Applying ERMIN to the Seoul Scenario

IAEA EMRAS II 3rd Plennary

Urban Working Group 5th meeting

Version: 1

Outline

- ERMIN model
  - ERMIN implementation in RODOS and ARGOS
  - RODOS demo
- Seoul Scenario
  - Interpretation for ERMIN
  - Results

- PRA and urban environment (PACE)

Model collaborators

EURANOS EC Project 2004-2008

- Health Protection Agency, Centre for Radiation, Chemical and Environmental Hazards, U K
- Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Denmark
- Helmholtz-Zentrum Muenchen, Germany
- Forschungszentrum Karlsruhe, IKET, Germany
- Danish Emergency Management Agency, Denmark
- Prolog Development Center, Denmark
- Bundesamt für Strahlenschutz, Germany

NERIS-TP EC Project 2011-2014

ERMIN future developments

NERIS-TP EC project (2011)

- Update RODOS (including ERMIN) to handle new ICRP approach, e.g. residual dose
- Modify ERMIN to allow projections of dose beginning months/years after initial deposition
- Allow the ERMIN to evaluate a number of predefined strategies

Also

- Development of new environments and automated approach to populating ERMIN UDL

ERMIN Design requirements

Model must

- be easy to use
- support a large range of different countermeasure types
- support countermeasure combinations
- account for early countermeasures
- to be implemented in RODOS and ARGOS DSS
- support extended releases
- be expandable for different scenarios, e.g nuclear power station accidents, explosions, weapons accidents – currently only nuclear power stations

ERMIN design

A grid approach

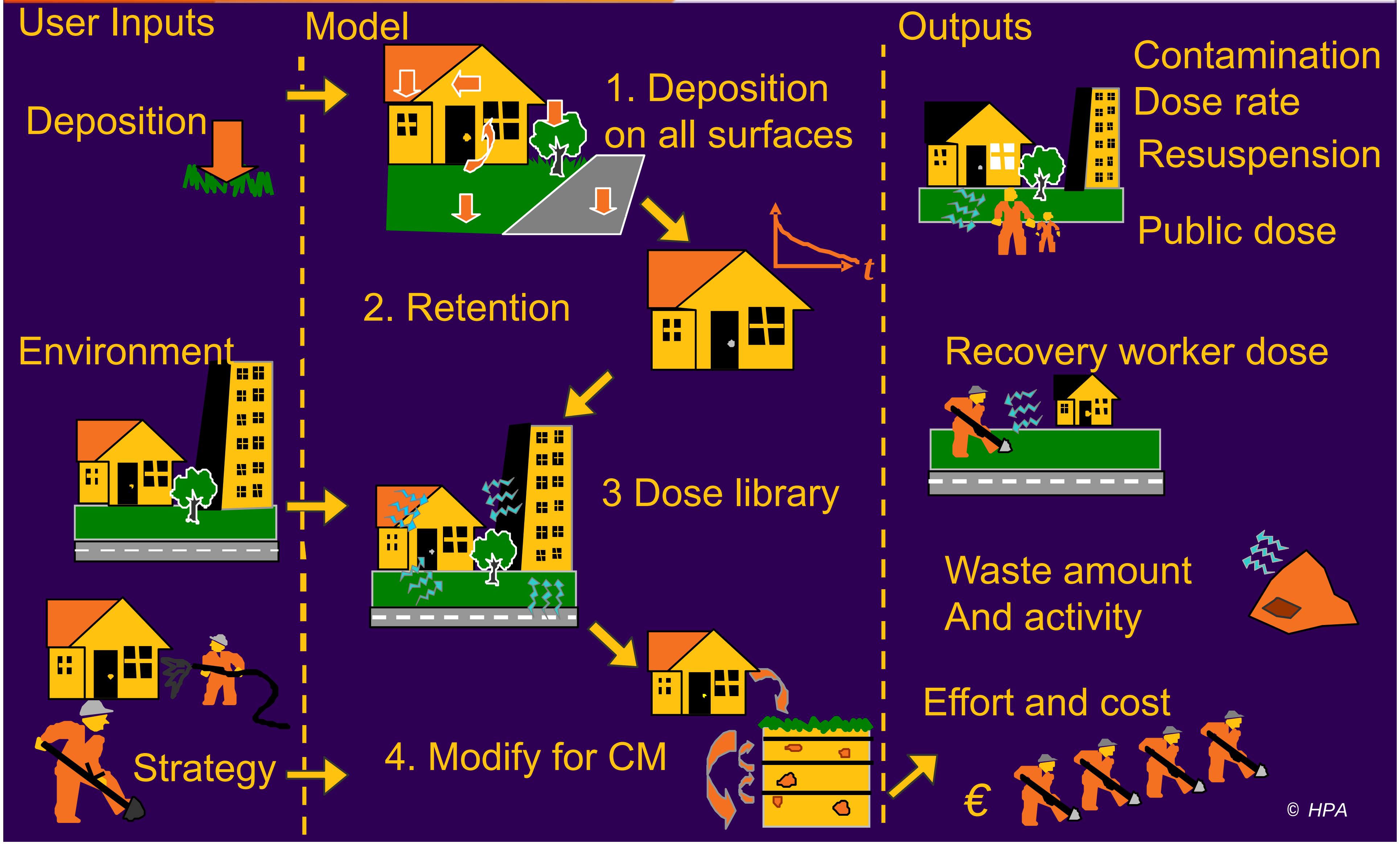
User divides region into grid squares

Each grid square considered homogeneous with respect to deposition, urban environment and countermeasures applied

ERMIN model run independently for each grid square

The ERMIN model

Health Protection Agency



ERMIN initial deposition

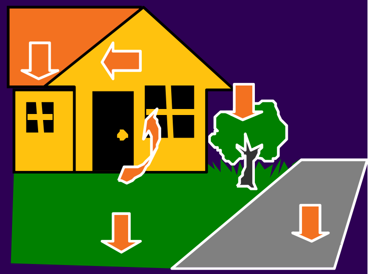
Health Protection Agency

CODEP calculates initial deposition on all urban surfaces from deposition to a reference surface

INDEPS stores deposition ratios for dry, wet and wet/dry conditions

- based on an extensive data review
- dominated by Chernobyl so most suitable for NPP accidents
- radionuclides partitioned into deposition groups by scenario (currently only NPP scenario)

Group	Weather	Paved	Roof	Walls	Interior	Trees	Grass	Plants	Soil
Elemental iodine	Dry	0.2	1.5	0.14	0.14	0.4	1	0.8	0.6
	Wet	0.025	0.0085	0.01	0.00701	0.01	0.01	0.01	1
	Dry/wet	0.42	0.84	0.07	0.0701	0.49	0.7	0.63	0.8
Aerosol AMAD < 2 µm	Dry	0.3	0.7	0.05	0.0417	2.5	1	1.5	0.3
	Wet	0.45	0.425	0.01	0.00208	0.5	0.1	0.2	1
	Dry/wet	0.57	0.7125	0.02	0.0208	1.53	0.8	1.105	0.65
Aerosol AMAD 2-5 µm	Dry	0.7	4	0.1	0.0411	5	1	1.5	0.3
	Wet	0.45	0.3825	0.01	0.00205	0.25	0.1	0.3	1
	Dry/wet	0.8075	2.28	0.05	0.0205	2.55	0.8	1.105	0.65



ERMIN retention

DIAM calculates retention and dose

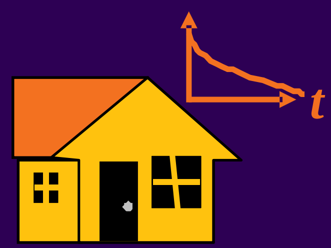
- empirical retention functions for most surfaces
- soil migration using a convective-dispersion model
- empirical resuspension

RADMOV dataset stores retention parameters in RADMOV dataset

- radionuclides assigned to retention groups depending on scenario chosen (currently one scenario and one group)

UDL stores gamma and beta unit dose rates for each surface in each environment for indoor and outdoor locations

UDL stores descriptive parameters for environments, including surface area and population density



ERMIN empirical retention functions

Health Protection Agency

$$C_{PR_p}(t) = C_{PR_p}(0)\left[a_{1,PR}\, e^{\left(-\frac{\ln(2)}{\tau_{1,PR}}t\right)} + a_{2,PR}\, e^{\left(-\frac{\ln(2)}{\tau_{2,PR}}t\right)}\right] e^{\left(-\frac{\ln(2)}{T_{1/2_p}}t\right)}$$

$C_{PRp}(t)$ is activity on roads of parent radionuclide at time t
a_1 and a_2 are the fractions of tightly and less tightly bound activity
τ_1, τ_2 are the half lives of weathering processes
$T_{1/2}$ is the half life of radionuclide

Coniferous trees include extra term to account for shedding of needles

Deciduous trees it is assumed all leaves shed at a specified time.

The only transfers considered are

Trees to soil

Plants and grass to soil

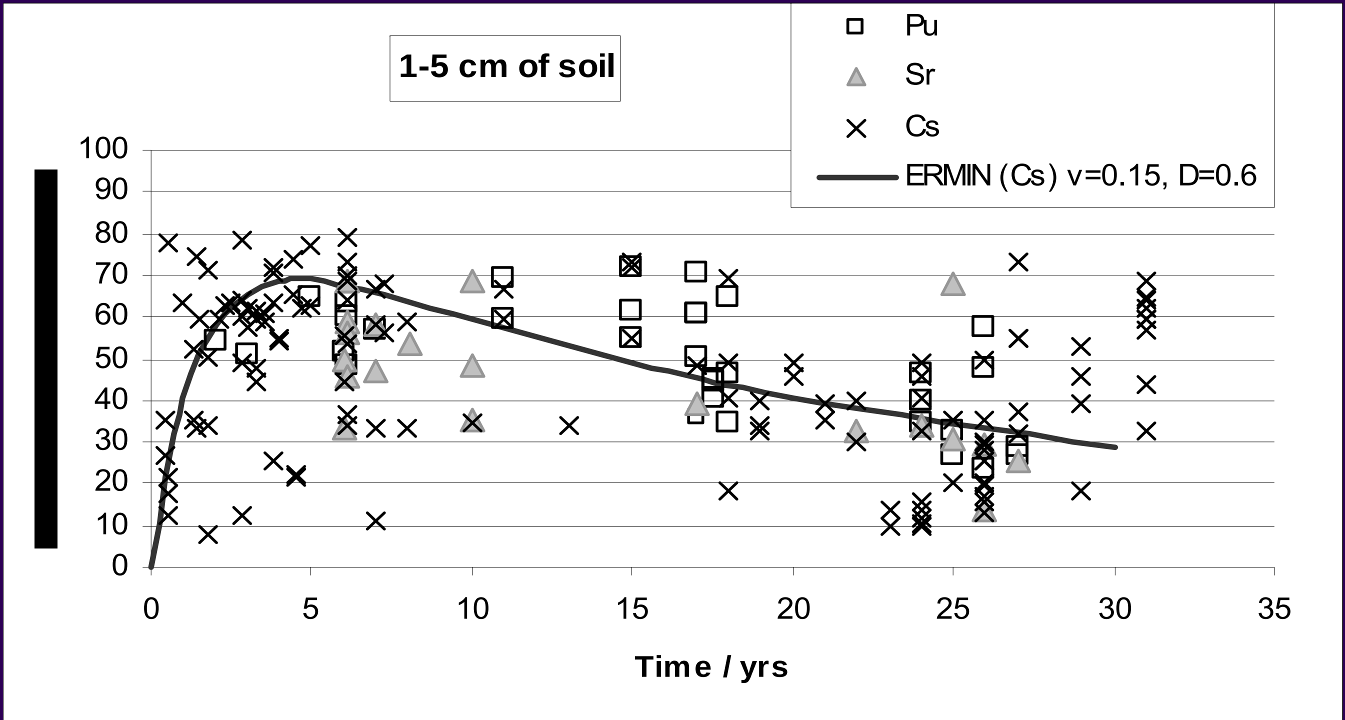
Cross-contamination following decontamination

Surface	T1 (days)	T2 (days)	a1	a2
Road	146	1095	0.7	0.3
Pavement/sidewalk	109.5	1825	0.8	0.2
Other paved	146	1825	0.9	0.1
Roofs	730	12775	0.5	0.5
External walls	2555	0	1	0
Internal surfaces	182.5	0	1	0
Deciduous	30	620.5	0.5	0.04
Coniferous	30	620.5	0.5	0.04
Grass	16	0	1	0
Plants	12	0	1	0

Soil model

Migration down the soil column simulated with a dispersive convective model

Bunzl K, Schimmack W, Zelles L and Albers B P. (2000) Spatial variability of the vertical migration of fallout ^{137}Cs in the soil of a pasture, and consequences for long-term predictions. Radiat Environ Biophys 39 197-205



ERMIN Resuspension

Outdoors simple empirical resuspension factor model

Chosen to be conservative at short times when there could be enhanced resuspension from trees

Very little data available

$$C_O = K(t) D_{RO}$$

D_{RO} is the initial deposition to the reference surface Bq m^{-2}

$$K(t) = 1.2 \times 10^{-1} \quad \text{for } t \leq 1\,\text{day}$$

$$K(t) = \frac{a_{RSO}}{t} e^{\left(-\frac{\ln(2)}{T_{1/2}}\right)} \quad \text{for } 1\,\text{day} < t \leq 40\,\text{days}$$

$$K(t) = a_{RLO} e^{(-b_{RLO} t)} e^{\left(-\frac{\ln(2)}{T_{1/2}}\right)} \quad \text{for } 40\,\text{days} < t$$

$K(t)$ is the resuspension factor m^{-1} (Bq m^{-3} per Bq m^{-2})

$$a_{RSO} = 1.2 \times 10^{-6}\ \text{m}^{-1}$$

$$a_{RLO} = 3.1 \times 10^{-8}\ \text{m}^{-1}$$

$$b_{RLO} = 0.51 \times \text{year}^{-1}$$

ERMIN resuspension

Very little data for typical residential rooms

Agglomeration with house dust may be important

$$C_i V(\lambda_d + \lambda_v) = \lambda_v f V C_O + C_{iP} A R$$

where

C_i is the activity concentration in indoor air (Bq m^{-3})

λ_d is the indoor deposition rate (s^{-1})

V is the volume of the room in question (m^3)

λ_v is the air exchange rate (s^{-1})

f is the filter factor(fraction of outside particle that enter house)

A is the surface area from which resuspension occurs (m^2)

C_{Ip} is the surface density on the resuspending surface.

R is the resuspension rate (s^{-1})

$C_o = K(t) D_{RO}$ is the outdoor activity concentration (Bq m^{-3})

K_t is the outdoor resuspension factor (m^{-1})

D_{RO} is the initial concentration to the reference surface (Bq m^{-2})

ERMIN urban environments

Based on existing studies; Monte Carlo modelling

Unit dose rates; modification and completion required

Beta dose;

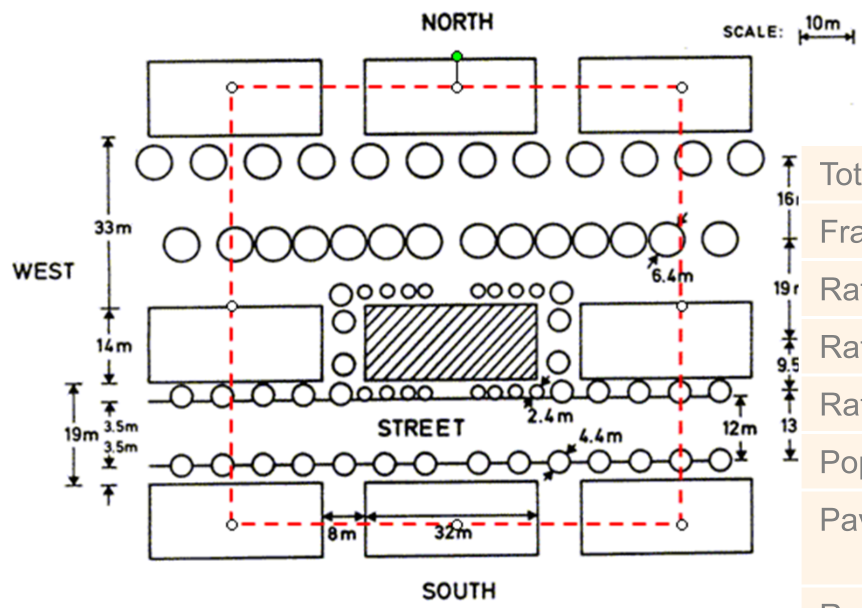
Street of detached prefabricated houses	Meckbach et al, 1988
Street of semi-detached houses with basement	Meckbach et al, 1988
Street of semi-detached houses without basement	Jones et al, 2006
Street of terraced houses	Meckbach, 1988
Multi-storey block of flats amongst other house blocks	Meckbach, 1988
Multi-storey block of flats opposite parkland	Meckbach, 1988
Industrial site (Incomplete dose library)	Kis et al, 2003
Large open area	Jones et al, 2006

ERMIN urban environments

ERMIN ideal environments	Available parameter sets to allow adjustment to proportions of outside surfaces
Street of detached prefabricated houses	No trees – low – default – high trees Low paved – medium (default) – high paved
Street of semi-detached houses with basement	No trees – low – medium (default) – high trees Low paved – medium (default) – high paved
Street of semi-detached houses without basement	No trees – low – medium (default) – high trees Low paved – medium (default) – high paved
Street of terraced houses	No trees – low – medium (default) – high trees Low paved – medium (default) – high paved
Multi-storey block of flats amongst other house blocks	No trees – low – medium (default) – high trees Low paved – medium (default) – high paved
Multi-storey block of flats opposite parkland	No trees – low – medium (default) – high trees Low paved – medium (default) – high paved
Industrial site (Incomplete library)	Medium trees (default) and paved
Large open area	Park (default); mostly grass, some trees, some paved Playing fields; mostly grass, few trees, little paved Car park; mostly paved, few trees little grass Ideal; all grass no trees no paved

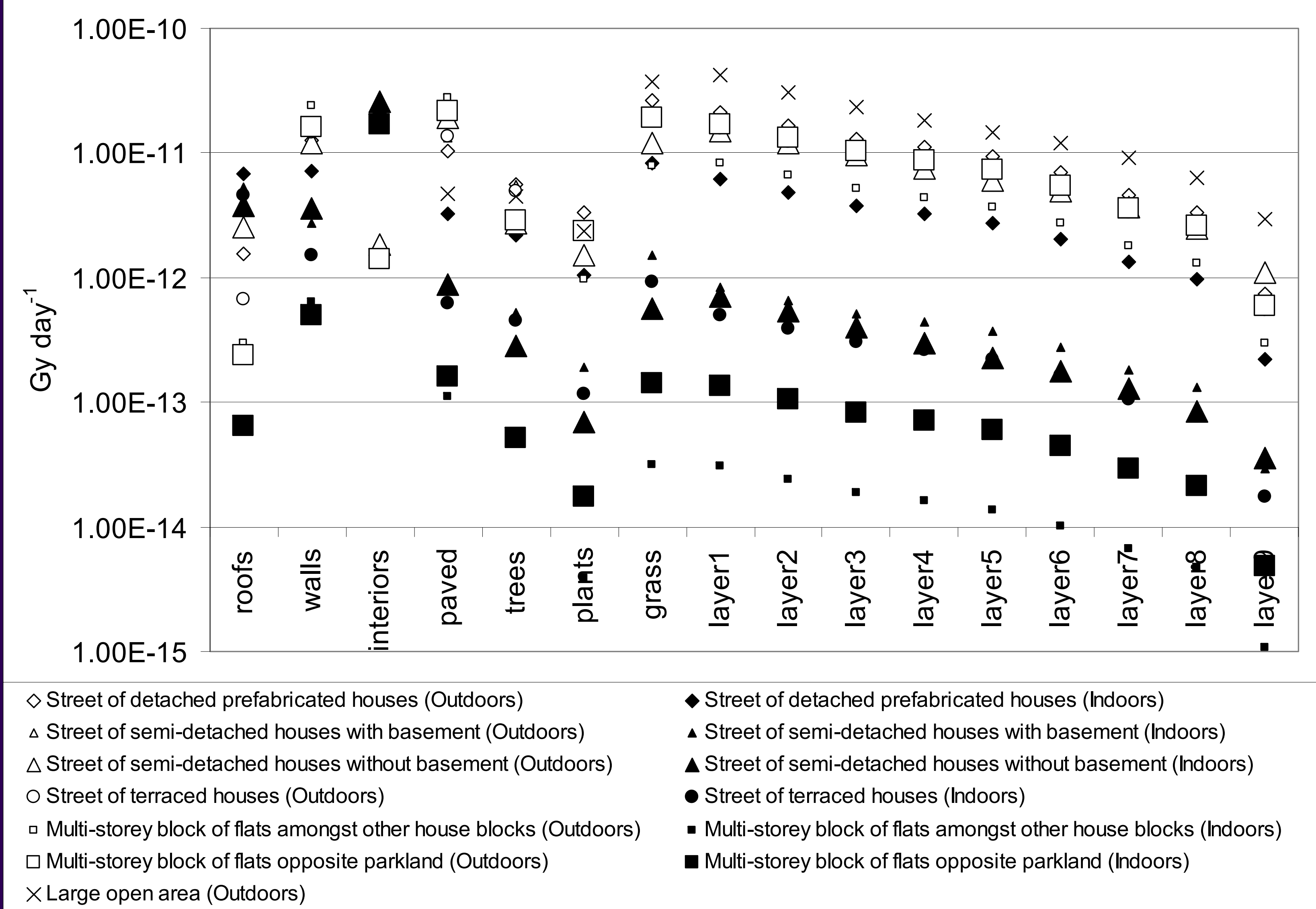
ERMIN environments - terrace house environment example

Health Protection Agency



Total cell area (m^2)	6400		
Fraction outside	0.720		
Ratio of roof to total cell area	0.305		
Ratio of wall to total cell area	0.371		
Ratio of internal surfaces to total cell area	1.120		
Population Density (people km^{-2})	12500		
Paved configurations	Default paved	High Paved	Low paved
Ratio of road to total cell area	0.150	0.225	0.075
Ratio of pavement to total cell area	0.038	0.056	0.019
Ratio of other paved to total cell area	0.063	0.105	0.035
Ratio mowable grass to total cell area	0.370	0.267	0.473
Ratio plant to total cell area	0.046	0.033	0.059
Ratio bare soil to total cell area	0.046	0.033	0.059
Tree Configurations	Default trees	High trees	Low trees
Ratio deciduous to total cell area	0.131	0.197	0.066
Ratio of coniferous to total cell area	0.033	0.049	0.016

ERMIN unit dose rate library



ERMIN modelling countermeasures

DRT dataset holds information on countermeasure options extracted from European Handbook for Inhabited areas

CMStrat combines user options with DRT to create numerical description of countermeasure strategy for DIAM

ERMIN developing DRT

Considered each countermeasure in handbook

- Should it be included?
- Identify categories of countermeasure that can be represented in the model in the same way
- Identify parameters needed to describe each category (DF, shielding etc)
- Is countermeasure likely to be applied to part of a surface?
- Extract parameters for each C/M from compendium and interpret where necessary

ERMIN selecting countermeasures for inclusion in DRT

Most countermeasures from EU generic handbook included

Omitted countermeasures dealing with surfaces not included in ERMIN e.g. snow removal, precious objects or for being too situation specific

Some countermeasures subdivided - variants with different properties

e.g. turf removal given as single option with various environmental restoration options (do nothing, add top soil and reseed, replace with new turf) each having different dose reduction properties, costs and work rates

ERMIN modelling countermeasure categories

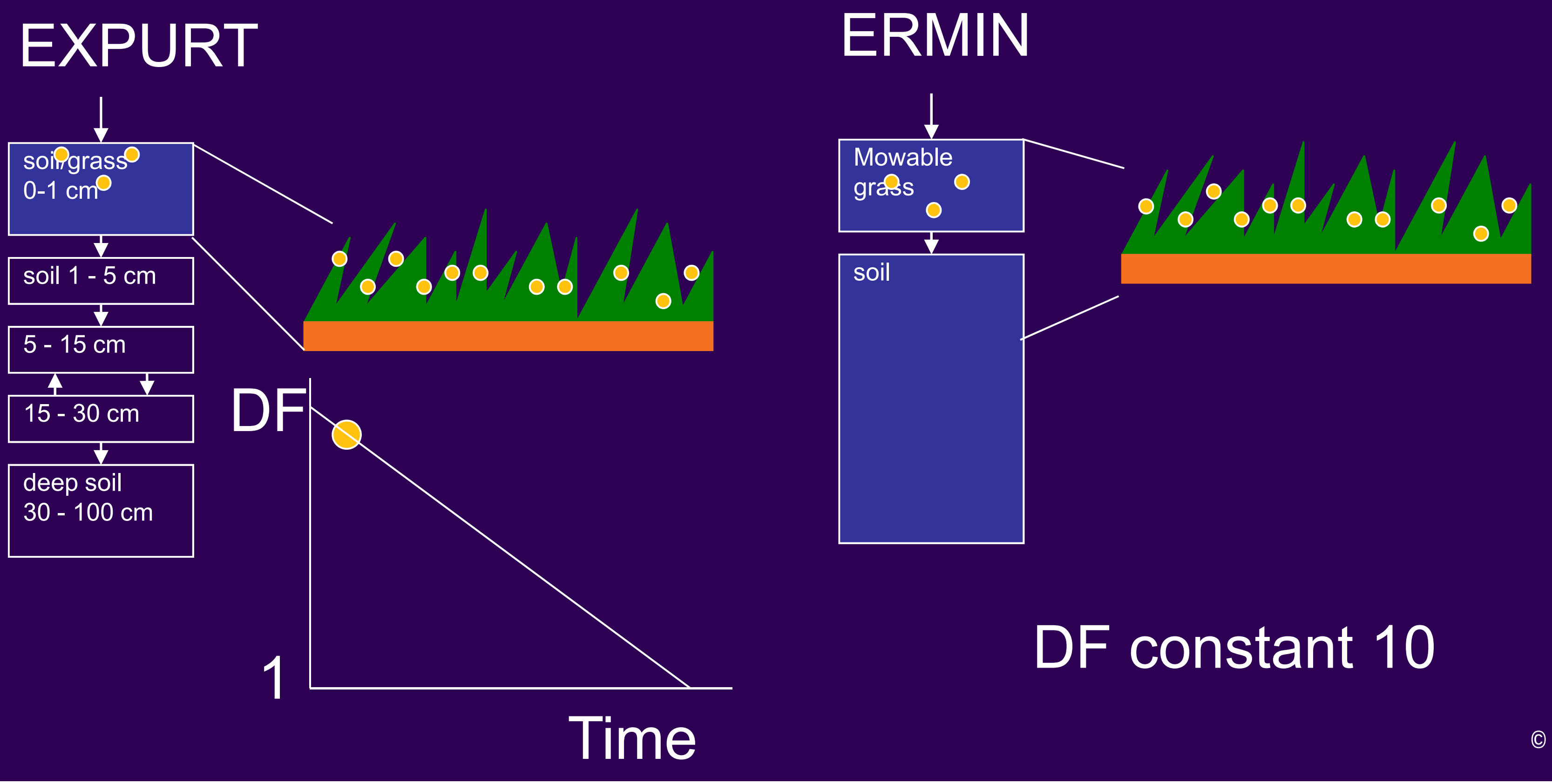
Category	Representation in ERMIN
Decontamination – e.g. road sweeping, indoor cleaning	step change in surface contamination resuspension reduced by proportion of material removed
Surface removal – e.g. turf removal, road surface planing	step change in surface contamination resuspension reduced by proportion of material removed cross contamination allowed
Soil mixing – e.g ploughing, digging	redistribute material in the soil profile
Fixing techniques – e.g. wetting surfaces (temporary), painting surfaces (permanent)	no resuspension whilst fixed no beta dose from surface while fixed
Shielding – e.g. turning paving slabs, putting asphalt over soil	modify unit dose rate, assume no beta dose from surface, assume no resuspension, assume no further loss of activity other than decay
Relocation	no dose while population is out of the area

Parameters need to represent countermeasure types

Category	Parameters
Decontamination	Decontamination factor (including time dependency) Waste material (dust, grass clippings etc) waste rate (kg m-2)
Surface removal	Waste (soil, asphalt, brick etc) Waste rate (kg m-2) Decontamination effectiveness (accounts for cross contamination)
Soil mixing	Amount of material from each layer that moves to each other layer
Fixing	Permanent/temporary Effectiveness period Waste rate (kg m-2)
Shielding	Shielding material thickness (concrete, soil, asphalt) Shielding material density relative to soil
All	Work rate (m2/team.h), team size (men) and cost rate (Euro m-2) given for equipment, material and labour

ERMIN Interpretation grass cutting example

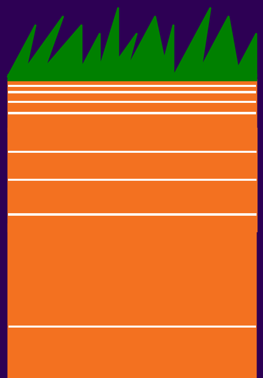
Grass area is mown and grass cuttings collected. The grass cutting height should be as low as possible. A decontamination factor (DF) of between 2 and 10 can be achieved if this option is implemented within one week (Brown et al 2005)



ERMIN interpretation digging countermeasure

Soil profile is divided into three sections. Top section is inverted and placed at the bottom and middle and bottom sections are shifted up.

		Fraction from layer:								
		1	2	3	4	5	6	7	8	9
Fraction to layer:	1	0	0	0	0	0	0.413	0	0	0
	2	0	0	0	0	0	0.400	0	0	0
	3	0	0	0	0	0	0.188	0.321	0	0
	4	0	0	0	0	0	0	0.464	0	0
	5	0	0	0	0	0	0	0.214	0.167	0
	6	0	0	0	0	0	0	0	0.444	0
	7	0	0	0	0	0	0	0	0.389	0.117
	8	0	0	0	0	0	0	0	0	0.300
	9	0	0	0	0	0	0	0	0	0.583
	Below 9	1	1	1	1	1	0	0	0	0



ERMIN other CM considerations - combinations

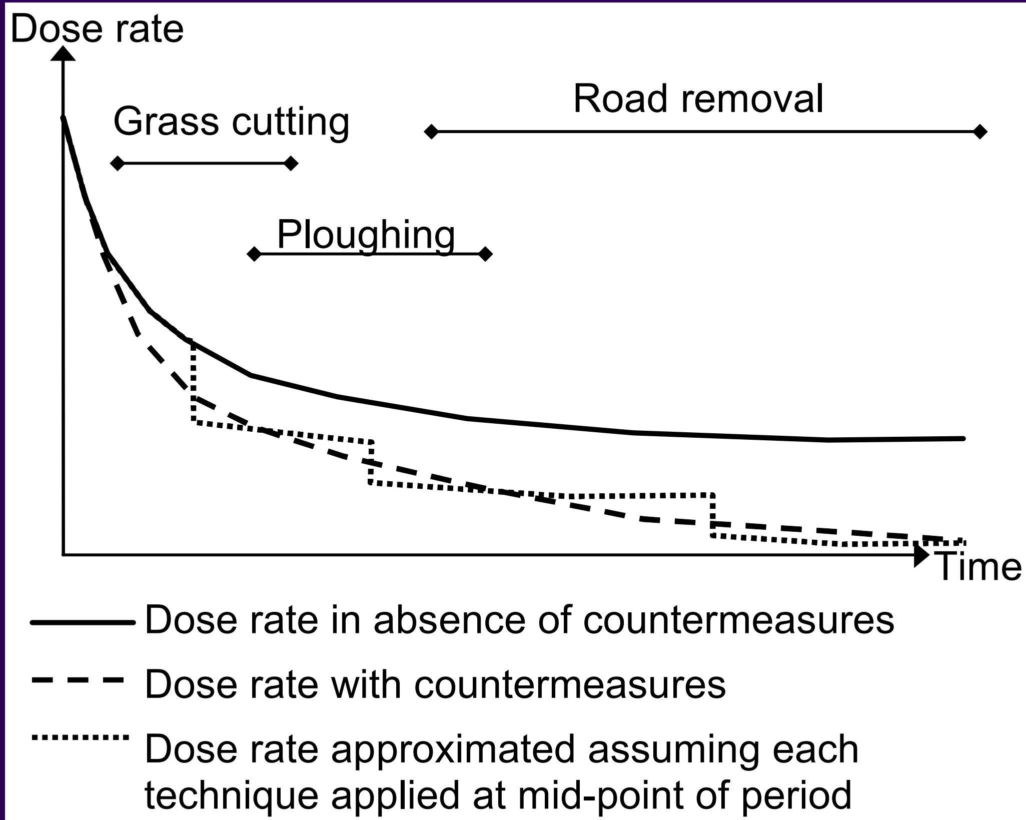
Countermeasure combinations

- Invalid combinations, e.g. hosing roofs after roof removal
- Combinations for which no data is available, e.g. hosing roads followed by vacuum sweeping roads

Timing of countermeasures

- Not applied instantaneously
- Worker dose calculation requires a period

Countermeasures that are begun before deposition ends



ERMIN other CM considerations – partial surface application

Some countermeasures applied to only part of surface

Not physically possible to apply a countermeasure to whole surface – ploughing not used in small gardens

Very different work and cost rates - road sweepers and pavement sweepers

Better techniques available - manual digging could be applied to large areas of grass but automated methods quicker and cheaper

In ERMIN

grass is subdivided into large continuous and small fragment areas and into grass, bare soil and plants.

Paved surfaces are divided into roads,

Proportions are environment dependent.

ERMIN Public dose calculations

DIAM calculates numerous indicative doses and dose rates indoors and outdoors in various environments

To avoid information overload results are aggregated

Typical outdoor weights by fraction of environments

$$Dose_{avg\ outdoor} = \Sigma\left(Dose_{outdoor\ env1} \times fraction_{env1}, \ldots Dose_{outdoor\ env\ n} \times fraction_{env\ n}\right)$$

Typical indoor dose weights by fractions and population density of environments

$$Dose_{avg\ indoor} = \frac{\Sigma\left(dose_{indoor\ env1} \times density_{env1} \times fraction_{env1}, \ldots dose_{outdoor\ env\ n} \times density_{env\ n} \times fraction_{env\ n}\right)}{\Sigma\left(density_{env1} \times proportion_{env1}, \ldots density_{env\ n} \times proportion_{env\ n}\right)}$$

Normal living dose, uses specified indoor occupancy

$$Dose_{avg\ nl} = dose_{avg\ indoors} \times \left(indoor\ occupancy\right) + dose_{avg\ outdoors} \times \left(1 - indoor\ occupancy\right)$$

ERMIN worker dose calculations

For each treatment user sets the period of application

Worker dose depends on

- surface area or population in grid square
- work rate, including the effect of PPE
- shorter period, more teams but less exposure to individual workers

Endpoints

- Collective dose in each grid square (man Sv)
- Total collective dose over all grid squares (man Sv)
- Maximum individual dose in each grid square (Sv)
- dose to a worker in a grid square performing the task estimated to give the highest dose – worker may acquire additional dose doing other tasks or working in other squares
- Overall maximum individual dose (Sv)
  - grid square size dependent

Environment doses are weighted by relative proportion of surface area in each environment (relocation by population density)

Workers gain no benefit from the task they are performing

Compartment model vs retention functions

Compartment models:

Generally slower

Easier to model transfers between surfaces

Easier to model some countermeasures

Retention functions:

Faster (soil model slower)

Harder to model transfers between surfaces

Harder to model some countermeasures

ERMIN implementation

Implemented in RODOS and ARGOS European Nuclear Emergency Decision Support Systems.

Graphical interface based on defining zones on a map

Seoul Scenario
Inputs: Deposition

Ground deposition calculated by Metro-K (provided by Dr Hwang, KAERI)

Air concentration	Deposition
1 MBq d m-3	Dry 5.29 10^{7} Bq m-2
	Light Rain 2.83 10^{9} Bq m-2
	Heavy Rain 1.72 10^{10} Bq m-2

ERMIN has three deposition: conditions: dry, wet/dry and wet

Seoul Scenario: environments representation of Region 1

Scenario location	Representation in ERMIN	Comments
Location 1, ground floor inside Building 1	Indoors in “Multi-storey block of flats amongst other house blocks” environment with default trees and high paved parameter set. No contribution from roofs.	Building 1 different from ideal environment; much taller and has glass walls.
Location 2, 10th floor inside Building 1	As Location 1 No contribution from roofs, paved or grass surfaces	As above
Location 3, top floor of building 1	As Location 2 but with an additional contribution from the roof	As above
Location 4 outdoors near building 1	As location 1	As above

Seoul Scenario: environments representation of Region 2

Scenario location	Representation in ERMIN	Comments
Location 5, centre of park	"Open area" using "Park" parameter set	Real environment has a large number of trees near location
Location 6, east side of park on paved	"Open area" using "Car park" parameter set	

Results

Three deposition conditions (dry, light rain, rain)

Two radionuclides (60Co and 239Pu)

Two times of year (1st June, 1st January)

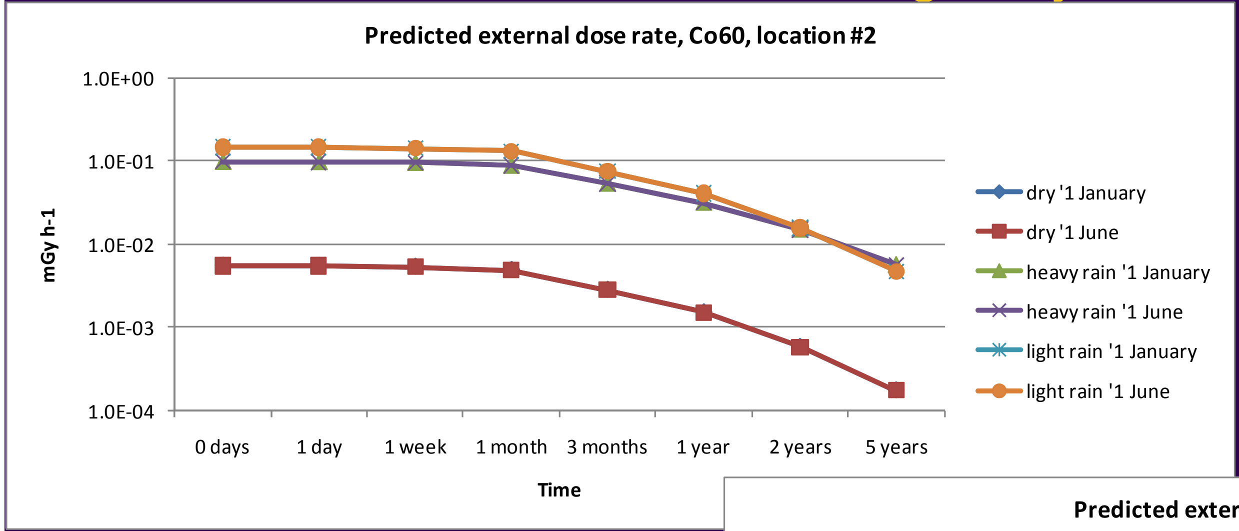
Ten countermeasure combinations (including no action)

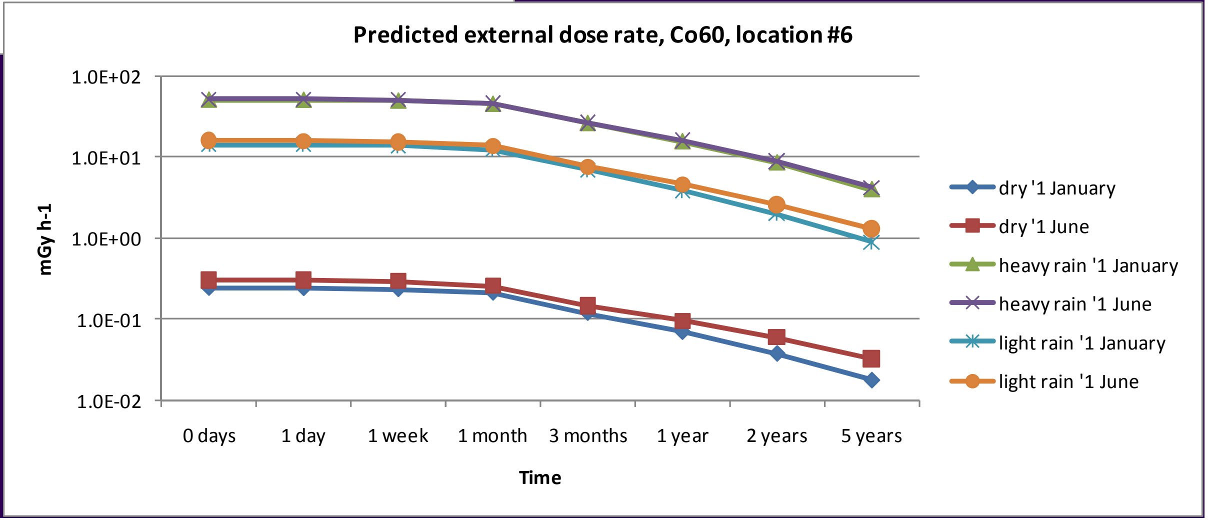
Six locations

= a lot of results

Results: effect of time of year and deposition conditions

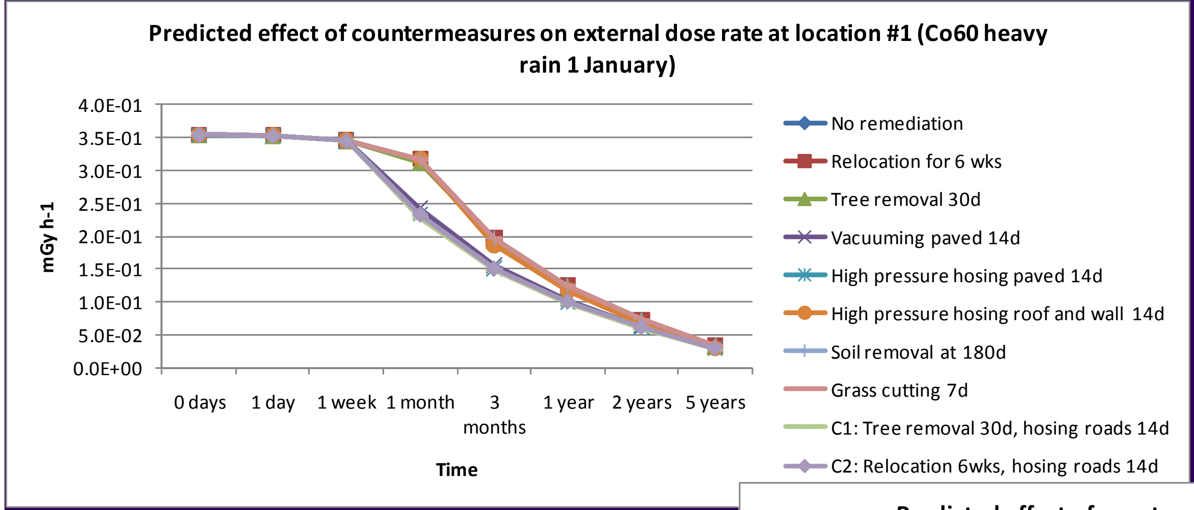
In ERMIN the time of year only effects whether leaves are on deciduous trees and how long they remain

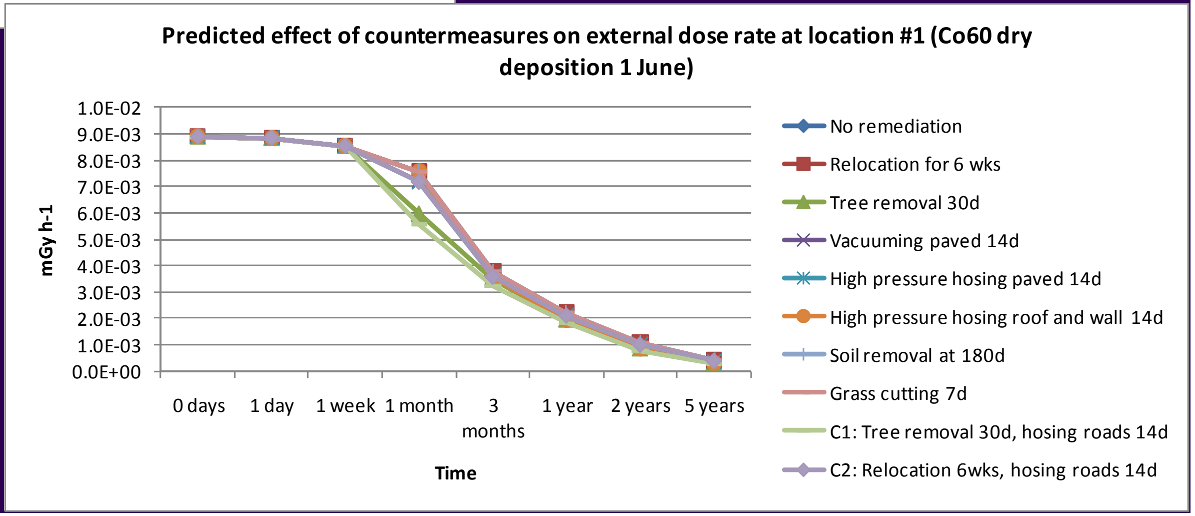




Results: effect of time of year and deposition conditions

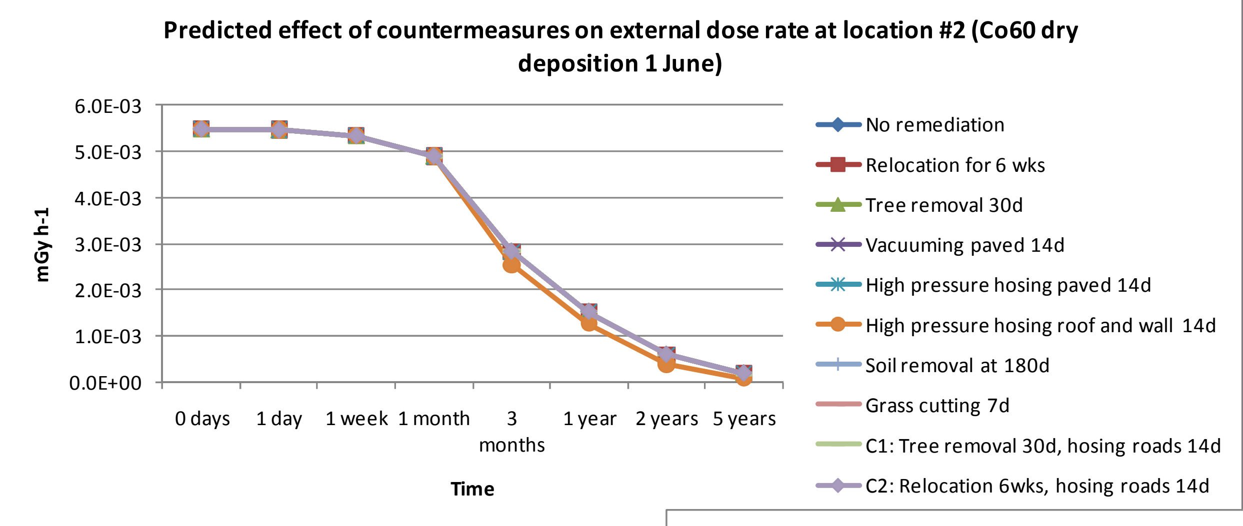
CM effectiveness depends on distribution of contamination on urban surfaces…

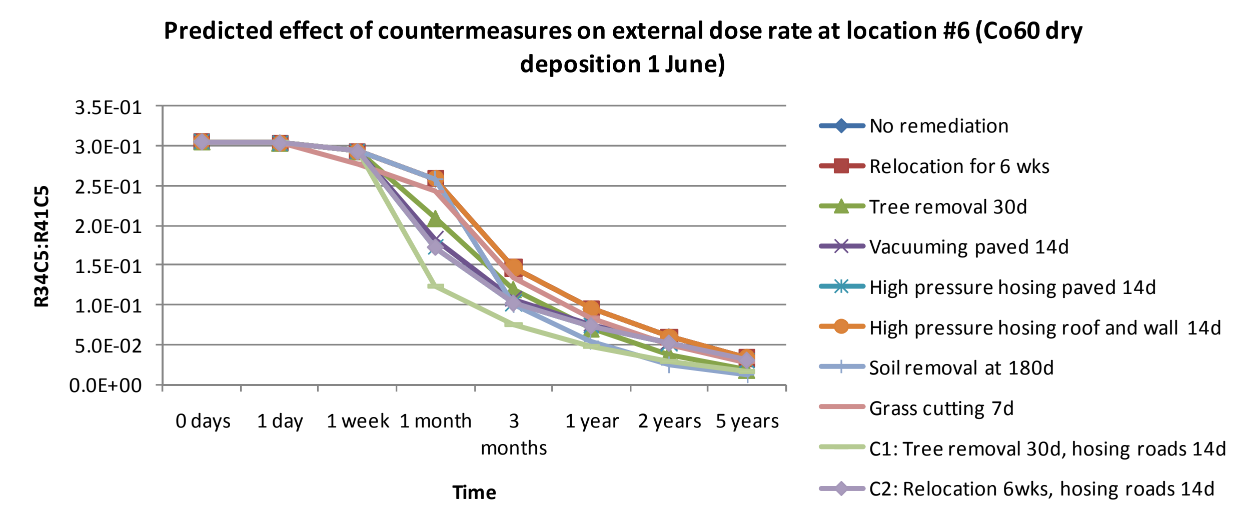




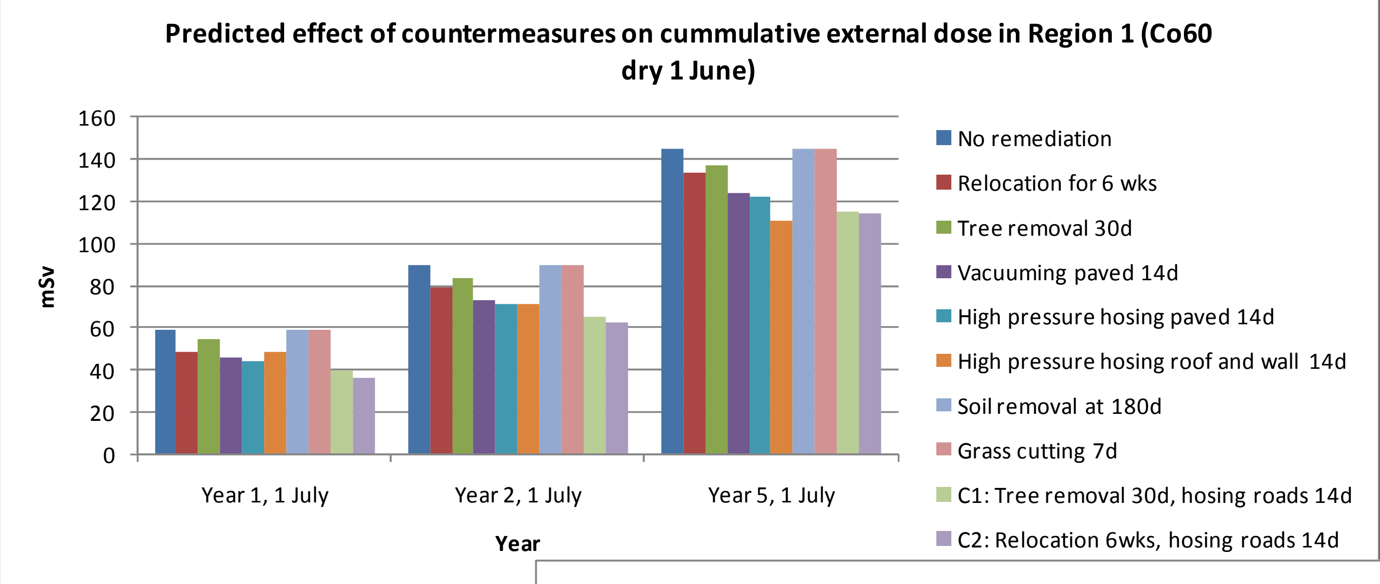
Results: effect of time of year and deposition conditions

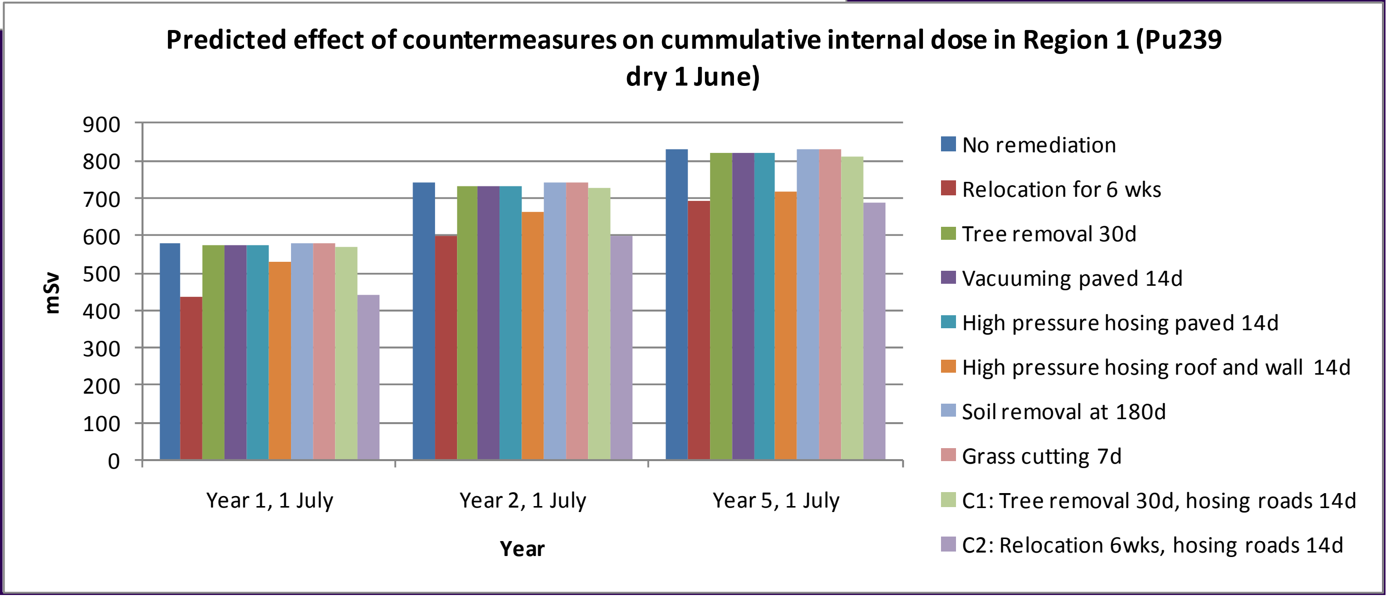
… and on the surface contributing to dose rate





Results: external and internal pathways





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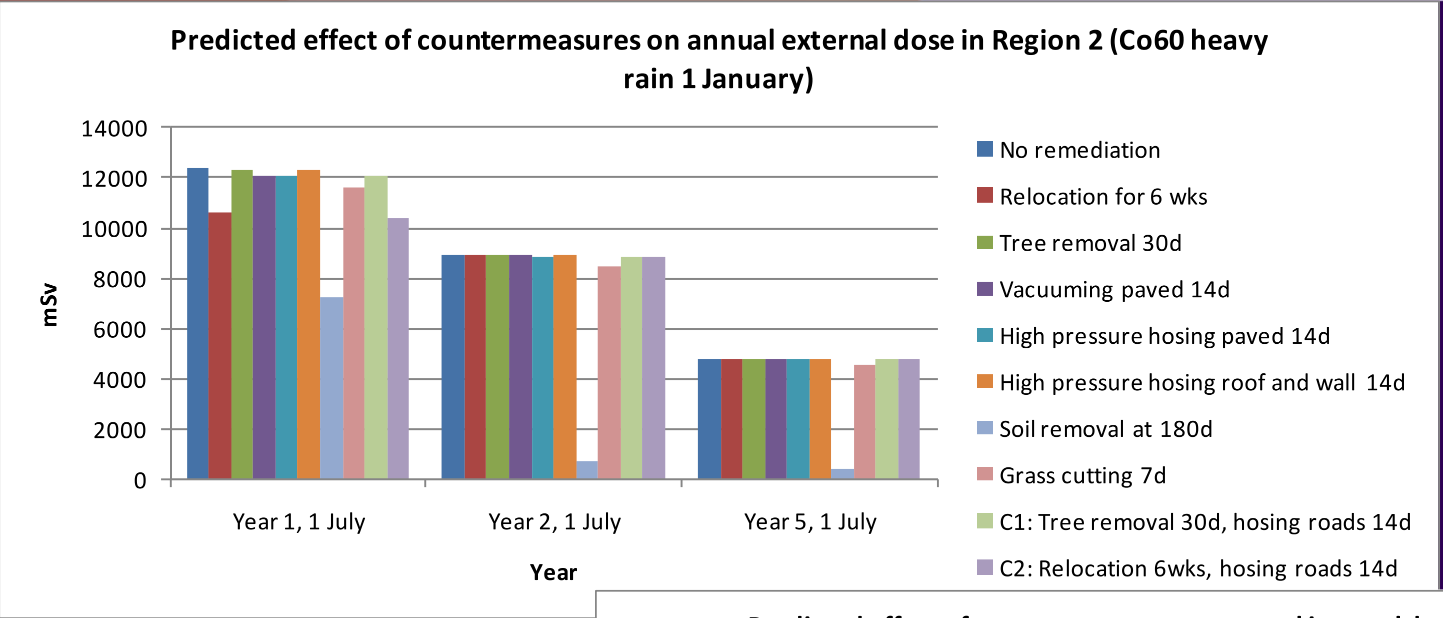
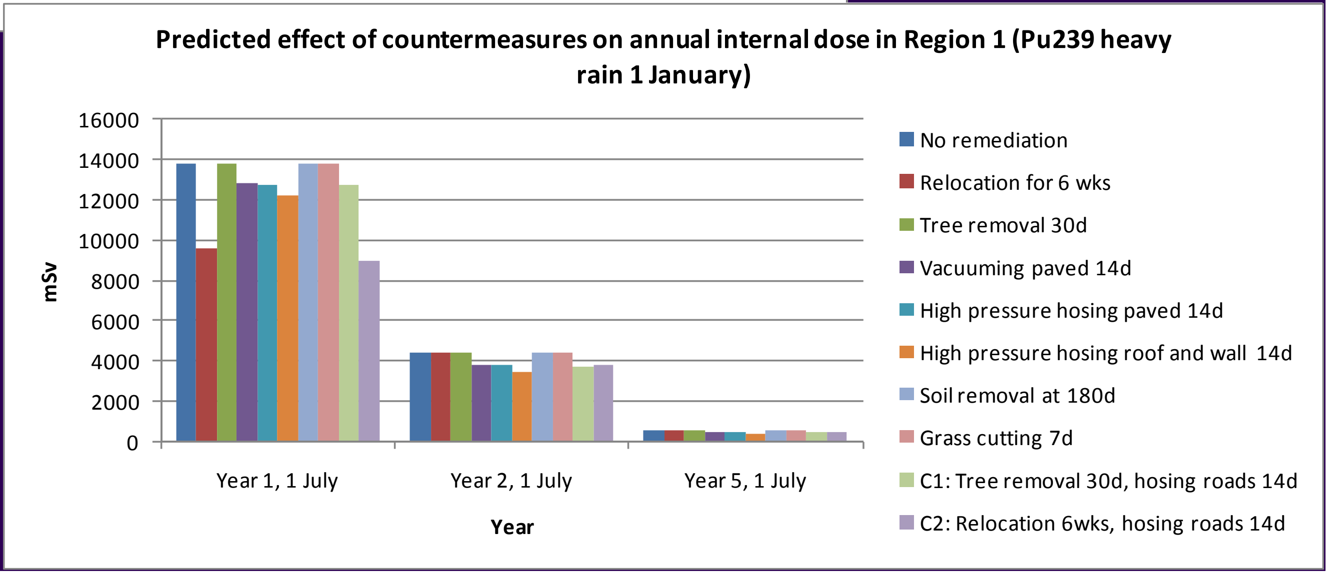




Summary

ERMIN model

- Initial deposition, retention, dose library, countermeasures
- Simple resuspension model

ERMIN Environments not ideal for Seoul

- Initial deposition: deposition onto glass? Penetration into the building (air conditioning? Tracking on feet, removing shoes)
- Retention: retention on glass, window cleaning?
- Shielding of glass

HPA and planning / site licensing processes

- 2008 Planning Act
  - Infrastructure Planning Process for nationally significant infrastructure
  - Infrastructure Planning Commission (IPC) – oversees planning process
  - National Policy Statements (NPS) including nuclear power stations
  - HPA is a Statutory Consultee *“Where any NPS includes policies relating to chemicals, poisons or radiation which could potentially cause harm to people”*
  - (NB government plans to abolish IPC and return responsibilities to ministers)
- HPA provides input
  - to DECC for NPS and associated consultations
  - to NII & EA generic design assessment for reactor designs
  - to IPC & NII for site specific planning applications
- HPA concerned with both normal operation (including building and decommissioning) and accident conditions

Probabilistic Risk Analysis (PRA)

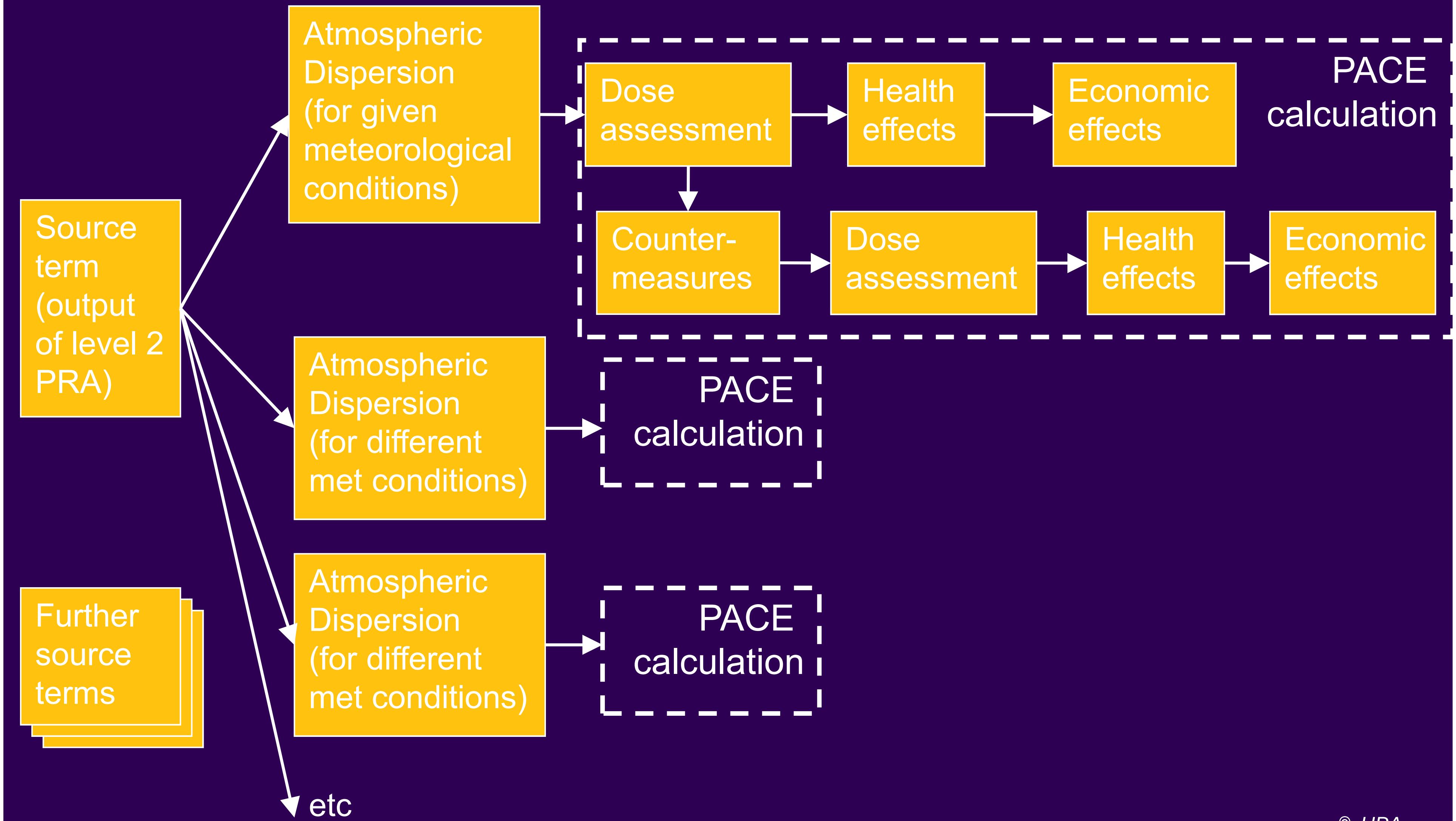
Accidents dealt with probabilistically:

- A Level 1 PRA estimates the frequency of accidents that cause damage to the nuclear reactor core.
- A Level 2 PRA, estimates the frequency of accidents that release radioactivity from the nuclear power plant.
- A Level 3 PRA, estimates the consequences in terms of injury and health impact to the public, damage to the environment and economic impact

Review of HPA capabilities concluded that existing Level 3 PRA codes required updating

PACE (Probabilistic Accident Consequence Evaluation) software project

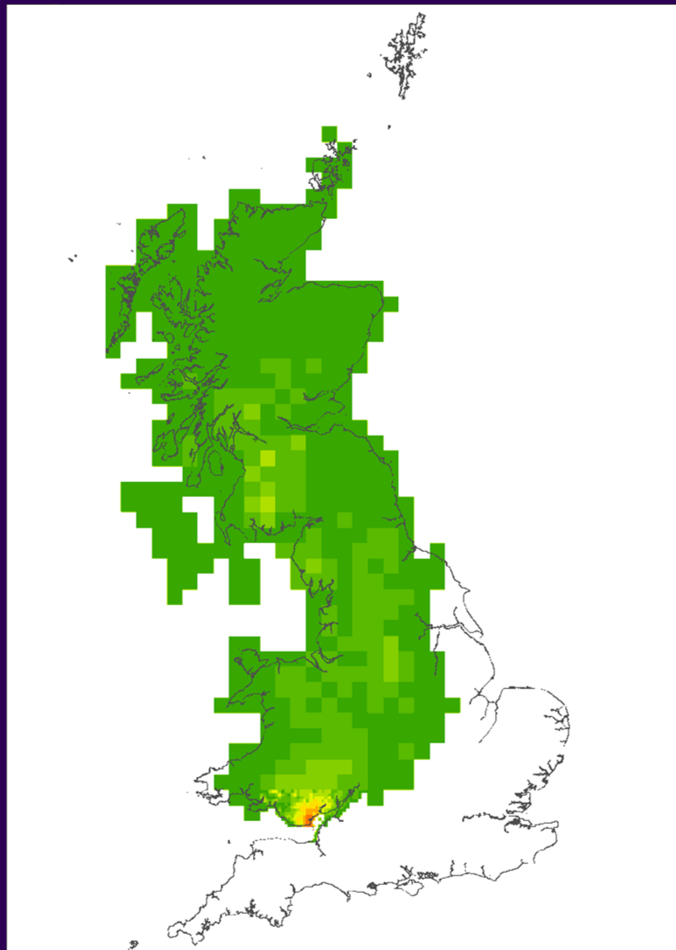
PACE


Source term (output of level 2 PRA)
Further source terms
Atmospheric Dispersion (for given meteorological conditions)
Atmospheric Dispersion (for different met conditions)
Atmospheric Dispersion (for different met conditions)
etc
Dose assessment
Health effects
Economic effects
PACE calculation
Counter-measures
Dose assessment
Health effects
Economic effects
PACE calculation
PACE calculation

Atmospheric Dispersion

Meteorological Office NAMEIII model or Gaussian plume

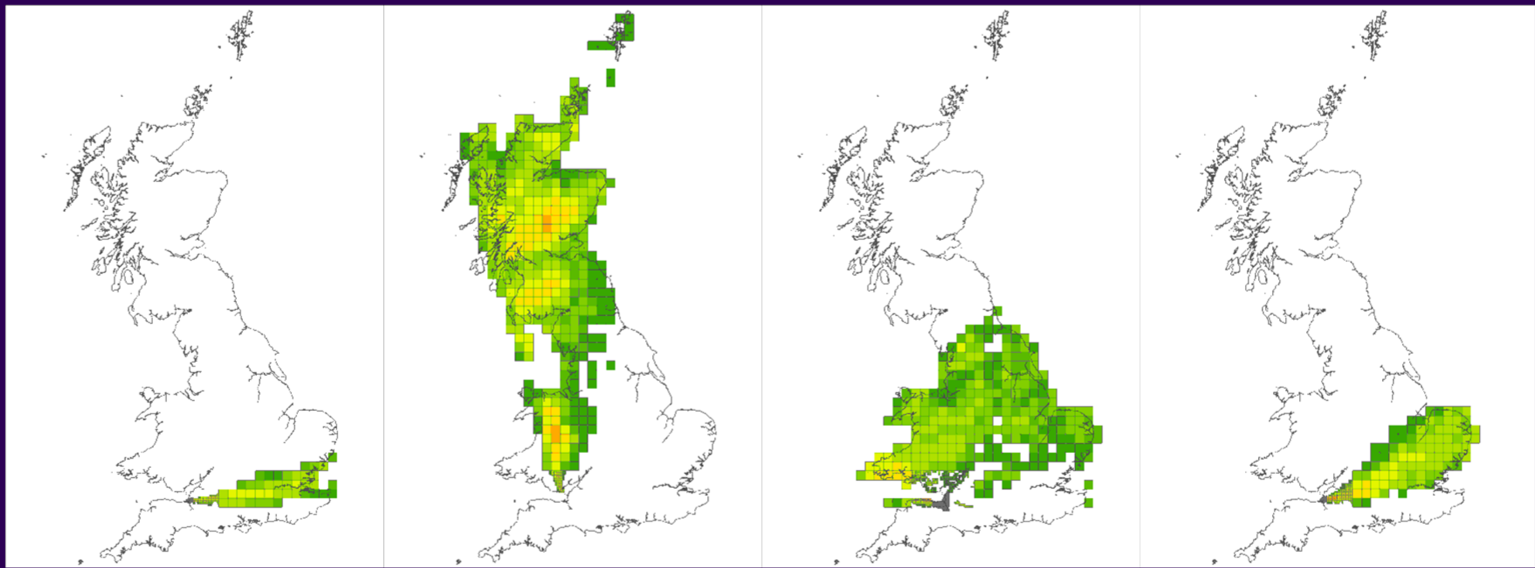
Cloud gamma, activity concentration in air & ground deposition



Atmospheric Dispersion

Meteorological Office NAMEIII model or Gaussian plume

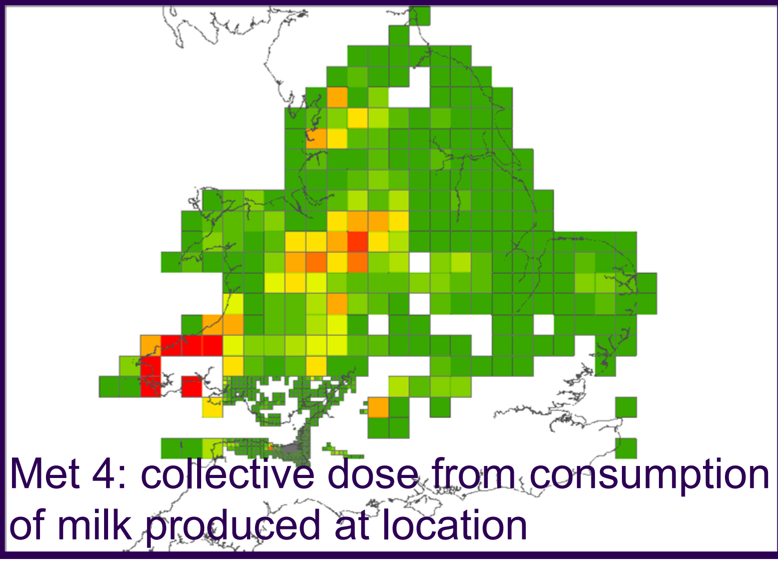
Cloud gamma, activity concentration in air & ground deposition

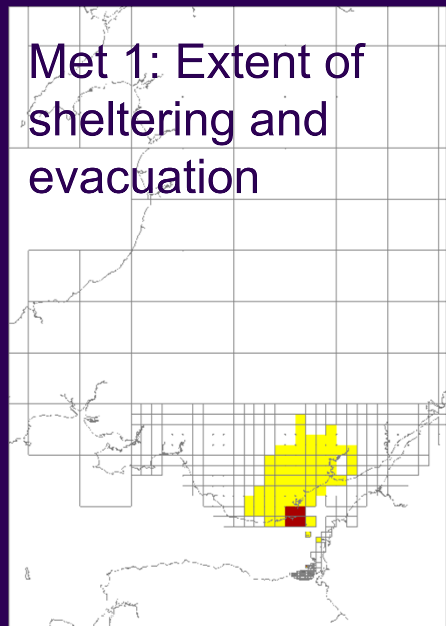


PACE Outputs for each set of Meteorological Conditions

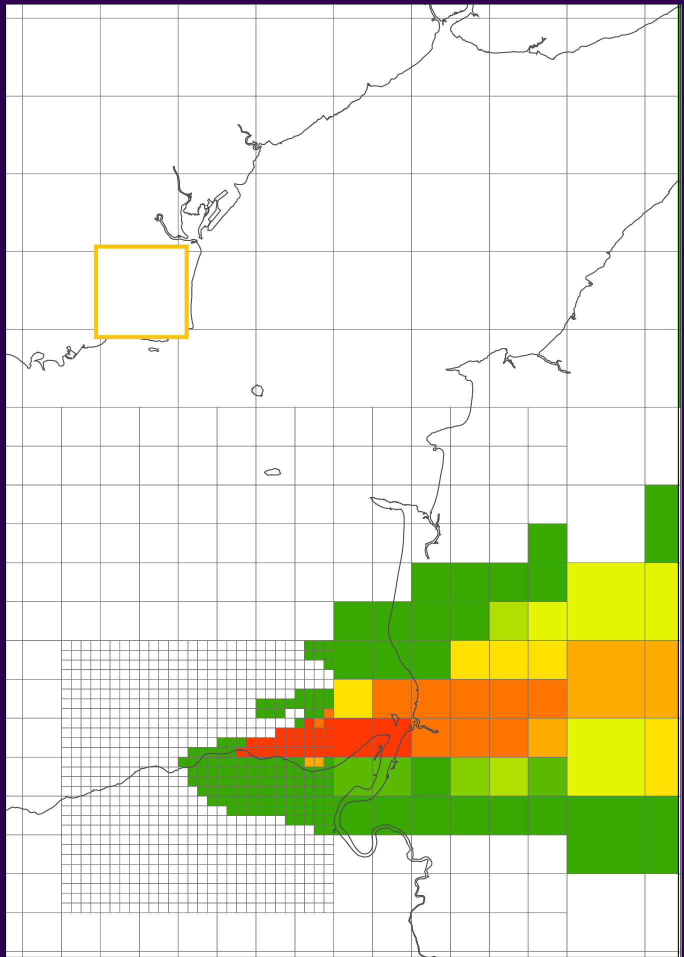
- Activity concentration in air and activity deposition on the ground
- Individual dose* due to external irradiation from the plume, inhalation, external irradiation from deposited material, resuspension and skin deposition pathways
- Collective dose from food ingestion pathway*
- Incidence and fatalities due to deterministic health effects*
- Incidence and fatalities of cancer and hereditary effects*
- Countermeasure extent of sheltering, evacuation, stable iodine, relocation and extent and duration of restriction of food
- Economic consequences*; health, agriculture, industry and tourism, cost of countermeasures

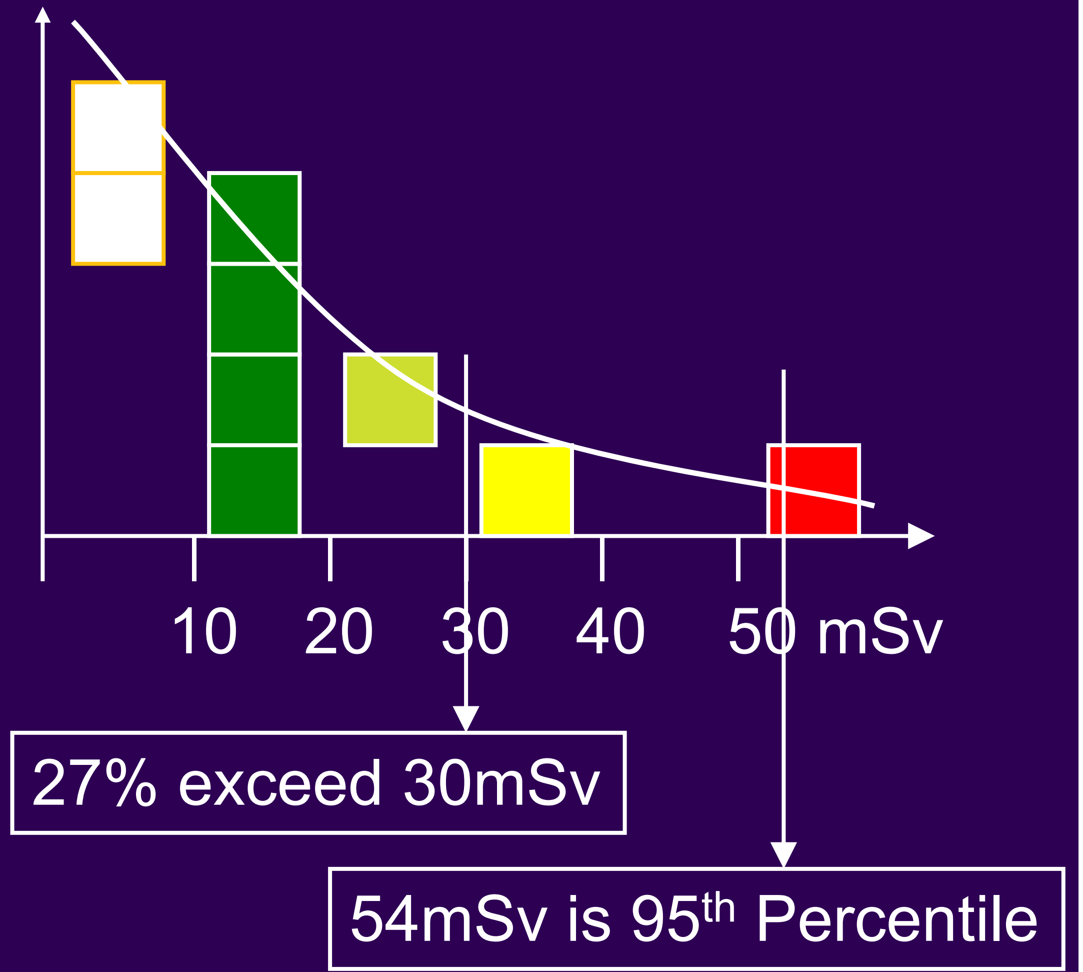
(* With and without countermeasures)


Met 4: collective dose from consumption of milk produced at location

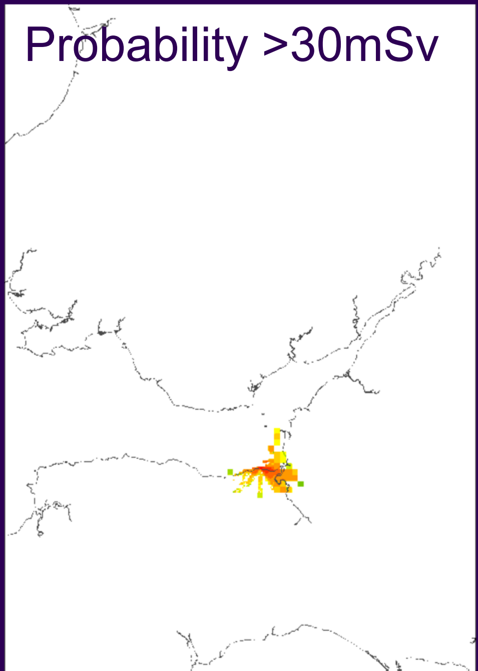

Met 1: Extent of sheltering and evacuation

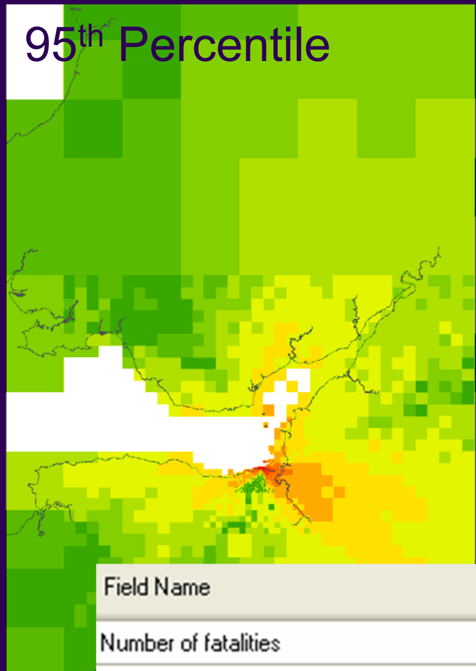
Probabilistic analysis





Probabilistic output





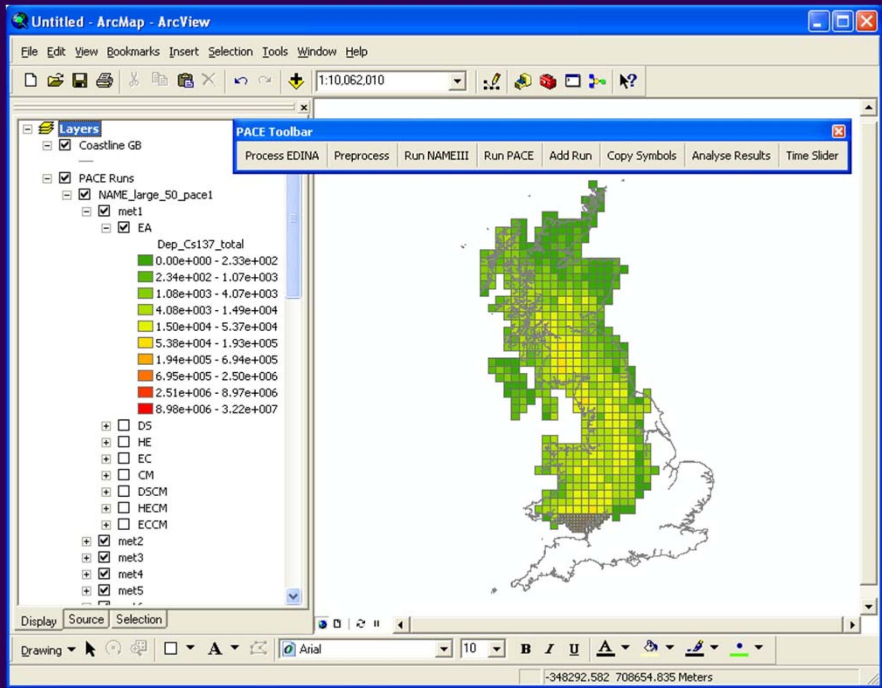
Field Name	Mean	Maximum	Minimum	5th Percentile
Number of fatalities	4.481905E-005	9.137408E-004	0.000000E+000	0.000000E+000
Number of fatalities with CM	3.239985E-005	6.377297E-004	0.000000E+000	0.000000E+000
Cost of fatalities (£)	7.094197E+004	6.096218E+005	0.000000E+000	0.000000E+000
Cost of fatalities with CM (£)	7.091888E+004	6.092318E+005	0.000000E+000	0.000000E+000
Number of non-fatal reactions	9.430228E-001	8.101472E+000	2.955417E-004	4.943025E-004
Number of non-fatal reactions with CM	9.414633E-001	8.072027E+000	2.507188E-004	3.854067E-004
Cost of non-fatal reactions (£)	7.178157E+004	6.166636E+005	2.374264E+001	3.971028E+001
Cost of non-fatal reactions with CM (£)	7.165758E+004	6.143200E+005	2.014175E+001	3.096203E+001
Total cost of deterministic effects (£)	1.427235E+005	1.226285E+006	2.374264E+001	3.971028E+001

*Conditional probability based on a given source term further combined with results for other source terms

PACE development

Implemented as an Add-on to ArcGIS™ (www.esri.com)

Enables developers to focus on radiological protection and environmental modelling etc



Future work: incorporate urban effects and decontamination, latest ICRP advice and develop a commercial version

PACE and the urban environment

Take into account different urban environments

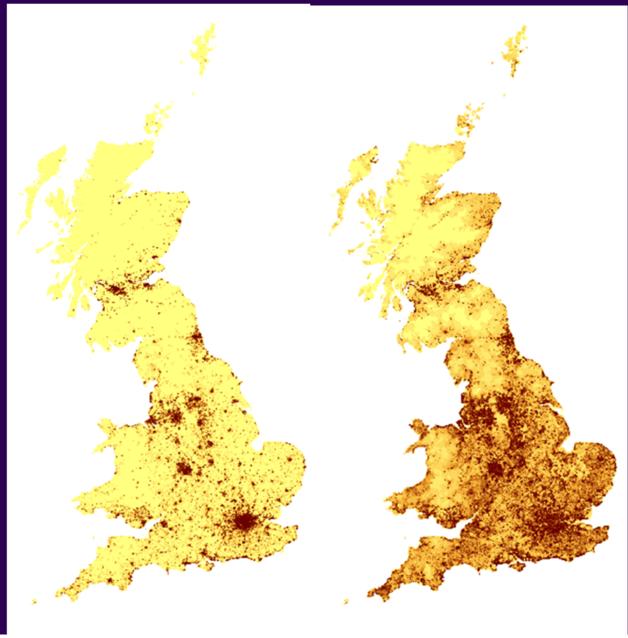
Take into account countermeasures in those environments

Minimal user interaction with the user (different met sequences imply different countermeasure strategies; areas and techniques) – robust algorithm for selecting strategy.

Run times

Data requirements

Flats



Houses

PACE and the urban environment: proposed approach

Inputs

- Spatial distribution of urban environments; 1-4 urban, suburban, no habitations (water, agriculture etc)
- Description of 1-4 countermeasure packages, including dose reduction in different environments, cost, waste etc. Generated by ERMIN. Ordered in preference; increasing intensity, cost, disruption.
- Trigger dose/target dose.

Application

- Assess dose without CM; period of relocation
- test each CM package; reduce period of relocation

ERMIN results for PACE