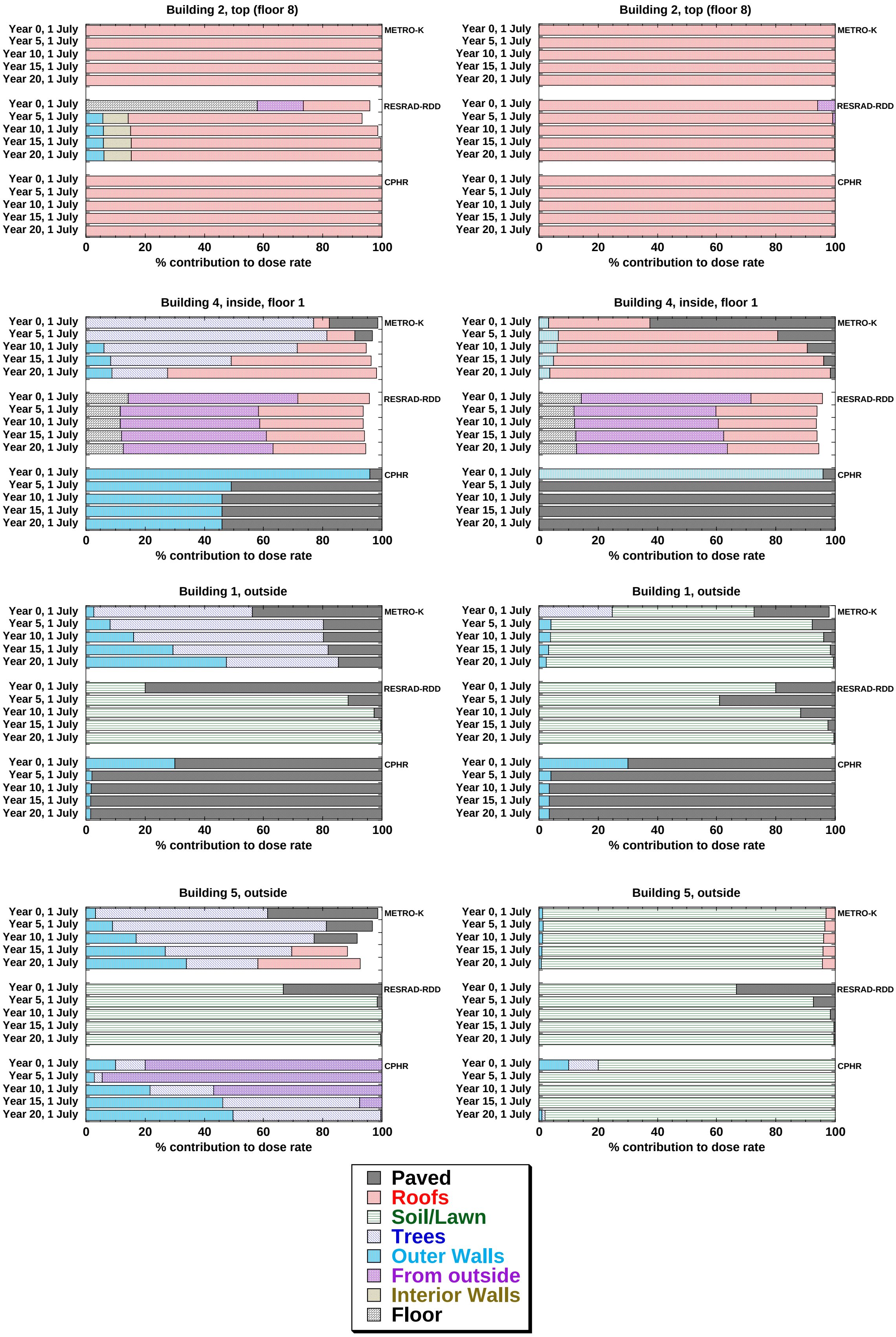


Fig. IV.69. Examples of initial (left) and revised (right) predictions for the contributions to dose rate (%) at selected locations, from all three models.

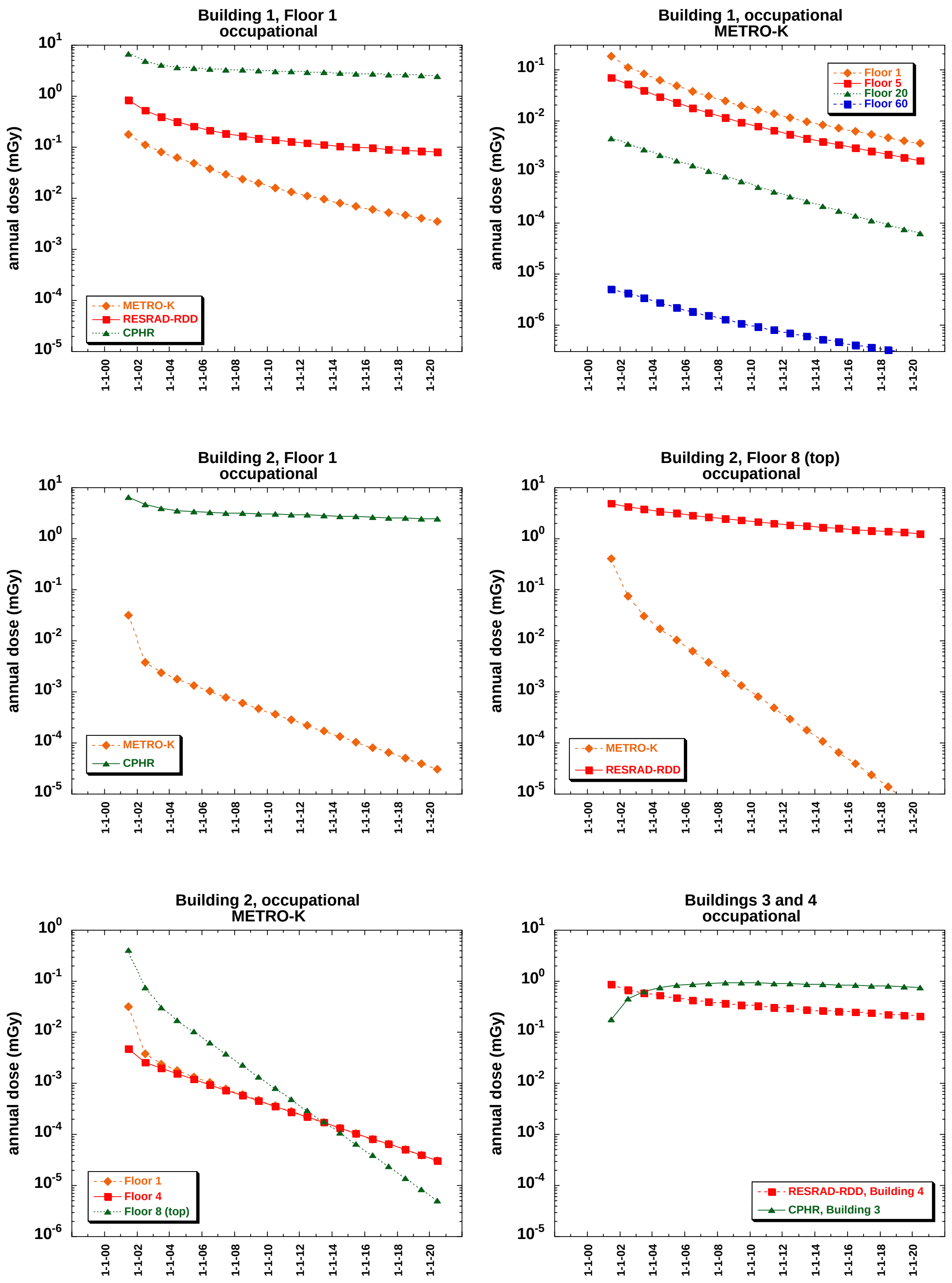


Fig. IV.70. Predicted annual doses (mGy) for occupational exposures at specified locations, assuming no countermeasures (no action situation).

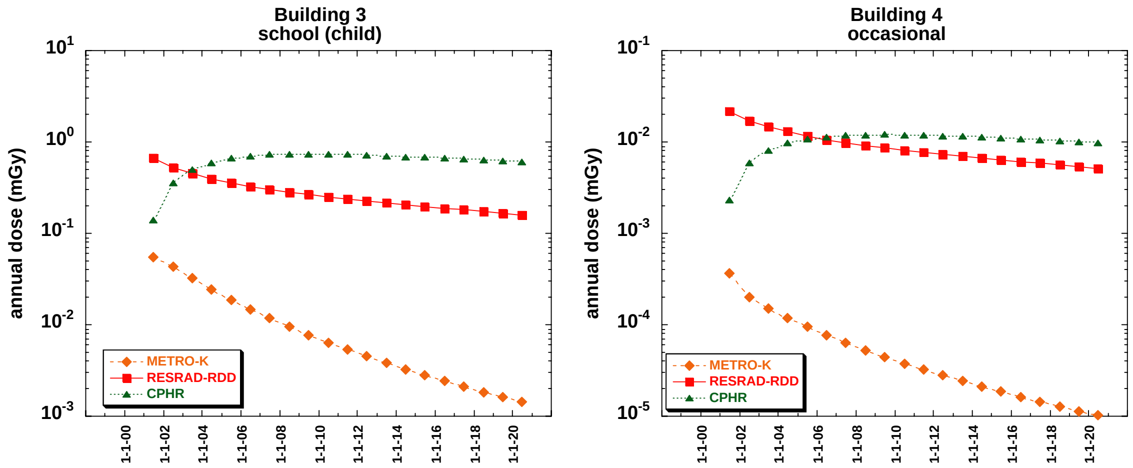


Fig. IV.71. Predicted annual doses (mGy) for a schoolchild's exposure in Building 3 (left) and occasional exposure at Building 4 (right), assuming no countermeasures (no action situation).

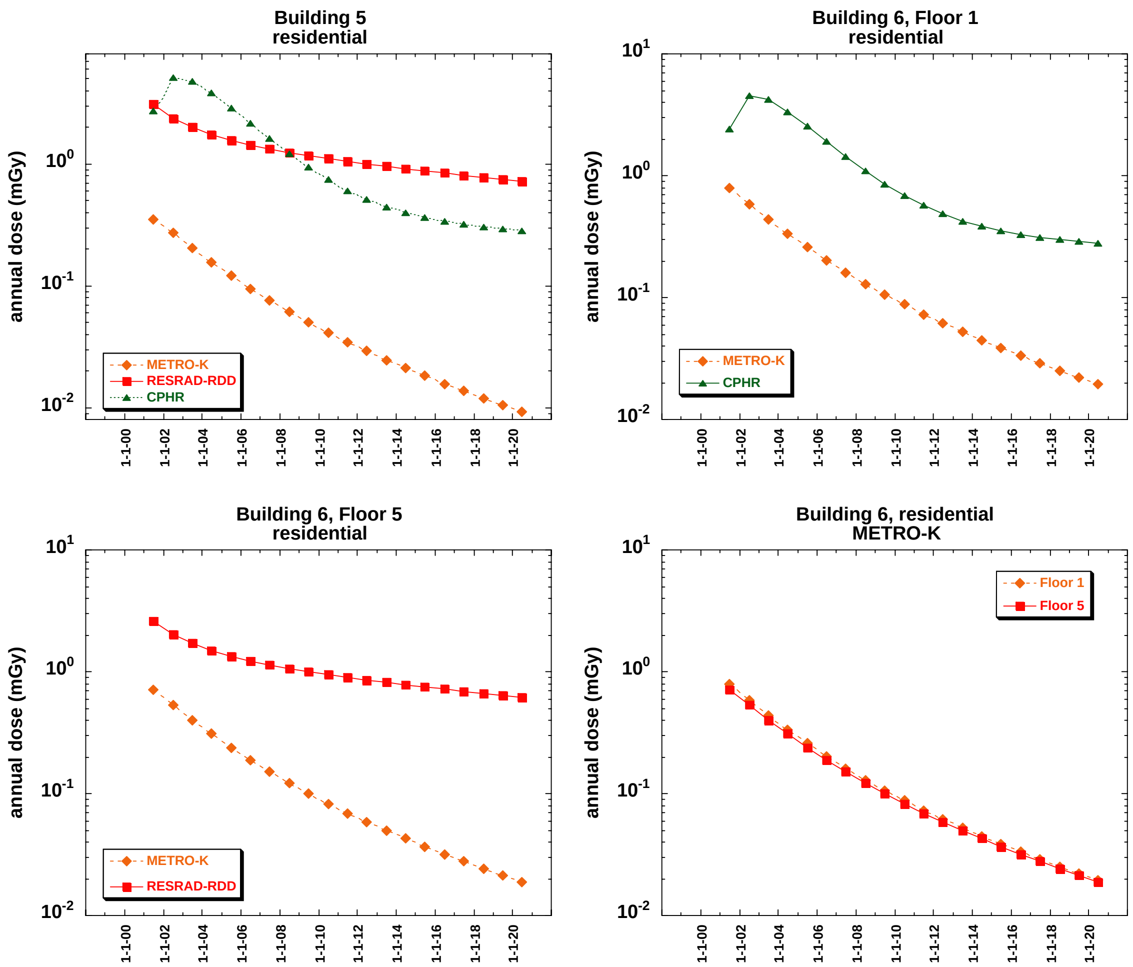


Fig. IV.72. Predicted annual doses (mGy) for residential exposure in Buildings 5 and 6, assuming no countermeasures (no action situation).

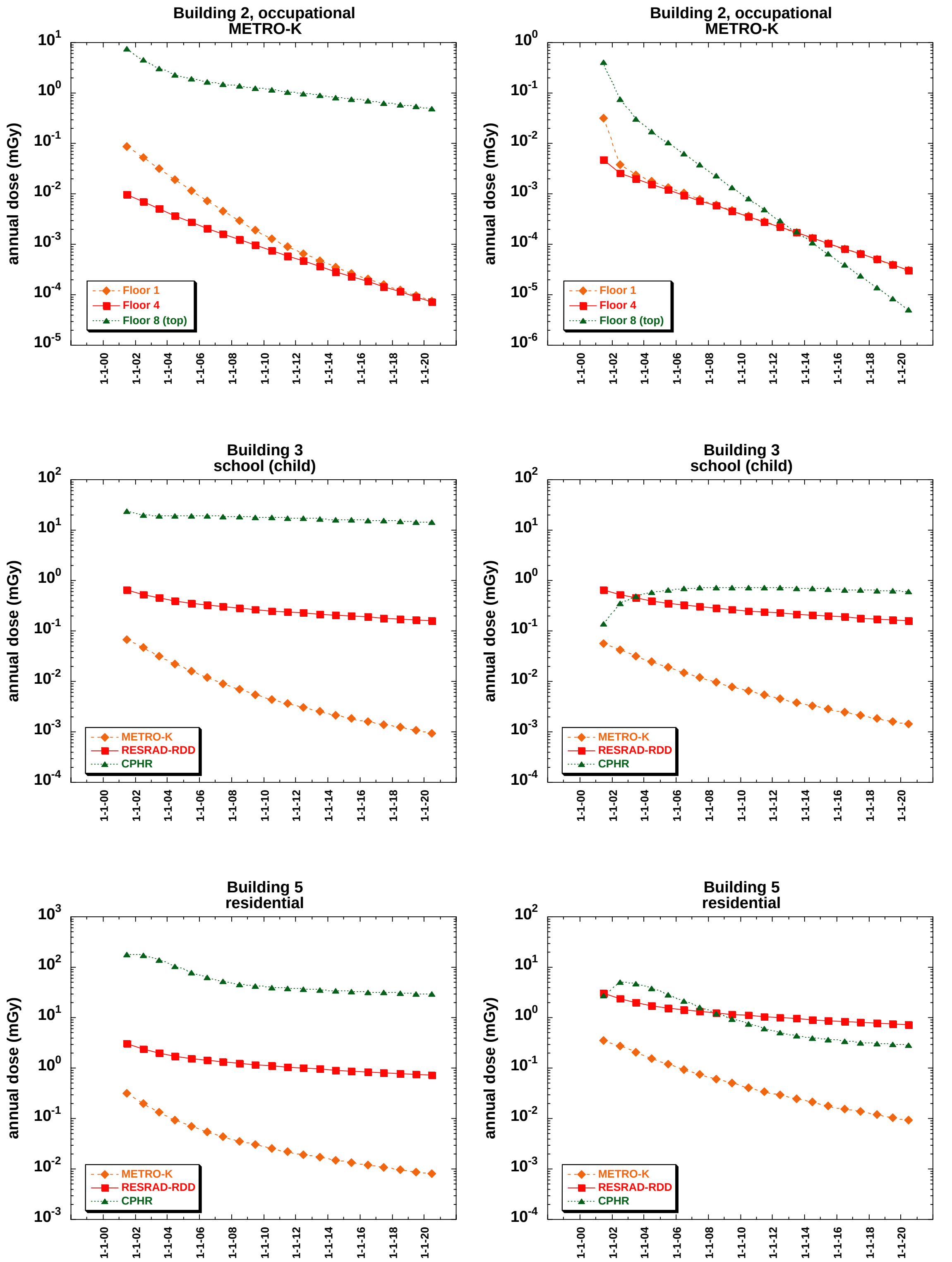


Fig. IV.73. Examples of initial (left) and revised (right) predictions for annual doses for specified exposures, assuming no countermeasures (no action situation). Occupational exposure at Building 2 is shown for METRO-K for three locations (top). Revisions from METRO-K and CPHR are shown for a schoolchild at Building 3 (middle) and residential exposure at Building 5 (bottom).

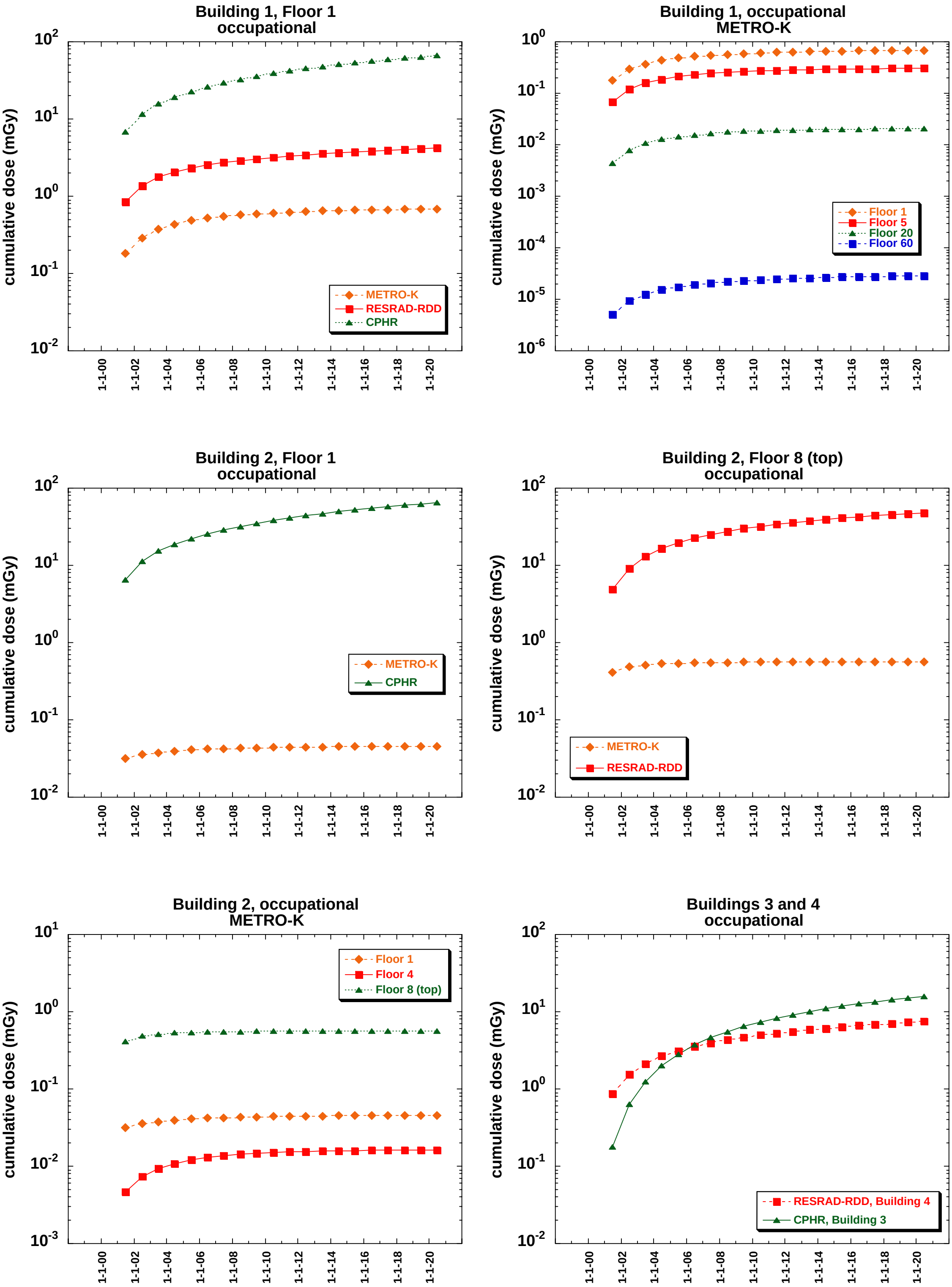


Fig. IV.74. Predicted cumulative doses (mGy) for occupational exposures at various locations, assuming no countermeasures (no action situation). (Scales are comparable, except for Building 1, METRO-K.)

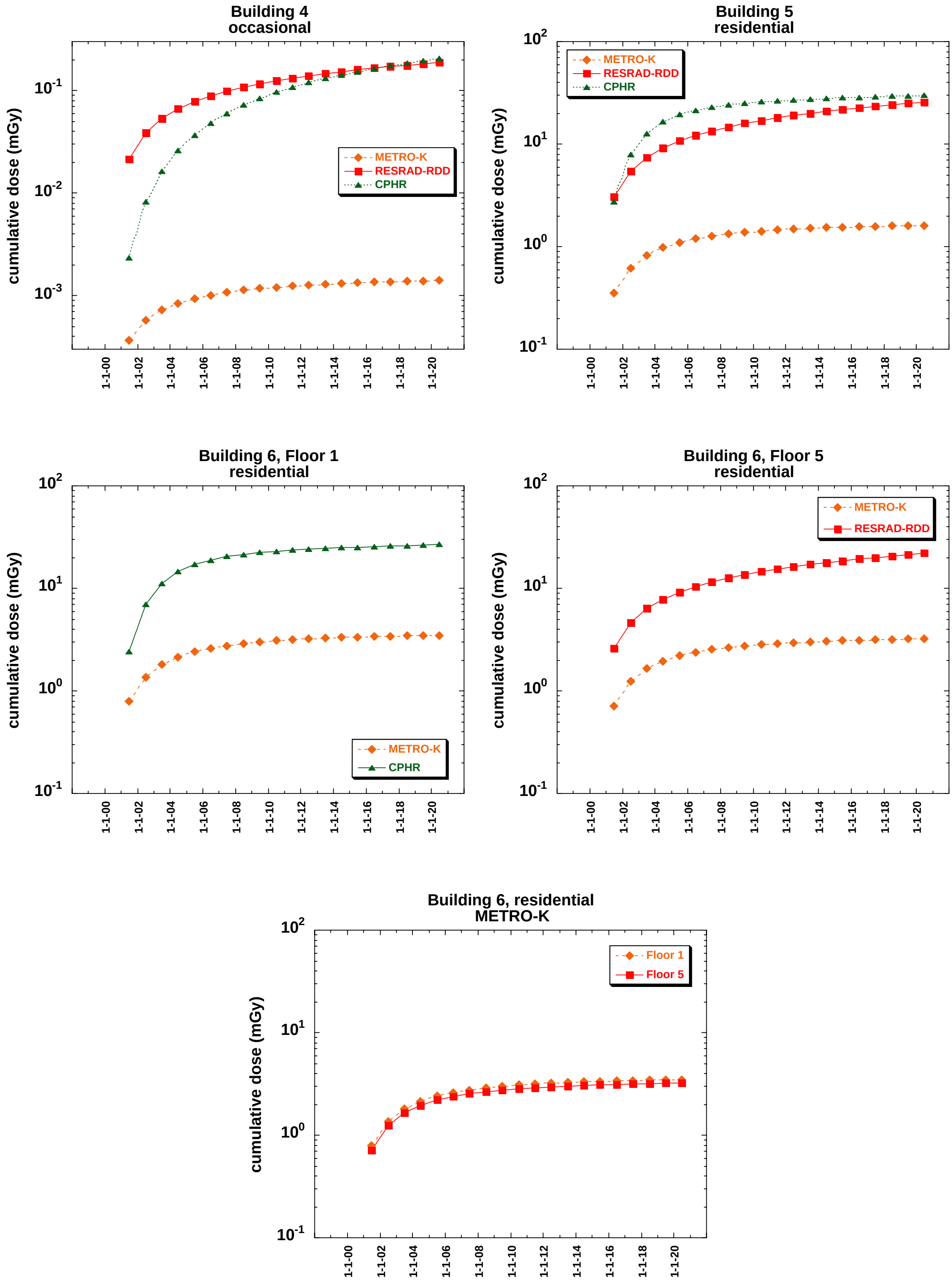


Fig. IV.75. Predicted cumulative doses (mGy) for occasional exposure in Building 4 and residential exposure in Buildings 5 and 6, assuming no countermeasures (no action situation).

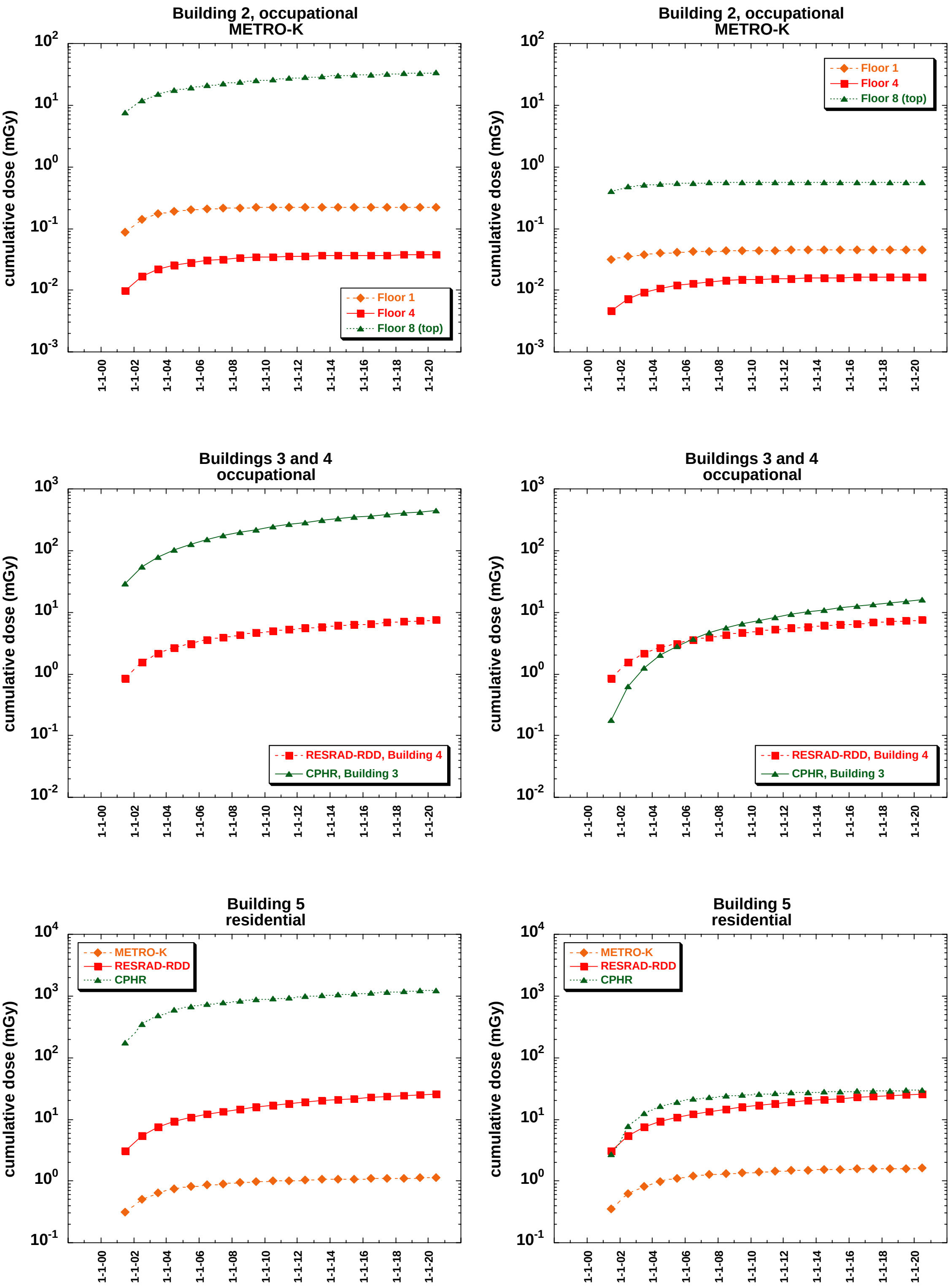


Fig. IV.76. Examples of initial (left) and revised (right) predictions for cumulative doses for specified exposures, assuming no countermeasures (no action situation). Occupational exposure at Building 2 is shown for METRO-K for three locations (top). Revisions are also shown for occupational exposure at Building 3 (middle, CPHR) and residential exposure at Building 5 (bottom, CPHR and METRO-K).

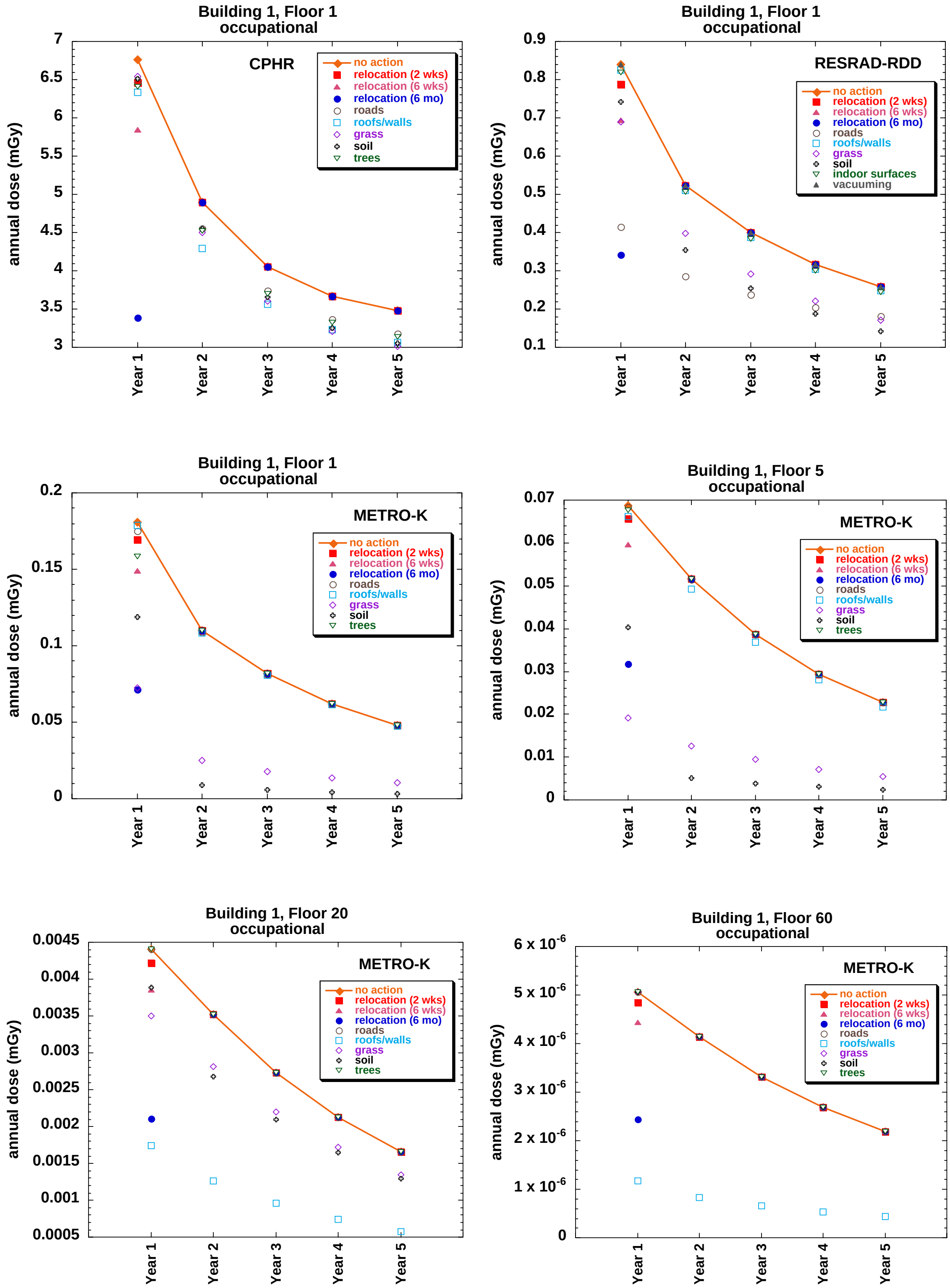


Fig. IV.77. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure in Building 1. (Vertical scales are linear and are not necessarily comparable.)

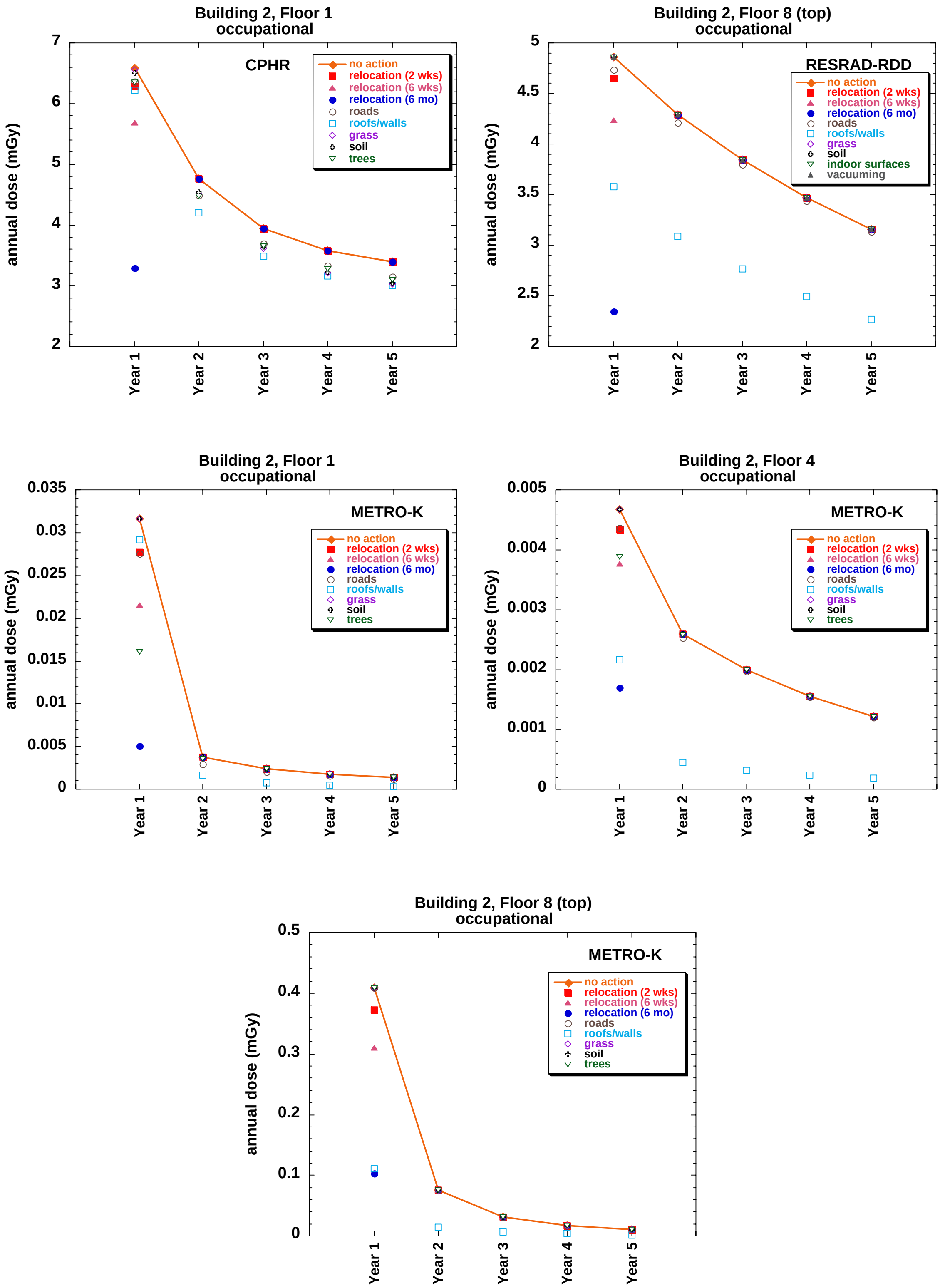


Fig. IV.78. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure in Building 2. (Vertical scales are linear and are not necessarily comparable.)

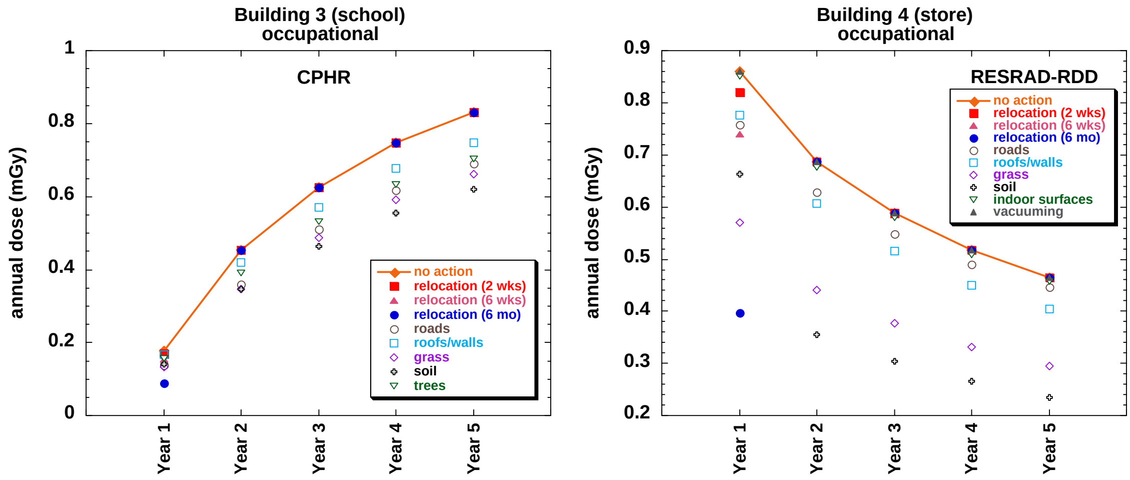


Fig. IV.79. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure (Buildings 3 and 4). (Vertical scales are linear and are not necessarily comparable.)

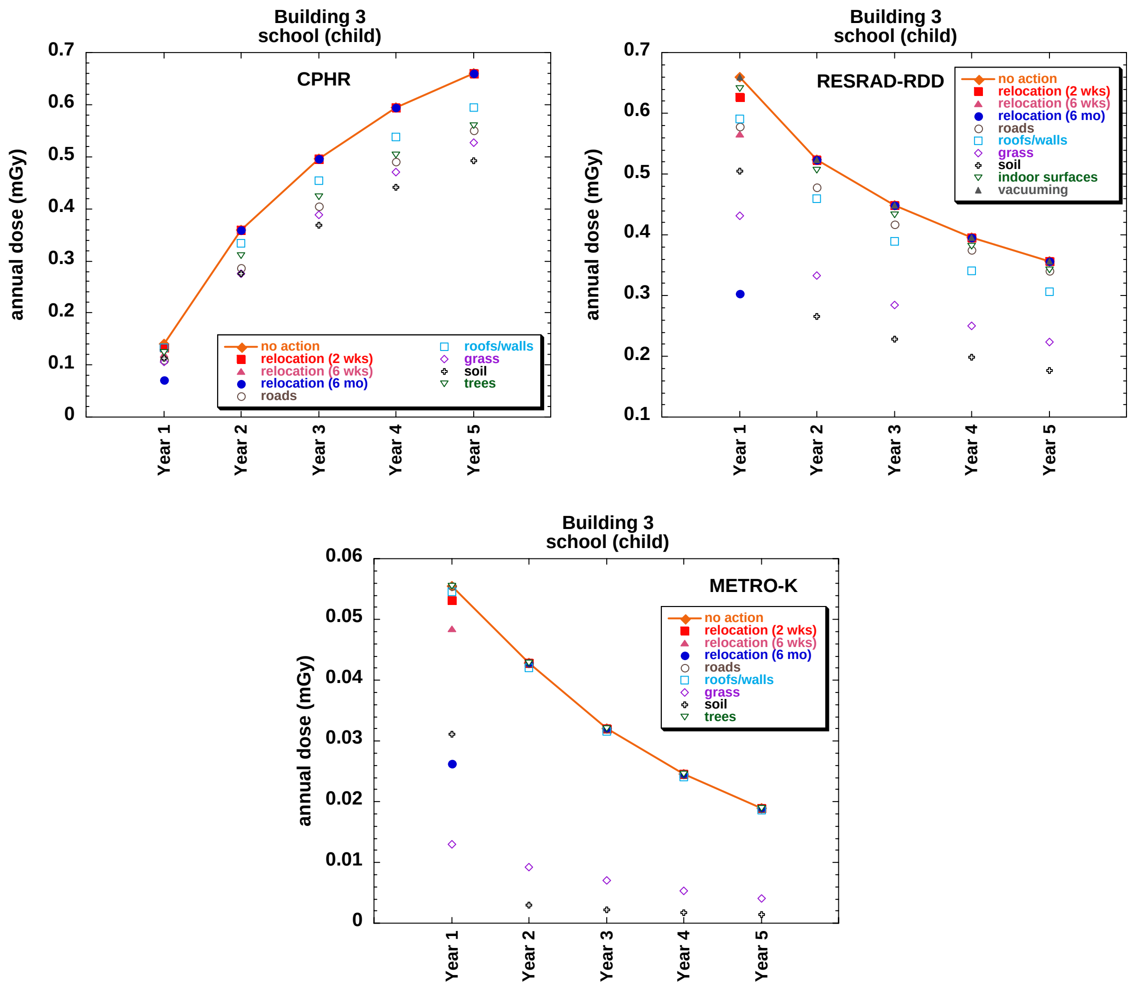


Fig. IV.80. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for exposure of a schoolchild (Building 3). (Vertical scales are linear and are not necessarily comparable.)

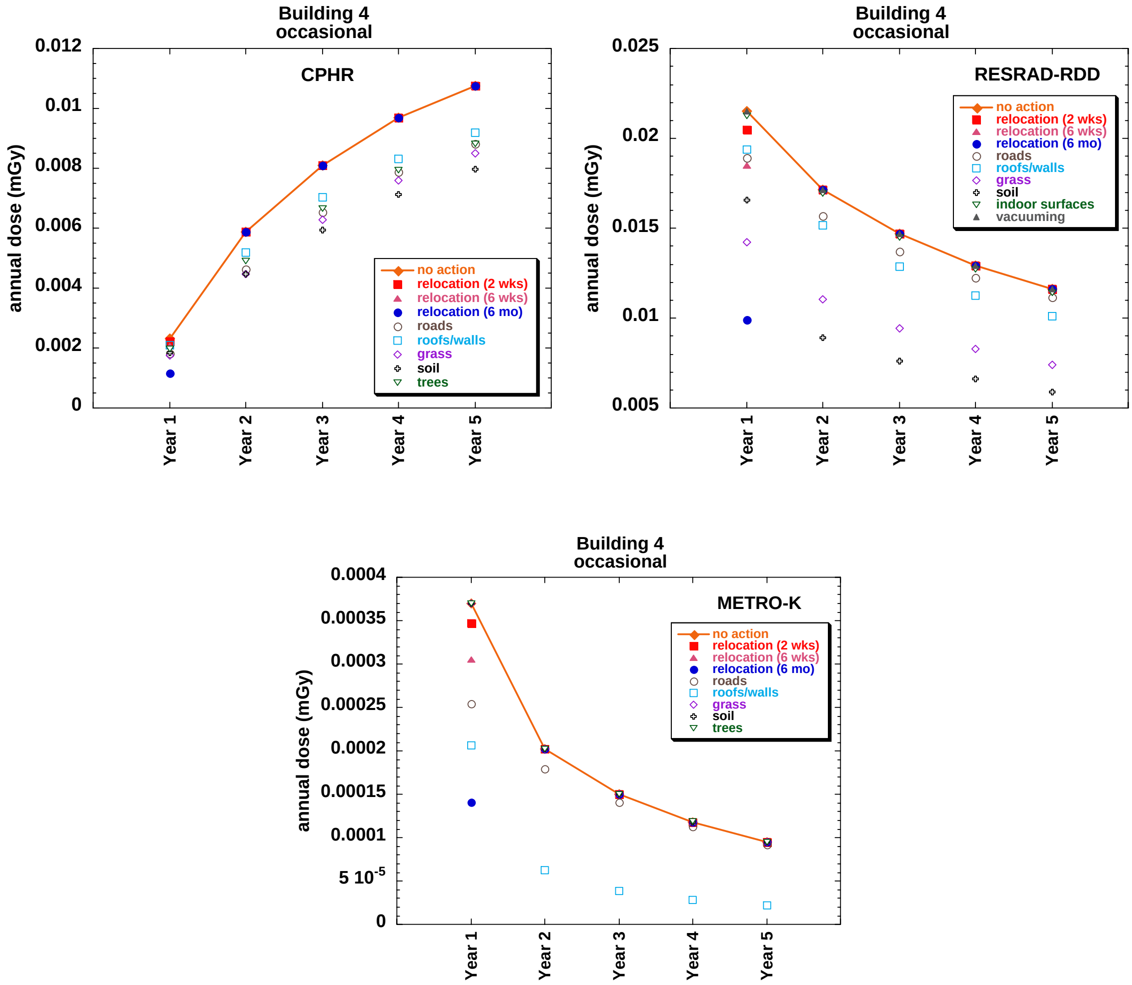


Fig. IV.81. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occasional exposure in Building 4 (a grocery store). (Vertical scales are linear and are not necessarily comparable.)

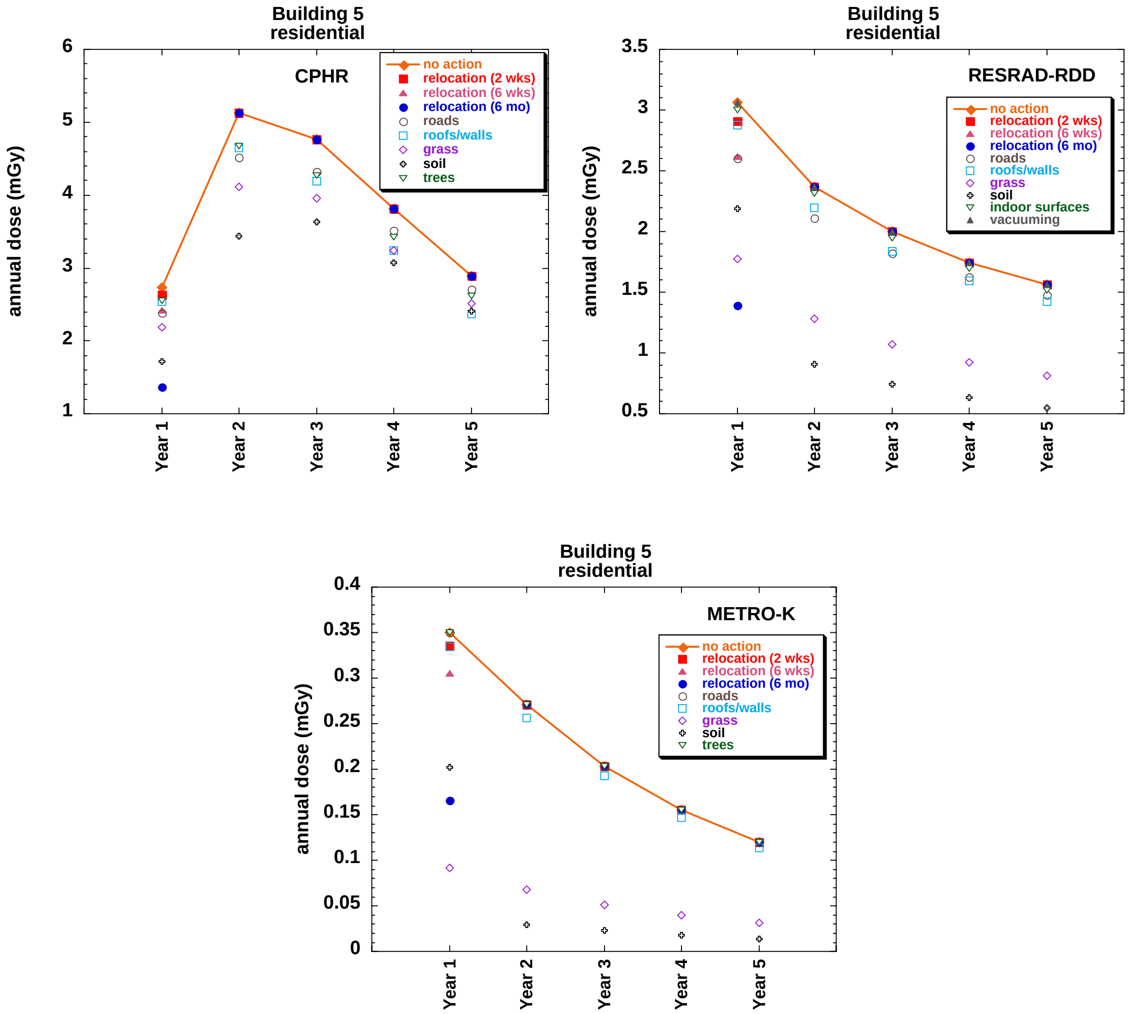


Fig. IV.82. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for residential exposure in Building 5. (Vertical scales are linear and are not necessarily comparable.)

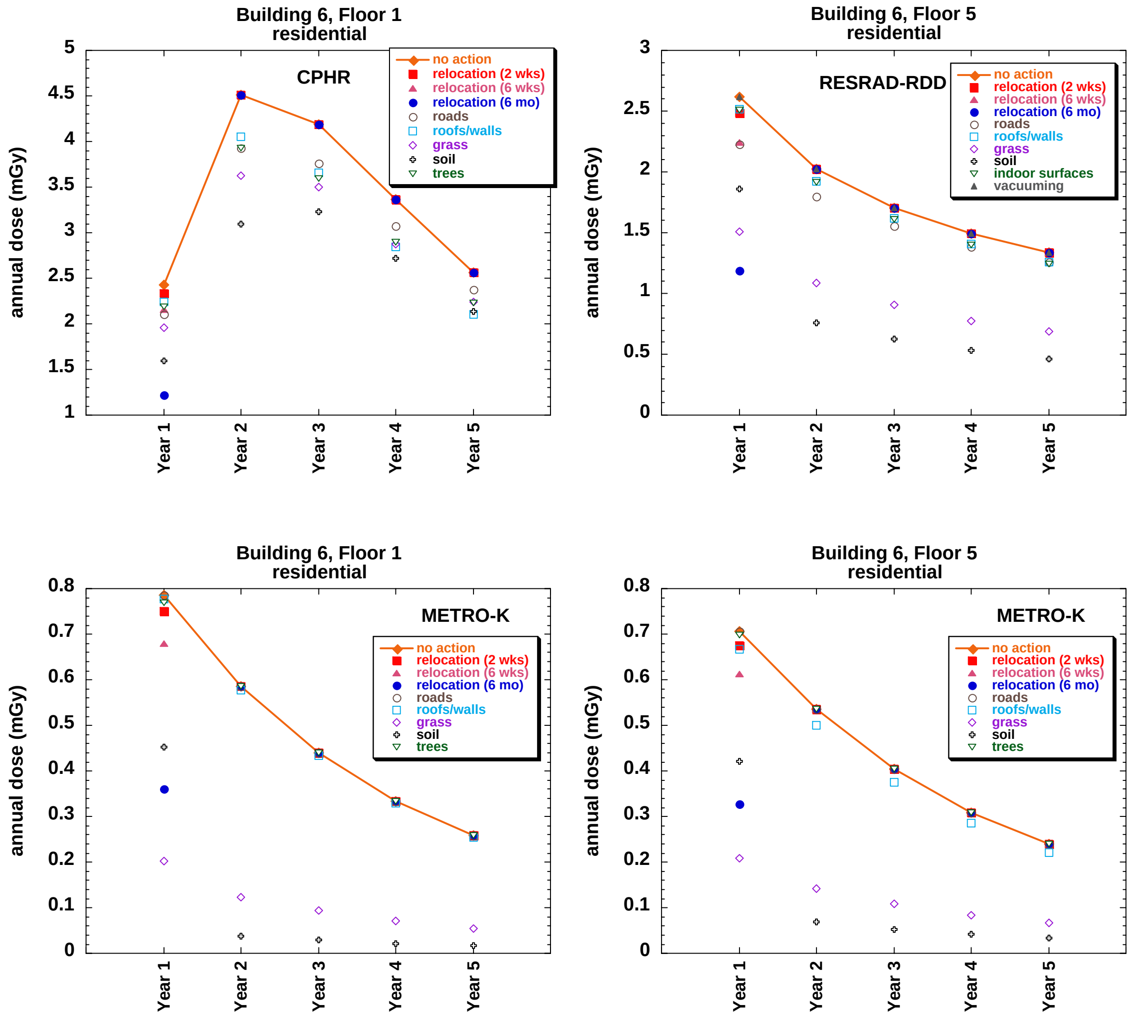


Fig. IV.83. Predicted annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for residential exposure in Building 6. (Vertical scales are linear and are not necessarily comparable.)

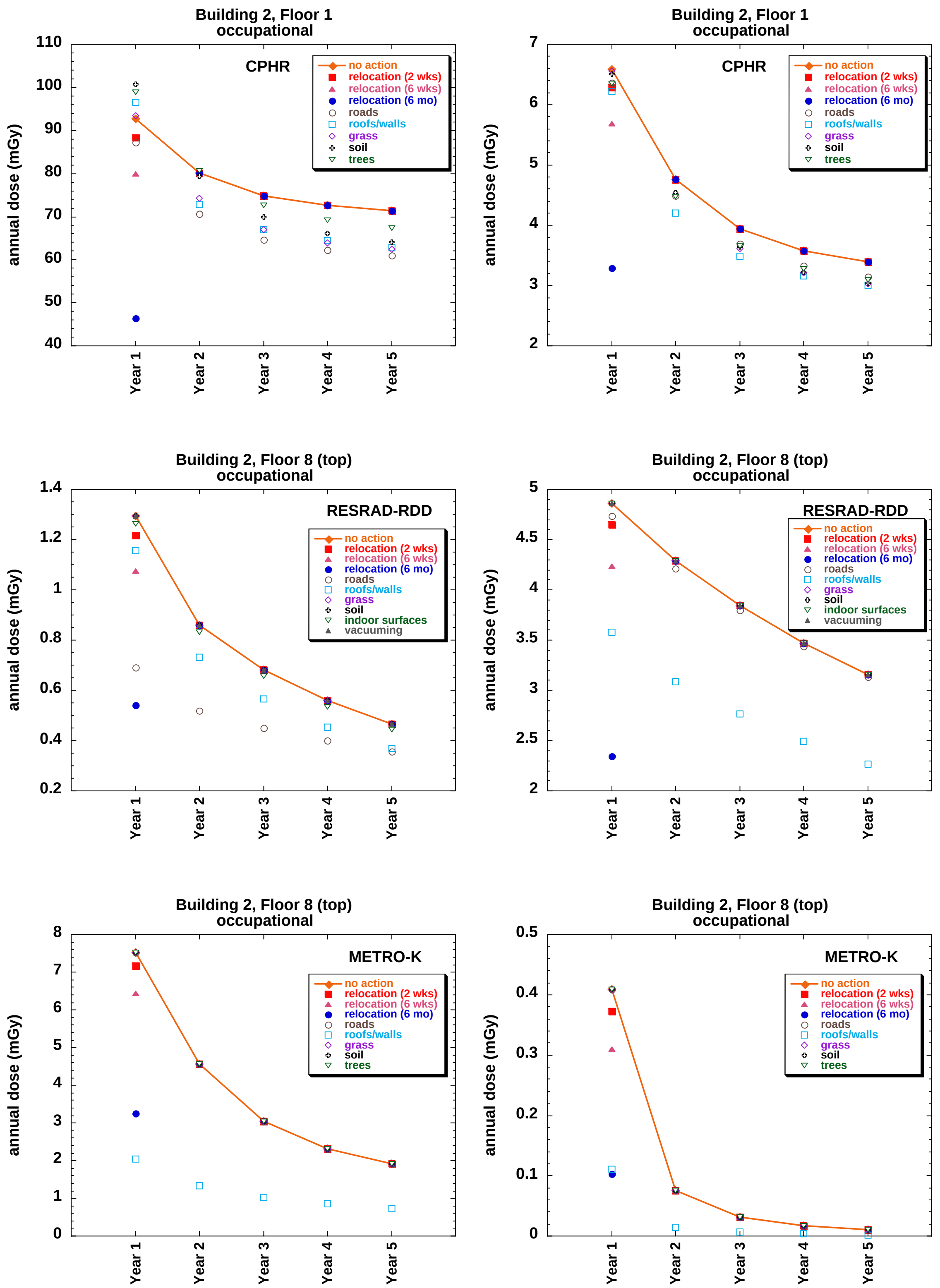


Fig. IV.84. Examples of initial (left) and revised (right) predictions for annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for occupational exposure in Building 2. (Vertical scales are linear and are not necessarily comparable.)

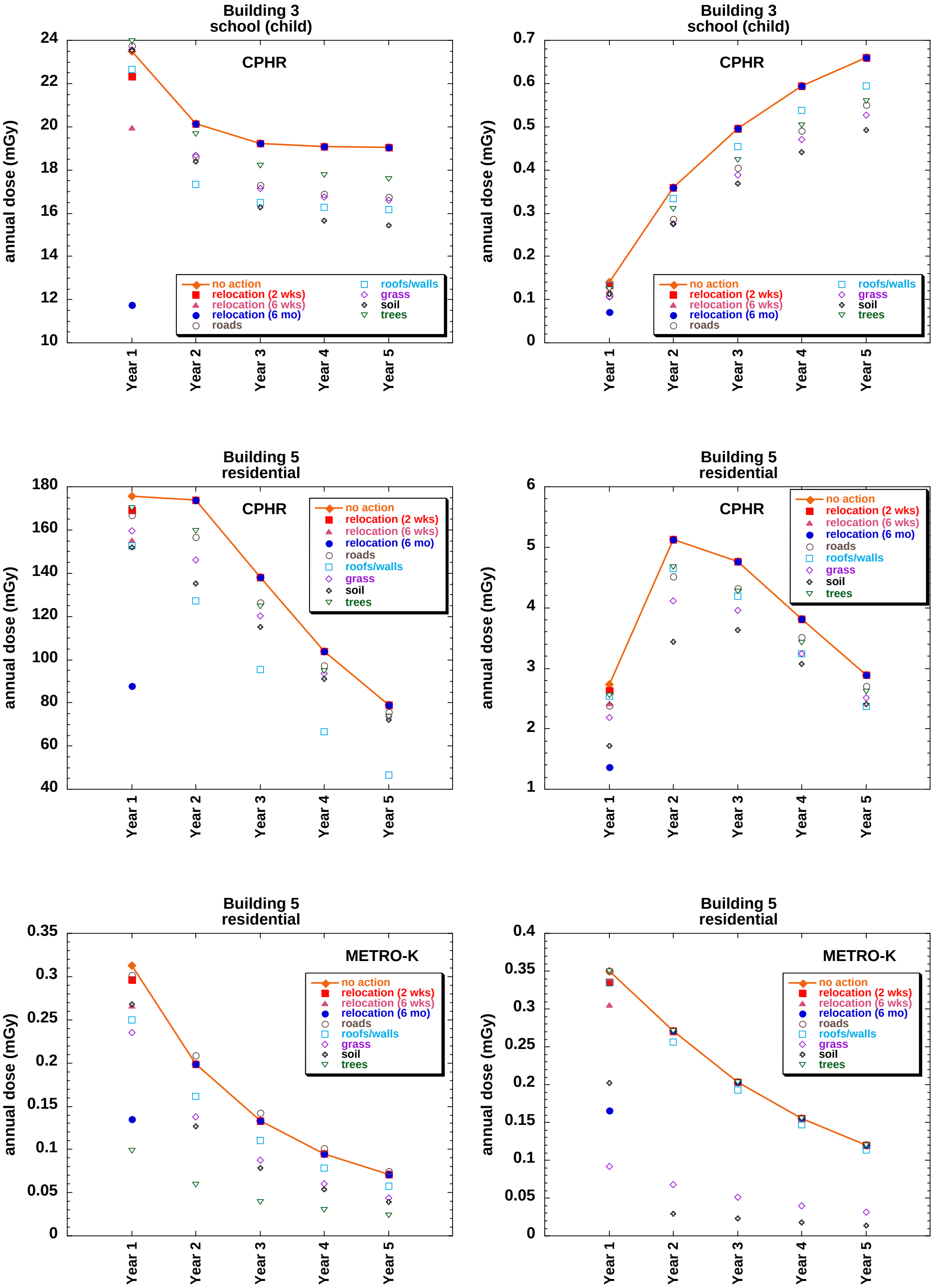


Fig. IV.85. Examples of initial (left) and revised (right) predictions for annual doses (mGy) for the first 5 years, showing the predicted effects on the annual dose of several different countermeasures. Results are shown for a schoolchild's exposure in Building 3 and for residential exposure in Building 5. (Vertical scales are linear and are not necessarily comparable.)

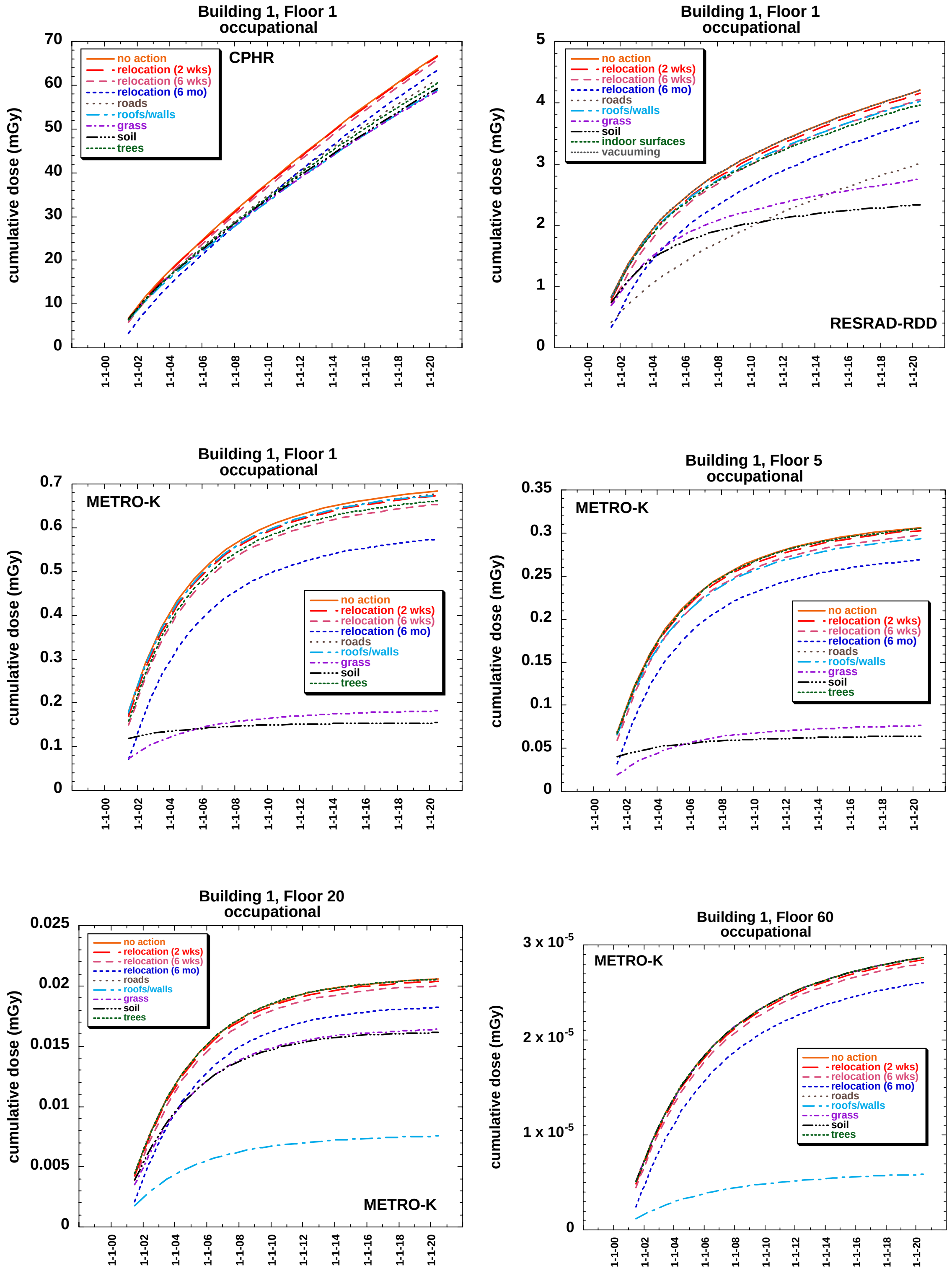


Fig. IV.86. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occupational exposure in Building 1. (Vertical scales are linear and are not necessarily comparable.)

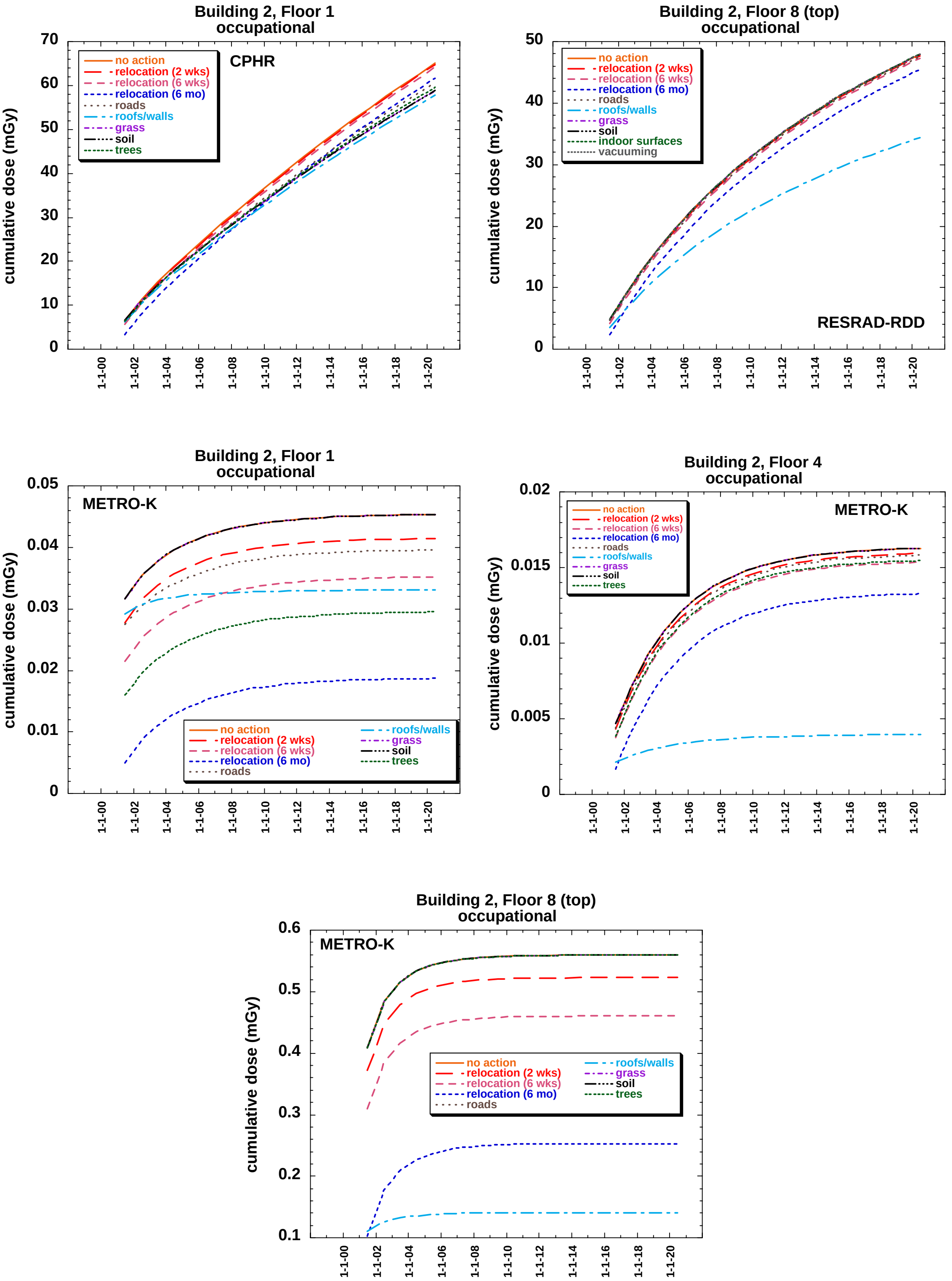


Fig. IV.87. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occupational exposure in Building 2. (Vertical scales are linear and are not necessarily comparable.)

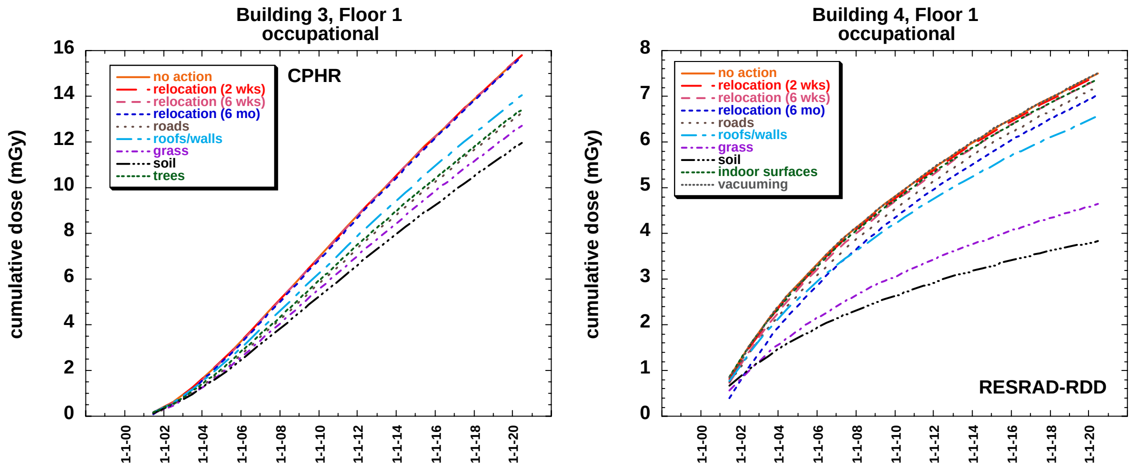


Fig. IV.88. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occupational exposure (Buildings 3 and 4). (Vertical scales are linear and are not necessarily comparable.)

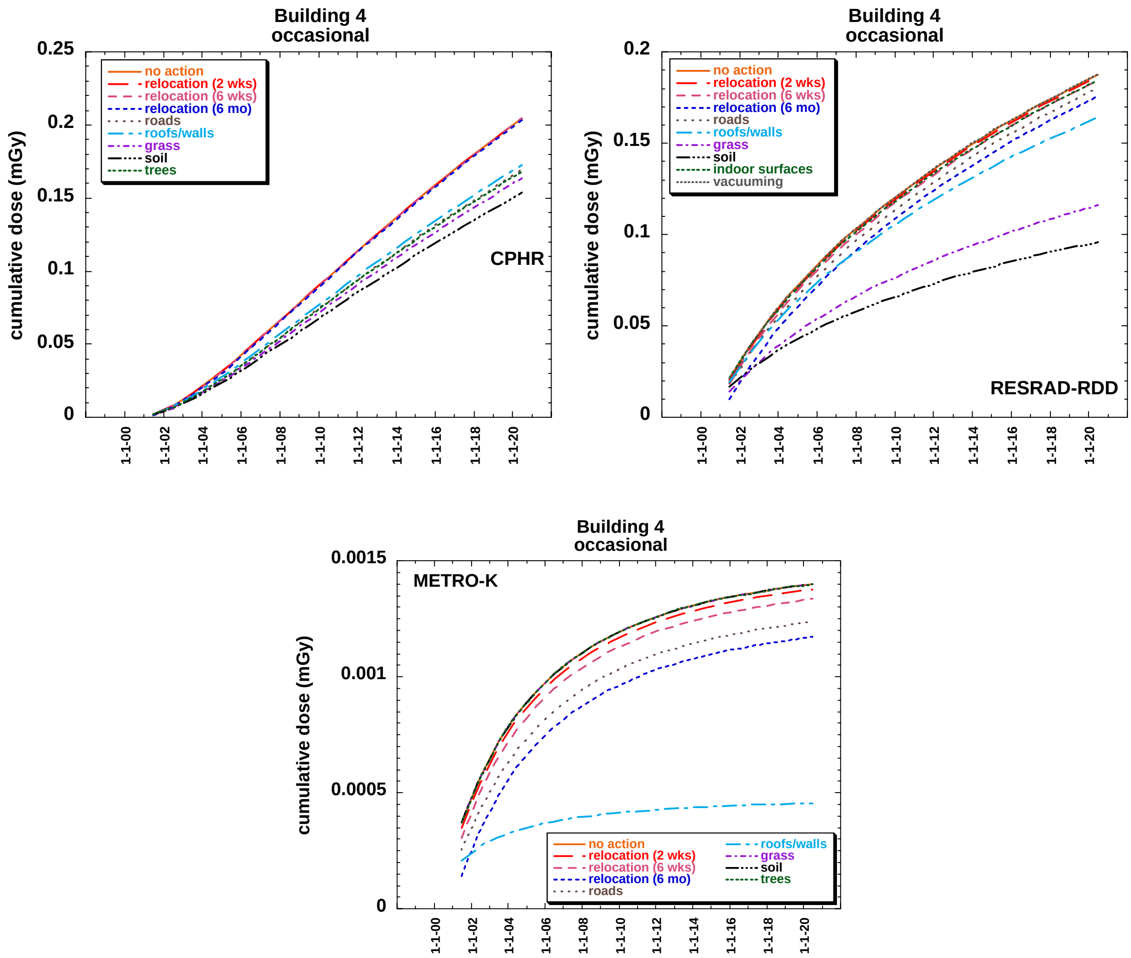


Fig. IV.89. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for occasional exposure in Building 4 (a grocery store). (Vertical scales are linear and are not necessarily comparable.)

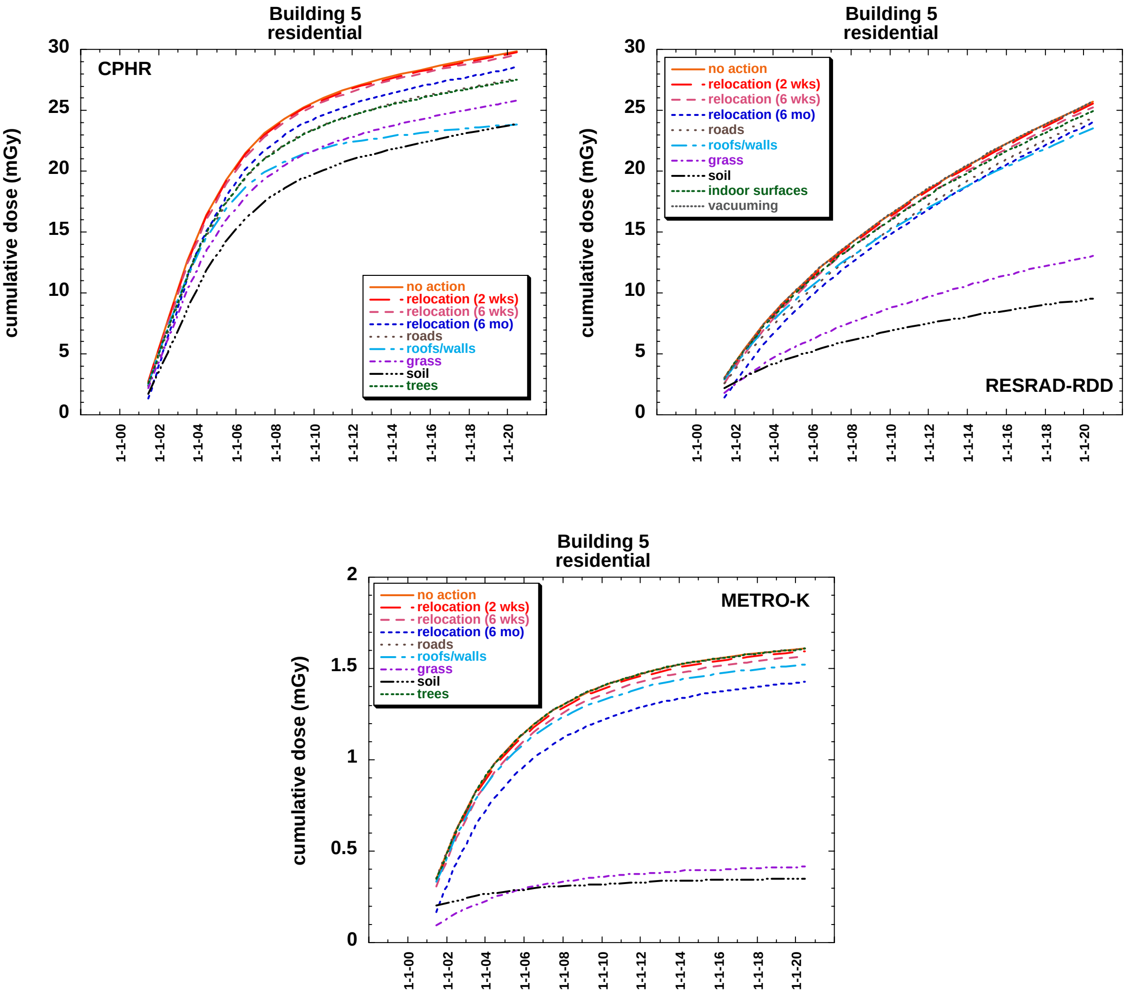


Fig. IV.90. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for residential exposure in Building 5. (Vertical scales are linear and are not necessarily comparable.)

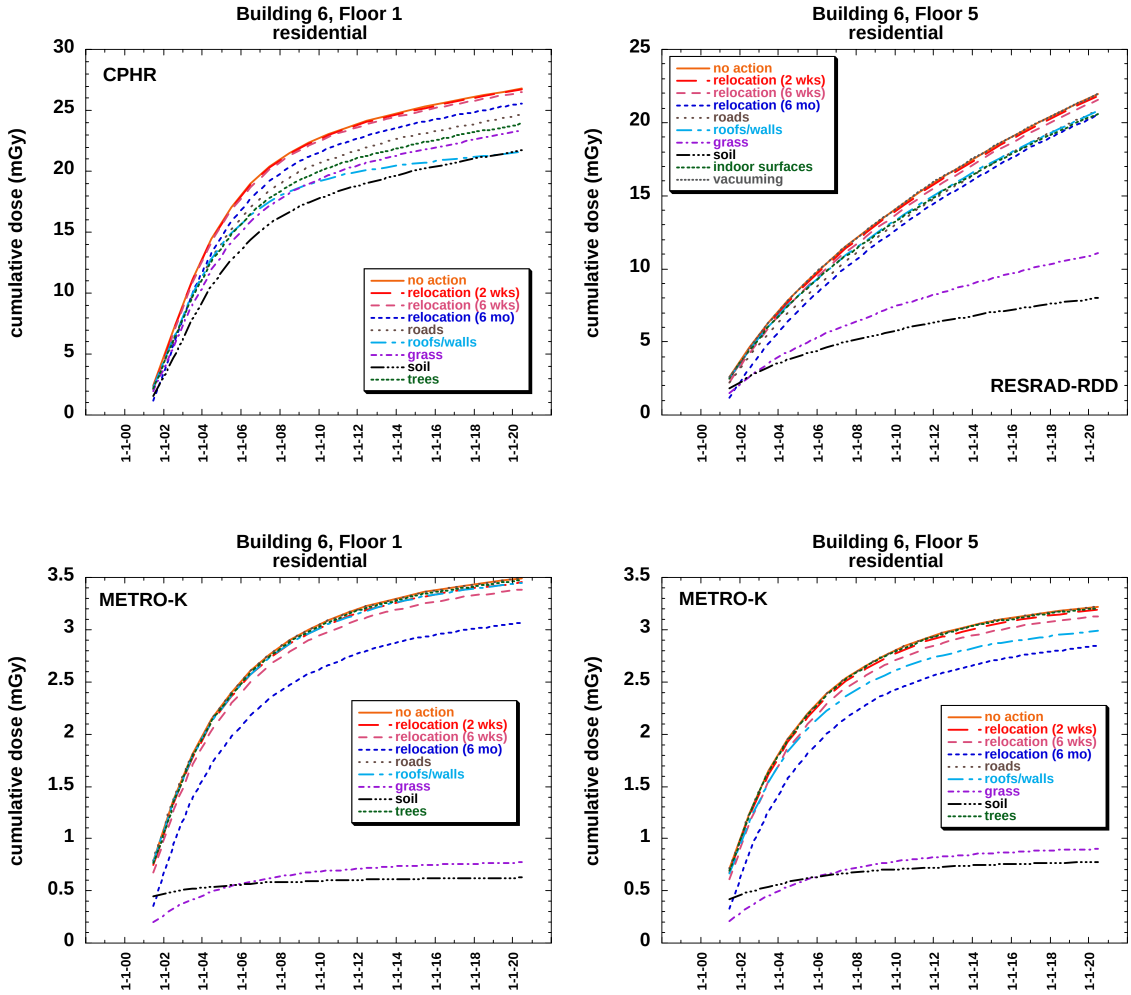


Fig. IV.91. Predicted cumulative doses (mGy), showing the predicted effects of several different countermeasures. Results are shown for residential exposure in Building 6. (Vertical scales are linear and are not necessarily comparable.)

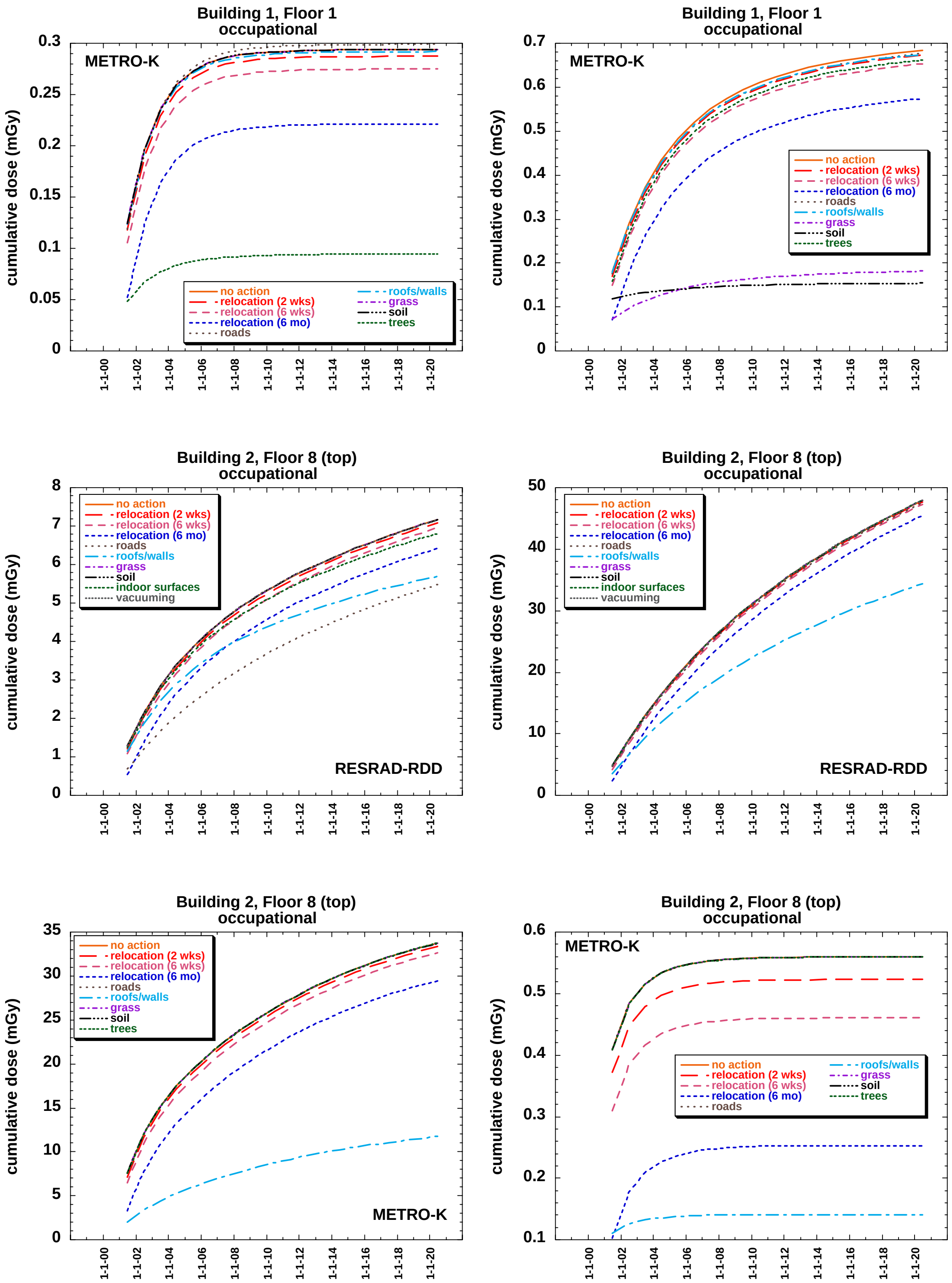


Fig. IV.92. Examples of initial (left) and revised (right) predictions for cumulative doses (mGy), showing the predicted effects on the cumulative dose of several different countermeasures. Results are shown for occupational exposure in Building 1 (first floor) and Building 2 (top). (Vertical scales are linear and are not necessarily comparable.)

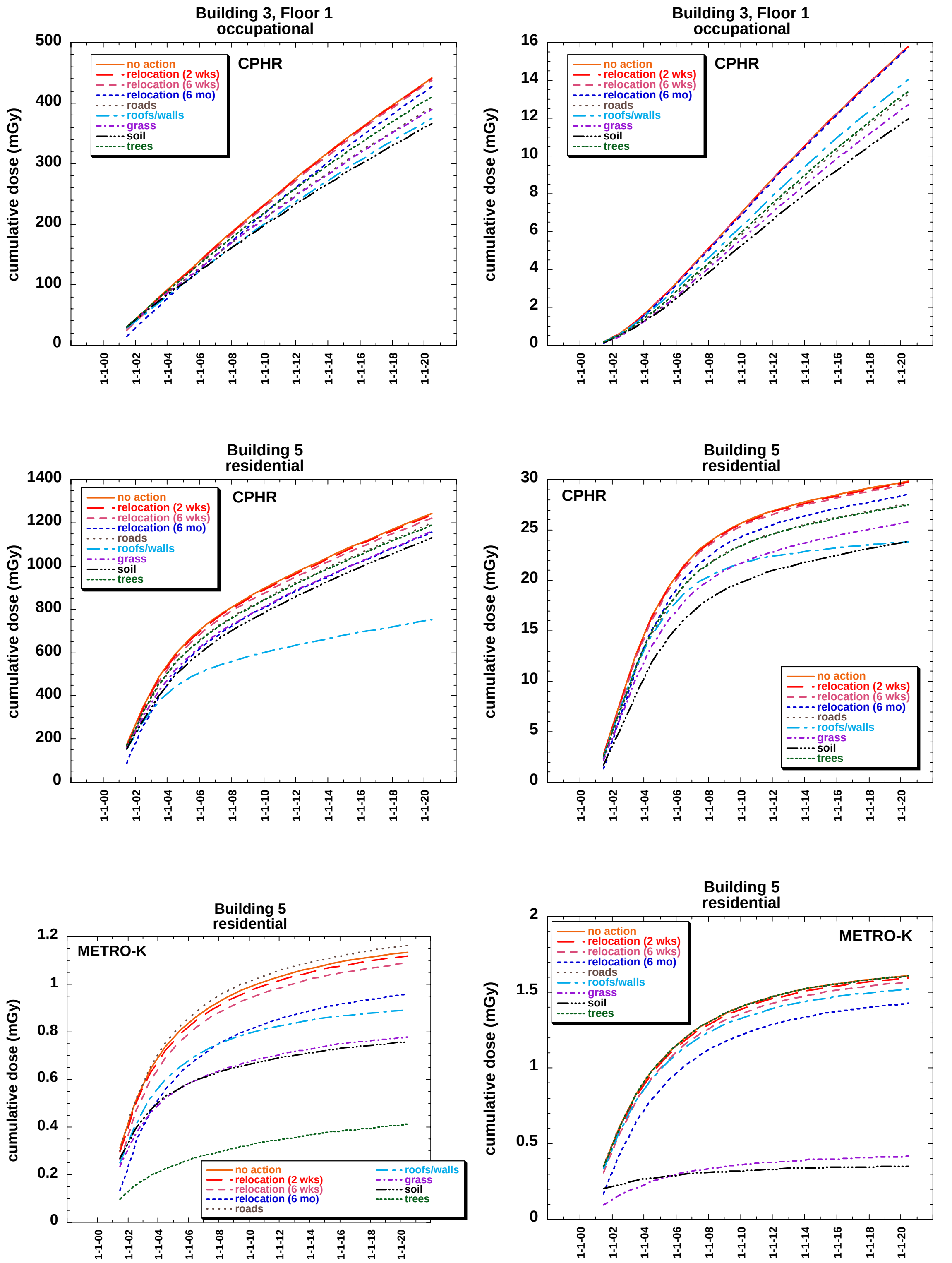


Fig. IV.93. Examples of initial (left) and revised (right) predictions for cumulative doses (mGy), showing the predicted effects on the cumulative dose of several different countermeasures. Results are shown for occupational exposure in Building 3 and residential exposure in Building 5. (Vertical scales are linear and are not necessarily comparable.)

APPENDIX V. SUPPLEMENTARY MATERIAL ON REMEDIAL ACTIVITIES IN PRIPYAT

V.1. Information about remediation activities
B. Zlobenko

According to the principles of radiation safety, decontamination must ensure a reduction of doses, radioactive contamination density and radionuclide concentrations in the air of inhabited places and in the areas of an adjoining protective zone.

The necessity of separating decontamination procedures for populated areas is explained below:

- Significant non-uniformity of radioactive contamination even within the borders of one individual farm;
- Variety of decontaminated surfaces within the borders of one object (roof, walls, fences, road covers, gardens, etc.);
- Presence of the population and industrial activity on decontaminated territories;
- Absence of experience with complex decontamination of populated areas; and
- Absence of effective technical means of decontamination of the populated areas.

The industrial methods of decontamination and their efficiency can be compared with the methods used for decontamination of populated areas for the purpose of fulfilling investigations. However, one cannot help but notice that the significant volume of decontamination procedures executed in the inhabited locality for the first two years after the accident (1986–1988) by military junctions were inefficient and economically deficient.

The experience of efforts after the Chornobyl accident has shown that decontamination of the populated areas must be carried out in a complex manner, using various methods for vertical decontamination (crowns of trees, roofs, walls of houses, fences) and horizontal decontamination (territory).

In estimating the significance of decontamination processes, one must take into account, that reduction of radioactive contamination levels of objects can take place both due to decontamination and due to radioactive decay and such external factors as atmospheric fallout and air flow. Also, it needs to be mentioned that it is impossible to evaluate the decontamination works without considering such measures as dust removal and putting populated areas in good order.

V.1.1. Decontamination works in the Ukrainian inhabited localities

Tables V.1 and V.2 review the volumes of the complex works on decontamination that were carried out in the Ukrainian inhabited places during the period of 1986–1989.

Reduction of internal irradiation doses can be achieved mainly by the carrying out of Administrative-Organizing measures. It is possible to classify them as:

- Delivery of clean food products;
- Radiation control for the local food production;
- Provision of stable elements to reduce accumulation of the radioisotopes; and
- Education of the public on safe methods for growing, preparing and processing agricultural products received from personal farms.

Table V.1. Volumes of both decontamination and dust-suppression procedures in the inhabited places in 1986.

Name of works	**Quantity**
Decontamination:	
Dwelling-houses and municipal buildings	22 570
Courtyards	over 1500
Schools and children's establishments	455
Stock-farm premises	about 300
Streets in the inhabited places, km	over 10, 00
Removal of contaminated ground, m^3	over 300 000
Covering with asphalt for dust-suppression:	
roads, km	387
road-sides, km	37
territory (in Pripyat and Polissky), km^2	38 000
Treatment of roads and road-sides with dust-suppression materials, km	2377

Table V.2. Volume of complex works completed together with decontamination of inhabited places in 1986–1989.

Name of works	**Indications**
Replacement of roofs on houses and buildings	14 077
Wrecking and disposal of ramshackle houses, buildings	2145
Replacement of fences, km	590
Decontamination of houses and within doors	7300
Decontamination of wells	2143
Transportation of contaminated ground and rubbish, th m^3	447.5
Delivery of clean ground, th m^3	312.3
Sanitary cleaning on the area, mln km^2	1.4
Building of hard-paved roads, km	567
Transmission line wiring, km	776
Water communication setting, km	570

Since all the actions for reduction of internal irradiation doses result in elimination of polluted food products from use and radiation control of their quality, the main efforts ought to be directed toward decreasing external irradiation doses.

As a result of radioactive fallout, spreading of the contamination had occurred for elements of the ecosystem and for inhabited and subsidiary constructions, roads, and pastures. This fallout forms the external irradiation dose.

Analysis of the radiation situation and dose loads for the population shows that choice of methods for decontamination and radioactive waste management are defined mainly by means of a balance between technical facilities available and by material and human resources. So the choice of decontamination technology presents by itself a compromise problem of minimizing two parameters: material outlay and risk for population health from remaining contamination of decontaminated territory.

Farmstead territory together with all complexes of buildings is taken as a conditional unit of populated area decontamination. Agricultural activity is a component of human life; therefore, the final goal of decontamination is to achieve radiation contamination control levels which ensure the possibility of getting products fit for food without limitations.

If the contamination level of yard subsidiary buildings and wooden barriers exceeds the fixed level (Table V.3), they are not subjected to decontamination. Instead, the intent is to replace them.

Replacing the roofs of dwelling houses and buildings attached to them is stipulated by the project if beta-activity exceeds more than 200 particles/cm^2/min).

The most polluted areas of farmsteads are buildings for public use (farms, enclosures, workshops and others); the most polluted objects of public service are blind areas and drains.

According to the radiometric survey, some areas of farmsteads and kitchen gardens for public use in the villages were found to be the most contaminated places.

The project provided in detail for manual removal of contamination from blind areas around the houses and buildings of public use, as well as polluted soil places in some narrow parts, with further loading into containers. Soil and builders' refuse must be loaded from containers in the backs of cars and transported to LSWD (Local Site Waste Disposal) locations. Moreover, waste of organic origin is transported separately, since it is expected to require some different technology for its disposal.

On the completion of removal and transport of contaminated soil and materials from the courtyards and places of public use, ploughing ought to be done, or manual re-plough, if the mechanized equipment will not fit. Lime (5 t/ha, according to the calculation) is inserted simultaneously and potassium-phosphoric fertilizers (125 kg/ha) of each type.

The final stages of decontamination of populated areas included improvement of the farmsteads and places attached to them as well as places of common use, including delivery of clean soil for the blind area hollows, gravel (crushed stones) and asphalt for blind areas and courtyards, covering with asphalt, making barriers, recovering of roofs and taking down of constructions, sowing grass to create a turfy layer on the places of common use, as well as turfing of waysides.

Table V.3. Control power levels from gamma-radiation exposure and surface contamination with beta-radiation radionuclides.

No.	Objects of contamination	Level of contamination by beta-particles part./cm^2/min
1	Pre-school institutions for children, schools, medical and preventive establishments and equipment inside, food shops, enterprises of food industry and public food and equipment:	20
	Within the premises	20
	Territory and equipment	50
2	Objects of cultural-mass purpose, sport buildings and complexes:	
	Within the premises	30
	Territory and equipment	50
3	Inner surfaces of dwelling premises and subjects of personal use	50
4	Inner surfaces of service premises and outer surfaces of equipment inside	50
5	Open surfaces of the city territory and outer surfaces of buildings	200
6	Transport means and mechanisms:	
	Inner surfaces	50
	Outer surfaces	100

V.1.2. Decontamination of soil

Dust particles, rain drops and flow, and contaminated leaves obey the principles of gravity which lead them to reach the soil at the final stage of natural transport. The soil around houses, yards, roads and pavements was found to be a significant contributor to the doses.

Skim and burial ploughing: In the urban environment, the application of skim and burial ploughing would be restricted to large areas, such as parks. The plough skims off the topmost layer of soil (about 5 cm) and buries it at a depth of some 40–50 cm without inverting the intermediate layer. The removal of only about a 5 cm layer of topsoil rarely affects the fertility of the land, and poorer quality subsoil is not brought to the surface. Overall, the skim and burial ploughing process greatly reduces radiation levels at the ground surface, the resuspension hazard is eliminated, most of the contamination is made inaccessible to plant roots, and soil quality is unaffected. The effect of the procedure, which has been tested in the former USSR, has been found to be a reduction of the dose rate by some 94%, but in very sandy soils it may be difficult to achieve the objective with this method.

Triple digging: Triple digging is an excellent method to reduce the dose to people, both where the uptake to plants is considered, and for external dose reduction. This method can be used in gardens and other places where it is impossible or expensive to use skim and burial ploughing. It can be seen that if the initial contamination is in the uppermost 10 cm of soil, then the dose reduction factor will range from 0.08 to 0.5, depending on the size of the plot and the initial distribution.

The sequence of the decontamination processes will be dictated by the actual conditions of locality, by weather conditions, and by the standard order for realization of decontamination works on populated areas. The order of priorities for works to be fulfilled is represented in Table V.4.

In the early stages, when there were still many short-lived gamma emitters, the following were carried out on the most heavily contaminated land:

- Removal of the top layer of soil on the most contaminated plots of land and in the places most frequented by people;
- Decontamination of buildings; and
- Resurfacing (repaving) of roads, etc.

Decontamination works cost 28×10^6 rubles for 4 years (in scale 1990). In 1987–1990 the next countermeasures were carried out:

- Washing of walls, roofs, houses (2127 yards) – 95%;
- Removal of contaminated soils (450 yards – 3100 m^3) – 14%;
- Changing of roofs – 81%;
- Changing of fences (13.4 km) – 13%; and
- Repaving of roads – 12%.

In 1987, 1560 workers using more than 90 units of equipment carried out decontamination procedures in Polesskoe.

Tables V.5 and V.6 summarize the volumes of materials remediated and waste removed during the decontamination efforts.

Table V.4. Sequence of decontamination work.

No.	**Name of works to be fulfilled**	**Order of work priorities**
1	Interim technological site set-up in the populated areas for the road engineering to be localized, and determination of routes for the waste resulting from decontamination to be transported away	I
1	Decontamination of populated area 500 m protected zone	II
2	Decontamination of village inhabited area zone (except courtyards)	III
3	Fence disassembling	III
4	Roof dismounting	III
5	Pulling down of ramshackle and neglected buildings	III
6	Digging out of soil under the drains	IV
7	Digging out of soil with 40 $\mu R\ h^{-1}$ exposure rate	IV
8	Cleaning of wells	IV
9	Infield spading by hand	IV
10	Infield ploughing	IV
11	Clean soil delivery	V
12	Setting up the blind areas	V
13	Covering courtyards with asphalt	V
14	Trimming of streets and inside roads	VI
15	Digging out of radiation-contaminated soil along the streets and inside roads	VII
16	Ploughing of street surfaces, inside roads and adjoining areas	VIII
17	Accomplishment of streets (covering with asphalt and sod)	IX
18	Decontamination and re-cultivation of verified routes for the waste to be transported away	X
19	Assessment of radiation situation on the inhabited area territory	XI
20	Surface treatment with dust-coupling solutions	Operation is carried out before the work fulfillment

Table V.5. Waste volumes realized from decontamination-remediation works.

No.	Name of works	Volume of works		Volume of waste		Technical support
		units	quantity	units	quantity	
1	Contaminated soil 0.2 m depth to be taken away under the drains by hand	m^3/t	4798/6717	m^3/t	4798/6717	Minimal mechanization (shovels, barrows, containers, etc.)
2	Contaminated soil 0.2 m depth with ≥ 4.0 μSv/h of exposure rate to be taken away Including: by hand by cleaners	 m^3/t m^3/t m^3/t	 2383/3336 300/420 2083/2916	m^3/t	2388/3336	Minimal mechanization means Bulldozer; pneumatic-wheel oader
3	Cleaning of the contaminated silts from wells by hand	m^3/t	34/61	m^3/t	34/61	Minimal mechanization (shovels, hoist, bins, barrows, containers, etc.)
4	Some separate plots digging out by hand (gardens, small fruit plantations, etc.) with introducing simultaneously: Chalk – 5.0 t/ha potash salt – 0.125 t/ha superphosphate – 0.125 t/ha	ha t t t	19.88 99.4 2.485 2.485			By hand
5	Surface treatment by 10% SSD solution when replacing the fences, digging out the soil, replacing the roofs, taking down ramshackle houses, ploughing (1.0 L/m^2 is a specific discharge of 10% solution)	T	1800			Street-flushing car
6	Fence disassembling and setting	100 lm m^3/t m^2	226 1011/809 18705	m^3/t	1011/809	Auto-crane, Pneumatic-wheel loader
7	Roof dismounting	m^2/t	189/268	m^3/t	179/268	Auto-crane
8	Roof setting up	m^2/t	18 705/266			Auto-crane
9	Pulling down of ramshackle and neglected buildings	m^3/t	70/56	m^3/t	70/56	Auto-crane, Tip-lorry, bulldozer
10	Clean soil delivery	m^3/t	7181/10053			Tip-lorry, bulldozer
11	Blind area setting up Crushed stone delivery Asphalt delivery	m^2 m^3/t m^3/t	24 350 2435/4357 730.5/1314.9			Tip-lorry, bulldozer, pneumatic-wheel roller, machine for covering with asphalt, hand road-roller

Table V.5. Waste volumes realized from decontamination-remediation works (cont.).

No.	Name of works	Volume of works		Volume of waste		Technical support
		units	quantity	units	quantity	
12	Covering courtyards with asphalt Crushed stone delivery Asphalt delivery	m^2 m^3/t m^3/t	35 300 3530/6330 1059/1906.2			Tip-lorry, bulldozer, pneumatic-wheel roller, machine for covering with asphalt, hand road-roller
13	Infield ploughing for 0.3 m depth by T-4A tractor with introducing simultaneously: chalk – 5.0 t/ha potash salt – 0.125 t/ha superphosphate – 0.125 t/ha	ha t t t	81.85 413.85 14.52 14.52			Tractor, arrangement for additional fertilizing to be applied
14	Transportation of contaminated soils and building rubbish over 10 km distance	m^3/t	8475/11 247			Dump-truck, dust-cart
15	WASTES Including organic waste			m^3/t m^3/t	8475/11 247 1171/999	

Table V.6. Decontamination of protected zone, territories for general use.

No.	Name of works	Units	Volume	Technical support
1	Ploughing of protected zone (500 m) 0.3 m depth by T-4A tractor (96 kWt) with introducing to soil: chalk – 5.0 t/ha potash salt – 0.125 t/ha superphosphate – 0.125 t/ha	ha t t t	270 1350 33.75 33.75	ULP-8 arrangement for additional fertilizing to be applied
2	Ploughing 0.3 m depth of territories for general use by T-4A tractor (96 kWt) with introducing to soil: chalk – 5.0 t/ha potash salt – 0.125 t/ha superphosphate – 0.125 t/ha	ha t t t	40 200 5.0 5.0	ULP-8 arrangement for additional fertilizing to be applied
3	Cleaning 0.2 m depth of reservoir-sides from contaminated soils (silts)	m^3/t	2480/3968	Tractor. Excavator pneumatic-wheel
4	Contaminated soil removal 0.2 m depth from the ditches near roads	m^3/t	3660/5124	Excavator pneumatic-wheel
5	Transportation of contaminated soils to the point of waste disposal over 10 km distance	m^3/t	6373/9418	Dump-truck
6	Contaminated soil removal 0.2 m depth and 1.0 m wide under the drains near the buildings of public use (farms, stock-houses etc.)	m^3/t	233/326	By hand (shovels, hoist, bins, barrows, containers and etc.)
7	Delivery and setting of soil layer 0.2 m depth for reservoir-sides and river-sides etc.	m^3/t	2480/3968	Dump-truck, bulldozer
8	Transportation of disassembled fences to the place of disposal over 10 km distance	m^3/t	332/266	Dump-truck
9	Road slopes sodding with grass-mix introducing	t	0.3	Seeding machine

The most radical way for reduction of exposure dose in the school and pre-school establishments is realisation of the decontamination process. Decontamination was made by removal of the top soil layer to the depth of 20 cm manually and with the help of a bulldozer. The removed soil was transported to the RW Disposal Point. The radionuclide content in this soil did not exceed 400 Bq/kg. In detail the technology of decontamination procedures for the schools and the volume of completed operations are represented in Table V.7.

Table V.7. Technology of decontamination procedure for the schools.

No.	Operation	Unit	Number
1	Removal of the contaminated soil layer by hand	m^3	60
2	Removal of the contaminated soil layer by bulldozers and transportation for a distance of 10 m	m^3	131
3	Per extra 10 m	m^3	191
4	Loading of the soil into vehicles by excavators (0.25 m^3)	m^3	191
5	Transportation of the soil to the burial ground for a distance of no more than 5 km	ton	306
6	Uncontaminated soil exploitation by bulldozers in pits and transportation for a distance of 20 m	m^3	130
7	Loading of the soil into vehicles by bulldozers	m^3	130
8	Transportation of the soil for a distance of 1 km	ton	203
9	Distribution of the soil between trees by hand	m^3	40
10	Transportation of the soil by bulldozers for a distance of no more than 30 m	m^2	90
11	Vegetable soil exploitation by excavators and loading of the soil into vehicles	m^3	13
12	Transportation of the vegetable soil for a distance of no more than 1 km	ton	16
13	Distribution of the vegetable soil between trees by hand	m^3	13
14	Roller compaction of the soil	m^3	143
15	Mechanical land leveling	m^2	1190
16	Disassembling of asbestos-cement roof coverings	m^2	253
17	Replacement of asbestos-cement roof coverings	m^2	253
18	Loading of the roof coverings disassembled	m^3	5
19	Transportation to the burial ground for a distance of no more than 5 km	ton	6
20	Dosimetry	m^2	1419

V.2. Decontamination of settlements
V. Golikov

V.2.1. Basic data for estimation of decontamination effectiveness

Decontamination of settlements was one of the main countermeasures during the initial stage of accidental response. The purpose of settlement decontamination after the Chernobyl accident was the removal of radiation sources distributed in the urban environment inhabited by humans and transport of these sources to isolated or remote places.

The decontamination efficiency may be determined by means of the following parameters:

- **(DF – Decontamination Factor)** The efficiency of techniques in removing radioactivity from a surface. For example, a DF of 2 means that a reduction in contamination (alpha or beta/gamma activity) on the surface by a factor of 2 is seen following decontamination;
- **(DRF – Dose Rate Reduction Factor)** The reduction in gamma dose rate above a surface following decontamination. For example, a DRF of 5 means that, following decontamination, the dose rate 1 m above the surface is reduced by a factor of 5;
- **(DR – Dose Reduction)** The reduction in overall external exposure from deposited gamma-emitting material from all surfaces in the environment where an individual is located, taking into account any decontamination that has taken place. For example, a DF of 2 on roofs may result in a DR of 10% in the first year following deposition.

Information about the effectiveness of different decontamination technologies accumulated by the present time can be structured chronologically and by subjects in the following way:

(1) Results of laboratory and field investigations both before and after the Chernobyl accident, during which values of the DF and DRF have been determined for separate decontamination technologies for different surfaces and objects in the environment [V.1–V.3];

(2) Results of large-scale remediation on the decontamination of settlements in the territories of Russia, Ukraine and Byelorussia radioactively contaminated after the accident at the Chernobyl NPP. After doing these actions, values of the DR factor were obtained for the first time based not on calculations, but on measurements of the dose reduction effect for external exposure among different groups of the population [V.4]; and

(3) Results of a number of local field experiments (in 1989, 1990, 1995 and 1997) upon decontaminating small areas and buildings situated on these areas, in the countryside of Russia and Belarus [V.4–V.6].

The most interesting results pertaining to the first group have been published as a Riso report [V.7]. It constitutes a catalogue of achievable 'local' dose reduction factors or decontamination factors and other important parameters for different clean-up procedures in various types of environmental scenarios. The estimates were based on experimental work to assess the effect of dose reducing countermeasures in areas contaminated about 9 years ago by radioactive material released during the Chernobyl accident. However, it is very difficult on this background to get a clear view of the total dose-reducing effect (in terms of DR) of carrying out a whole series of countermeasures on different surfaces in the populated areas, as would be done in practice.

Large-scale decontamination was performed in 1986–1989 in cities and villages of the FSU most contaminated after the Chernobyl accident. This activity was performed usually by military personnel and included washing of buildings with water or special solutions, cleaning of residential areas, removal of contaminated soil, cleaning and washing of roads, and decontamination of open water supplies. Special attention was paid to kindergartens, schools, hospitals, and other buildings frequently visited by large numbers of persons. During the large-scale decontamination campaign in 1986–1989, about one thousand settlements were treated, tens of thousands of inhabited and social buildings, and more than a thousand agricultural farms. Depending on decontamination technologies, the dose rate over different visited plots was decreased by a factor of 1.5 to 15. But the high cost of this activity hindered the total cleaning of the whole settlement territory and especially its vicinity, fields, meadows, and forests, where a significant part of the population spends a lot of time. Due to these conditions, the actual effectiveness of the annual external dose decrease after removal of the upper soil layer around houses, social and production buildings usually was 10 to 20% for an average population, ranging from about 30% for children visiting kindergartens and schools to less than 10% for outdoor workers (herders, foresters, etc.). These data were confirmed by individual external dose measurements [V.4]. The averted collective external dose in 90 thousand inhabitants of the 93 most contaminated settlements of the Bryansk region in Russia due to large-scale decontamination in 1989 was estimated to be about 1 thousand man Sv [V.4].

In the early period of the accident, inhalation of resuspended radioactive particles of soil and nuclear fuel could significantly contribute to the internal dose. To suppress dust formation the method of dispersion of an organic solution over contaminated plots was chosen; this created an invisible polymer film after natural drying. This method was implemented on the Chernobyl NPP and in a 30 km zone during the Spring–Summer of 1986. Streets in cities were watered to prevent dust formation and to remove radionuclides in the sewerage system. The effectiveness of early decontamination efforts in 1986 still remains to be quantified. However, daily washing of streets in Kiev decreased the collective external dose to its 3 million inhabitants by 3000 man Sv, and decontamination of schools and school areas saved 600 man Sv.

The third data group contains the most interesting results from the point of planning the decontamination strategy in a remote period after radioactive fall-out. These data were obtained in the course of carrying out local decontamination of 3–5 houses and the surrounding territory in a rural areas of the Bryansk region (Russia) and Belarus 3–14 years after the radioactive fall-out [V.5, V.6]. The analysis of the results of this work leads to the following conclusions that have practical importance for choosing decontamination strategies and methods:

- 10 years after the radioactive fall-out, the main sources that define the external radiation dose rate outdoors are the contaminated areas of soil. The dose rate contributions from roads and trees practically disappear within the first five years;
- The main contributor to the dose rate inside the one-story houses was the contaminated soil around houses, but roofs also made a significant contribution, whereas radiation from the walls was comparatively insignificant; and
- More than 90% of the activity in soil is accumulated in the upper 10 cm layer.

V.2.2. List of recommended decontamination technologies

When planning decontamination activity, it is important to take into account the contribution of the external dose to the total dose. In areas where clay soil dominates, there is low transfer of cesium radionuclides along the food chain and consequently low internal dose; therefore, the relative decrease of the total dose is related to decontamination effectiveness. In contrast, in the peaty soil areas where long-term internal exposure dominates, a relative decrease of the total dose due to village decontamination is expected to be insignificant.

Following dry deposition, street cleaning, removal of trees and shrubs and digging the garden are efficient and inexpensive means of achieving very significant reductions in dose, and would rate highly in a list of priorities. Roofs are important contributors to dose, but the cost of cleaning roofs is high, and this would not rank as high in a list of priorities. Walls contribute little to dose, are expensive and difficult to decontaminate and would, therefore, carry a very low rating in a list of priorities.

In the case of wet deposition, gardens will be given first priority since a considerable reduction in dose (~60%) can be achieved at relatively low cost. Street cleaning would also be useful.

The priorities that different procedures would be given in a decontamination strategy would be greatly environment-specific. Nevertheless, based on the accumulated experience of the study of this problem, the following set of major decontamination procedures can be recommended:

(1) Removal of the upper 5–10 cm layer of soil (depending on the activity distribution with depth) in courtyards in front of residential buildings; around public buildings, schools and kindergartens; and from roadsides inside a settlement. The most contaminated layer of soil removed gets placed into holes specially dug on the territory of a private homestead land, or on the territory of a settlement when decontaminating the settlement as a whole. The clean soil (sand) from the dug holes gets used for covering decontaminated areas. Such technology excludes the formation of special burials of radioactive waste;

(2) Deep ploughing of territory with private fruit gardens (if they have not been ploughed up by this time), or removal of the upper 5–10 cm layer of the soil. By this time vegetable gardens have been ploughed up many times, and in this case the activity distribution in soil will be uniform in a layer 20–30 cm deep (it might be different in abandoned areas);

(3) Covering the decontaminated parts with a layer of “clean sand”, or, where possible, with a layer of gravel to diminish residual radiation (see item 1); and

(4) Cleaning the roofs or their replacement (the roof decontamination needs to be done before decontaminating surfaces below the roof).

This list of procedures can be applied both for decontaminating single private homestead lands and houses, and also for decontaminating settlements as a whole. It is evident that in the latter case the influence of the decontamination upon the further external radiation dose reduction will be greater. Achievable decontamination factors for various urban surfaces are presented in Table V.8. Detailed data on the efficiency, realisation technology, necessary equipment, cost and time expenses, quantity of radioactive waste, and other parameters of separate decontamination procedures are contained in the report [V.7].

Table V.8. Achievable decontamination factors for various urban surfaces.

Surface	Decontamination Method	Achievable Decontamination Factor
Windows	Washing	10
Walls	Sandblasting	10–100
Roofs	Hosing and/or sandblasting	1–100
Gardens	Digging	6
Gardens	Removal of surface	4–10
Trees and Shrubs	Cut back or remove	~10
Streets	Sweeping and vacuum cleaning	1–50
Streets (asphalt)	Planing	>100

V.2.3. Justification and optimization

In accordance with the present methodology of radiation protection, a decision on intervention (decontamination) and selection of an optimal decontamination technology needs to be made after calculating costs of all the actions and social factors. Calculated cost of actions relates to various decontamination technologies for which the assessment of the averted dose has been made. Benefit (averted collective effective dose) and detriment (expenses, collective dose of decontamination workers) are also compared for each decontamination technology with the accepted cost of one man Sv [V.8] or by means of multi-factorial analysis [V.9]. If the projected value of net effects of decontamination for all the considered technologies is positive, the application of these protection measures have be considered of value.

The list of decontamination procedures provided below was prepared primarily by J. Roed (Risø, Denmark) within IAEA TC Project RER/9/059 ”Reducing External Exposure Doses in Contaminated Villages” [V.10]. References to a “separate Chapter” mean a chapter in that report.

Name of countermeasure	Topsoil removal by machines (e.g., 'bobcat')
Countermeasure description	It is generally expected that much of an airborne caesium deposition to soil will for several years remain distributed in the upper few centimetres of the soil profile. Gamma spectrometric analysis of soil core sample sections shows how deep a layer needs to be removed to maximise dose reduction with minimal impact on soil fertility and to create a minimum amount of waste. The removal may be carried out by 'bobcat' mini-bulldozers (easy to manoeuvre in small areas) or similar available equipment.
Targeted surface type / scale of application	Grassed areas and other areas of soil. The effect is highest if the soil has not been tilled since contamination. Can be carried out in large scale where equipment is available.
Time of application (number of days after deposition, season, etc.)	Even after a decade can save a significant fraction of the 70 y dose.
Practicability:	
– Required equipment and remedies	'Bobcat' or bulldozer. Also waste transport truck to repository and machinery for constructing repository, dependent on waste action scheme.
– Required consumables and other infrastructural elements	Petrol, roads to repository.
– Required man-power skills	Local entrepreneurs or municipal workers who have the required skills/routine, and could, if necessary, instruct others. Care must be taken to remove soil to the optimal depth and not 'plough' the contamination into the clean surface.
– Required operator safety precautions	Under dusty conditions respiratory protection and protective clothes may be recommended.
– Other potential restrictions on practicability	In some cases frost may be a restriction.
Costs (excluding waste):	
– Costs of equipment and remedies	'Bobcat' (ca. 40 000 EURO), larger bulldozer (ca. 90 000 EURO) or Belarusian front loader (22 000 EURO).
– Costs of consumables	Ca. 0.04 L m^{-2} of petrol (excluding waste transport) at current cost per litre.
– Operator time consumption	Typically some 5–10 man-days per ha, excluding waste transport and work at repository.
– Factors influencing costs	Depth of soil layer to be removed. Distance to equipment, consumables and repository. Soil type and conditions, area size, shape, topography, vegetation, operator skills.
Effectiveness (DF or 'surface' DRF):	
– 'Likely' countermeasure effectiveness	DF: ca. 10–30 if optimised according to contaminant distribution in soil. Corresponding to DRF: > 10–30

– Factors influencing effectiveness	Optimisation of thickness of removed soil layer (operator skills). Evenness of ground surface. Vertical Cs distribution homogeneity. Soil texture. Time (downward migration of Cs in soil).
Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter
– Extra dose/risk	Over a limited period the operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area. The collective dose to the operators, however, is much lower than that to the population.
– Factors influencing averted dose	Consistency in carrying out the procedure over a large area.
Waste:	
– Amount and type	If 5 cm topsoil is removed, this produces a waste corresponding to some 70 kg m^{-2}.
– Possible transport, treatment and storage routes.	See separate Chapter
– Specific waste problems	Transport and deposit of large amounts.
– Waste scheme cost estimate	See separate Chapter
Environmental impact	Possible (partial) loss of soil fertility and bio-diversity. Soil erosion. May in some soils remove the entire fertile layer. Requires fertilisation / replanting. Adverse esthetical effect of treatment.
Other side effects, positive or negative	–
State of testing/acceptability	Tested in semi-large scale (ca. 2000 m^2) on several occasions in the CIS.
Key references	[V.6] ,[V.7], [V.11], [V12]

Name of countermeasure	High pressure water hosing of walls
Countermeasure description	Using pressure-washing equipment, water may be applied to a wall at a pressure of some 150 bar. This will loosen contamination from the wall and wash it off. A continuous water flow needs to be applied on the wall to transport contamination to the ground. The washing must start at the top of the wall. Alternatively, fire-hosing at hydrant pressure may be applied instead, with considerably less effect.
Targeted surface type / scale of application	Highly contaminated outer walls of buildings.
Time of application (number of days after deposition, season, etc.)	The immediate effect (DF) may decrease with time of application.
Practicability:	
– Required equipment and remedies	Hose pipe, turbo nozzle, mobile pressure washer (typical weight ca. 80 kg), and transport vehicle. Scaffolds or mobile lifts for tall buildings.
– Required consumables and other infrastructural elements	Water supply (water may be pumped from a lake or a stream if tap/hydrant is not available). Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for equipment transport vehicle.
– Required man-power skills	Special firms dealing with decontamination normally have the skill. The experience of the local fire brigade may also be exploited, but also less skilled personnel (e.g., house owners) can carry out the job with only a little instruction.
– Required operator safety precautions	For tall buildings: lifeline. Water proof safety clothing recommended. Due to the water there will be very little dust.
– Other potential restrictions on practicability	Walls must be water-resistant.
Costs (excluding waste):	
– Costs of equipment and remedies	Cost of mobile pressure washer with turbo nozzle: typically ca. 3000 EURO. (Or fire-hosing equipment ca. 1000 EURO). Variable costs for scaffolding/lifts according to need.
– Costs of consumables	Ca. 20 L per m^2 of water for mobile pressure washing or fire-hosing; power: typically 380 V at 12 A (with petrol-driven generator: ca. 4 L of petrol per hour) and petrol for equipment transport; at current prices.
– Operator time consumption	Pressure washing: Ca. 1–2 min. per m^2 (fire-hosing: 0.1–0.2 min. per m^2) plus variable time for setting up scaffolds/transport.
– Factors influencing costs	Need for scaffolds /mobile lifts, operator skills.
Effectiveness (DF or 'surface' DRF):	
– 'Likely' countermeasure effectiveness	Expected DF: 1.5–4. The lower values relate to fire-hosing, the higher to high pressure washing.

– Factors influencing effectiveness	The procedure followed. Amount of water/time used and pressure. Increased water temperature (60–80 °C) increases the effect especially on painted or dirty surfaces. Somewhat higher effect on painted walls, but otherwise, wall material generally has little influence.
Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter
– Extra dose/risk	The operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area. Collective dose to the operators, however, is low compared to the collective dose to the affected population.
– Factors influencing averted dose	Consistency in procedure application, care taken to wash contamination to the ground and not just translocate on the wall. The horizontal surface below the wall must ideally be treated *afterwards*.
Waste:	
– Amount and type	Generates some 20 L m^{-2} of liquid waste, and ca. 0.4 kg m^{-2} of solid waste containing nearly all contamination.
– Possible transport, treatment and storage routes.	None possible.
– Specific waste problems	Waste is in practice impossible to collect.
– Waste scheme cost estimate	Costs of contamination of underlying horizontal surface (incorporated in strategy).
Environmental impact	If no drain, the water may damage basements
Other side effects, positive or negative	Cleaning of buildings.
State of testing/acceptability	Tested on a number of single house walls in CIS and Sweden.
Key references	[V.1], [V.7], [V.11], [V.13]

Name of countermeasure	Road planing
Countermeasure description	Road planing, using machines applied by the asphalt industry, removes a thin top layer (ca. 1 cm) of an asphalted road surface in ca. 2 m wide 'tracks'. The grinding is usually accomplished by a rotating 'drum' with grinding picks. Machines are often equipped with a rotating brush device for debris collection to a truck. If not, machine or manual sweeping must be added. As penetration of contaminants in asphalt will be negligible, nearly all contamination can be removed in this way. Similar effect on concrete roads.
Targeted surface type / scale of application	Contaminated asphalt (or concrete) roads.
Time of application (number of days after deposition, season, etc.)	Decontamination effectiveness depends on the amount of traffic. (Decrease in contamination level by factor of 3 over first year for heavily trafficked roads has been observed). The method is effective 15 years after the accident on lightly trafficked roads.
Practicability:	
– Required equipment and remedies	'Professional' road planer (alternatively, small planers may be used, e.g., mounted on a mini-bulldozer, though these are much more time consuming). Also waste transport truck and machinery for constructing repository must be available.
– Required consumables and other infrastructural elements	Diesel. Roads to repository.
– Required man-power skills	4 operators (skilled workers from a contractor company).
– Required operator safety precautions	Casing protects operators against loosened debris. In strongly contaminated areas respiratory protection may be recommended.
– Other potential restrictions on practicability	If the road surface is very arched the grinding depth may have to be great.
Costs (excluding waste):	
– Costs of equipment and remedies	'Professional' road planer (ca. 70 000 EURO)
– Costs of consumables	Ca. 8 L h^{-1} of diesel (excluding waste transport) at current cost per litre.
– Operator time consumption	Typically the procedure is carried out at a speed of 1000 $m^2 h^{-1}$, and requires 4 workers. In addition: time consumption for waste collection/transport and work at repository.
– Factors influencing costs	Evenness and condition of roads (required grinding depth), planer size, sweeping device, distance to equipment and consumables, topography, operator skills, resurfacing (normally not necessary).
Effectiveness (DF or 'surface' DRF):	
– 'Likely' countermeasure effectiveness	DF: 5–10 expected (if loose debris is carefully removed).

– Factors influencing effectiveness	Homogeneity of treatment, evenness and condition of roads in relation to grinding depth, operator skills.
Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter.
– Extra dose/risk	Depends on short-lived radionuclides (time). Over a limited period the operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area (see also separate Chapter).
– Factors influencing averted dose	Time of application after accident. Consistency in carrying out the procedure over a large area. Measures taken to protect operators against inhalation, where required.
Waste:	
– Amount and type	If a 1 cm deep layer is removed, this produces some 15 kg m^{-2} of solid waste.
– Possible transport, treatment and storage routes.	See separate Chapter.
– Specific waste problems	Collection, transport and deposit of large amounts of solid waste.
– Waste scheme cost estimate	See separate Chapter.
Environmental impact	Toxicity of waste to be considered at repository.
Other side effects, positive or negative	The road surface is planed.
State of testing/acceptability	Tested in small scale in the CIS, pre-Chernobyl tests in USA.
Key references	[V.6], [V.7], [V.14], [V.15[

Name of countermeasure	Triple digging
Countermeasure description	It is generally expected that much of an airborne Cs deposition to soil will for several years remain distributed in the upper few centimetres of the soil profile. The order of three vertical layers of soil is changed manually (by spade). The thin top layer (ca. 5–10 cm (optimised according to contamination depth) carrying nearly all contamination is buried in the bottom, with the vegetation (turf) facing down. The bottom layer (ca. 15–20 cm) is placed on top of this, and the intermediate layer (ca. 15–20 cm), which needs to not be inverted, is placed at the top. Thereby the contamination is shielded against, and impact on fertility is minimised.
Targeted surface type / scale of application	Grassed areas and other areas of soil. The effect is higher if the soil has not been tilled since contamination. Can be carried out in garden areas by house owners.
Time of application (number of days after deposition, season, etc.)	Even after a decade can save a significant fraction of the 70 y dose. Not possible during periods of frost.
Practicability:	
– Required equipment and remedies	Spades and in some cases shovels (with very loose soil /sand digging would partly be carried out from the side of the trench). Readily available in many households.
– Required consumables and other infrastructural elements	–
– Required man-power skills	Can be carried out by local inhabitants given instruction.
– Required operator safety precautions	None
– Other potential restrictions on practicability	High groundwater level. The method involves 'hard' work, not all can carry out.
Costs (excl. waste):	
– Costs of equipment and remedies	Spades: ca. 15 EURO.
– Costs of consumables	–
– Operator time consumption	Ca. ½ hour per m^2.
– Factors influencing costs	Individual work rates, soil type and conditions (e.g., moisture, season), vegetation, topography.
Effectiveness (DF or 'surface' DRF):	
– 'Likely' countermeasure effectiveness	'Surface' DRF: ca. 5–10, if optimised according to contaminant distribution in soil.
– Factors influencing effectiveness	Soil type and conditions ('Loose' soil will be more difficult to treat optimally). Optimisation of layer depths. Vertical Cs distribution homogeneity. Time (downward Cs migration in soil).

Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter
– Extra dose/risk	The operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area. Collective dose to the operators is low compared to the collective dose to the affected population.
– Factors influencing averted dose	Consistency in carrying out the procedure over a large area.
Waste:	
– Amount and type	None
– Possible transport, treatment and storage routes.	–
– Specific waste problems	None
– Waste scheme cost estimate	–
Environmental impact	The procedure brings contamination closer to the groundwater. Caesiums will however normally be very strongly bound. Possible (partial) loss of soil fertility and bio-diversity. Soil erosion risk. Adverse esthetical effect of treatment.
Other side effects, postive or negative	Severely complicates subsequent *removal* of the contamination.
State of testing/acceptability	Tested several times after the Chernobyl accident, in ca. 100–200 m^2 plots in CIS.
Key references	[V.1], [V.7], [V.11], [V.16]

Name of countermeasure	Roof cleaning by cleaning device
Countermeasure description	Rotating brush driven by pressurised air at 700 L min^{-1} (water at ordinary mains pressure). Cleaning is performed in a closed (shielded) 'box' system. The device is mounted with an extendible rod that allows operation from the top of the roof or from the ground below single-storey buildings.
Targeted surface type / scale of application	Contaminated roof. Applicable at large scale, if device is available.
Time of application (number of days after deposition, season, etc.)	Even after a decade may save a significant fraction of the 70 y dose, depending on roof type (material).
Practicability: Feasibility??	
– Required equipment and remedies	Roof cleaning device (+mobile air compressor for generating pressurised air, if not locally readily available), scaffolds or mobile lifts for operation from the roof. Also waste transport truck to repository and machinery for constructing repository must be available.
– Required consumables and other infrastructural elements	Water (and e.g., petrol for portable compressor if required). Petrol for equipment/ waste transport, roads to repository.
– Required man-power skills	Can be carried out by one (but more easily by two) unskilled workers given little instruction. Workers could be from specialised firms, but also, e.g., house owners, fire brigade, or civil defense.
– Required operator safety precautions	Lifeline. Water proof safety clothing recommended. As the cleaning is carried out in wet medium the dust (inhalation) hazard is negligible.
– Other potential restrictions on practicability	–
Costs (excluding waste):	
– Costs of equipment and remedies	Roof cleaning device (ca. 6000 EURO), (+ 1–2000 EURO for mobile compressor if required and variable costs for scaffolding/lifts according to need).
– Costs of consumables	13 L m^{-2} of water (and, e.g., 5 L petrol per hour for mobile compressor), at current prices.
– Operator time consumption	Estimated to ca. 4–8 minutes per m^2 depending on number of operators (1 or 2), excluding waste transport and work at repository.
– Factors influencing costs	Need for scaffolds /mobile lifts, need for mobile compressor, operator skills.
Effectiveness (DF or 'surface' DRF):	
– 'Likely' countermeasure effectiveness	DF of 2–10 expected (lowest value for eternite, clay and concrete roofs, highest value for silicon-treated eternite, and possibly even higher for aluminium/ iron).

– Factors influencing effectiveness	Contaminant aerosol type (size, solubility). Amount of water/time used. Increased water temperature (60–80 °C) may increase effect slightly on dirty surfaces. Roof material (see above), operator skills. The contamination will become somewhat more fixed after some months.
Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter.
– Extra dose/risk	Depends on short-lived radionuclides (time). Over a limited period the operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area (see also separate Chapter).
– Factors influencing averted dose	That also *neighbouring* roofs in the area are treated. Special care must be taken to clean roof gutters and drain pipes well.
Waste:	
– Amount and type	Typically some 0.2 kg m^{-2} of solid waste in 13 L m^{-2} of water.
– Possible transport, treatment and storage routes.	After filtration in a simple filter the water can be recycled on the roof. See also separate Chapter.
– Specific waste problems	Solid waste can not be avoided. Waste is impossible to collect without roof gutters – then ground below roof needs to be treated *after* the roof.
– Waste scheme cost estimate	See separate Chapter
Environmental impact	Solid waste toxicity problem if asbestos roof.
Other side effects, postive or negative	Moss, algae and dirt are removed from roof.
State of testing/acceptability	Tested on several roofs in the CIS contaminated by the Chernobyl accident.
Key references	[V.1], [V.5], [V.7], [V.12]

Name of countermeasure	Skim-and-burial ploughing
Countermeasure description	It is generally expected that much of an airborne Cs deposition to soil will for several years remain distributed in the upper few centimetres of the soil profile. A skim coulter on the plough first places the upper 5 cm of soil in a trench made by the main ploughshare. In one movement, the main ploughshare then digs a new trench and places the lifted subsoil on top of the thin layer of topsoil in the bottom of the trench of the previous run. The skim coulter simultaneously places the top layer from the next furrow in the new trench, etc. Thereby the contamination is shielded against, and impact on fertility is minimised.
Targeted surface type / scale of application	Grassed areas and other areas of soil, which have not been tilled since contamination. Ploughs are not readily available, but can be supplied over a period of a few years.
Time of application (number of days after deposition, season, etc.)	Even after a decade can save a significant fraction of the 70 y dose. Not possible during periods of frost.
Practicability:	
– Required equipment and remedies	Tractor and skim-and-burial plough
– Required consumables and other infrastructural elements	Petrol.
– Required man-power skills	Can be carried out by farmers who are experienced with ploughing, but the objective must be carefully explained.
– Required operator safety precautions	Under very dusty conditions respiratory protection and protective clothes may be recommended.
– Other potential restrictions on practicability	High groundwater level. In sandy soil the performance of the plough may be less ideal. Application of fertilisers may be called for.
Costs (excluding waste):	
– Costs of equipment and remedies	European tractor: ca. 50 000 EURO. Tractor produced in Belarus named “Belarus” 15 000; Plough: ca. 4000 EURO.
– Costs of consumables	Petrol: ca. 15 L ha^{-1}.
– Operator time consumption	Ca. 3 h per ha^{-1} (one operator).
– Factors influencing costs	Individual work rates, soil type and conditions (e.g., moisture, season), vegetation, topography.
Effectiveness (DF or 'surface' DRF):	
– Countermeasure effectiveness	Surface DRF: ca. 6–15, if optimised according to contaminant distribution in soil.
– Factors influencing effectiveness	Soil type and conditions ('Loose' soil will be more difficult to treat optimally). Optimisation of layer depths. Vertical Cs distribution homogeneity. Time (downward Cs migration in soil).

Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter
– Extra dose/risk	Over a limited period the operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area.
– Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Measures taken to protect operators against, e.g., inhalation, and contamination of skin/clothes, where required.
Waste:	
– Amount and type	None
– Possible transport, treatment and storage routes.	–
– Specific waste problems	None
– Waste scheme cost estimate	–
Environmental impact	The procedure brings contamination closer to the groundwater. Cs will however normally be very strongly bound. Possible (partial) loss of soil fertility and bio-diversity. Soil erosion risk. Future restriction on land use: should not be deep-ploughed. Adverse aesthetical effect of treatment (e.g., in parks).
Other side effects, positive or negative	Severely complicates subsequent *removal* of the contamination.
State of testing/acceptability	Tested several times after the Chernobyl accident, in CIS and in Denmark (typically in 1000–2000 m^2 areas).
Key references	[V.1], [V.6], [V.13], [V.17]

Name of countermeasure	**Roof cleaning by roof cleaning trolley**
Countermeasure description	Rotating nozzles are driven by hot water (ca. 65 °C) at high pressure (typically ca. 150 bar). Cleaning is performed in a closed (shielded) 'box' system. The device is mounted on a trolley that can be drawn up and down on a roof. Operated from the top of the roof – lowered using the pressure hose.
Targeted surface type / scale of application	Contaminated roof. Applicable at large scale, if device is available.
Time of application (number of days after deposition, season, etc.)	Even after a decade may save a significant fraction of the 70 y dose, depending on roof type (material).
Practicability:	
– Required equipment and remedies	Roof cleaning trolley (+high pressure hot water generator), scaffolds or mobile lifts for operation from the roof. Also waste transport truck to repository and machinery for constructing repository must be available.
– Required consumables and other infrastructural elements	Water (and, e.g., petrol for heating and generating pressurised water). Petrol for equipment/ waste transport, roads to repository.
– Required man-power skills	Carried out by two (unskilled) workers (one on the rooftop and one on the ground administrating supplies (given little instruction). Workers could be, e.g., house owners, fire brigade, civil defense, or professional roof workers.
– Required operator safety precautions	Lifeline. Water proof safety clothing recommended. As the cleaning is carried out in wet medium the dust (inhalation) hazard is negligible.
– Other potential restrictions on practicability	–
Costs (excluding waste):	
– Costs of equipment and remedies	Roof cleaning trolley (ca. 500 EURO), (+ 37 500 EURO for hot water high pressure aggregate and variable costs for scaffolding/lifts according to need).
– Costs of consumables	30 L m^{-2} of water (and, e.g., 8 L petrol per hour), at current prices.
– Operator time consumption	Estimated to ca. 10 minutes per m^2 for each of 2 workers, excl. waste transport and work at repository.
– Factors influencing costs	Need for scaffolds /mobile lifts, operator skills.
Effectiveness (DF or 'surface' DRF):	
– 'Likely' countermeasure effectiveness	DF of 3 expected
– Factors influencing effectiveness	Contaminant aerosol type (size, solubility). Amount of water/time used. Roof material (see above), operator skills. The contamination will become somewhat more fixed after some months.

Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter.
– Extra dose/risk	Depends on short-lived radionuclides (time). Over a limited period the operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area (see also separate Chapter).
– Factors influencing averted dose	That also *neighbouring* roofs in the area are treated. Special care must be taken to clean roof gutters and drain pipes well.
Waste:	
– Amount and type	Typically some 0.2 kg m^{-2} of solid waste in 30 L m^{-2} of water.
– Possible transport, treatment and storage routes.	After filtration in a simple filter the water can be disposed of.
– Specific waste problems	Solid waste can not be avoided. Waste is in practice impossible to collect without roof gutters – then ground below roof must be treated *after* the roof.
– Waste scheme cost estimate	See separate Chapter
Environmental impact	Solid waste toxicity problem if asbestos roof.
Other side effects, positive or negative	Moss, algae and dirt are removed from roof.
State of testing/acceptability	Tested on a roof in the CIS contaminated by the Chernobyl accident.
Key references	[V.10]

Name of countermeasure	Normal digging to 30 cm (manual)
Countermeasure description	It is generally expected that much of an airborne Cs deposition to soil will for several years remain distributed in the upper few centimetres of the soil profile. Therefore, if the top layers of the soil are dug to a depth of 15–20 cm and it is attempted to bring the turf to the bottom of this vertical profile, a significant shielding against radiation from the contaminants is provided.
Targeted surface type / scale of application	Grassed areas and other areas of soil, which have not been tilled since contamination. Can be carried out in garden areas by house owners.
Time of application (number of days after deposition, season, etc.)	Must generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Even after a decade can save a significant fraction of the 70 y dose. Not possible during periods of frost.
Practicability:	
– Required equipment and remedies	Spades. Readily available in many households.
– Required consumables and other infrastructural elements	–
– Required man-power skills	Can be carried out by local inhabitants given only little instruction.
– Required operator safety precautions	Under very dusty conditions respiratory protection and protective clothes may be recommended.
– Other potential restrictions on practicability	High groundwater level. The method involves 'hard' work, not all can carry out.
Costs (excluding waste):	
– Costs of equipment and remedies	Spades: ca. 15 EURO.
– Costs of consumables	–
– Operator time consumption	Ca. 15 minutes per m^2.
– Factors influencing costs	Individual work rates, soil type and conditions (e.g., moisture, season), vegetation, topography.
Effectiveness (DF or 'surface' DRF):	
– Likely countermeasure effectiveness	DRF: typically ca. 2–4.
– Factors influencing effectiveness	Soil type and conditions ('Loose' soil will be more difficult to treat optimally).
Doses:	
– Fractional averted dose in 'typical' environments	See separate Chapter

– Extra dose/risk	Depends on short-lived radionuclides (time). Over a limited period the operator dose contribution from external radiation could be up to 2–3 times as great as that to individuals living in the contaminated area (see also separate Chapter).
– Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes, where required.
Waste:	
– Amount and type	None
– Possible transport, treatment and storage routes.	–
– Specific waste problems	None
– Waste scheme cost estimate	–
Environmental impact	Adverse esthetical effect of treatment.
Other side effects, positive or negative	Severely complicates subsequent *removal* of the contamination and make a triple digging procedure considerably more difficult.
State of testing/acceptability	Tested in CIS after the Chernobyl accident.
Key references	[V.1], [V.7], [V.14]

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