Addressing the uncertainties in urban/inhabited scenarios in transition phase of a nuclear accident

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This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287

Outline

- Transition
- Urban Areas
- Management options
- Residual dose and Reference levels
- Predicting Residual Dose
  - ERMIN model
  - Uncertainty in ERMIN
- Example
- Conclusions


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Japan

Fukushima disaster: first residents return to town next to nuclear plant

Parts of Okuma are open for business once again, but only a few hundred former residents have moved home

▲ An aerial view of Fukushima Dai-ichi nuclear power plant in Okuma, which remains mostly-off-limits. Photograph: AP

Justin McCurry *in Tokyo*
Wed 10 Apr 2019 05.54 BST

Based on CONFIDENCE/CONCERT deliverable D9.20 “Addressing the uncertainties in urban/inhabited scenarios”

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Transition

Preparedness	Response				Recovery
	Early		Intermediate		Late
Planning stage	Event/ response initiation	Crisis management	Consequence management	Transition to recovery (including recovery planning)	Recovery/long-term rehabilitation
	Emergency exposure situation				Existing exposure situation

(NEA 2010)

"The process and the time period during which there is a progression to the point at which an emergency can be terminated" (IAEA, 2018).

"… when the source has been brought under control, no further significant accidental releases or exposures resulting from the event are expected and the future development of the situation is well understood" (IAEA, 2018)

Features of transition:

- No clear cut boundary between emergency and existing exposure situations
- Off site situation not fully characterised, paucity of measurements particularly in the far field, predominantly dose rates
- Less urgency, allowing for:
  - planning/implementation of actions to declare emergency over
  - adapting, justifying and optimizing specific protection strategies for late phase recovery
  - engagement of the interested parties in decisions regarding the long-term recovery
  - further characterisation of the current spread of contamination and prediction of future exposures

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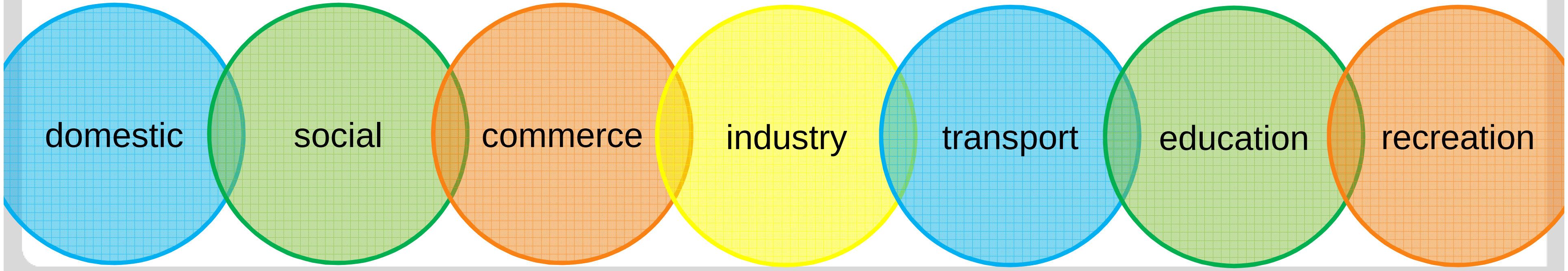
Urban area

- More than a physical landscape: interlocking spheres of human activity:
  - domestic, social, recreation, commercial, industrial, transportation, educations and other activities
- Disruption is costly, and has consequences that are hard to predict and may extend beyond physical boundaries of contamination.
- Disruption beyond a certain time will see the systems that support the urban area degrade; both physical systems such as utilities and non-physical such as social cohesion or services. ‘Restarting’ human activities within the area will become very much harder
- This presents a considerable challenge for a decision-maker faced with an urban area that has been contaminated following a nuclear accident



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Management options

- Consequences of living with radioactive contamination
  - Dose (health effects), stigmatization (economic, social effects), non-radiological health effects (e.g. mental health)
- For dose reduction the principal option is full or partial, temporary or permanent restriction of access to the affected area.
  - Very disruptive: resident population to be housed elsewhere (disruption to the host community), businesses/facilities cannot operate, infrastructure/services(schools, hospitals, shops, churches etc.) are unobtainable to the wider population.
- Radiological options (e.g. clean-up) to reduce extent and duration of restriction
  - E.g. Fukushima: garden top soil removal, pavement removal, roof cleaning in residential areas
- Non-radiological options to mitigate the disruption, stigma, non-radiological health effects
  - E.g. Salisbury: free parking, business tax reduction, to support the economy
- All options have negative impacts:
  - Waste, disruption, stigma, doses to workers, non-radiological health effects
  - -> further mitigation options.
- Complicated/evolving combination options: optimised

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Residual dose and Reference level

Residual dose

- *"The dose expected to be incurred after protective measure(s) have been fully implemented (or a decision has been taken not to implement any protective measures)."* (ICRP 103 2007)
- In transition/recovery generally expressed as an total annual normal-living effective dose.
- Typical pathways considered; external exposure from deposited activity, and internal dose from ingestion and inhalation of resuspended activity

Reference level (in emergency and existing exposure situations)

- *… the reference levels represent the level of dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur and for which therefore protective actions should be planned and optimised.* (ICRP 103 2007)
- [When a situation has occurred] *"The reference level may then assume a different function as a benchmark against which protection options can be judged retrospectively."* (ICRP 103 2007)

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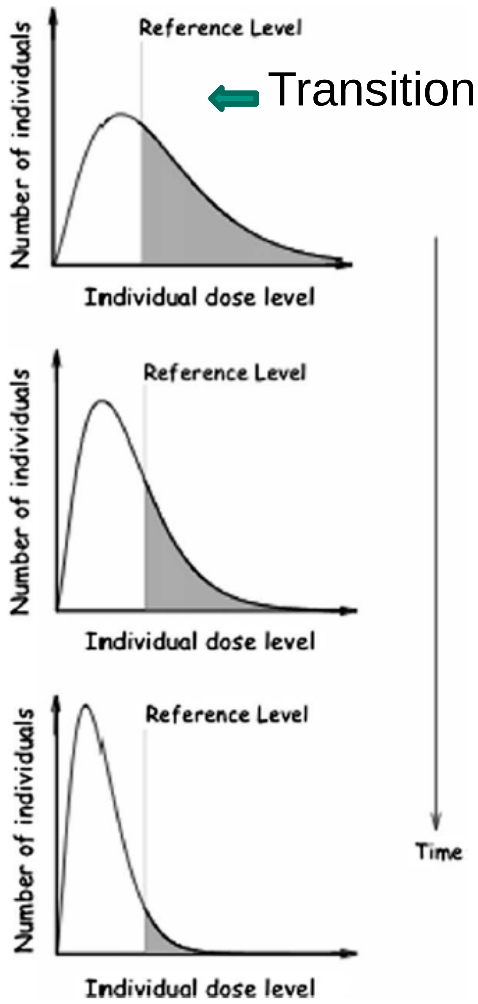
Reference levels (RL) at transition

- *the reference level is set at the end of the emergency exposure situation phase, … . … represents a level of dose which is intended not to be exceeded, and to strive to move all individual exposures below this level as low as reasonably achievable, with social and economic factors being taken into account.* (ICRP 111 2009)
  - At the start of the process not every individual is expected to be exposed at a level below the RL
  - Viewed as a step by step optimisation process, in which the distribution of individual doses is driven downward, prioritising those above the RL but not forgetting those below.
  - Not a threshold between safe and unsafe

- *The reference level for the optimisation of protection of people living in contaminated areas should be selected in the lower part of the 1–20 mSv/y band recommended in Publication 103* (ICRP, 111, 2009)



(from ICRP 111 2009)

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Predicting Residual Dose

"*External dose rates decline due to physical decay, weathering from surfaces and vertical migration down soil and sediment profiles. The rate at which the latter two processes occur varies for different types of contaminated surfaces and soils."*

"Remediation decision making generally involves an assessment of future doses following and in the absence of remedial actions."

"It is therefore helpful to be able to make predictions regarding the variation in external dose rates, and doses to defined groups of the population, with time. " (IAEA Fukushima Daiichi Accident, Technical Volume 5, Post Accident Recovery 2015)

Subject to many sources of uncertainty

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The ERMIN model

- Predict residual doses with clean-up options in an inhabited area
- Implemented in RODOS and ARGOS decision support systems
- Inputs:
  - Deposition to reference surface (grass away from trees, buildings paved)
  - Urban environment description: selected from idealised environments in database
  - Clean-up options applied (time and location) selected from database
  - Occupancy, where people spend time
- Model:
  - A database of empirical particle/condition dependent parameters used to estimate initial deposition onto other urban surfaces (trees, walls, roofs, paved, interiors)
  - Empirical functions represent the surface retention and downward migration in soil
  - Environment/radionuclide specific factors calculate dose-rates as function of time from surfaces to locations indoors and outdoors
- Endpoints:
  - Dose and dose-rates at different times and locations
  - (By applying occupancy assumptions) Normal-living residual doses
  - Worker doses, waste amount and activity, cost and effort

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Sources of uncertainty in ERMIN

- Under the CONFIDENCE project the sources of uncertainties and impact on Normal-living residual dose were explored
- Identified and qualitatively assessed all sources of uncertainty
- Quantitatively assessed parameter uncertainty
  - Considering: initial surface deposition (including building ingress), retention on urban surfaces, soil migration and occupancy. For different environments, wet and dry deposition conditions without and with various countermeasures. Focussing on ^{137}Cs in a soluble aerosol form.
  - Explored the recent literature and proposed suitable distributions;
  - Sensitivity and uncertainty analysis to quantify the sources of uncertainty and their impact on the residual dose prediction: A MC procedure, running ERMIN repeatedly, in each run changing the value of a single parameter or set of parameters by sampling the assumed distributions

- CONFIDENCE deliverable "D 9.20 - Addressing the uncertainties in urban/inhabited scenarios"
  - Appendix 1:Urban Scenario Parameter Uncertainty, Kasper Andersson (DTU)
  - Appendix 2: ERMIN uncertainty, Tom Charnock (PHE)

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Sources of uncertainty in ERMIN

- Stochastic (related to physical randomness)
  - e.g. relative deposition to different surface, weathering rates, occupancy
- Judgemental (choice of parameters)
  - e.g. choice of appropriate 'representative' value for deposition, weathering etc

Parameter uncertainty

- Epistemological (lack of knowledge)
  - e.g. reference surface deposition, environment, degree of paving etc, countermeasure timing
- Computational (coding on specific hardware)
  - e.g. temporal steps, numerical integration etc
- Model uncertainty (simplification from the real world)
  - e.g choice of urban surfaces, continuous empirical retention functions, grid size
- Ambiguity (lack of clarity and endpoint uncertainty)
  - e.g. occupancy weighting scheme, what is 'other' paved surface, what is 'interior' surface?
- Social and ethical uncertainty, uncertainty relating to value judgments.
  - Not considered, related to how ERMIN output is used

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ERMIN parameter distributions

- Example: dry deposition relative to that on a well-defined reference surface (based on knowledge from actual measurements)

Surface	Elemental iodine		AMAD < 2 µm		AMAD 2-5 µm		AMAD 5-10 µm		AMAD 10-20 µm	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Short grass*	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.
Bare soil	0.6	0.4	0.3	0.15	0.3	0.15	0.17	0.10	0.23	0.12
Soil and short grass*	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-
Small plants*	0.8	0.5	1.4	0.7	1.6	0.8	1.0	0.5	1.2	0.7
Trees and shrubs*	0.4	0.25	2.5	1.2	4.3	2.5	1.7	1.2	1.5	1.1
Paved area	0.2	0.1	0.25	0.15	0.75	0.35	0.3	0.15	0.3	0.25
Clay tile roof	1.5	0.3	0.8	0.1	3.0	0.8	1.9	0.5	1.5	0.4
Concrete tile roof	1.8	0.4	1.0	0.2	4.0	1.0	2.2	0.6	1.6	0.4
Fibre cement roof	1.6	0.3	0.9	0.1	3.6	0.9	2.1	0.5	1.6	0.4
Silicon covered fibre cement roof	1.0	0.2	0.7	0.1	2.5	0.6	1.7	0.4	1.4	0.4
Glass roof	0.5	0.1	0.4	0.1	1.4	0.4	1.5	0.4	1.3	0.3
Smooth metal roof	0.7	0.1	0.5	0.1	1.6	0.4	1.6	0.4	1.3	0.3
External walls	0.15	0.1	0.03	0.02	0.07	0.04	0.1	0.07	0.05	0.03

*Values given per area of ground covered by the vegetation.
Note: typical dry deposition velocities to ref. surface (unit: 10-4 m/s) are respectively (left to right): 20, 4, 7, 30 and 130.

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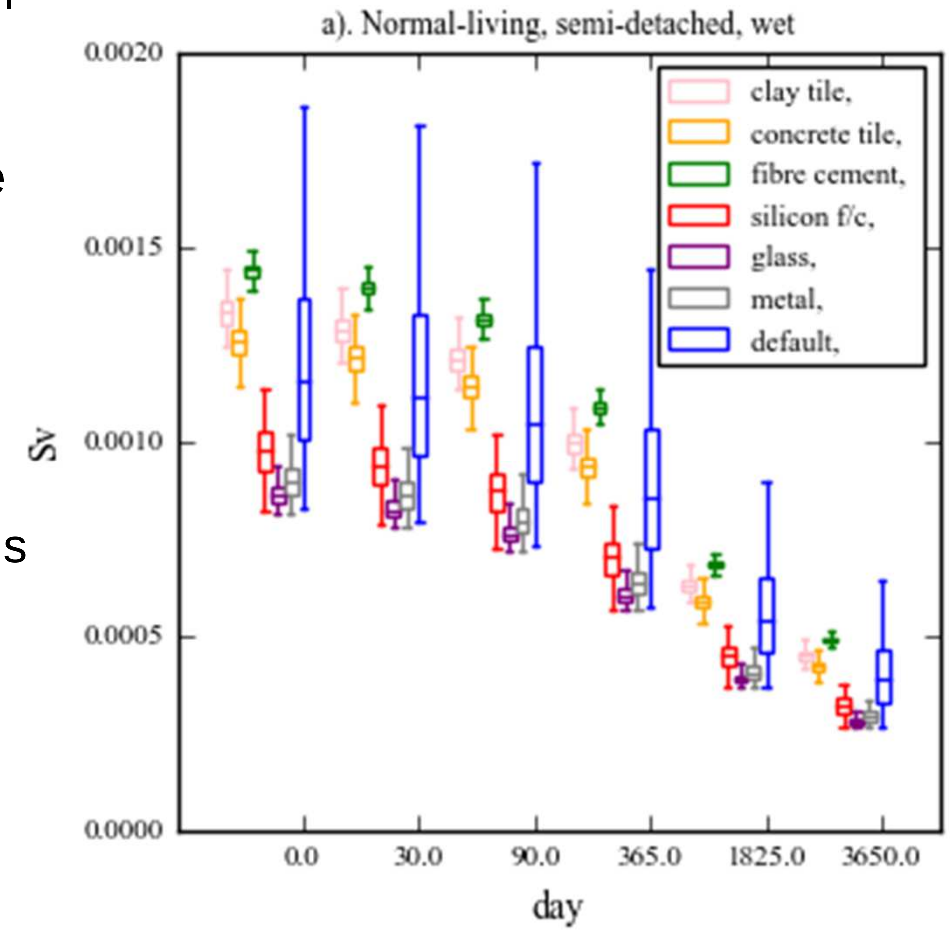
ERMIN parameter sensitivity analysis

- Example: Normal living residual dose in a semi detached brick house environment following wet deposition.
- Currently ERMIN has a single roof type with a set of particle/condition dependent parameters
- SA using distributions of initial deposition parameters for default roof type, and other roof materials
- demonstrates that different assumptions about roof materials can impact on the total projected normal living dose



[Dose are integrated over 1 year from the time shown]

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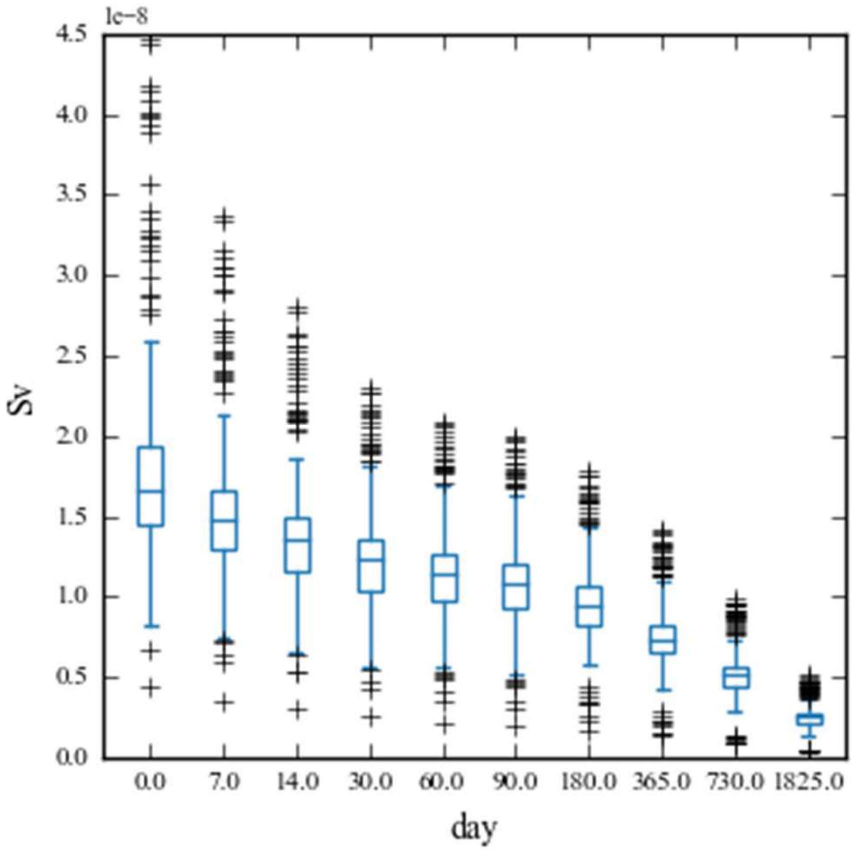
ERMIN parameter uncertainty analysis

Example uncertainty analysis, including:

- Initial deposition (including initial deposition conditions; wet/dry*, radionuclide mix*)
- Deposition onto different surfaces (distributions from Andersson 2018 and Jones 2009)
- Surface retention/weathering (distributions from Andersson 2018 and Jones 2009)
- Environment variation* (80% brick house, 10% lightweight house, 10% multi-storey)
- Occupancy (EXPOLIS data)

* assumed a plausible but arbitrary binned distribution ignoring correlations

Dose factors normalised on $1 Bqm^{-2}$ of ^{137}Cs deposition (Netherlands)



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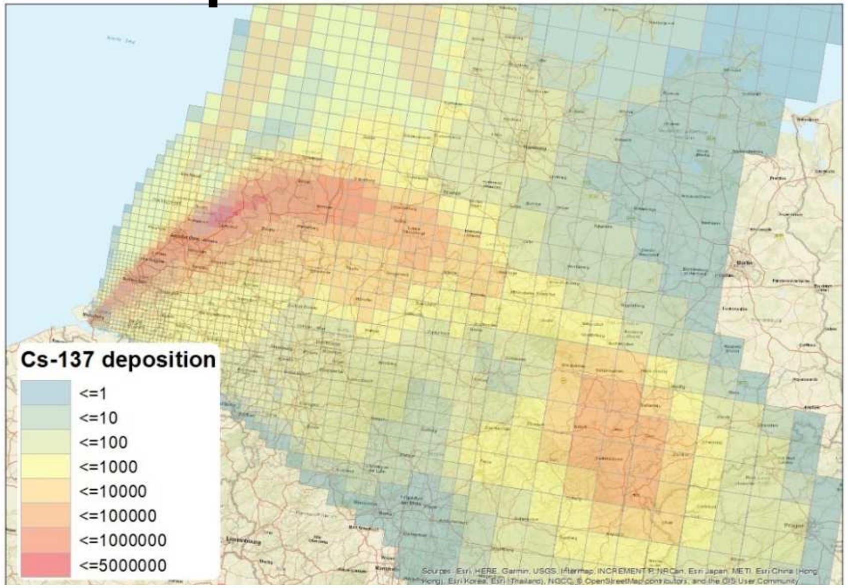
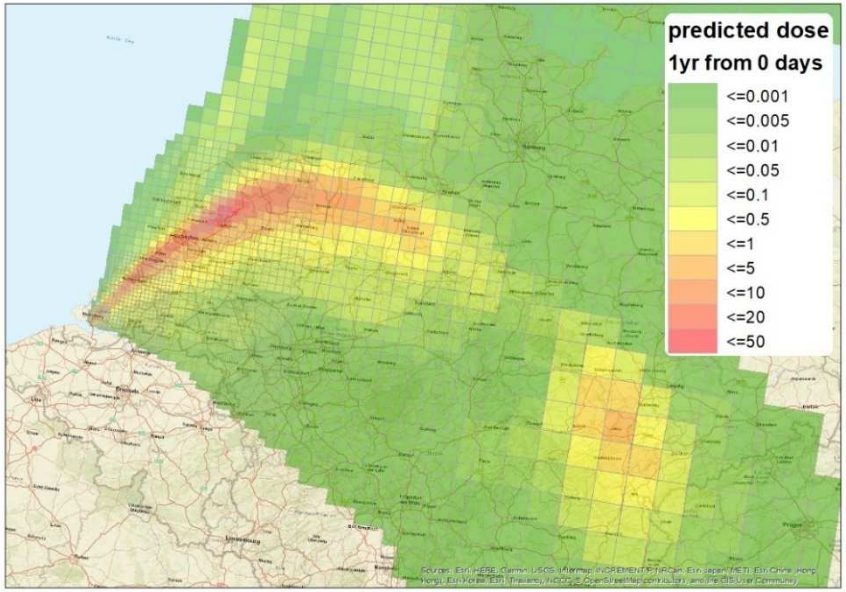
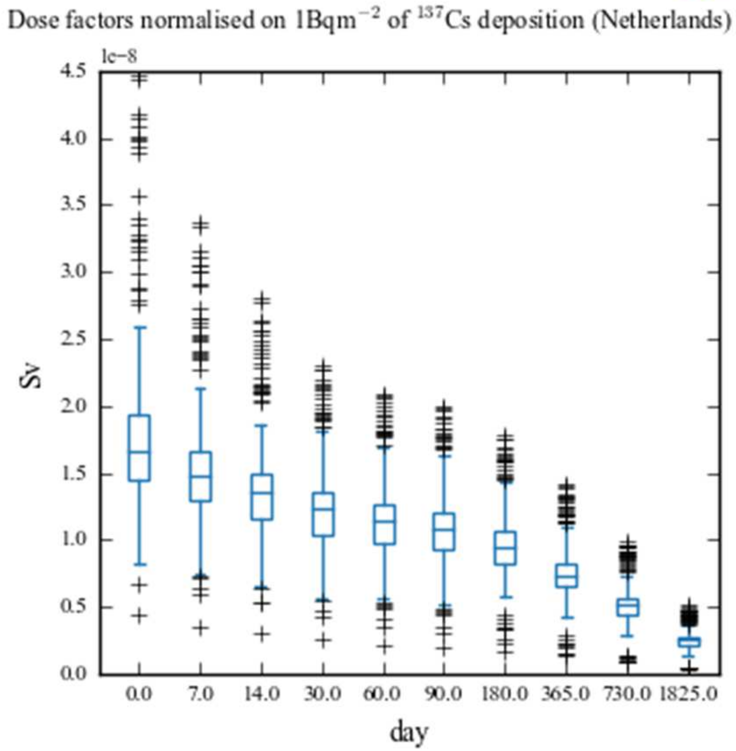
Example scenario







- Hypothetical scenario set in the Netherlands, generated by CIEMAT

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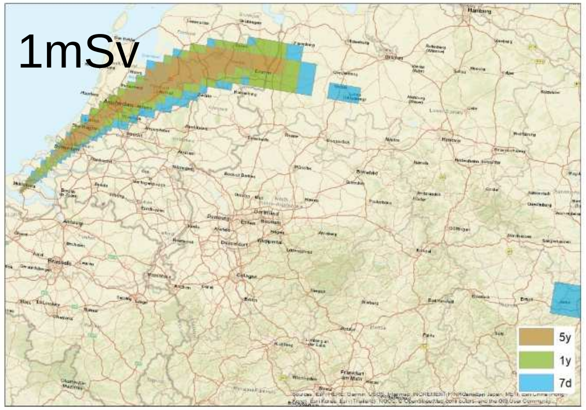
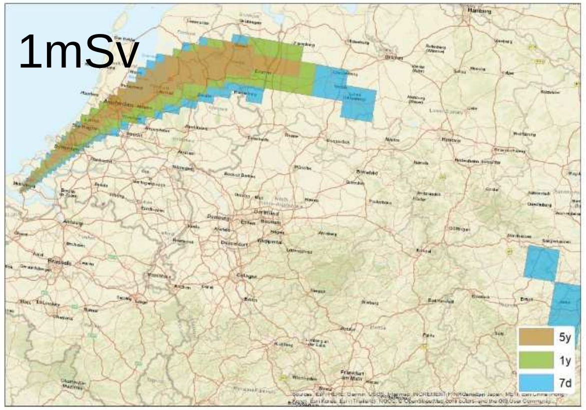
Example scenario: mean predicted dose exceeding reference level

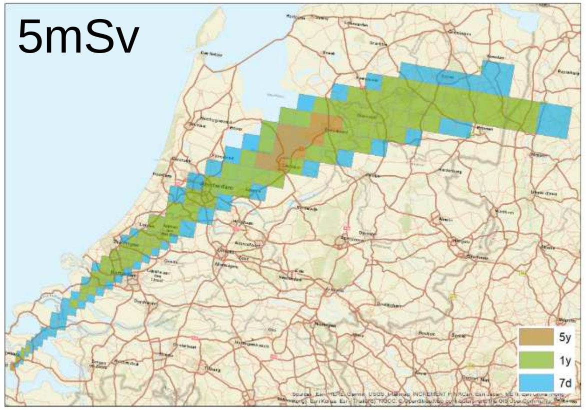


Reference level		1mSv/y	5mSv/y	20mSv/y
7 days to 1 year + 7days	Area km²	7205 (1791)	3594 (180)	124
	Pop*	4778180 (286336)	2143049 (16027)	25319
	Schools+	187	81	0
	Hospitals+	22	12	0
1 to 2 year	Area km²	5916 (762)	1550	6
	Pop*	3758335 (107658)	770484	1125
	Schools+	117	34	0
	Hospitals+	17	3	0
5 - 6 years	Area km²	3323 (180)	16	0
	Pop*	2066410 (16027)	1451	0
	Schools+	80	0	0
	Hospitals+	12	0	0

* Residential population from GEOSTATS 2011 https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat (Number in brackets refers to Germany)
+ Schools (kindergarten, primary, secondary, college and university) and hospitals from OpenStreetMap 2014 for Netherlands only

Example scenario: 95th percentile dose exceeding reference level





Reference level		1mSv/y	5mSv/y	20mSv/y
7 days to 1 year + 7days	Area km²	8379 (3221)	4975 (304)	1250
	Pop*	5540338 (452838)	3256952 (37080)	562515
	Schools+	220	109	28
	Hospitals+	26	16	2
1 to 2 years	Area km²	6970 (1322)	3323 (180)	16
	Pop*	4671277 (192247)	2066410 (16027)	1451
	Schools+	185	80	0
	Hospitals+	21	12	0
5 to 6 years	Area km²	4468 (304)	290	0
	Pop*	2847204 (37080)	129100	0
	Schools+	102	24	0
	Hospitals+	14	1	0

* Residential population from GEOSTATS 2011 https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat (Number in brackets refers to Germany)
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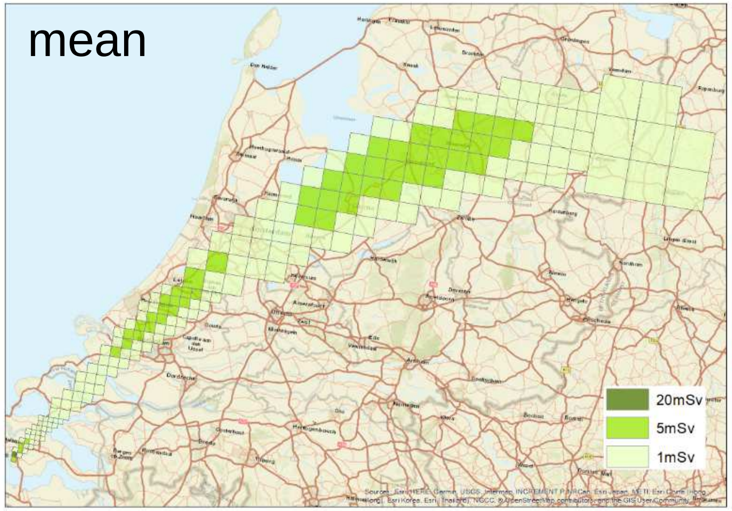
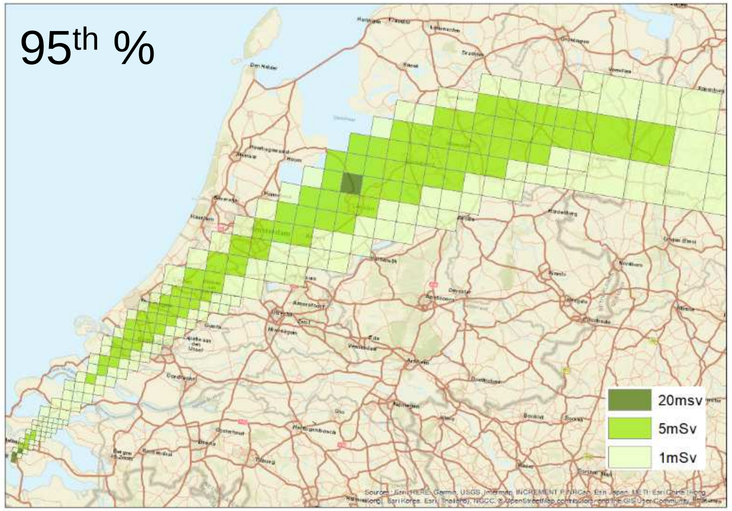
Example scenario: 2nd year predictions exceeding reference levels





Reference level		1mSv/y	5mSv/y	20mSv/y
1 to 2 years mean	Area km2	5916 (762)	1550	6
	Pop*	3758335 (107658)	770484	1125
	Schools+	117	34	0
	Hospitals+	17	3	0
1 to 2 years 95th percentile	Area km2	6970 (1322)	3323 (180)	16
	Pop*	4671277 (192247)	2066410 (16027)	1451
	Schools+	185	80	0
	Hospitals+	21	12	0

* Residential population from GEOSTATS 2011 https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/population-distribution-demography/geostat
+ Schools (Kindergarten, primary, secondary, college and university) and hospitals from OpenStreetMap 2014

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Some conclusions

- Urban/inhabited areas are complex and the consequences of living with contamination and with disruption of mitigation are hard to predict but could be very large (both extent and duration)
- Strategy for recovery will be complex and evolving (as is the decision-making process to reach that strategy)
- Prediction of residual doses at transition are subject to uncertainties
- Selection of appropriate reference level(s) at transition needs to be managed carefully with the uncertainties in mind.

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Question facing decision-makers at transition

- How to define the affected area, i.e. reference level, criteria of dose/dose-rate/contamination?
  - Prediction into the future: how long is it going to last, how big an area is affected and the implications of uncertainty on that prediction?
- Activities in this area? consequences (direct/indirect) of disruption?
  - living, transport, industry, commercial etc,
- What different populations use the area?
  - residents, workers, school children, people travelling through?
- Are there vulnerable/special populations who need special support
  - elderly, disabled, sick, prison communities, migrant communities?
- Are there any services or items of infrastructure to be maintained?
- Similar questions for indirectly affected areas. e.g. host communities?
- Capacity/acceptability to implement options?
- Considering the above are the appropriate stakeholders involved?

Not an exhaustive list!

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