وزارة العلوم و التكنولوجيا
Ministry Of Science & Technology

IDP
IRAQI DECOMMISSIONING PROGRAMME

Decommissioning of Destroyed Nuclear Facilities and Sites in Iraq

Workshop on Safety Assessment for Decommissioning
Denmark, 4 to 8 Oct. 2010

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Iraqi Decommissioning Programme
October, 2010

INTRODUCTION

- ✓ Al-Tuwaitha Nuclear Research Site (20 km to the south of Baghdad) was established in the 1960's and grew to include three reactors and facilities for nuclear fuel fabrication, radiochemistry, uranium enrichment, radioactive waste treatment, and biological research.
- ✓ In addition to the facilities at Al-Tuwaitha Nuclear Research Site, Iraq's former nuclear facilities included operations at several other sites.
- ✓ In 1991 war, the IRT-5000 reactor, the Tammuz-2 reactor and the majority of the other facilities were bombed and disabled. This followed the 1981 bombing of the Tammuz-1 reactor. Although the nuclear facilities remained inoperative after 1991, Al-Tuwaitha site was used for storage of nuclear materials between 1992 and 2003.
- ✓ Iraqi citizens have long been concerned about the environmental impacts and health consequences of the radiological contamination remains in the former nuclear program.

Photo montage of some of the existing facilities requiring decommissioning in Iraq

Current Status of Decommissioning

The following nuclear facilities were chosen as low radiological risk facilities to be decommissioned first as a short term decommissioning plan starting from Jan. 2008 till Dec. 2010. These are:

- ✓LAMA Nuclear Facility
- ✓Geo. Pilot Plant Site
- ✓Italian Radioisotope production lab.
- ✓Addressing the scrap at Al-Tuwaitha site
- ✓Controlling and monitoring the radioactive liquid waste tanks at Al-Tuwaitha site

LEGAL AND REGULATORY FRAMEWORK

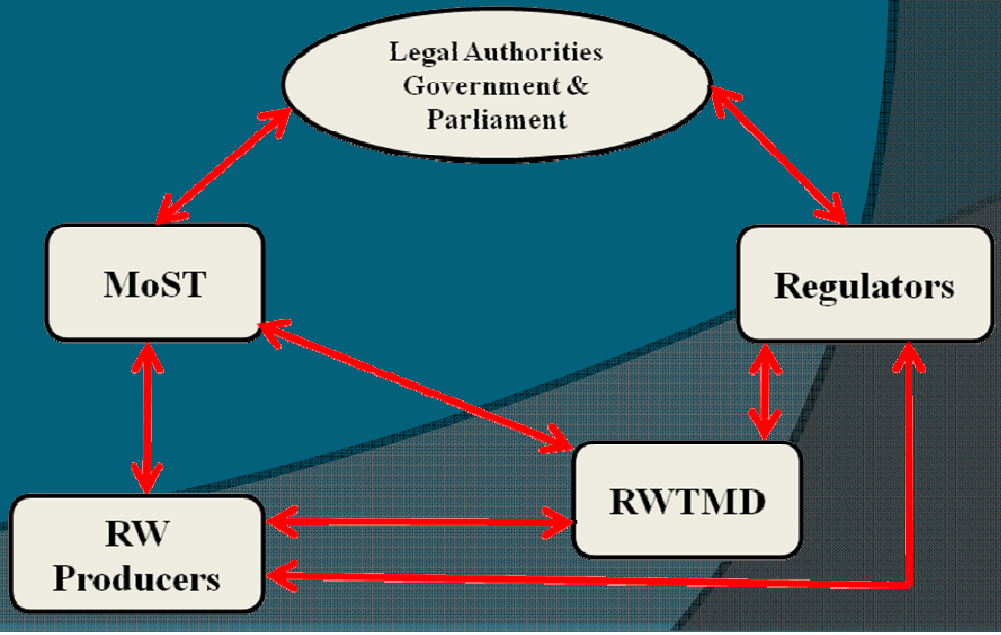
Two national laws exist in Iraq. These are:

- ✓ Law 99, issued in 1980 "Protection from Ionizing Radiation Law". This law is regulated by the Radiation Protection Center (RPC)/Ministry of Environment.
- ✓ Order No. 72 issued in 2004 to establish IRSRA "Iraqi Radioactive Sources Regulatory Authority". This order is regulated by IRSRA.

These two laws do not cover the requirements for decommissioning nuclear facilities and radioactive waste management.

Both laws shall continue in force until new nuclear laws are enacted.

Regulatory organization chart



Decommissioning Plan

- The decommissioning plan for the IDP is currently under development.

Characterization Survey

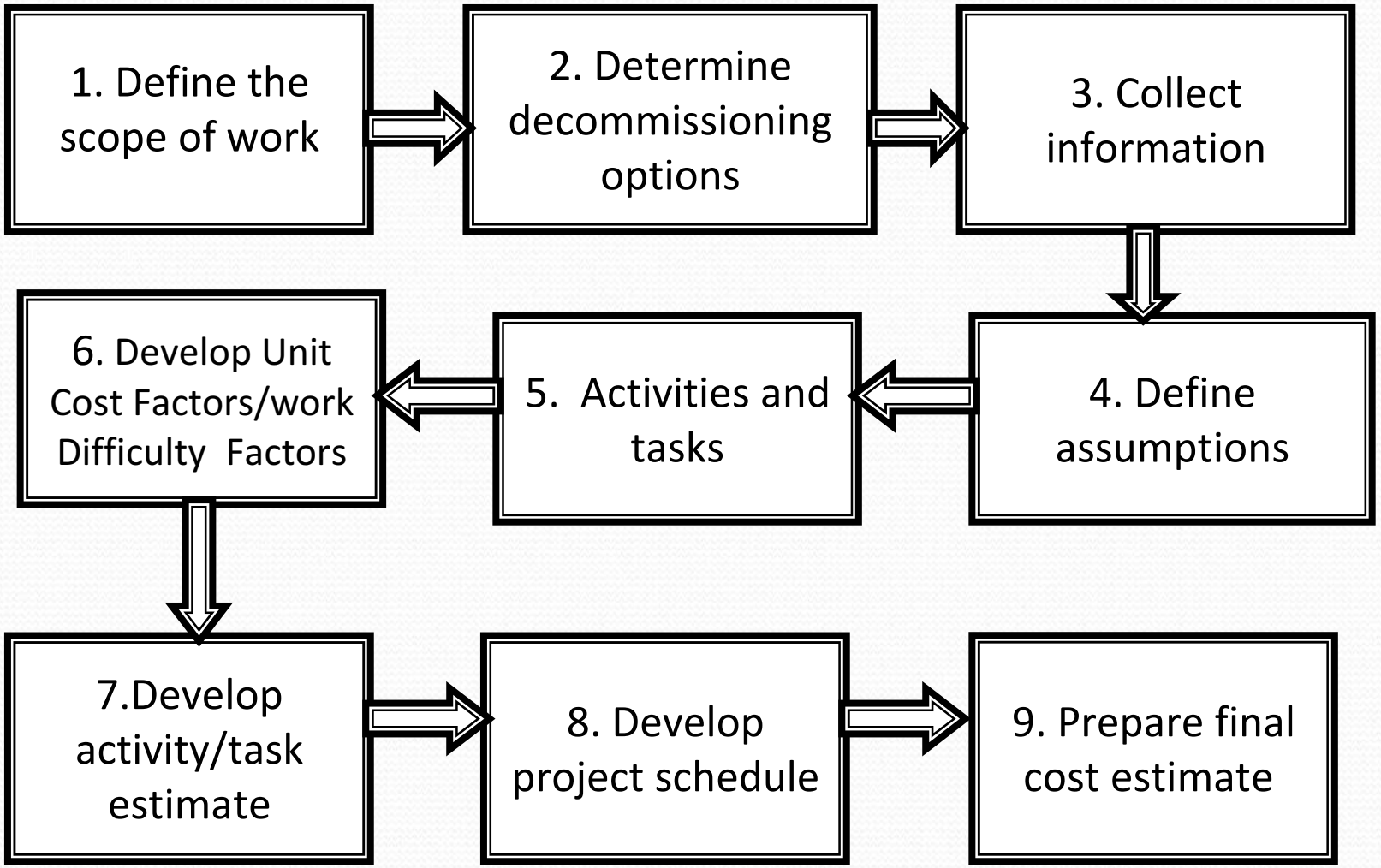
- ✓ Facility-specific characterization plans describe the processes of gathering existing data, identifying conditions, defining requirements, performing sampling, measuring, analyzing, documenting the data and interpreting the results.
- ✓ Physical characterization involves an inspection of the facility by observers with sufficient experience to detect hazards and identify the arrangements required for protection against any abnormal radiological or conventional conditions. The purpose of such an examination is to document the current state of the facility through photographs, videos, maps and diagrams that may help determine what hazards are present.
- ✓ Hand-held and laboratory analysis instruments are used to provide a detailed information about contaminant's extent, nature, concentration, hot spots location and determine borders and depth of contamination.

Budget and Finance

- ✓ The budgeting system that will be applied for the decommissioning projects follows the governmental accounting system which is used by all the Iraqi ministries.
- ✓ The budget of the Iraqi Decommissioning Programme (IDP) is funded by the Iraqi government through the investment project (decommissioning of destroyed nuclear facilities and sites in Iraq).
- ✓ The manager of nuclear facilities decommissioning center and the decommissioning project manager are responsible for identifying the funds needed to perform the decommissioning project according to the decommissioning plan.

Cost Estimate for Decommissioning Projects

Cost estimating mechanism

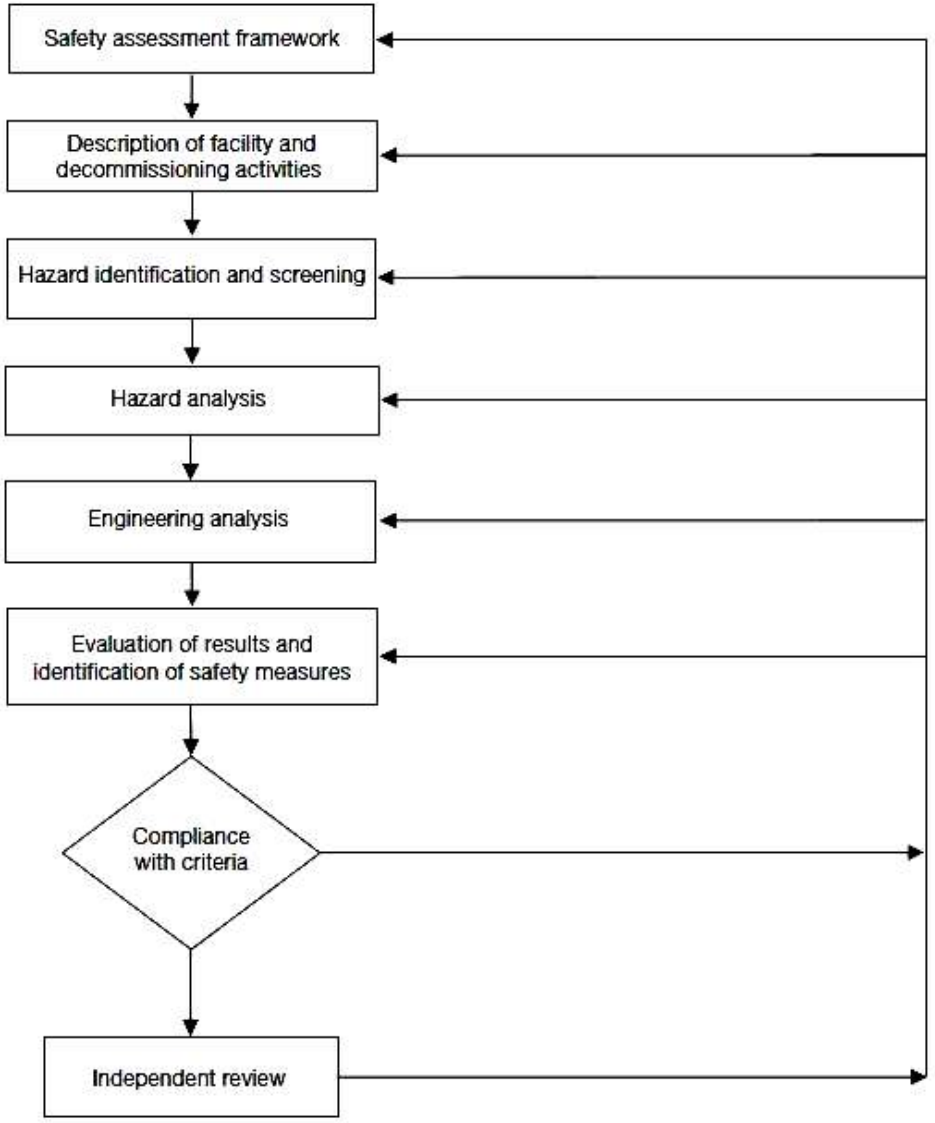


Decommissioning Techniques

- ✓ Heavy concrete structures are dismantled using diamond wire cutting technique.
- ✓ The equipments, walls and floors are radiologically characterized before performing any dismantling activity.
- ✓ The basement structure will be used for clean rubbles storage.
- ✓ The generation of radioactive waste is minimized through performing decontamination activities.
- ✓ All the hazardous materials resulted from dismantling processes are segregated, containerized and relocated into a transitional accumulation zone.

Safety Assessment

The safety assessment is an evaluation of the potential hazards associated with the implementation of the decommissioning activities and their potential consequences, includes a risk assessment specific to the proposed activities.



Safety Assessment Goals (I)

An appropriate safety assessment is performed with the following objectives:-

1- Demonstrate that exposure of the site workers and of the public are as low as reasonably achievable (ALARA) and do not exceed the relevant limits or constraints.

2- Control the radiation exposure of people and the release of radioactive materials to the environment.

3- Provide guidance on a systematic methodology for the evaluation of radiological consequences for workers, the public and the environment of planned activities and of potential accidents during decommissioning.

4- Address Non-radiological hazards to site workers, the public and the environment.

Safety Assessment Goals (II)

5- Assess the quality and extent of the protection and safety required.

6- Provide an accurate representation of the physical, chemical and radiological state of the facility as the decommissioning activities proceed.

7- Identify and mitigate unsafe conditions that may arise prior to decommissioning, and preventing accidents.

8- Protect the environment in which the facility is located.

9- Prevent and reduce workers injury and illness during decommissioning.

10- Ensure that the decommissioning of the facility can be completed safely and in accordance with applicable safety requirements.

Decommissioning Safety Issue

Safe Release of LAMA Facility from Radiological Control

LAMA Facility ?

- LAMA Facility is located at Al-Tuwaitha site, 20Km south of Baghdad.
- The previous owner of this facility was the Iraqi Atomic Energy Commission (IAEC). The present owner is the Ministry of Science and Technology (MoST).
- LAMA Facility is a part of the nuclear complex built by France, which consists of five facilities: Tammuz-1 Reactor (40Mw), Tammuz-2 Reactor (500Kw), Radioactive Waste Treatment Station (RWTS), Laboratory Workshop Building (LWB) and LAMA Facility.
- LAMA facility was constructed as an active-irradiated, materials processing facility to operate in conjunction with Tammuz-1 reactor.
- LAMA facility was operated in 1981 and destroyed in 1991.

Current Status of LAMA Decommissioning

Stage-1: Removal of all contaminated and uncontaminated rubbles and scrap surrounding the LAMA facility.

Stage-2: Dismantling the unsafe structure and decommissioning the building except the three concrete hot cells, basement and the chimney.

Stage-3: Dismantling the three concrete hot cells and the chimney

Stage-4: Dismantling the basement and it's equipment.

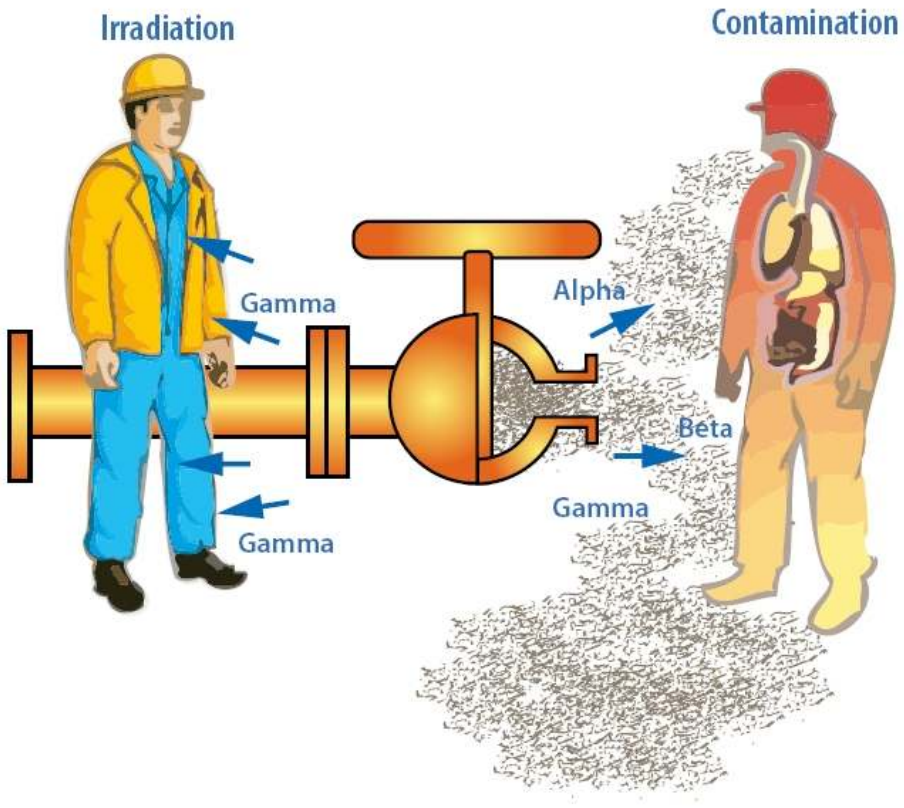
LAMA Facility Before and after stages 1 & 2 Decommissioning

Before
Decommissioning

After stages 1 & 2
Decommissioning

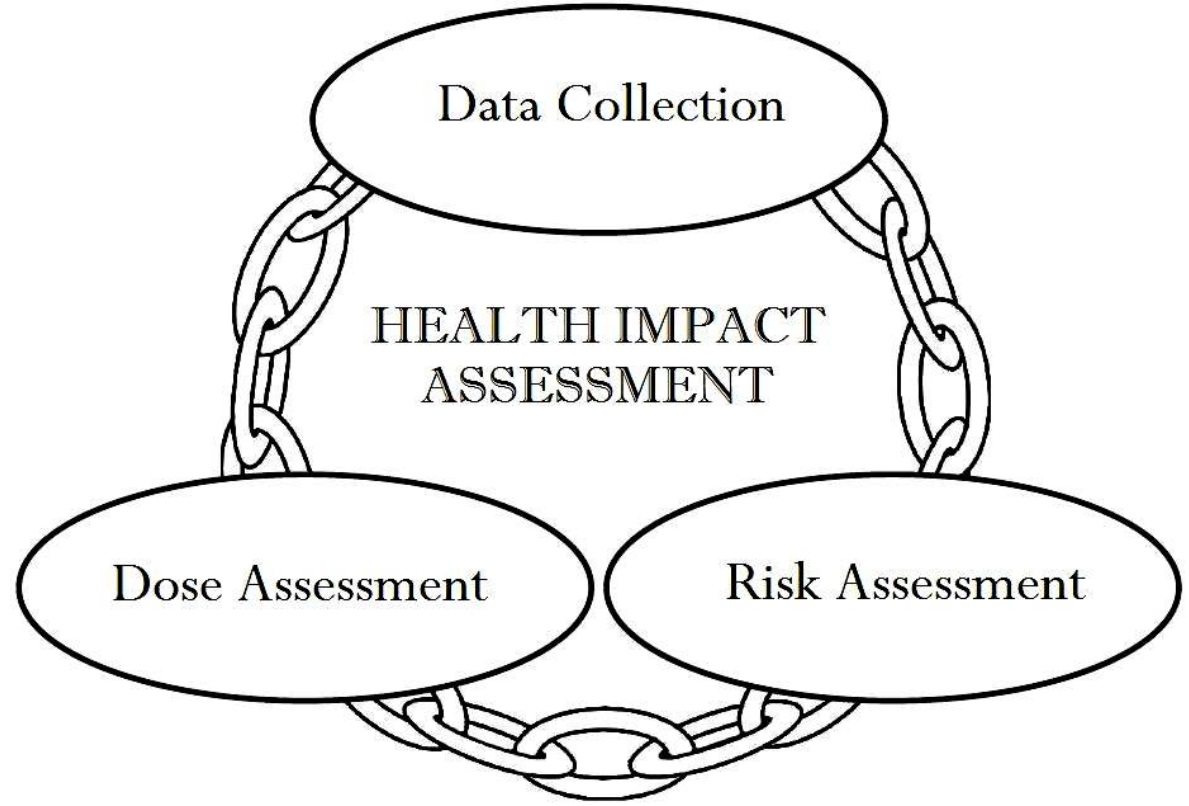
Radiation Risk

- Risk is defined as "some impact on health and safety".
- Radiation risk can be defined as the probability that the subsequent radiation doses will give rise to deleterious health effects or incidence of chronic diseases in an irradiated human population.

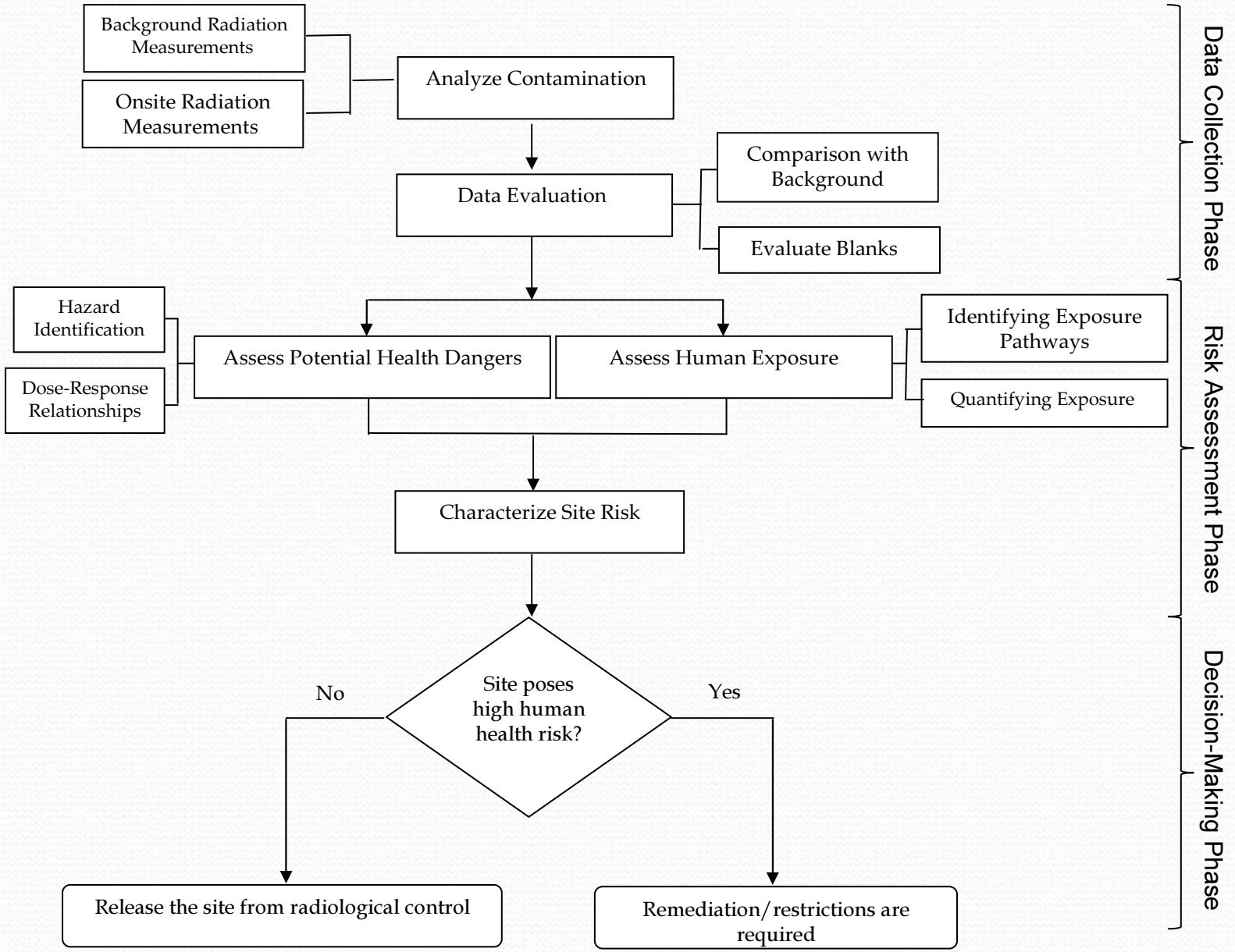


Risk Assessment

- ✓ Risk assessment is a technical measure of health impacts.
- ✓ Release of radioactively contaminated sites and facilities from radiological control requires a demonstration that the residual radioactivity levels in these sites meet a dose and risk-based release criteria.



Risk Assessment Plan



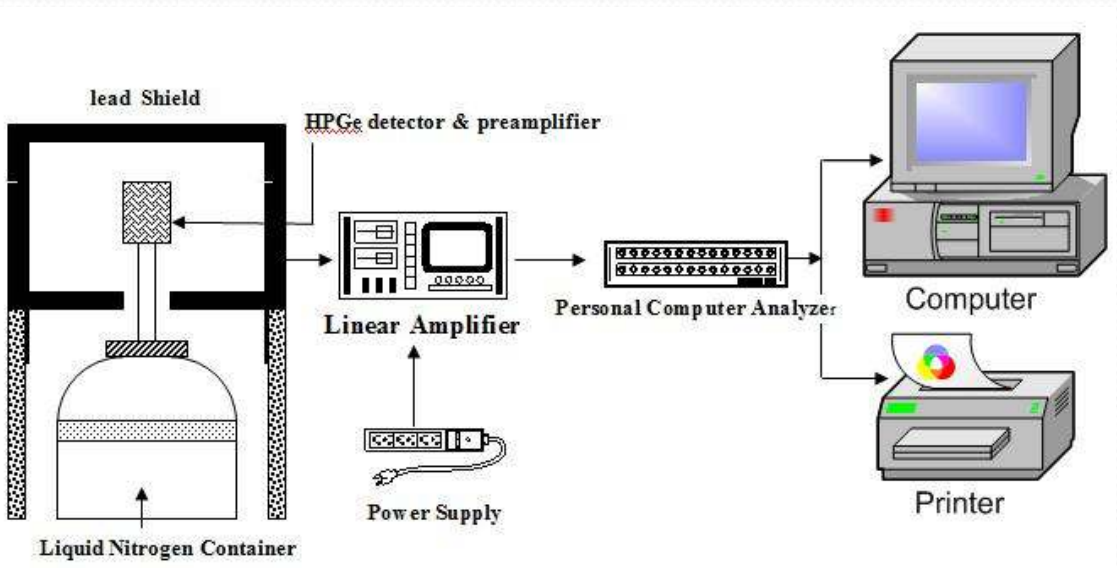
Contamination Analysis

✓ This phase includes systematic collection of a number of soil samples as being representative of the entire survey unit.

✓The radiometric analysis of the exterior soil samples was conducted using gamma-ray spectroscopy system to provide radionuclide-specific results.

✓ The radiometric analysis reveal the extent of radiological contamination and identify types of radionuclides cause the contamination.

✓ The results of laboratory analysis confirmed that ^{137}Cs and ^{60}Co radionuclides present in the surface soil of LAMA facility as residual contamination.

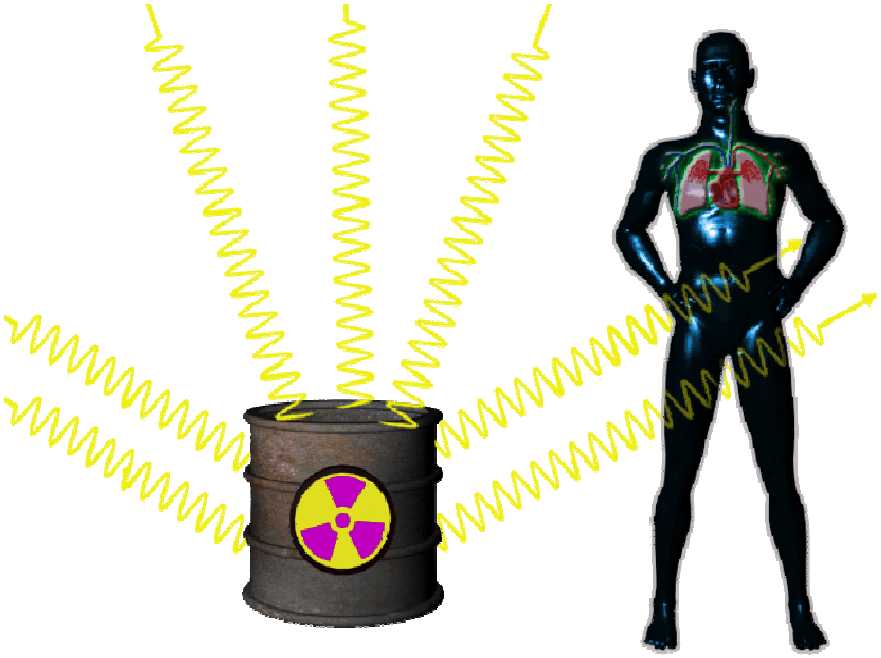


Human Exposure Assessment

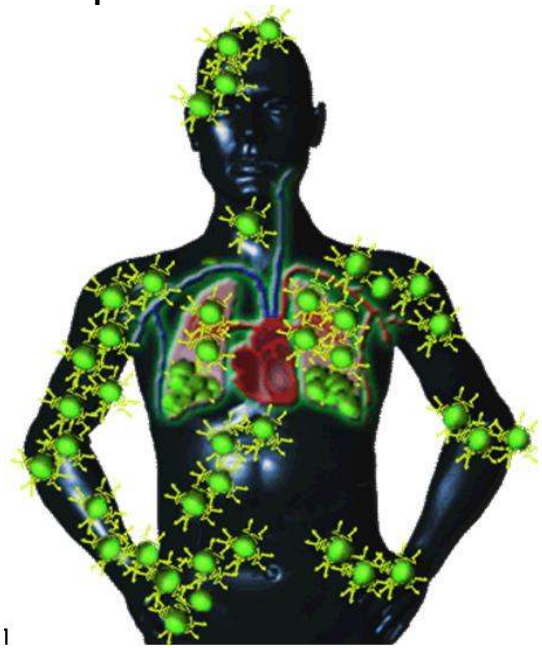
This phase includes evaluation of quantities of a given radionuclides that are present at or migrating from LAMA site and could reach a person's lung, digestive system, or skin through the use of environmental pathway modeling, and determine how the site might be used in the future after release.

✓ Human exposure pathways considered for decommissioning workers are:-

a) External irradiation



b) Internal irradiation from inadvertent ingestion or inhalation of resuspended ^{137}Cs and ^{60}Co particles.

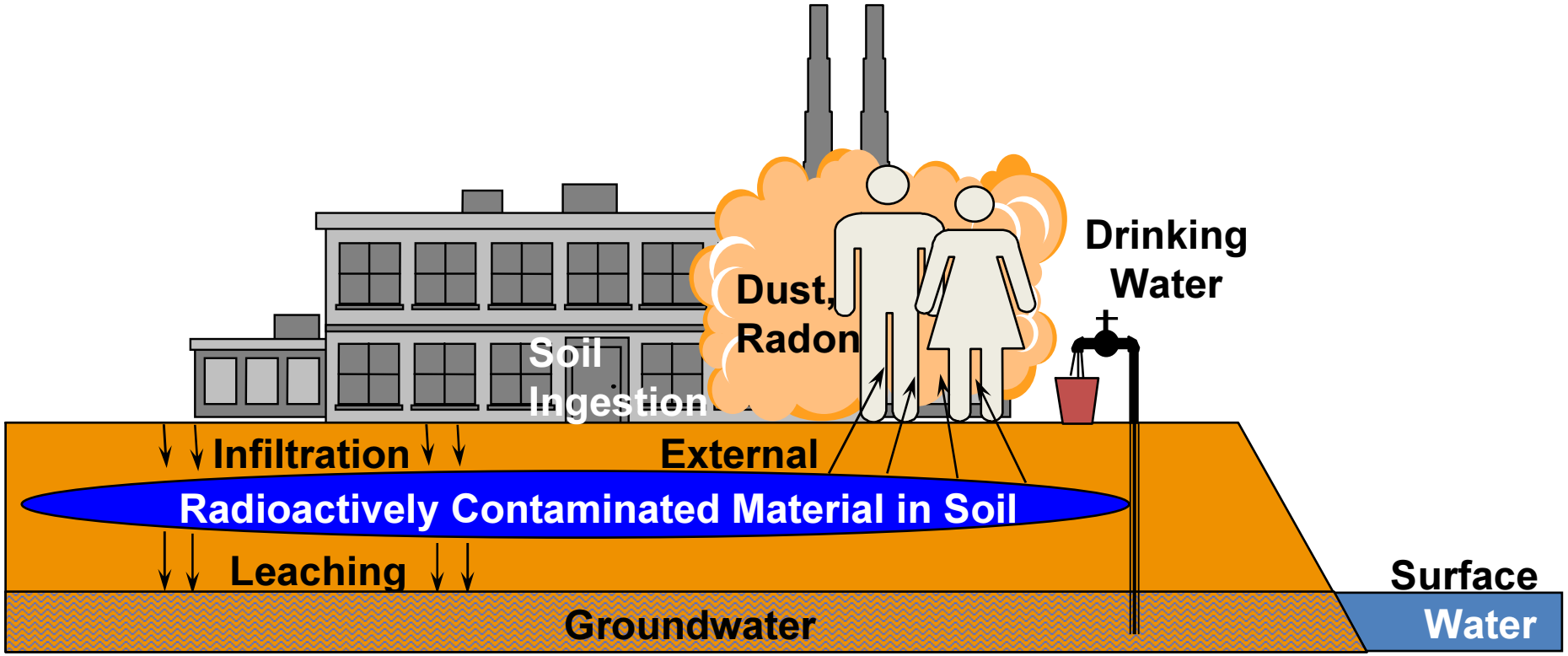


Human Exposure Scenarios After Site Release

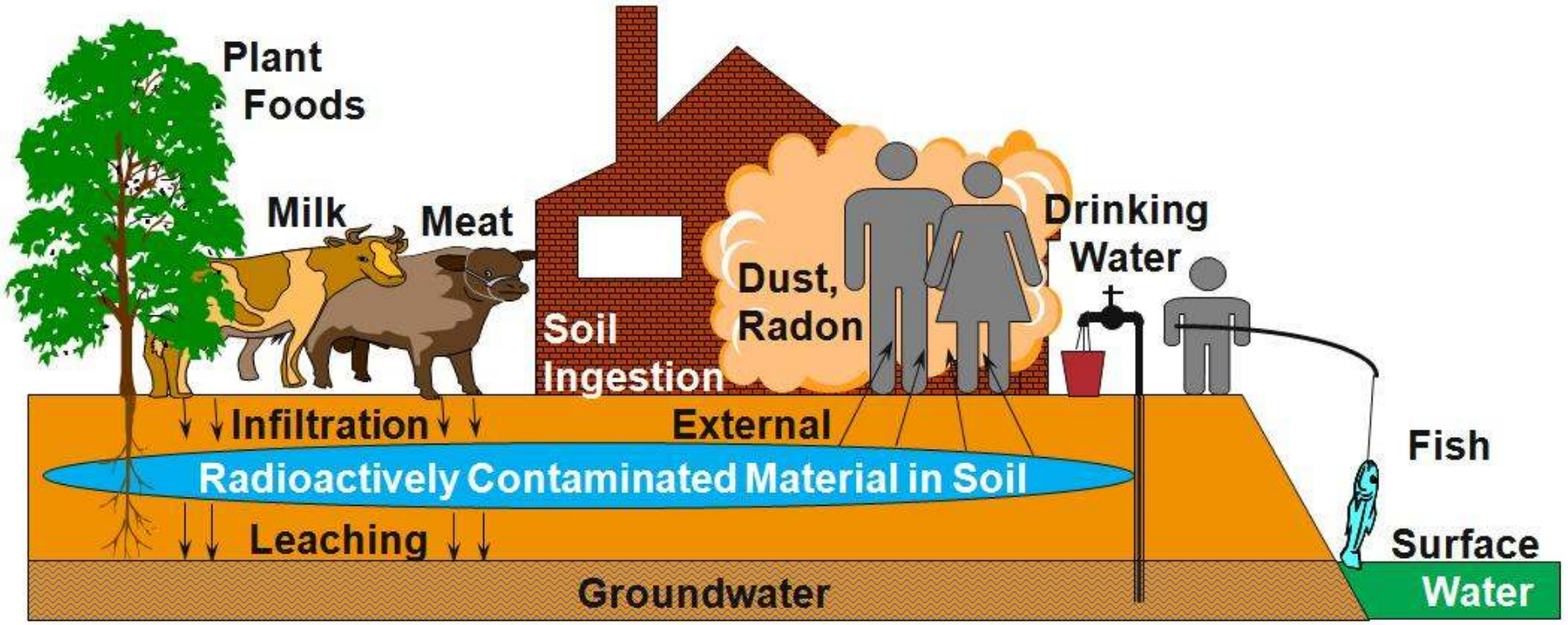
✓ A number of possible scenarios arise in which the future LAMA site users could be affected by residual radioactive material at the released site.

✓ The potential final land use scenarios for LAMA facility include use for industrial activities, residential occupancy, agricultural production and recreational occupancy.

Human Exposure Pathways Considered for Industrial Final Land Use Scenario



Human Exposure Pathways Considered for Residential Final Land Use Scenario



Potential Health Dangers Assessment

✓ This phase includes determine the harmfulness of each radionuclide identified. Fundamentally, the harmful consequences of ionizing radiations to a living organism are due to the energy absorbed by the cells and tissues which form the organism.

✓ Exposure to ^{137}Cs can increase the risk of cancer because of exposure to high-energy gamma radiation. Internal exposure to ^{137}Cs, through ingestion or inhalation, allows the radioactive material to be distributed in the soft tissues, especially muscle tissue, exposing these tissues to the beta and gamma radiation and increasing cancer risk.

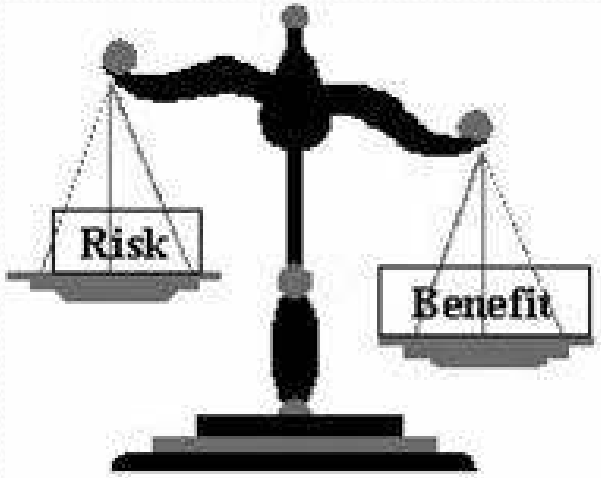
✓ Most ^{60}Co that is ingested is excreted in the feces; however, a small amount is absorbed by the liver, kidneys, and bones. ^{60}Co absorbed by the liver, kidneys, or bone tissue can cause cancer because of exposure to the gamma radiation.

Risk Characterization

✓ Risk characterization incorporates the outcomes of previous phases and evaluates the radiation–derived risk resulting from potential exposure to residual radioactivity via the pathways and routes of exposure determined appropriate for the LAMA site.

✓ Radiation Risk is expressed in the following mathematical form:

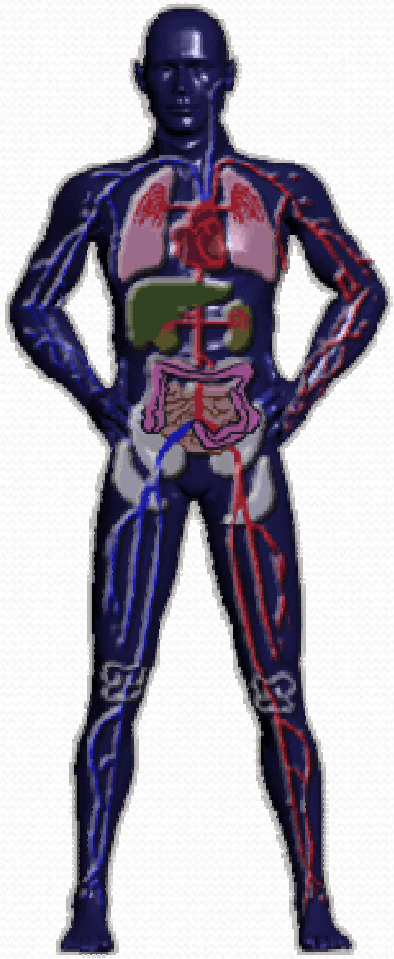
$$Radiation\ Risk = \frac{No.\ of\ Injuries\ or\ Deaths}{No.\ of\ People\ Exposed\ to\ Radiation\ Hazard}$$



Morbidity and Mortality Risk

✓ The morbidity risk is an estimate of the average total risk of experiencing a radiogenic cancer, whether or not the cancer is fatal.

✓ The mortality risk is an estimate of the risk of dying from cancer as a result of intake of the radionuclide or external exposure to its emitted radiations.



Release Criteria for LAMA Facility

Dose Limits

✓ The dose assessment for decommissioning should demonstrate that the potential effective dose to a member of the critical group, once the site is released for unrestricted use, will be below 0.3 mSv in a year and will be optimized.

✓ If the identified dose restriction measures were to fail in the future, the effective dose to the critical group from all sources should not exceed 1 mSv in a year.

✓ Dose reduction measures are unlikely to be warranted for dose levels < 10 μSv/y.

Risk Limits

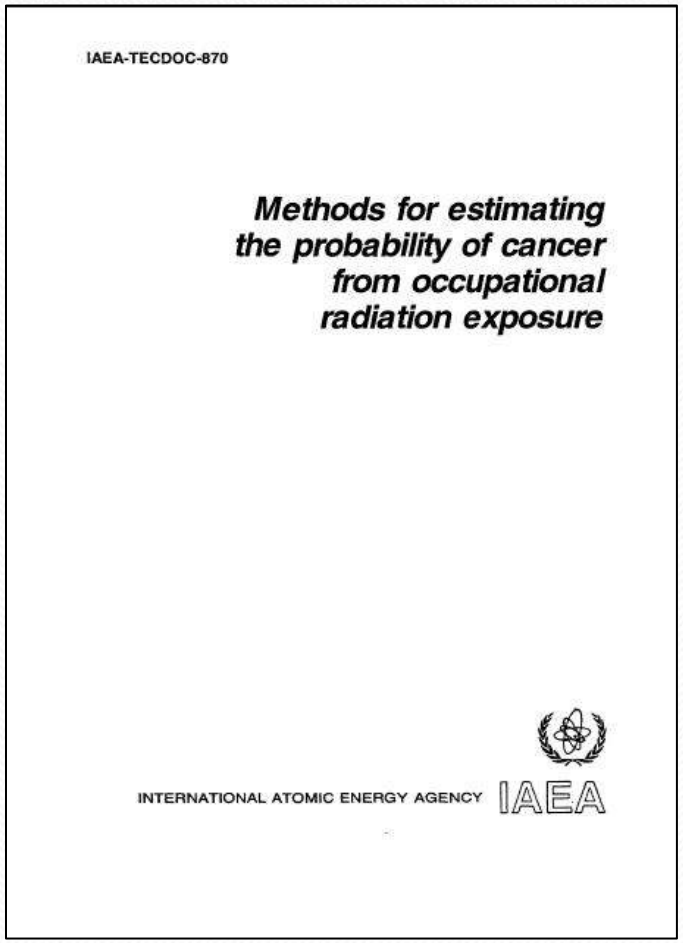
✓ The annual risks of fatality from an environmental source of 10^{-6} to 10^{-5} would be likely to be acceptable to any individual member of the public.

Probability of Causation (PC)

✓ A radiation induced cancer is indistinguishable from one induced by other environmental agents.

✓ The concept of the probability of causation (PC) has been developed to answer the question " if a person has been exposed to ionizing radiation and subsequently gets a cancer, what is the probability that the cancer was due to the earlier exposure ?".

✓The PC values have been estimated for workers exposed to radiological contamination in LAMA facility before and after remediation, according to a procedure recommended by the IAEA (TECDOC-870, 1996)



Radiological Assessment Tool

✓ RESRAD computer code is used as a multifunctional tool to assist in assessing the dose and risk associated with residual radioactive material, making regulatory decisions about residual radioactivity levels at nuclear sites, and developing cleanup criteria.

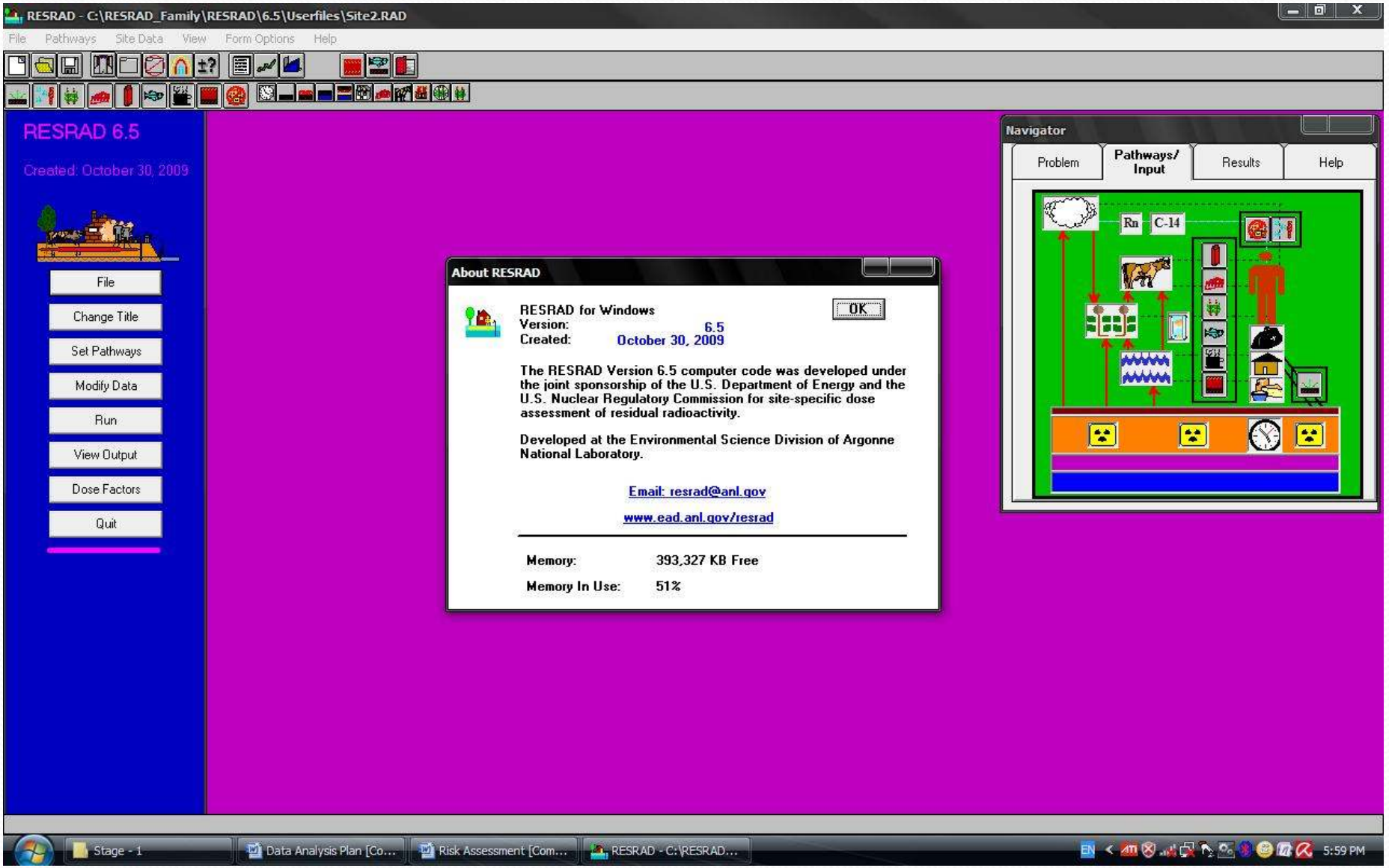
✓ RESRAD (RESidual RADioactivity) family of computer codes was developed by Argonne National Laboratory, under the joint sponsorship of the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC).

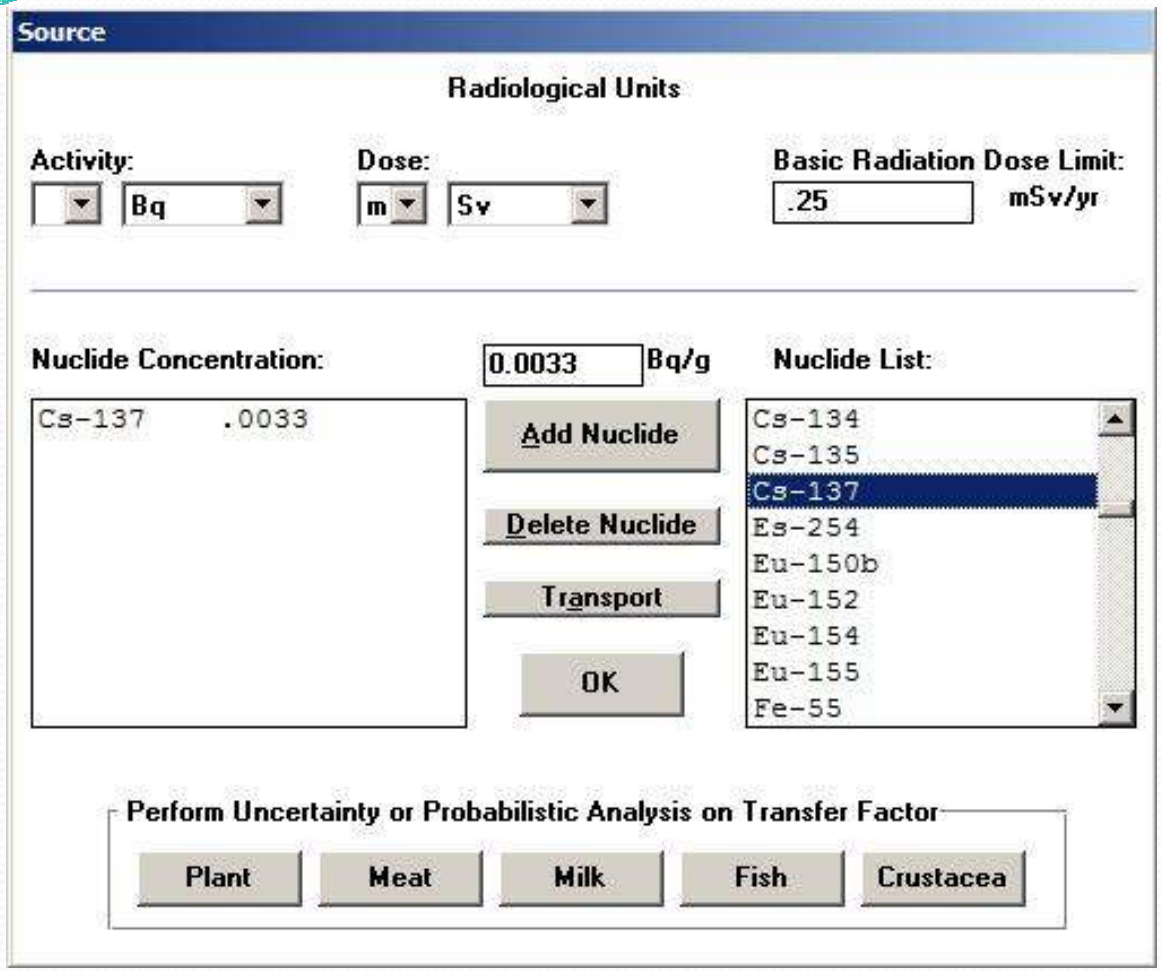
✓ RESRAD (On-site) Version 6.5 (2009) computer code is used for estimating radiation doses and human health risks from residual radioactive contamination for site workers and future site users after release.

✓ RESRAD (off-site) Version 2.5 (2009) computer code is used for evaluating long term exposure of the public arising from migration of on-site contaminants through atmospheric and groundwater pathways to nearby population.

✓ These computer codes handle exposure from inhalation, external exposure and ingestion of contaminated agricultural crops and animal products.

Main Window for RESRAD Onsite Version 6.5 (2009) Computer Code





Radionuclides Selection Option

Human Exposure Pathways Selection Option

Program Outcome (Report)

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RESRAD, Version 6.5      T« Limit = 180 days        04/25/2010  10:34  Page    1
Summary : RESRAD Default Parameters
File    : C:\RESRAD_FAMILY\RESRAD\6.5\USERFILES\SITE15.RAD

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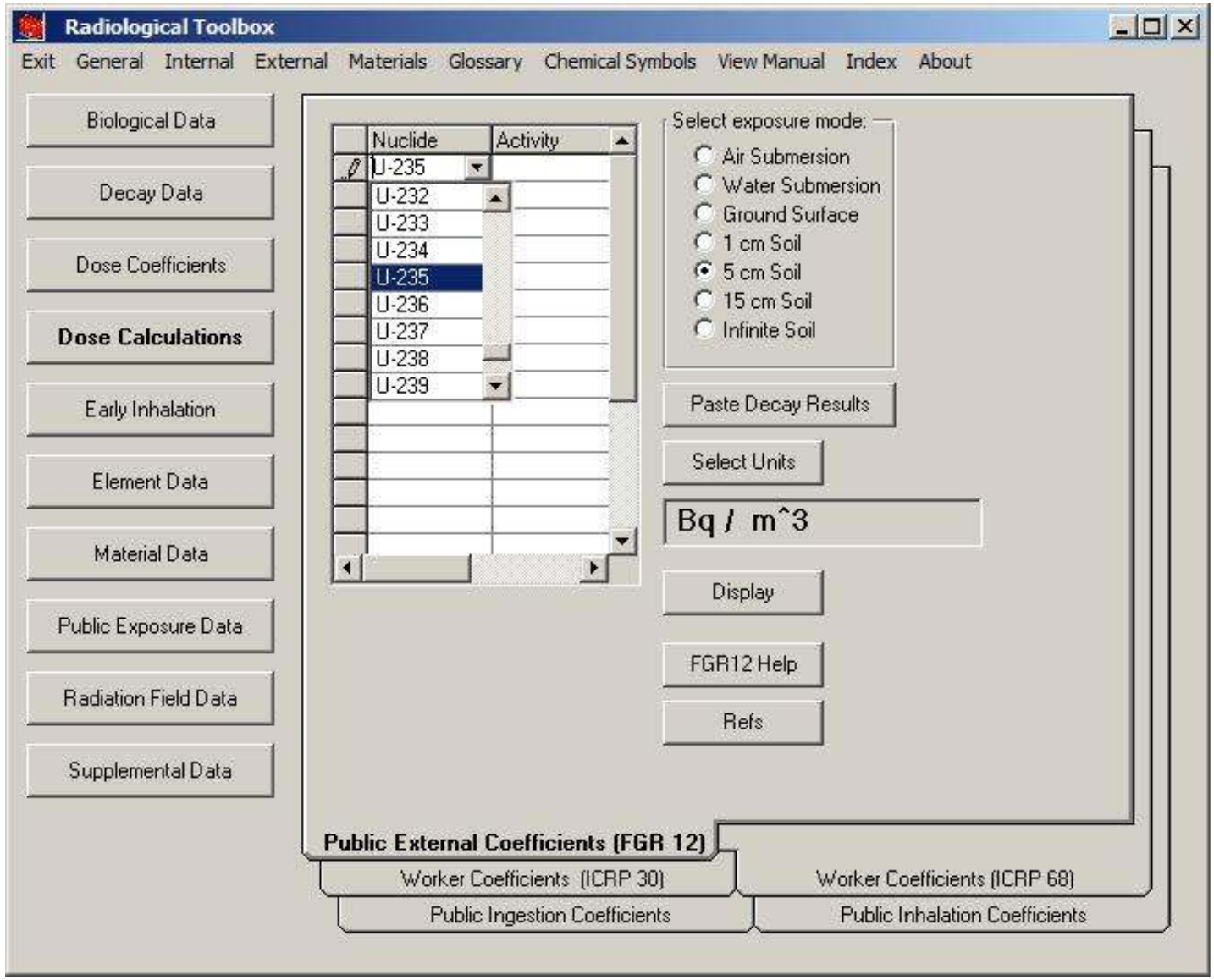
Radiological Toolbox Version 2.0 (2006) software package developed by Oak Ridge National Laboratory has been used to predict radiation doses received by different body organs and tissues



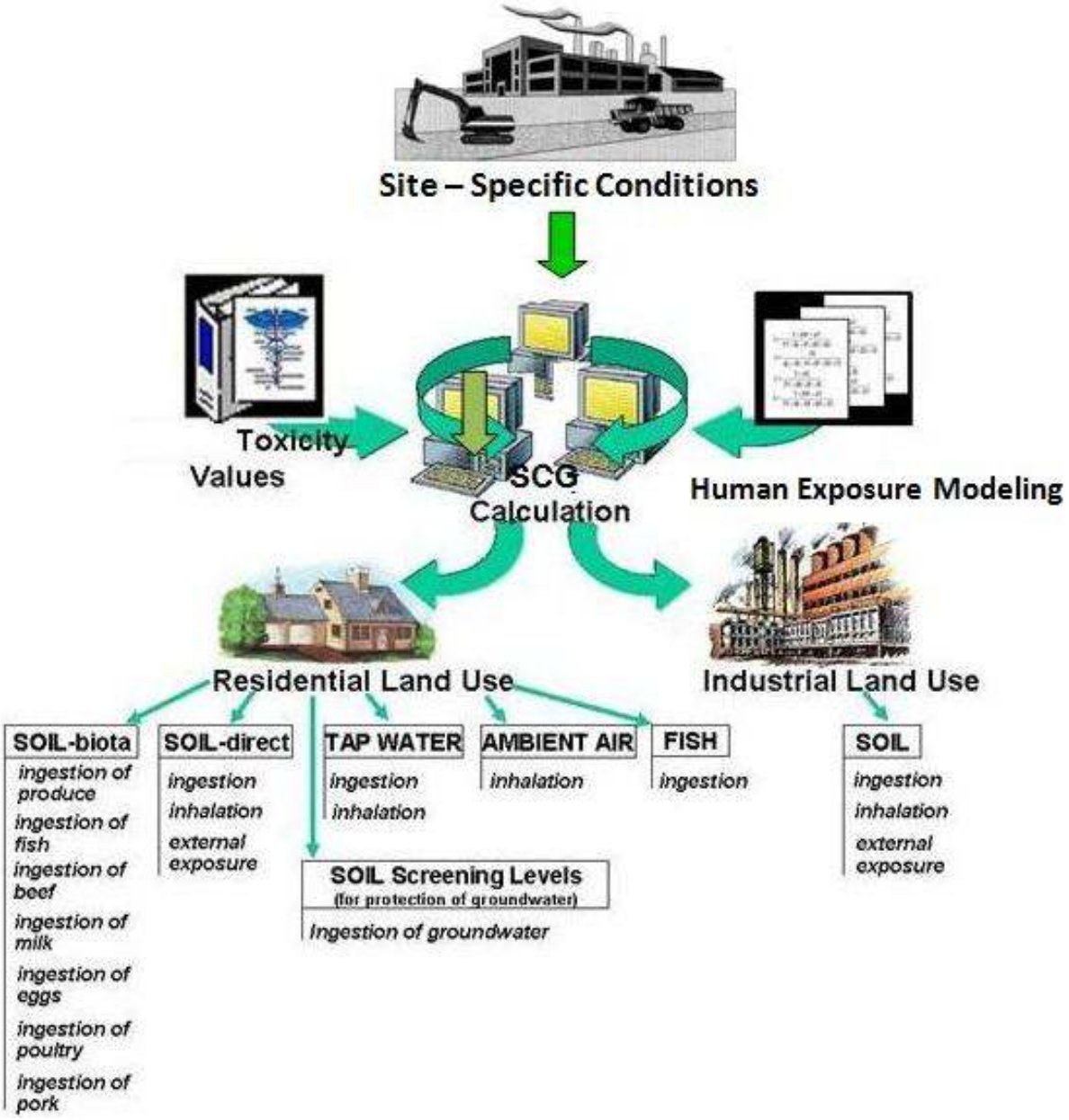
Derivation of Site-Specific Soil Cleanup Guidelines Using RESRAD Code

✓ Because of the large variability in the types of radiation sites, it is impossible to provide criteria that apply to every site.

✓ RESRAD code is used to translate the dose-based release criteria of 0.3 mSv/y into a corresponding derived soil decontamination guidelines for the appropriate final land-use scenarios and human exposure pathways determined appropriate for the site after release.

✓ The input parameters are modified to create site-specific soil cleanup guidelines.

The planned and Systematic Activities Needed to Derive Site-Specific Soil Cleanup Guidelines



Sensitivity Analyses

- ✓ Sensitivity analyses is performed to identify and assess those parameters and values with the highest impacts on the assessment results.
- ✓ If the outcome is particularly sensitive to an input parameter or assumption, efforts are directed towards reducing the uncertainties and repeating that part of the risk assessment.

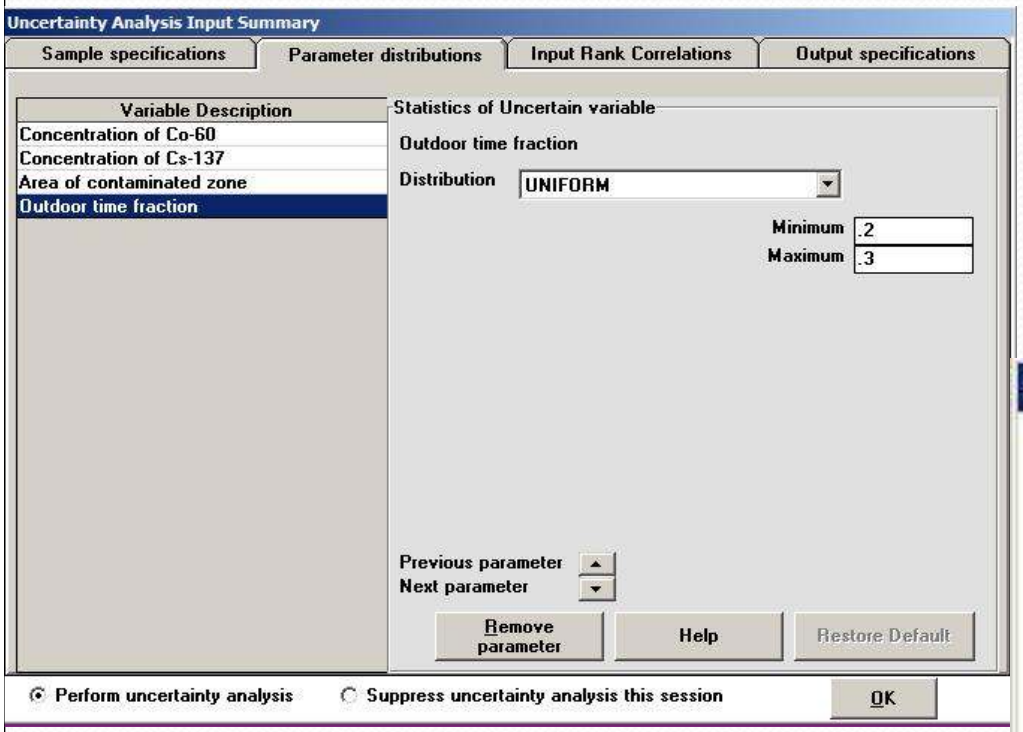
Uncertainty Analysis

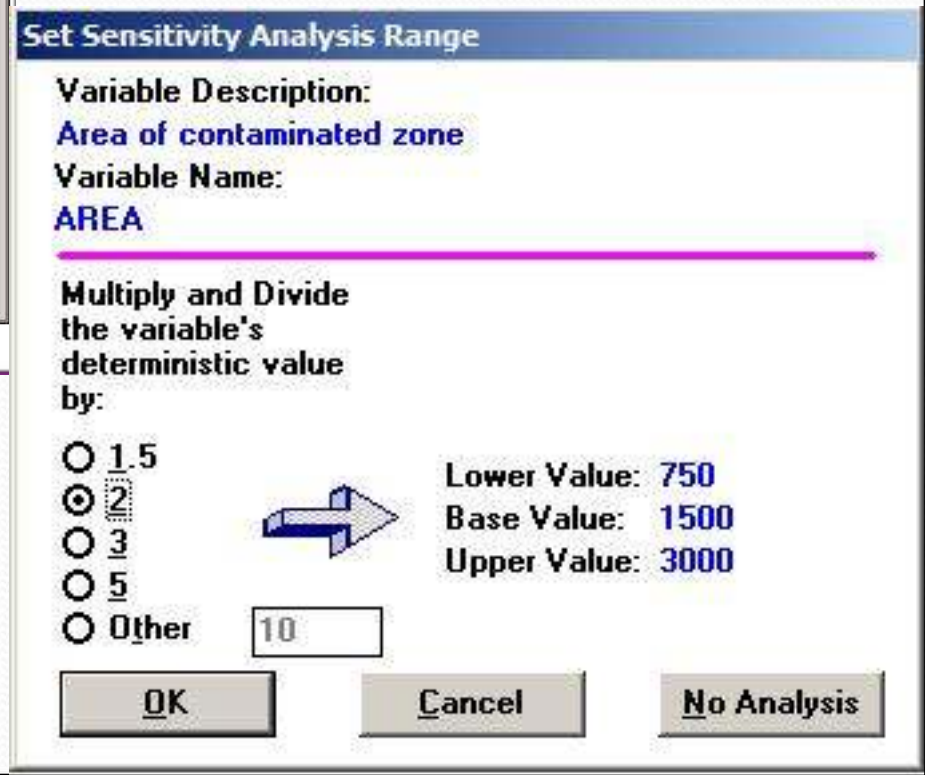
✓ Uncertainty (or margin of error) is the range of values within which the true value is estimated to lie, states to what extent the estimated value may differ from its actual (true) value. It is a best estimate of possible inaccuracy in the assessment process.

✓ The results of uncertainty analysis will provide an answer to the following question: "How well the dose assessment result represents the true level of radioactivity in the survey unit ?".

✓ Uncertainties, such as those relating to the level of contamination, the quality, reliability and availability of information from the characterization of the facility are taken into account in determining the radiological impact of the release of the site.

Uncertainty/ Sensitivity Analysis Input Windows for RESRAD Code





Verification of Compliance with the Dose-Based Release Criteria

✓ 100% confidence in decision cannot be proven because the parameters used for dose and risk assessment and the assessment results always contain some degree of uncertainty.

✓Compliance testing consists of comparing an estimate of the radiological dose to a "critical value", taking into account the uncertainty (σ) of the dose assessment result.

✓ The dose assessment result will be judged to be clearly less than the site release criteria if the following condition is satisfied:-

✓ Dose Assessment Result + $Z_{1-\alpha}\,\sigma <$ 0.3 mSv/y

where $Z_{1-\alpha}$ is 1–α quantile of the standard normal distribution.

✓ The type I decision error rate (α) represent the probability that a contaminated site will be released from radiological control as clean.

✓ Compliance with the dose-based release criteria is verified at a confidence level of 95%.

Exemption of Residual On-Site Contamination from Radiological Control

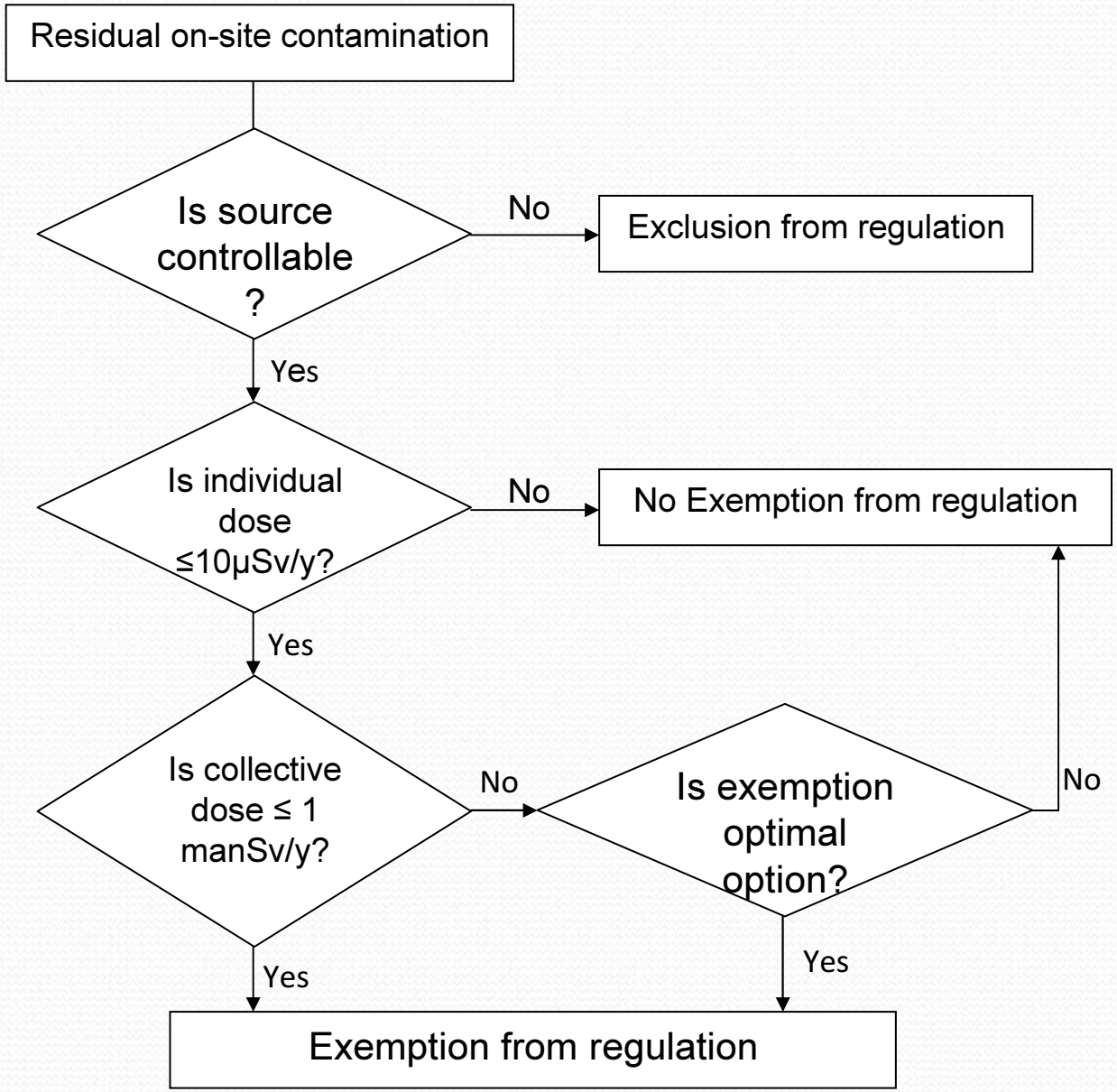
✓ The residual on-site contamination may be released from subsequent regulatory control if the remaining radiological impact of the site is within an acceptable level, according to applicable radiological criteria.

✓ If the site is contaminated with a mixture of radionuclides, then compliance with the exemption criteria is demonstrated using the sum of fractions rule:-

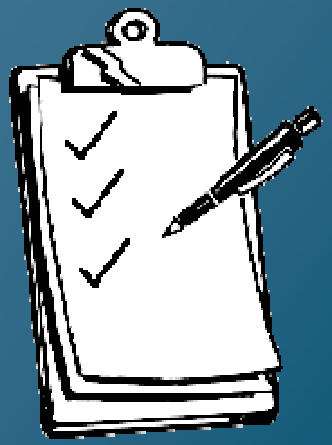
$$\frac{C_1}{AL_1}+\frac{C_2}{AL_2}+\frac{C_3}{AL_3}+.....+\frac{C_n}{AL_n}\leq 1$$

where C is the radionuclide concentration and AL is its action level.

Verification of Compliance with the Exemption Criteria



Results of Safety Assessment



Radiological contamination levels in LAMA facility (stage –2 data) used for radiological dose and health risk assessment:-

Radionuclide	Activity concentration (Mean ± SD) (Bq/kg)		Residual radioactivity (Bq/kg)
	LAMA	Background area	
^{137}Cs	2.25 ± 1.13	1.85 ±0.74	0.45
^{60}Co	5.58 ± 0.45	Not detected	5.58

✓ In spite that ^{137}Cs is not a constituent of background, ^{137}Cs radioactivity have been significantly detected in background samples as a result of global fallout.

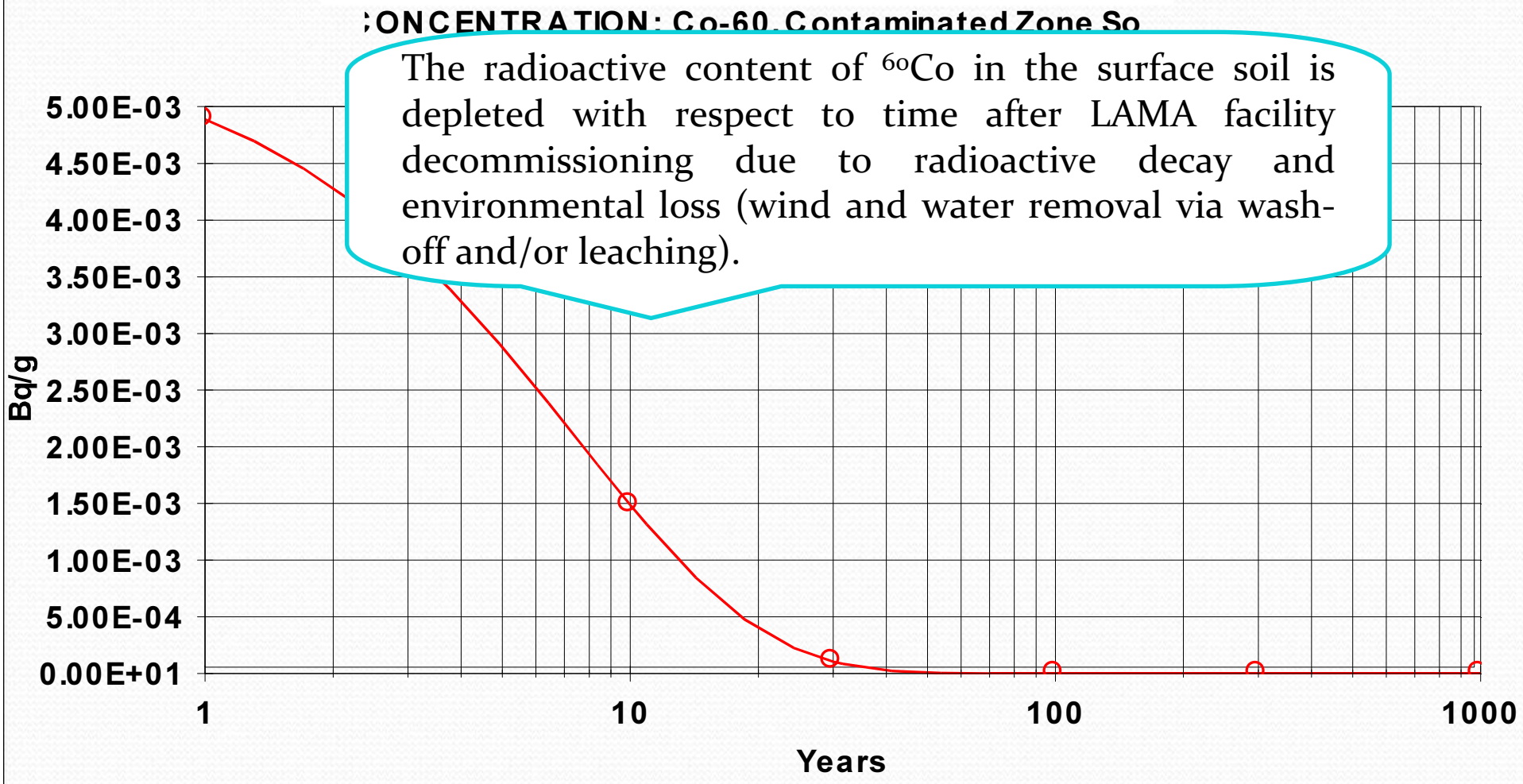
✓ ^{60}Co does not have a significant background in soil.

✓The amount of residual radioactivity above background is estimated to be the difference between the mean concentrations in the area of interest and the reference (background) area.

✓ The surface soil ^{60}Co content of 5.58 Bq/kg does not exceed the exemption level established by the International Atomic Energy Agency (IAEA) of 100 Bq/kg, and the derived concentration guideline level (DCGL) proposed by the U.S. Nuclear Regulatory Commission (NRC) of 140 Bq/kg.

✓ The surface soil ^{137}Cs content of 2.25 Bq/kg is about 1.2 times greater than the background level, but considerably less than the exemption level established by the IAEA of 100 Bq/kg, and the DCGL proposed by the U.S. NRC of 407 Bq/kg.

Depletion of ^{60}Co Content with Respect to Time



The radioactive content of ^{60}Co in the surface soil is depleted with respect to time after LAMA facility decommissioning due to radioactive decay and environmental loss (wind and water removal via wash-off and/or leaching).

Quantitative Human Exposure Assessment

A quantitative description of the routes by which human exposure to ^{137}Cs and ^{60}Co occurs onsite and offsite are evaluated to interpret the significance of the consequences as contributors to risk.

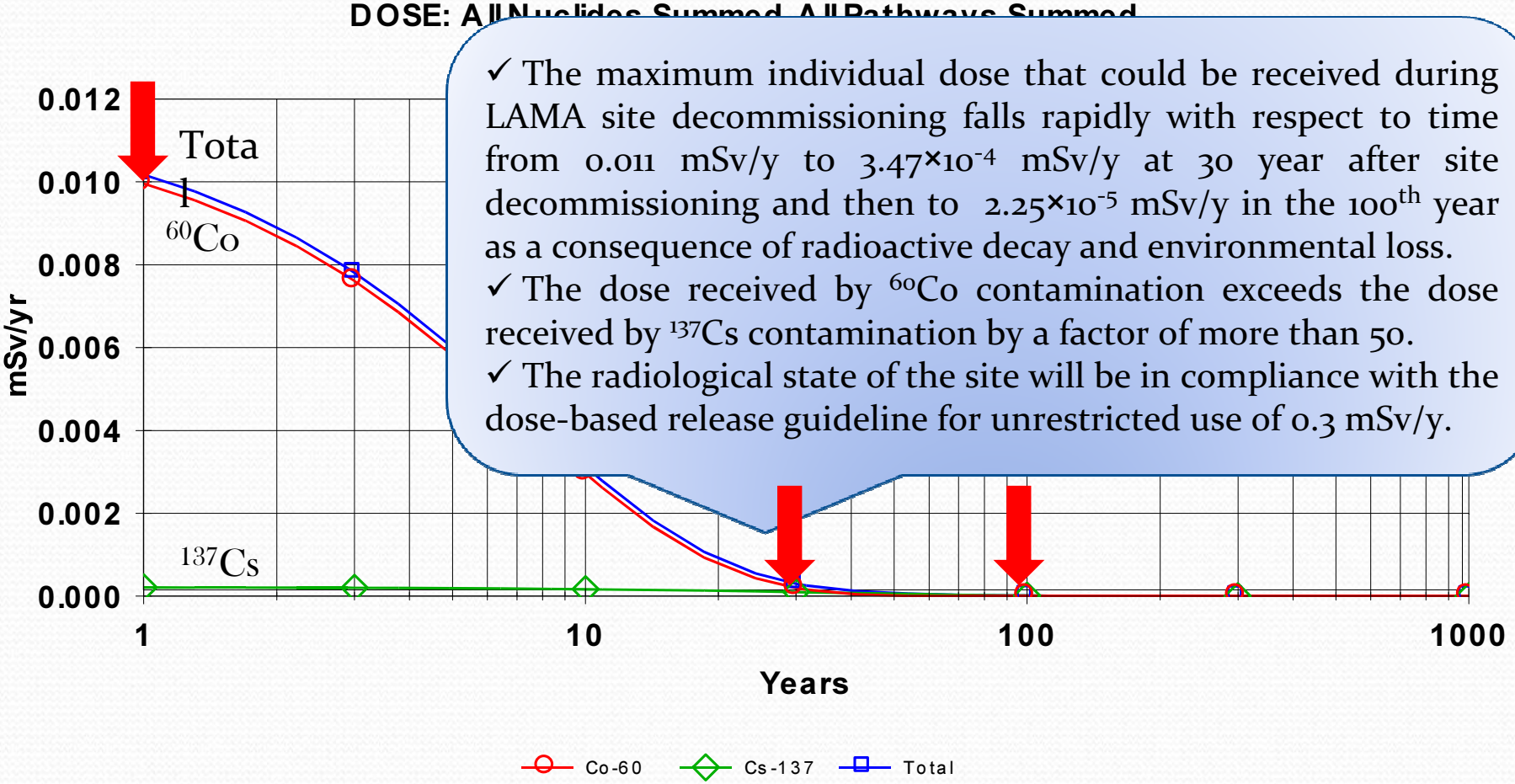
Predicted radiological dose received by onsite workers:

Exposure route	Estimated dose (mSv/y)
External dose from remaining on contaminated ground at outdoor time fraction of 25%.	0.011
Breathing air contaminated with resuspended ^{60}Co and ^{137}Cs particles at 8400 m^3/y	1.45E-8
Ingestion of contaminated soil at 36.5 g/y	1.07E-06
Total	0.011

✓ More than 98% of the overall dose is derived from ^{60}Co exposure.

✓ The radiation injury of ^{137}Cs and ^{60}Co exposure is found to be entirely from external irradiation; while the internal irradiation is not thought to be significant.

Forecasted occupational ^{60}Co and ^{137}Cs dose received by LAMA workers associated with the time of occurrence

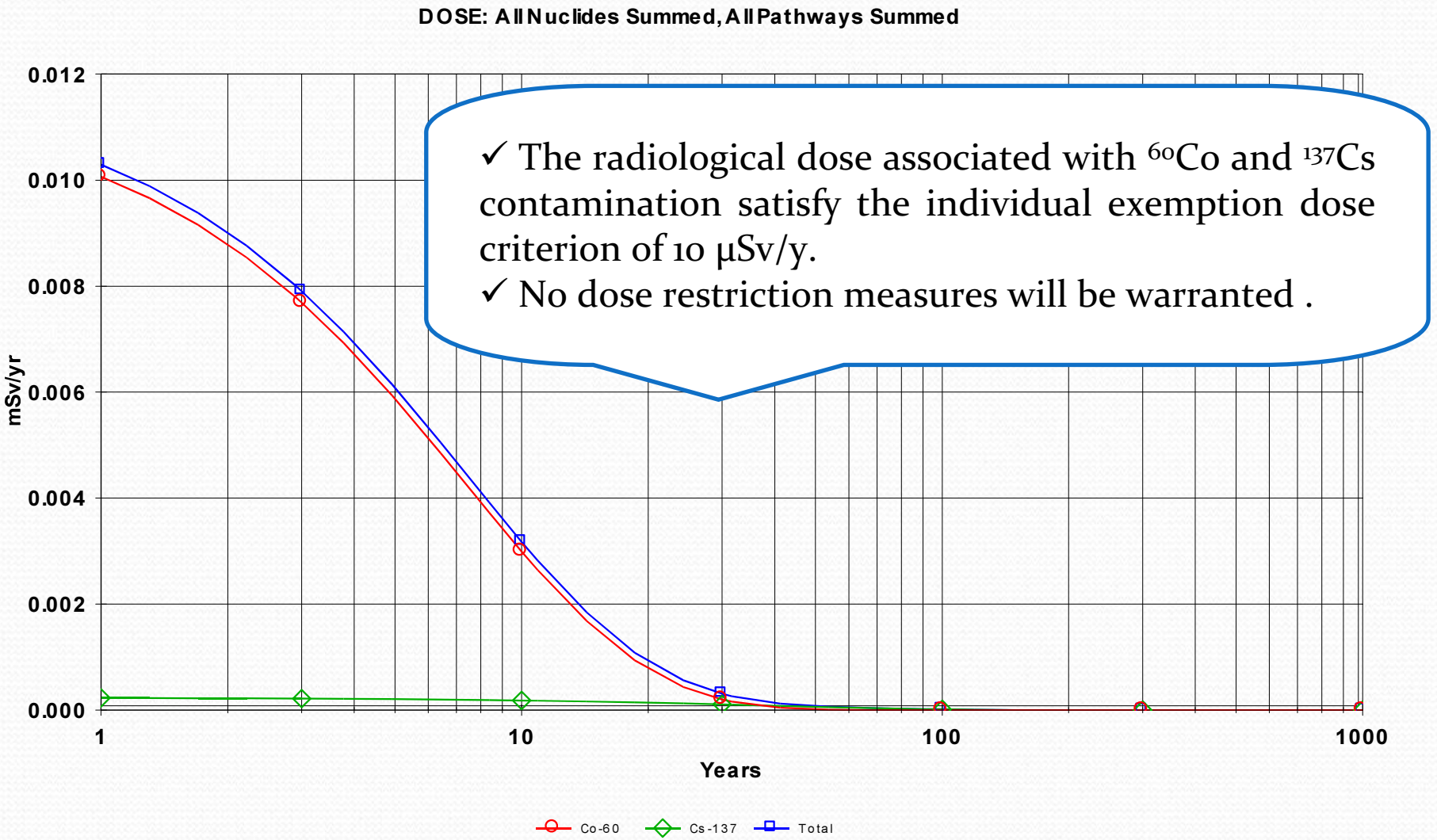


✓ The maximum individual dose that could be received during LAMA site decommissioning falls rapidly with respect to time from 0.011 mSv/y to 3.47×10^{-4} mSv/y at 30 year after site decommissioning and then to 2.25×10^{-5} mSv/y in the 100th year as a consequence of radioactive decay and environmental loss.

✓ The dose received by ^{60}Co contamination exceeds the dose received by ^{137}Cs contamination by a factor of more than 50.

✓ The radiological state of the site will be in compliance with the dose-based release guideline for unrestricted use of 0.3 mSv/y.

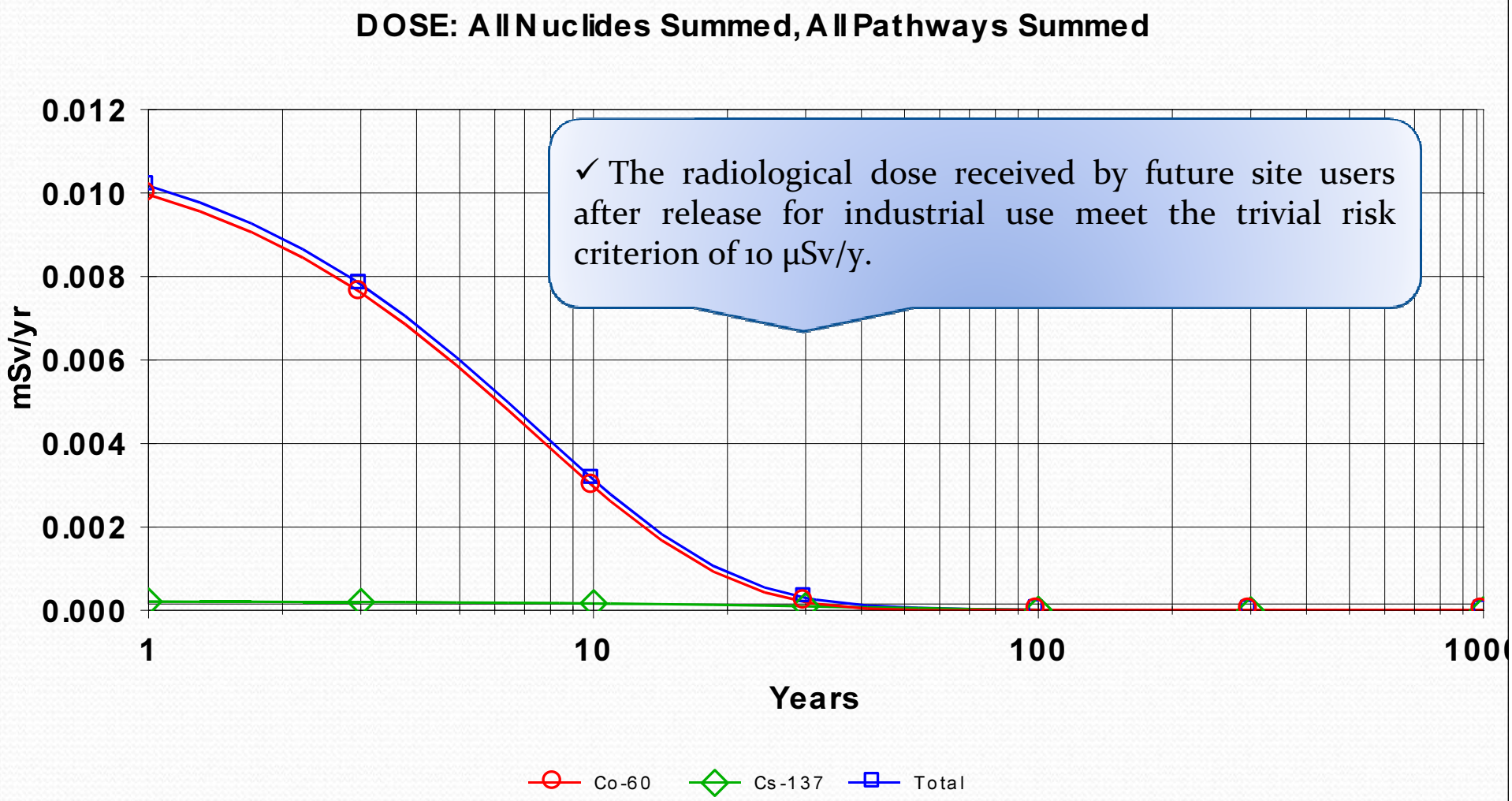
Forecasted ^{60}Co and ^{137}Cs dose Received by Future Site Users for Residential Scenario



✓ The radiological dose associated with ^{60}Co and ^{137}Cs contamination satisfy the individual exemption dose criterion of 10 μSv/y.

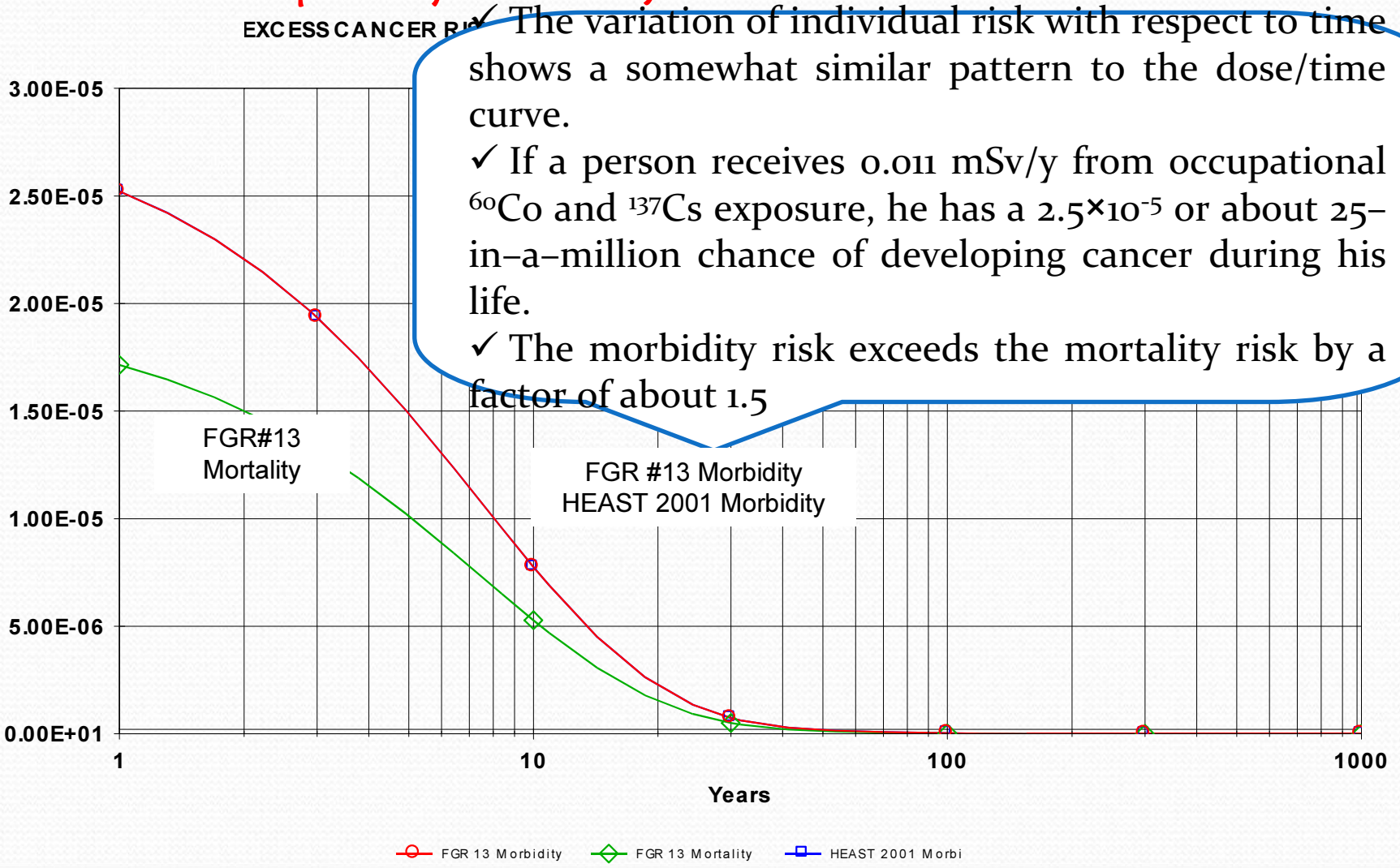
✓ No dose restriction measures will be warranted .

Forecasted ^{60}Co and ^{137}Cs dose Received by Future Site Users for Industrial Scenario



✓ The radiological dose received by future site users after release for industrial use meet the trivial risk criterion of 10 μSv/y.

Forecasted excess cancer risk for residential final land use scenario using different risk factors (FGR #13 and HEAST 2001 developed by the EPA).



✓ The variation of individual risk with respect to time shows a somewhat similar pattern to the dose/time curve.

✓ If a person receives 0.011 mSv/y from occupational ^{60}Co and ^{137}Cs exposure, he has a 2.5×10^{-5} or about 25–in–a–million chance of developing cancer during his life.

✓ The morbidity risk exceeds the mortality risk by a factor of about 1.5

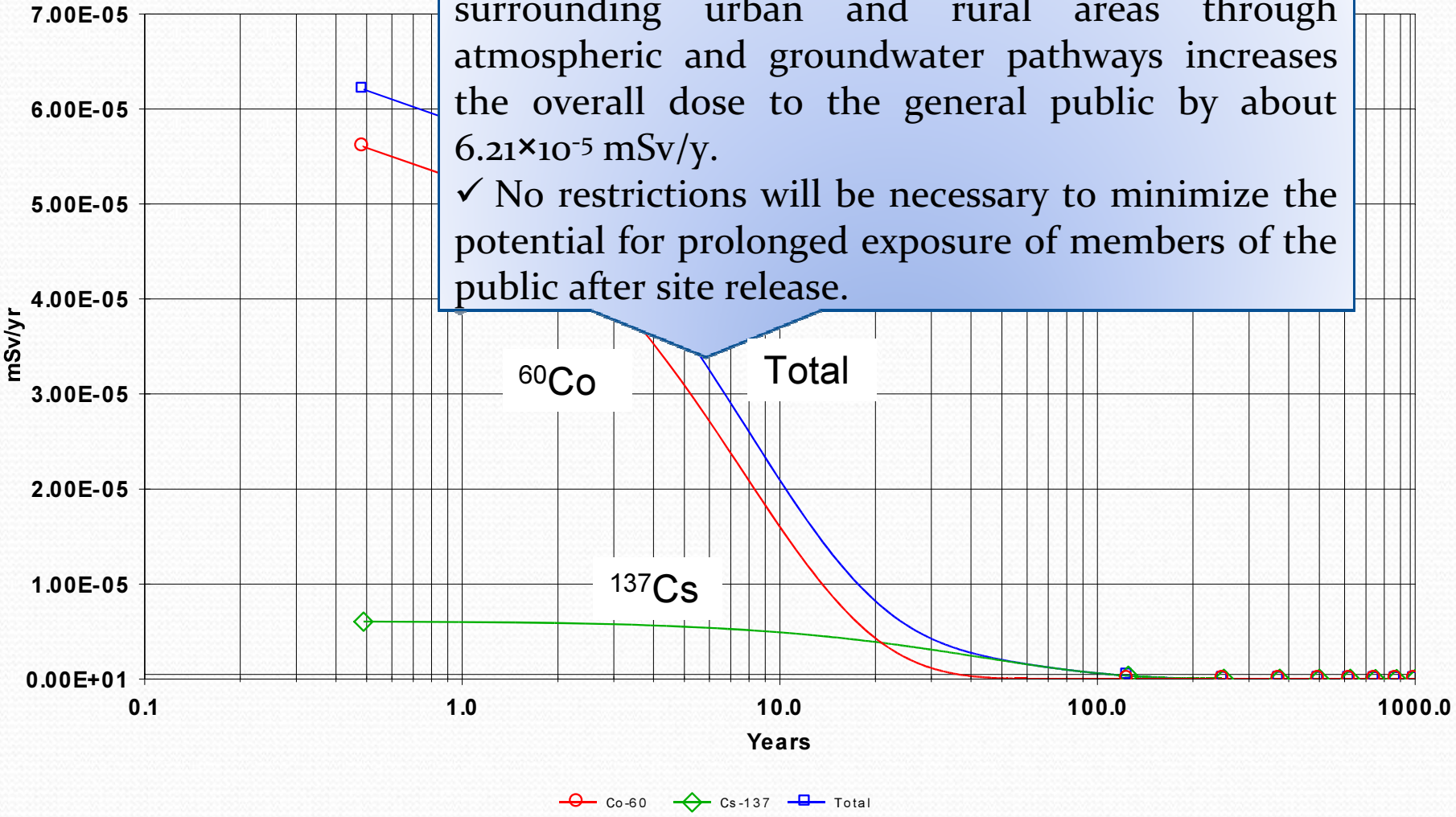
Predicted radiation doses to nearby population associated with radionuclides migration to nearby population:

Exposure route	Estimated dose (mSv/y)
External dose from remaining on contaminated ground at outdoor time fraction of 25%.	6.15E-5
Breathing air contaminated with resuspended particles at 8400 m^3/y	5.78E-10
Ingestion of contaminated soil at 36.5 g/y	1.4E-13
Consumption of contaminated fruits, vegetables and grain at 160 kg/y	2.66E-17
Meat consumption at 63 kg/y	6.09E-11
Milk consumption at 92 liters/y	1.98E-11
Drinks 510 liters of water per year	Insignificant
Fish consumption at a rate of 5.4 kg/y.	1.32E-7
Total	6.21E-5

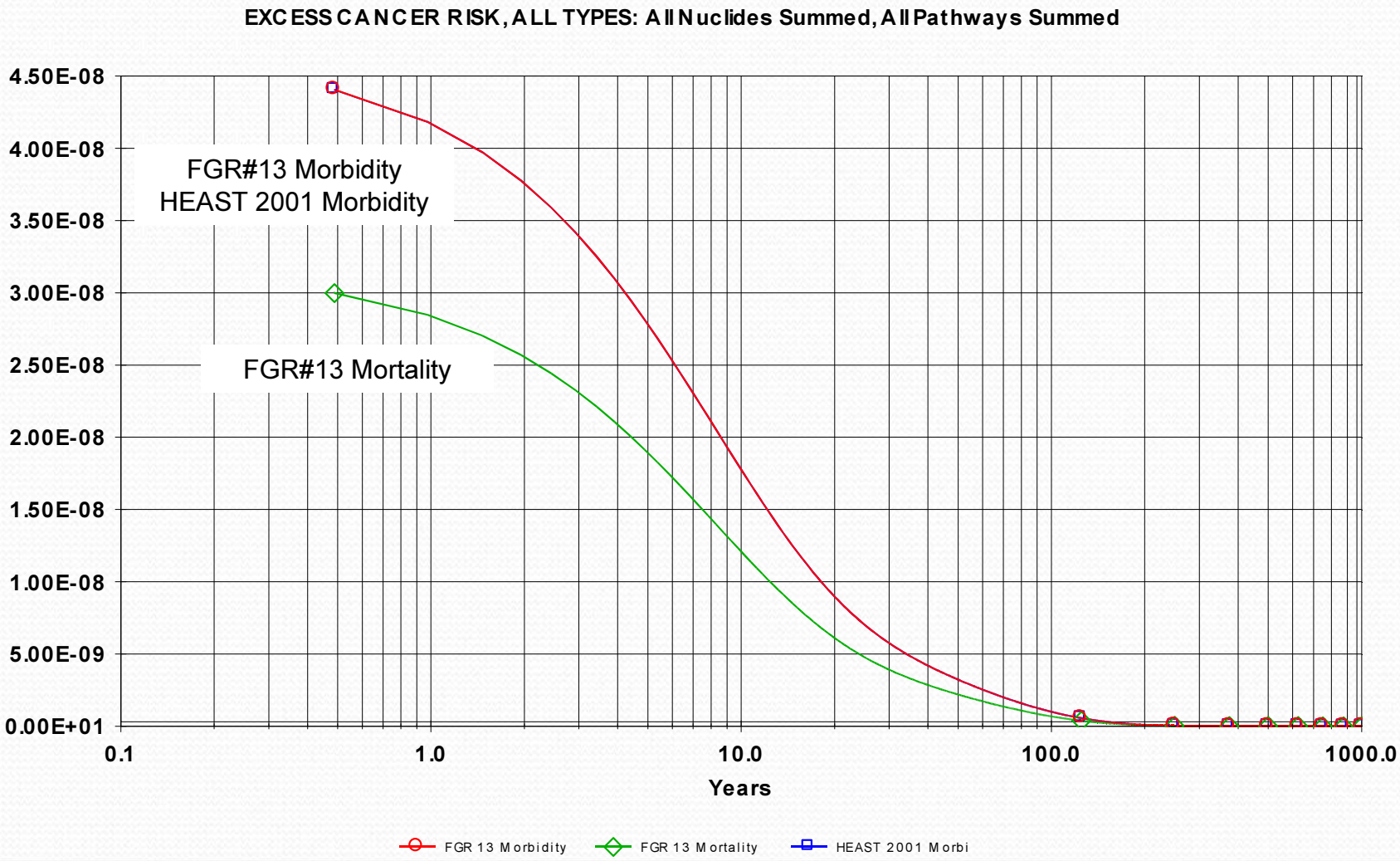
Forecasted radiological dose to offsite receptors associated with the time of occurrence

✓ Migration of ^{60}Co and ^{137}Cs isotopes to the surrounding urban and rural areas through atmospheric and groundwater pathways increases the overall dose to the general public by about 6.21×10^{-5} mSv/y.

✓ No restrictions will be necessary to minimize the potential for prolonged exposure of members of the public after site release.



Probable morbidity and mortality radiogenic excess health risks to the nearby population related to ^{60}Co and ^{137}Cs exposure using different risk factors (FGR #13 and HEAST 2001).



✓ The incidence of cancer for occupationally exposed individuals is estimated to be 568 times higher than the expected extra cancer incidence rate to the nearby population.

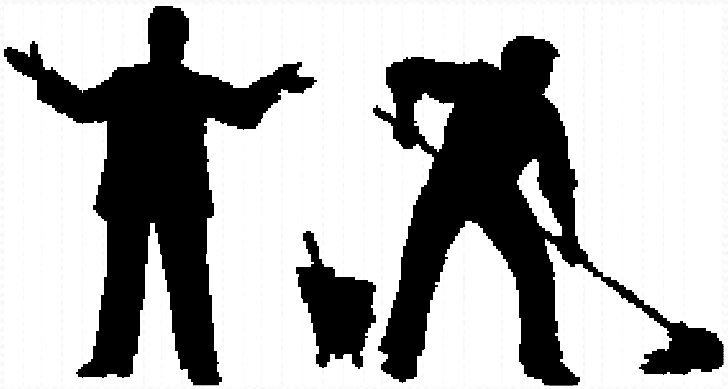
✓ It can be seen that the forecasted individual dose and radiation–derived risk remain below the dose and risk release guidelines (0.3 mSv/y, 10^{-6} to 10^{-5} risk/y) with respect to time after site release.

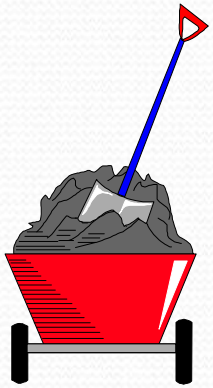
✓ The presented results support the belief that the erosion of land surfaces radionuclides to nearby urban and/or rural areas is not a major contrib[illegible]r to the public health risk.

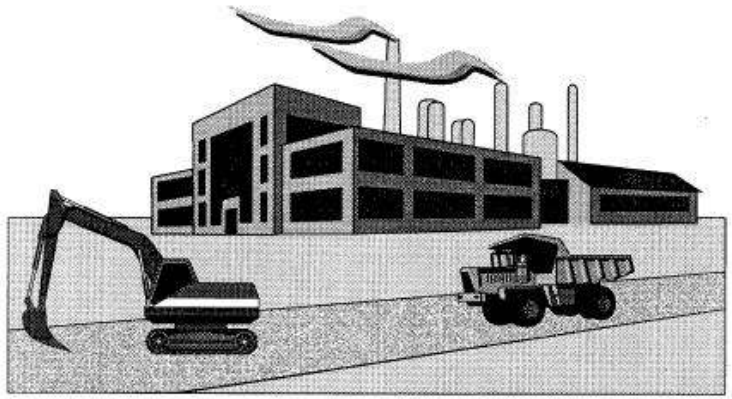
Quantitative Evaluation of the Cleanup Effectiveness on the Basis of Radiation Risk

Radionuclide	Activity (Bq/kg)	PC			
		Leukemia	Respiratory	Digestive	Liver
^{60}Co	53080 (before decontamination)	42%	22%	11%	46%
	5.58 (after decontamination)	0.008%	0.008%	0.003%	0.025%

✓ The Probability of Causation (PC) values have been reduced by remediation to a negligible level since the decontamination activities result in approximately 100% removal of ^{60}Co contamination.







Verification of Compliance with the Exclusion and Exemption Guidelines

For Radionuclides of Natural Origin:-

Radionuclide	Observed activity (Bq/kg)	Exclusion level (Bq/kg)
^{212}Bi	11.83	1000
^{214}Bi	11.8	1000
^{212}Pb	13.12	1000
^{214}Pb	13.4	1000
^{40}K	224	10000

For Radionuclides of Artificial Origin:-

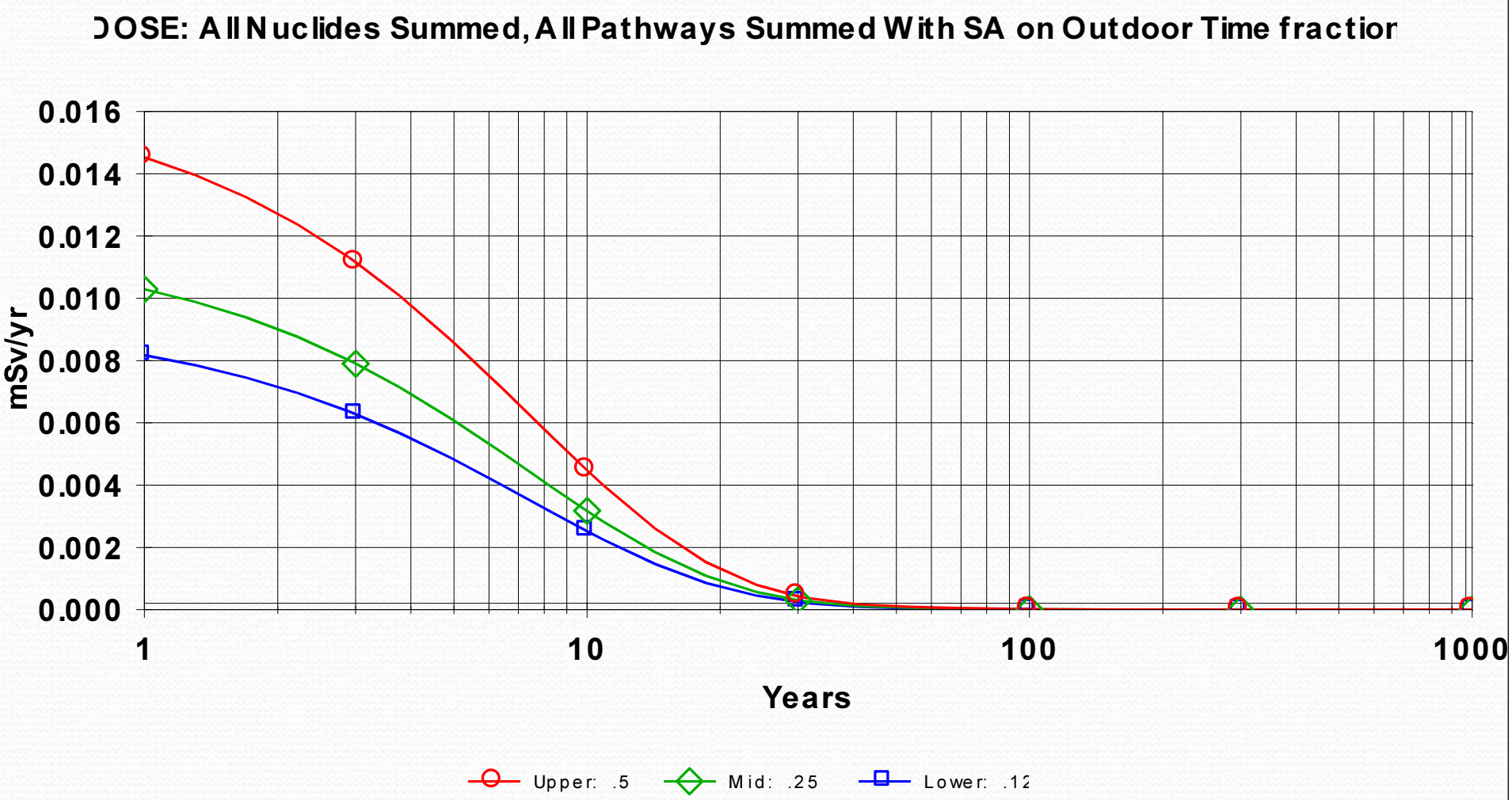
Radionuclide	Observed activity (Bq/kg)	Exemption level (Bq/kg)	Fraction
^{60}Co	5.58	100	0.055
^{137}Cs	2.25	100	0.022
Sum of Fractions			0.077

✓ The sum of fractions for artificial radionuclides is estimated to be 0.077 (less than the multiple radionuclides criterion of 1).

✓ This result will ensure that the total dose or risk due to the sum of all the radionuclides does not exceed the individual trivial risk criterion established by the IAEA.

Results of Sensitivity Analysis

The (outdoor time fraction) parameter has the highest impact on the dose assessment results.



Results of Uncertainty Analysis

Uncertainty and probabilistic analysis are used to determine the variation in the dose predictions due to uncertainties regarding the extent, depth, area of contamination and outdoor occupancy fraction:-

Parameter	Mean	Min.	Max.
Concentration of Co-60 (Bq/kg)	5.58	5.13	6.03
Concentration of Cs-137 (Bq/kg)	0.45	0.05	2.28
Thickness of contaminated zone (m)	0.15	0.10	0.20
Area of contaminated zone (m^2)	62500	65000	70000
Outdoor time fraction	25%	20%	30%

✓ The assessed radiological dose range from a minimum of 0.009 mSv/y to a maximum of 0.0146 mSv/y due to variability of the above parameters.

✓ The overall uncertainty of the mean assessed dose is 9.54×10^{-7} mSv/y.

✓ The 95% upper confidence limit on the true (actual) dose is evaluated at 0.011 mSv/y, less than the IAEA release criteria of 0.3 mSv/y.

✓ The radiological dose of ^{137}Cs and ^{60}Co exposure is clearly judged to be less than the release criteria at 95% confidence level.

Derived Soil Cleanup Guidelines

The land contamination levels in LAMA facility should not exceed the following derived guidelines to maintain the dose received by future site users below the release criteria of 0.3 mSv/y:-

Radionuclide	Final land-use scenario	
	Industrial	Residential
^{60}Co (Bq/kg)	155	153
^{137}Cs (Bq/kg)	603	551

✓ The derived guidelines could be used to compare with onsite measurements, serve as indicators of whether remediation is necessary, indicate when remediation is sufficient, and provide direction for soil monitoring programme.

Summary (I)

- A residual radioactivity contents of 5.54 Bq ^{60}Co /kg and 0.45 Bq ^{137}Cs /kg produce a radiological dose of about 0.011 mSv/y to onsite workers and about 6.21×10^{-5} mSv/y to nearby population.
- The ^{60}Co and ^{137}Cs contamination contribute about 3% of the total radiation dose delivered to LAMA workers during decommissioning measured using Electronic Personal Dosimeter (EPD) (0.33 mSv/y). In view of the natural ambient background radiation level of 0.28 mSv/y measured using RadEye field survey instrument, the incremental onsite and offsite doses are insignificant.
- ^{60}Co contamination poses the greatest threat to the human health than ^{137}Cs and contributes about 77% of the total radiation-derived risk for onsite receptors.

Summary (II)

- According to the results of quantitative health risk assessment for stage-2, LAMA site will be considered acceptable for unrestricted release since the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent to an average member of the critical group of 0.011 mSv/y, that does not exceed the release guideline of 0.3 mSv/y.
- The results of radiological dose assessment are of satisfactory quality for supporting the release decision with reasonable assurance.
- The treatment of dose assessment uncertainty is unnecessary since the 95% confidence level on the true mean dose rate is found to be clearly below the dose-based release criterion.
- The uncertainty regarding outdoor occupancy fraction has the greatest impact on the dose assessment results.
- The radiological dose to the members of the general public of 6.21×10^{-5} mSv/y is found to be considerably less than the dose limit of 1 mSv/y recommended by the IAEA.

Summary (III)

- Radiation-derived health risk for offsite receptors is found to be within the acceptable annual risk level to the public from an environmental source (10^{-6} to 10^{-5} risk/y). Accordingly, the respective offsite individuals are exposed to the radionuclides of concern within the recommended dose and risk limits.
- The radiological contamination that remains in the LAMA facility after remediation satisfy the trivial risk criterion of 10 μSv/y.
- There is a reasonable agreement between the findings of concentrations, dose and health risk comparisons with the applicable radiation protection guidelines. Therefore, further radiological survey is not recommended.
- The external exposure pathway is the most significant route for onsite and offsite exposure and contributes more than 99% of the total effective dose equivalent.
- Risk management action and dose restriction measures are not required since the results of radiological risk analysis performed in this work indicate that people are exposed to the radiation threat within acceptable dose and risk limits.


Thanks for Listening