Monitoring strategies to support model evaluations in emergency situations: Some insights from HARMONE WP4

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Goal of modelling & monitoring efforts

CFD - Large Eddy Simulation (LES), Lucas et al, 2016 (LLNL)

For emergency response and recovery:

- ✓ Information on impact
- ✓ Trend towards an "individual" dose assessments
  - ✓ Retrospective dose reconstruction: interesting, but too late;
  - ✓ Real-time
    - ✓ Countermeasure implementation/evaluation
  - ✓ Predictive (E.g.; 1st year dose)
  - ✓ Link with emergency framework (radiological and societal)

✓ Preparedness phase (research):

- ✓ Need for test cases (Ru-106)
- ✓ Need for validation data sets

Overview

DATA ASSIMILATION

Modelling

- ✓ Fast
- ✓ High spatial resolution, large extend
- ✓ Predictive and diagnostic
- ✓ Time resolution?
- ✓ Reality or representation of reality
- ✓ Uncertainty?

Monitoring

Early warning networks

- ✓ Real time
- ✓ High temporal resolution
- ✓ Spatial resolution?
- ✓ All info we need?

Mobile surveys: aerial, car-borne, ...

- ✓ Real time?
- ✓ High spatial resolution
- ✓ High flexibility

Detailed in-situ measurements or sampling

- ✓ Real time?
- ✓ Detailed info
- ✓ Limited region
- ✓ Time consuming

Monitoring of people, food, goods

- ✓ Close to real endpoint
- ✓ Screenings versus detailed assessments

Monitoring by the public

- ✓ Very high spatial/temporal resolution
- ✓ Real time?
- ✓ Uncertainty?
- ✓ Only dose rate?

MONITORING STRATEGIES

Example: atmospheric models

optimization

Source term

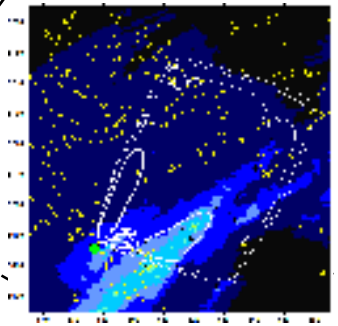
Observations
(for response: real-time)

Dispersion model

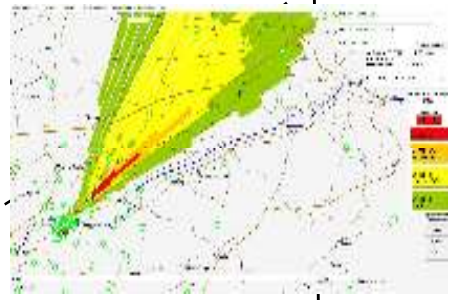
Plume predictions

Impact assessments

Meteorological data

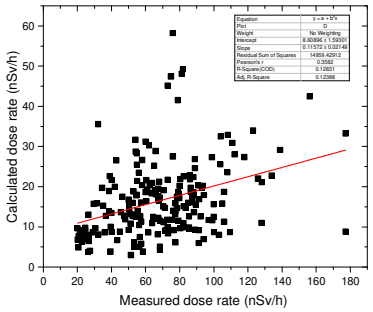


optimization



Observations
(e.g. food activity)

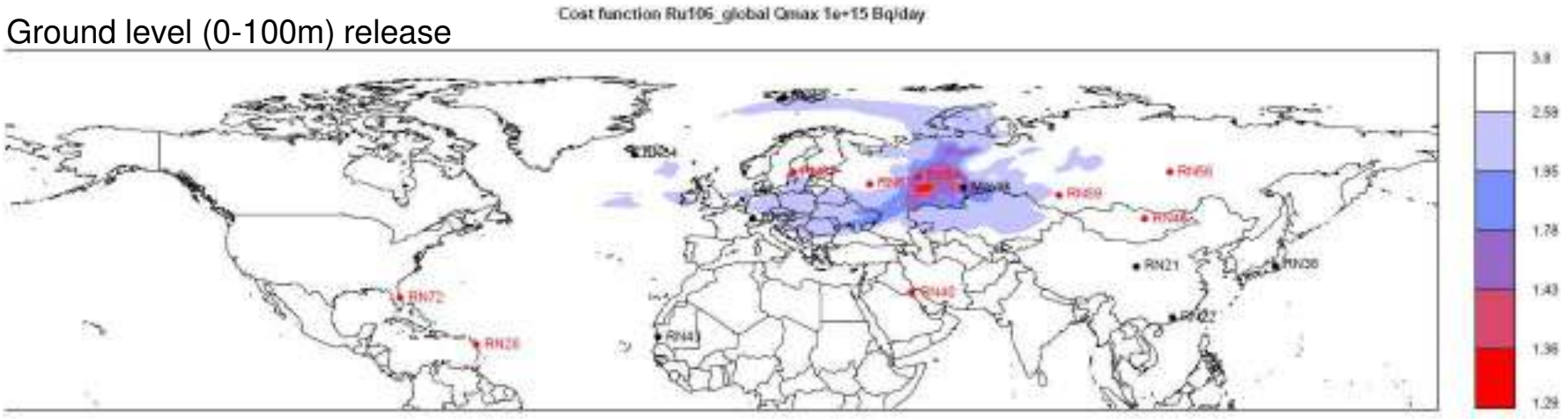
Model - observation discrepancy



Optimizing our models:
Type of observations, at what location and when?
→ MONITORING STRATEGIES

Example: Ru-106

Ground level (0-100m) release



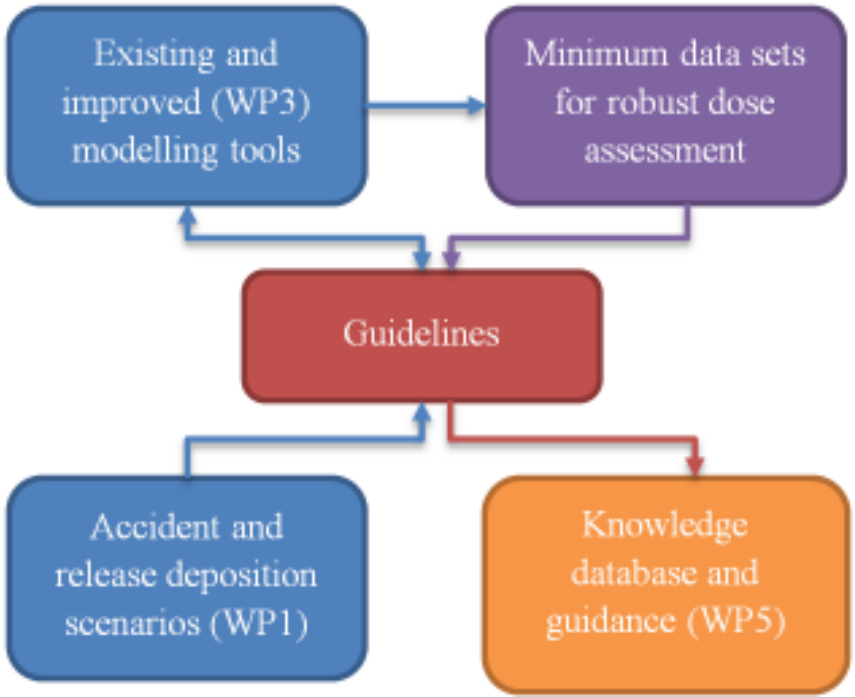
P. De Meutter et al., 2018

HARMONE project – Objectives WP4

HARmonising MOdelling strategies of European decision support systems for Nuclear Emergencies (OPERRA-2014 Call)

WP4 – Monitoring strategies:

- Enhance robustness of human and environmental dose assessment (especially for the first year dose)
- Strengthen the interaction between monitoring strategies and dose assessment models
- Development of guidelines (WP1 as illustrative examples) on the joint use of monitoring and model results for improved dose assessment

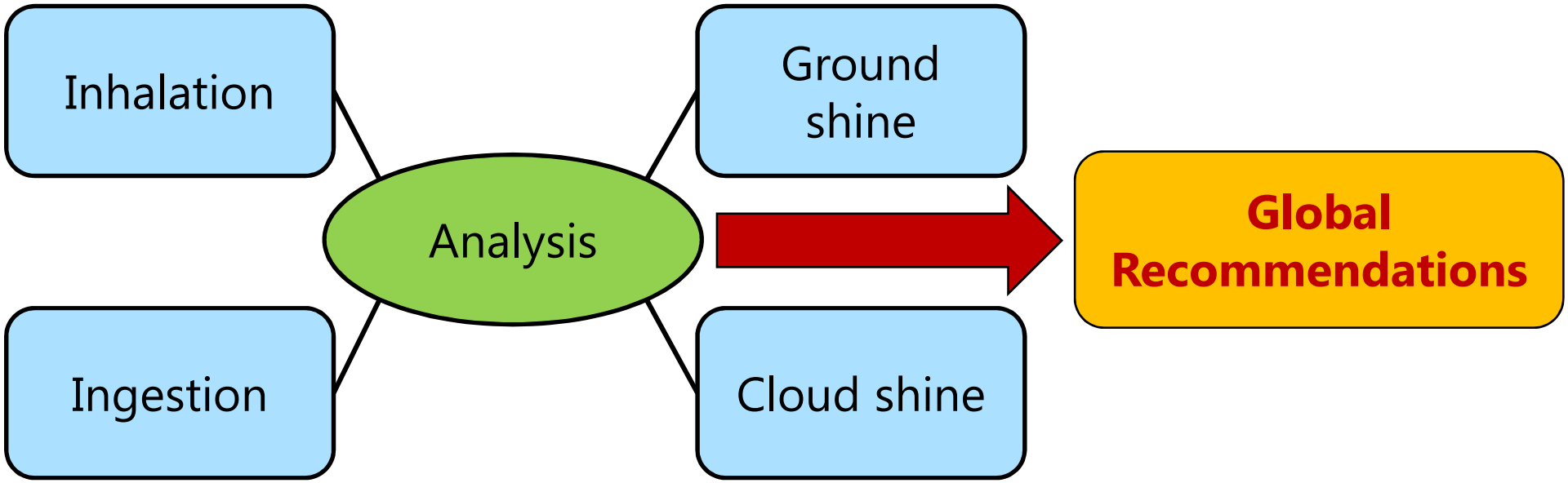


Deliverables

- Recommendations on the minimal sets of parameters necessary for human dose assessments for different regions and related monitoring strategies
- Development of monitoring strategies using relevant scenarios from WP1
- Guidelines on the joint use of monitoring and model results for improved dose assessments, using the WP1 scenarios as illustrative examples

Recommendations on the minimal sets of parameters

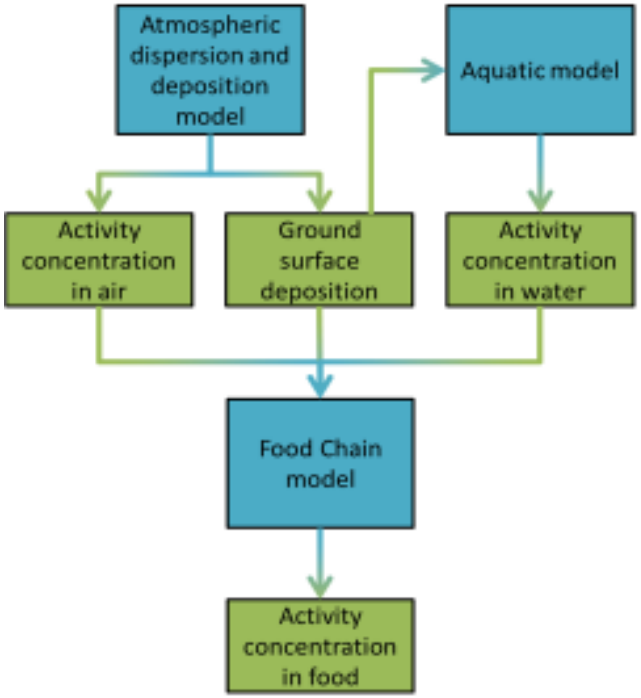
- Analysis of each exposure pathway (w.r. modelling tools)
- Recommendation considering all exposure pathways
- Farming and fishing also considered

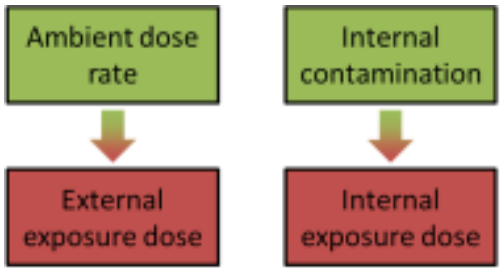


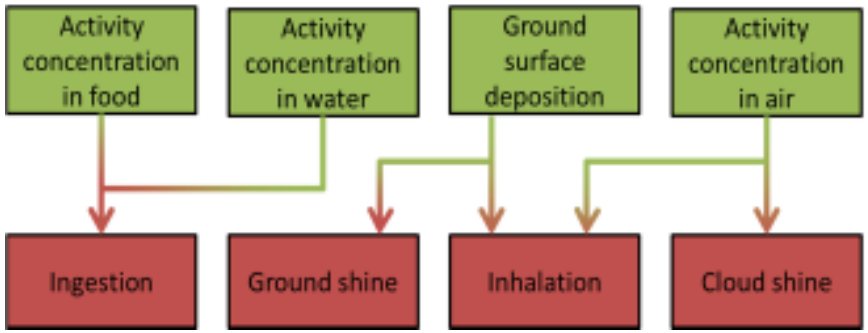
Recommendations on the minimal sets of parameters

Outcome

- List of input, intermediate and output parameters for modelling tools
  - Input vs validation/confidence building
  - Different entry level for the dose assessment
  - Preparedness phase vs acute phase
  - Temporal resolution
  - Spatial resolution







Recommendations on the minimal sets of parameters

Model	I/O	Parameter	Unit	Type	A/P
ADD	I	Release rate	$[T^{-1}]$	Variable (t)	A
ADD, RDL, RDE	*I*	*Wind direction*	*[°]*	*Variable (s,t)*	A
ADD, RDL, RDE	*I*	*Wind speed*	*$[L\ T^{-1}]$*	*Variable (s,t)*	A
ADD	I	Atmospheric stability class	[-]	Variable (s,t)	A
ADD, TFC, RDW, RDL, RDE	*I*	*Amount of rainfall of a rainfall event*	*$[L\ T^{-1}]$*	*Variable (s,t)*	A
ADD	I	Release height	[L]	Constant	P/A
ADD	I	Release velocity	$[L\ T^{-1}]$	Constant	P/A
ADD	I	Air Temperature at source	[T[°C]]	Constant / variable (t)	A
ADD	I	Release diameter	$[L^2]$	Constant	P/A
ADD	I	Release temperature	[T[°C]]	Constant / Variable (t)	A
ADD, TFC	*I*	*Deposition velocity*	*$[L\ T^{-1}]$*	*Constant*	P
ADD, RDW	*I*	*Topography*	*[L]*	*Variable (s)*	P
ADD, TFC, RDW, RDR, RDL, RDE	*I*	*Nuclear data[1]*	-	*Parameter*	P
ADD, TFC	*O*	*Activity concentration in air*	*$[T^{-1}\ L^{-3}]$*	*Variable (s,t)*	-
ADD, TFC	*O/I*	*Surface deposition (Dry)*	*$[T^{-1}\ L^{-2}]$*	*Variable (s,t)*	A
ADD, TFC	*O/I*	*Surface deposition (Wet)*	*$[T^{-1}\ L^{-2}]$*	*Variable (s,t)*	A
TFC	O	Total deposition (Dry + Wet)	$[Bq\ L^{-2}]$	Constant	A
TFC	I	Interception fraction	[-]	Constant	-
TFC	I	Plant leaf area index (maximum)	$[L^2\ L^{-2}]$	Constant	P
TFC	I	Plant leaf area index (time-dependent)	$[L^2\ L^{-2}]$	Variable (t)	P
TFC	I	Retention coefficient of plant	[L]	Constant	P
TFC	I	Yield of grass at the time of deposition	$[M\ L^{-2}]$	Variable (t)	P
TFC	I	Yield of crop at the time of harvest	$[M\ L^{-2}]$	Constant	P
TFC	I	Weathering rate constant	$[L^{-1}]$	Constant	P
TFC	I	Growth dilution rate constant	$[L^{-1}]$	Constant	P
TFC	I	Root-to-soil release rate constant	$[L^{-1}]$	Constant	P
TFC	I	Harvest date	[-]	Constant	P
TFC	I	Deposition date	[-]	Variable (s)	A
TFC	I	Fraction of activity translocated from foliage to the root	[-]	Constant	P
TFC	I	Translocation factor (plants)	[-]	Constant	P

ADD Atmospheric Dispersion and Deposition
RDL Radionuclide Dispersion in Lakes
RDE Radionuclide Dispersion in Estuaries
I Input
RDW Radionuclide Dispersion in Watersheds
RDR Radionuclide Dispersion in Rivers
RDRe Radionuclide Dispersion in Reservoirs
O Output
AEP Aquatic Exposure Pathway
TFC Terrestrial Food Chain
A Acute
P Preparedness

Recommendations on the minimal sets of parameters

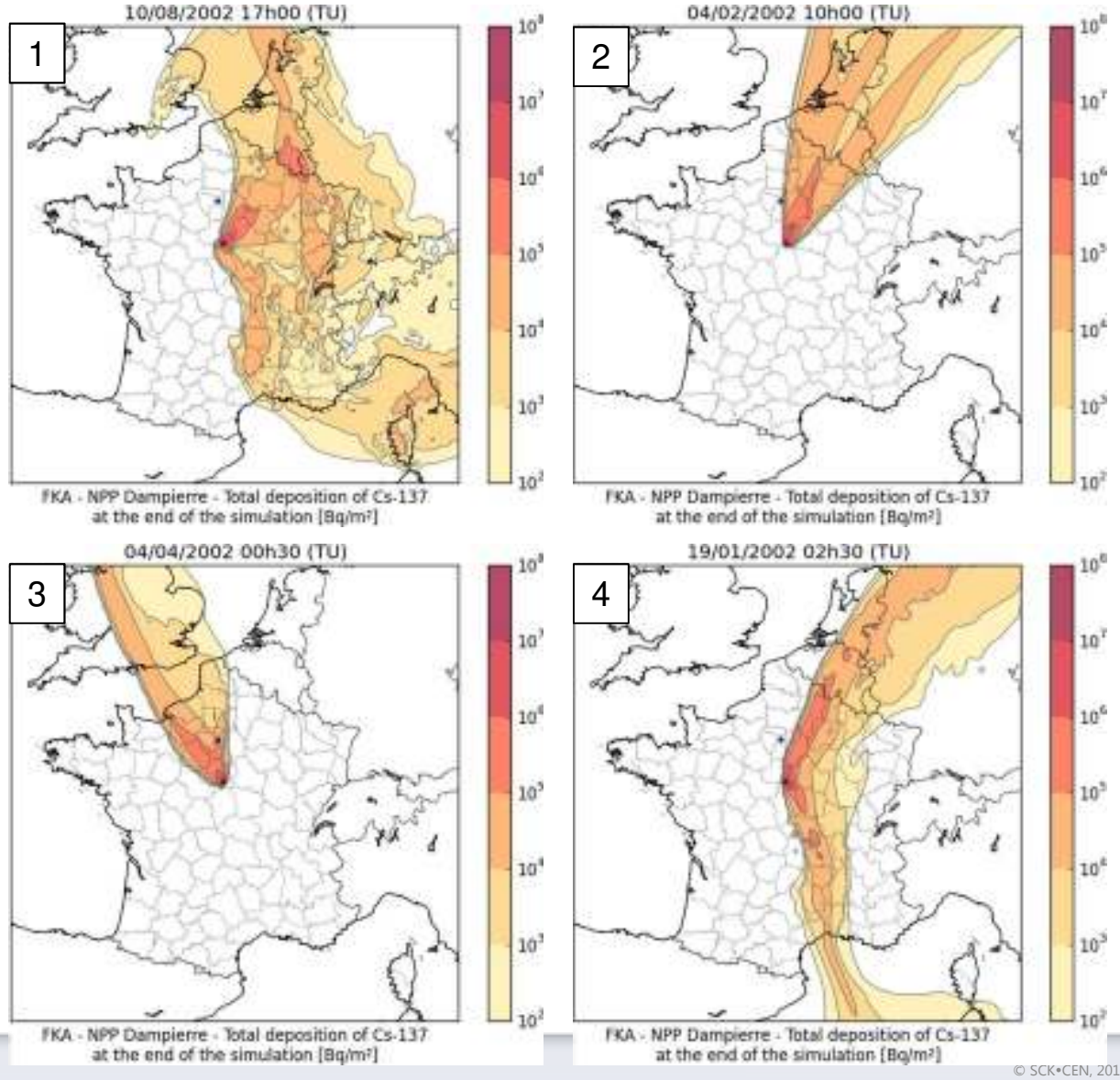
TFC	I	Soil-to-plant transfer factor	[Bq M^{-1} plant (dw) / Bq M^{-1} (soil)]	Constant	P
TFC	I	Depth of root zone	[L]	Constant	P
TFC	I	Density of soil	[M L^{-3}]	Constant	P
TFC	I	Sorption rate constant	[T^{-1}]	Constant	P
TFC	I	Desorption rate constant	[T^{-1}]	Constant	P
TFC	I	Migration rate constant (leaching from the root zone)	[T^{-1}]	Constant	P
TFC	I	Resuspension transfer factor	[Bq M^{-1} plant (dw) / Bq M^{-1} (soil)]	Constant	P
TFC	I	Enrichment factor for resuspension	[-]	Constant	P
TFC	I	Activity intake rate of animal m	[Bq T^{-1}]	Variable (t)	P
TFC	I	Number of different feedstuffs fed to animal m	[-]	Constant	P
TFC	O	Activity concentration in feedstuffs	[Bq M^{-1}]	Variable (t)	-
TFC	I	Feeding rate	[M T^{-1}]	Variable (t, animal, feedstuff)	P
TFC	I	Inhalation rate of animal m	[L^3 T^{-1}]	Constant	P
TFC	O	Activity concentration in animal product p	[Bq M^{-1}]	Variable (t)	-
TFC	I	Feed-to-animal product p transfer factor	[Bq M^{-1} / Bq T^{-1}]	Constant	P
TFC	I	Fraction of biological transfer	[-]	Constant	P
TFC	I	Biological transfer rate constant for animal product p	[T^{-1}]	Constant	P
TFC	O	Activity concentration in foodstuff/feedstuff ready for consumption	[Bq M^{-1}]	Variable (t)	-
TFC	O	Activity concentration in raw foodstuff/feedstuff (at the beginning of storage period or before processing)	[Bq M^{-1}]	Variable (t)	-
TFC	I	Processing factor for foodstuff/feedstuff	[-]	Constant	P
TFC	I	Storage and processing time for foodstuff/feedstuff	[T]	Constant	P
TFC	O	Activity concentration in foodstuff p	[Bq M^{-1}]	Variable (t)	-
TFC	I	Production rate of foodstuffs	[M T^{-1}]	Constant (foodstuff)	P
RDR, RDL, RDE	*I*	*(Non-)Point source*	*[$T^{-1}L^{-3}$] [$T^{-1}M^{-1}$]*	*Variable (t)*	*A/P*
RDW, RDR, RDL, RDE	*I/O*	*Activity in the dissolved phase of the water column*	*[$T^{-1}L^{-3}$]*	*Variable (s,t)*	*A/P*
RDW, RDR, RDL, RDE	*I/O*	*Activity in the particulate phase of the water column*	*[$T^{-1}M^{-1}$]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*I*	*Bathymetry*	*[L]*	*Variable (s)*	*P*
AEP	I	Biological transfer rate for fish	[T^{-1}]	Constant	A/P
RDR, RDL, RDE	*I*	*Burial rate (per layer)*	*[T^{-1}]*	*Constant*	*A/P*
RDR, RDL, RDE	*I*	*Calibration coefficients for settling velocity*	*[-]*	*Constant*	*P*
RDR, RDL, RDE	*I*	*Calibration coefficients for settling velocity (flocculation)*	*[-]*	*Constant*	*P*
RDR, RDL, RDE	*I*	*Critical shear stress for deposition*	*[$ML^{-1}T^{-2}$]*	*Variable (s)*	*P*
RDR, RDL, RDE	*I*	*Critical shear stress for erosion*	*[$ML^{-1}T^{-2}$]*	*Variable (s)*	*P*
RDR, RDL, RDE	*I*	*Critical Shields shear stress*	*[$ML^{-1}T^{-2}$]*	*Variable (s)*	*P*
RDR, RDL, RDE	*I*	*Density of the bed material*	*[ML^{-3}]*	*Variable (s)*	*P*
RDR, RDL, RDE	*I*	*Desorption rate*	*[T^{-1}]*	*Constant*	*A/P*
RDR, RDL, RDE	*I*	*Diffusion coefficient*	*[L^2T^{-1}]*	*Variable (s)*	*P*

Recommendations on the minimal sets of parameters

RDW	I	Evapotranspiration rate	[L]	Variable (s,t)	A/P
RDW	I	Effective porosity	[ ]	Variable (s)	P
RDL, RDE	*I*	*Evaporation rate*	*[LT^{-1}]*	*Variable (s,t)*	*A/P*
AEP	I	Food uptake rate (prey-predator)	[MT^{-1}]	Variable (s)	A/P
AEP	I	Fraction biological transfer rate	[-]	Constant	A/P
RDW, RDR, RDL, RDE	*I*	*Friction coefficient*	*[TL$^{1/3}$]*	*Variable (s)*	*P*
RDL	I	Groundwater flow	[L^{3}T^{-1}]	Variable (s,t)	A/P
RDR	I/O	Hydraulic area	[L^2]	Variable (s,t)	A/P
RDW	I	Hydraulic conductivity	[LT^{-1}]	Variable (s)	P
RDL, RDRe	I	Latitude	[degrees]	Constant	P
RDW, RDR, RDL, RDE	*I*	*Particle size*	*[L]*	*Variable (s)*	*P*
RDW, RDR, RDL, RDE	*I*	*Partition coefficient*	*[L^{3}M^{-1}]*	*Constant*	*A/P*
RDR, RDL, RDE	*I*	*Porosity of the bed material*	*[ ]*	*Variable (s)*	*P*
RDR, RDL, RDE	*I*	*Reference height*	*[L]*	*Variable (s)*	*P*
RDR, RDL, RDE	*I*	*River inflows*	*[L^{3}T^{-1}]*	*Variable (t)*	*A/P*
RDR, RDL, RDE	*I*	*River Outflows*	*[L^{3}T^{-1}]*	*Variable (t)*	*A/P*
RDR, RDL, RDE	*I/O*	*Salinity*	*[ML^{-3}]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*I*	*Sediment erosion rate*	*[ML^{-2}T^{-1}]*	*Constant*	*P*
RDR, RDL, RDE	*I*	*Sediment settling rate*	*[ML^{-2}T^{-1}]*	*Constant*	*P*
RDW, RDR, RDL, RDE	*I*	*Settling velocity*	*[LT^{-1}]*	*Constant*	*P*
RDR, RDL, RDE	*I*	*Sorption rate*	*[T^{-1}]*	*Constant*	*A/P*
RDR, RDL, RDE	*I*	*Suspended sediment concentration*	*[ML^{-3}]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*I/O*	*Air and water temperature*	*[°C]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*I*	*Tides*	*[L]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*O*	*Total activity in the bed sediment layers*	*[T^{-1}M^{-1}]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*O*	*Total activity in the water column*	*[T^{-1}L^{-3}]*	*Variable (s,t)*	*A/P*
AEP	I	Transfer factor for fish	[M^{-1}]	Constant	P
RDR, RDL, RDE	*I/O*	*Water depth*	*[L]*	*Variable (s,t)*	*A/P*
RDR, RDL, RDE	*I/O*	*Water discharge and/or Velocity*	*[L^{3}T^{-1}] [LT^{-1}]*	*Variable (s,t)*	*A/P*
AEP	I	Water feeding rate for animals	[MT^{-1}]	Variable (s)	P
RDR, RDL, RDE	*I/O*	*Water levels*	*[L]*	*Variable (s,t)*	*A/P*

Monitoring strategies using WP1 scenarios

- Case 1
  Complex deposition pattern (rain)
- Case 2
  Narrow plume
- Case 3
  Coastal impact
- Case 4
  Change of wind direction

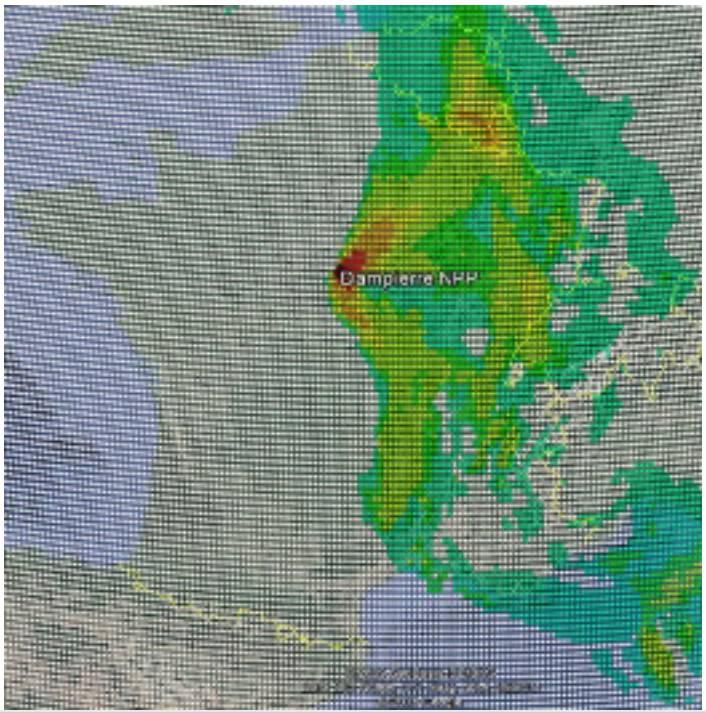


Analysis example cloud and ground shine

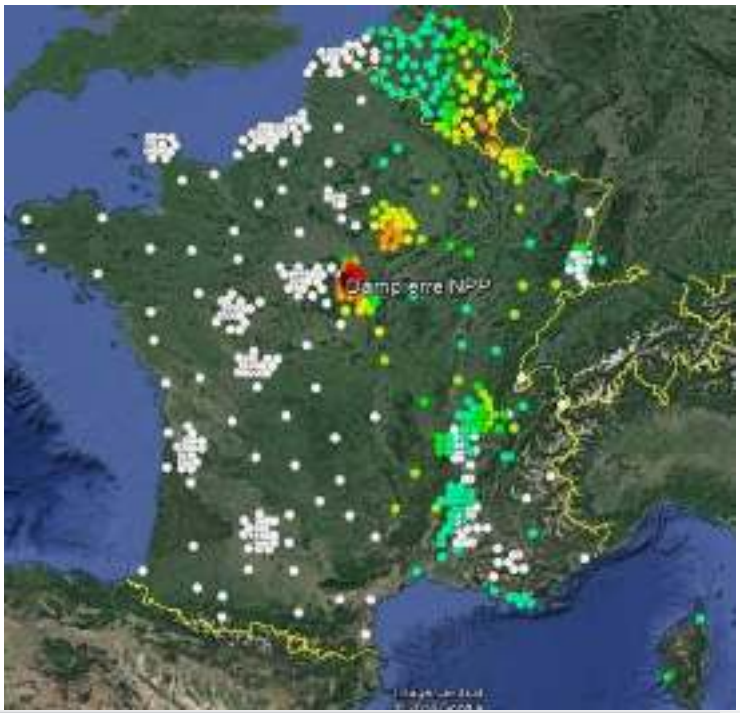
Spatial resolution

- e.g. national early warning dose rate stations

Simulated 1st year ambient dose [mSv]



"Measured" 1st year ambient dose [mSv]



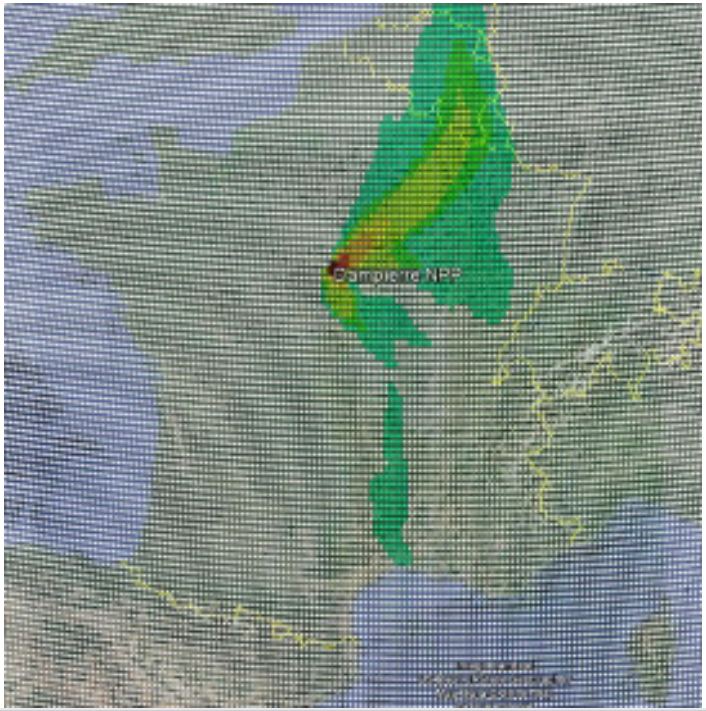
< 0.1
[0.1; 0.5[
[0.5; 1.0[
[1.0; 5.0[
[5.0; 10.0[
[10.0; 50.0[
≥ 50.0

Analysis example inhalation

Spatial resolution

- e.g. national early warning aerosols/iodine stations
  - Spatial resolution?

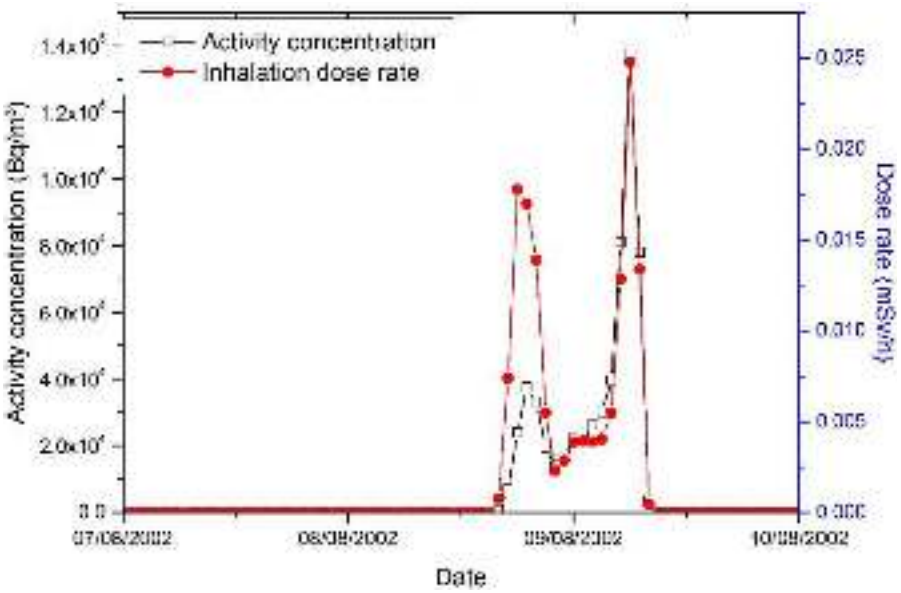
Simulated inhalation dose [mSv]

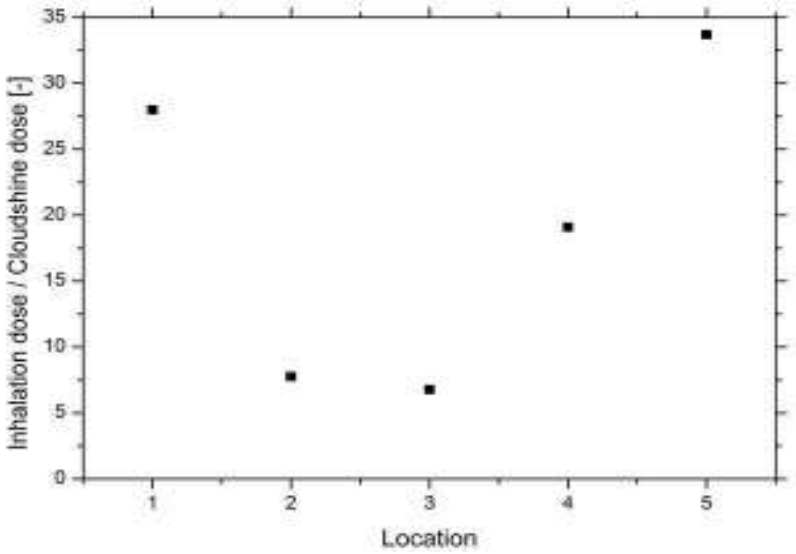


"Measured" nuclide specific air concentration (inhalation dose)

Example assessment inhalation dose

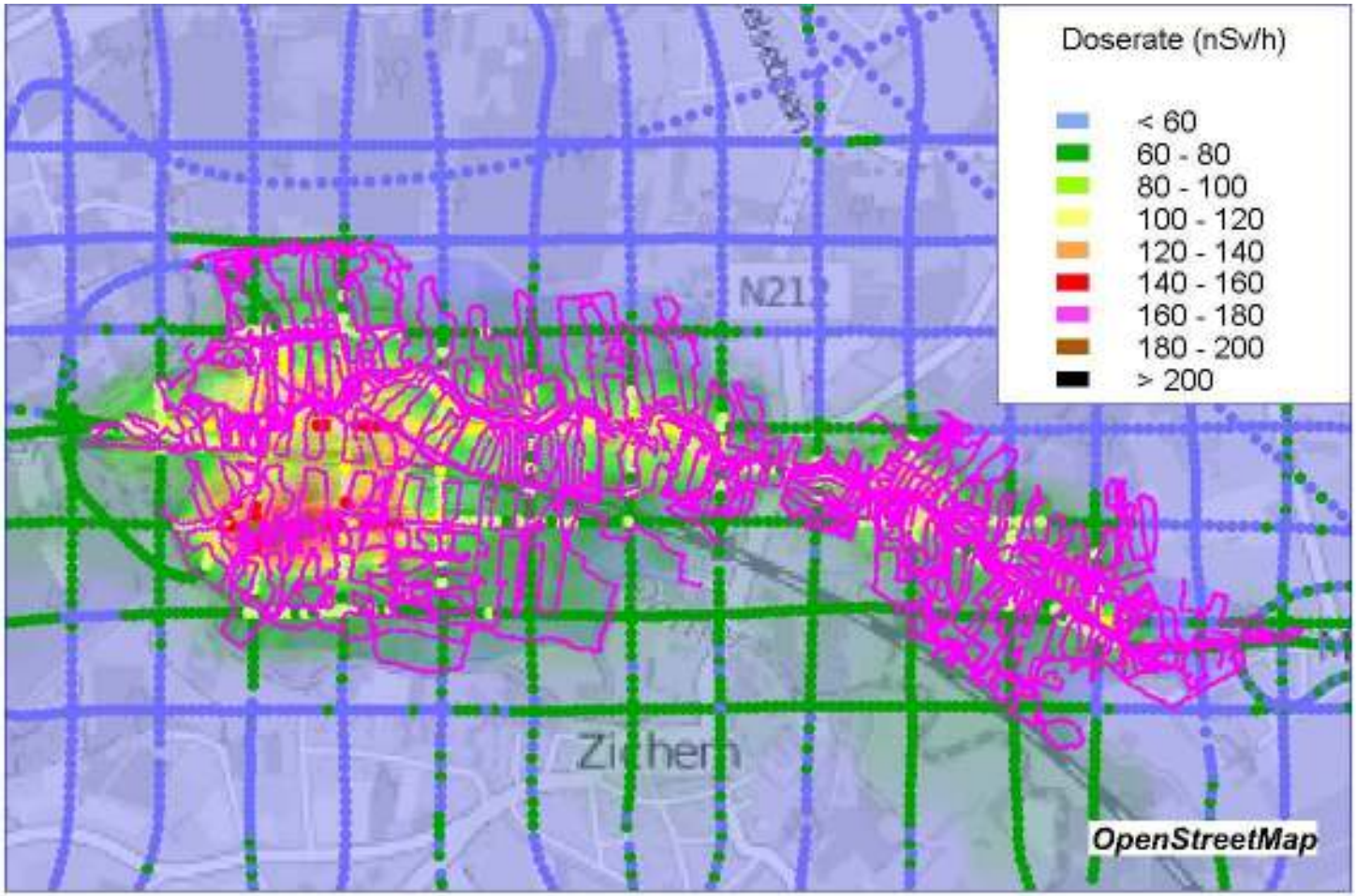
- ✓ Scenario 1 – different locations





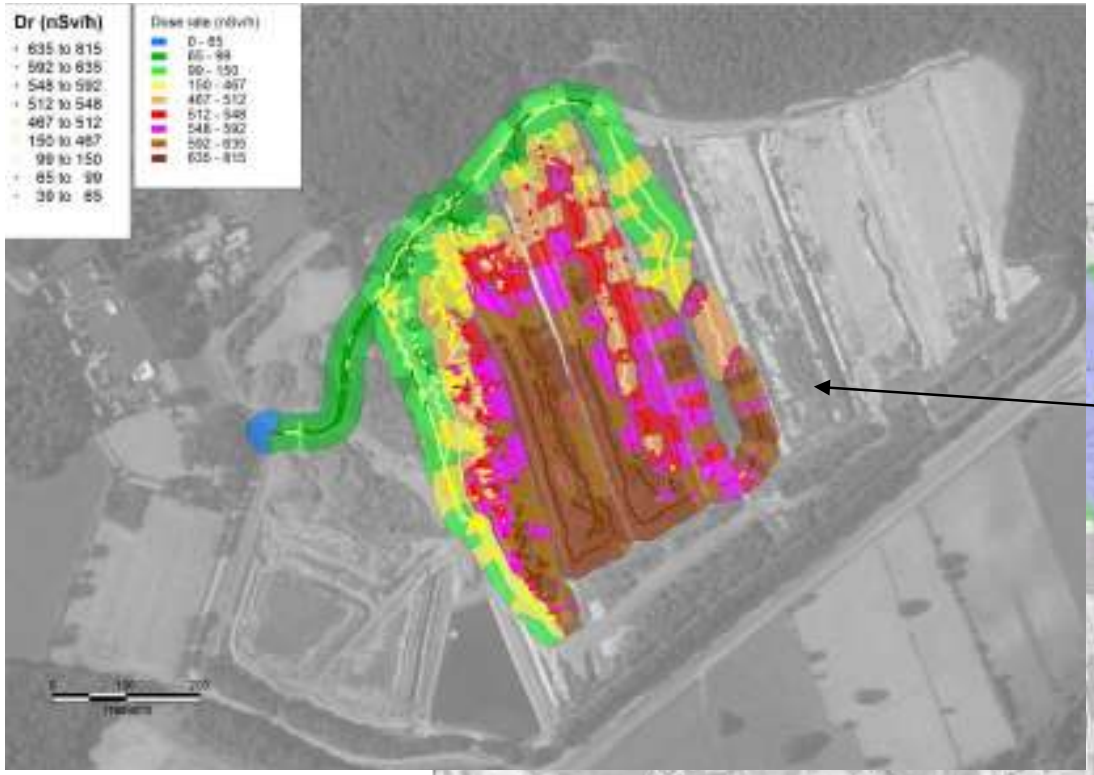
- ✓ Inhalation/cloudshine dose: location dependent (factor 6 difference)
- ✓ In addition: chemical form (e.g.; Iodine isotopes)
- ✓ Shielding factors, location of people, …
- → Assessment of inhalation dose based on dose rate not guaranteed within order of magnitude
- → Dose reconstruction: additional monitoring required (real-time info available?)

Aerial surveys



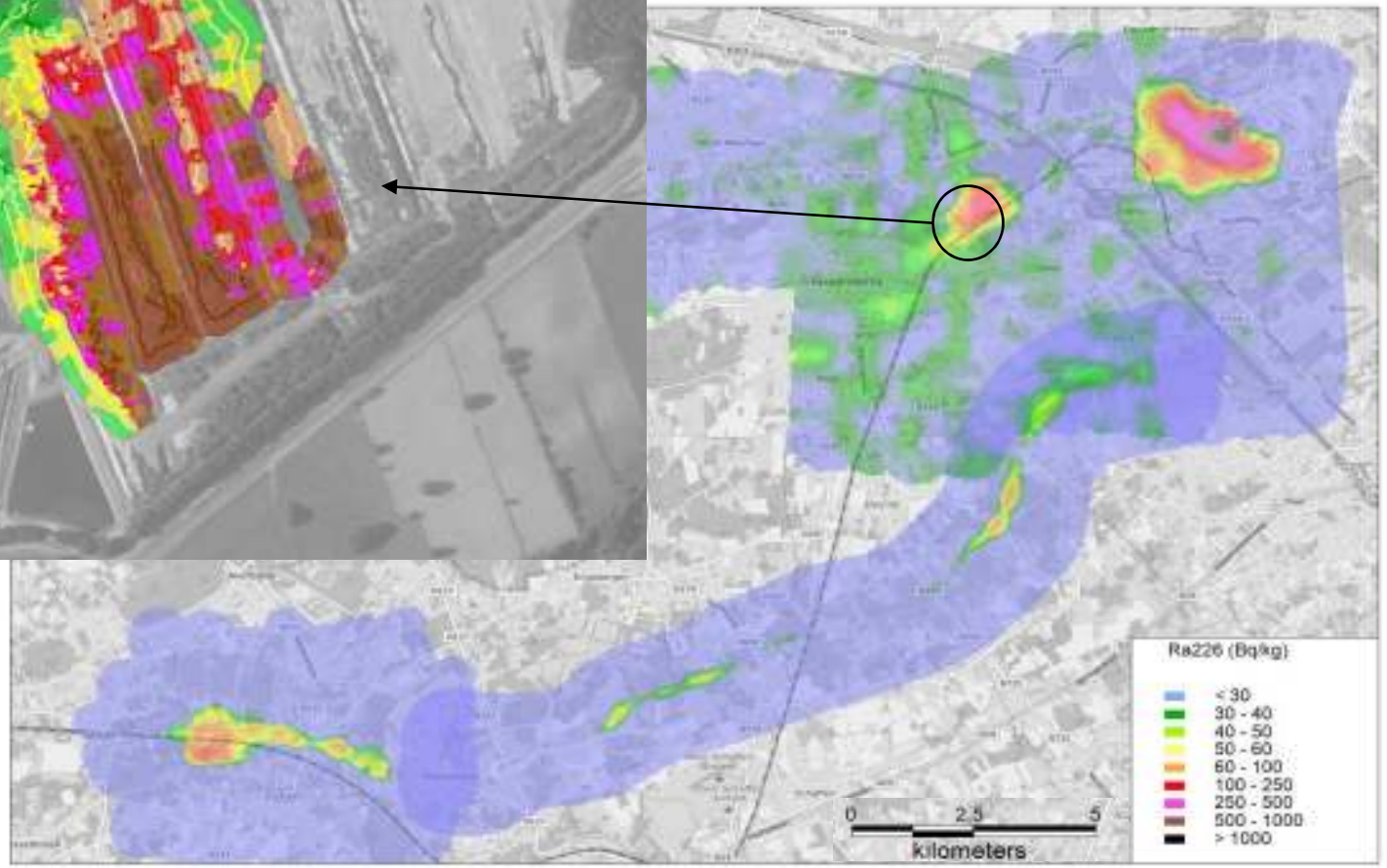
SCK **Doserate** Aerial survey (May 2016) compared with former foot campaign (3” NaI detector)

Spatial resolution (Kepkensberg)

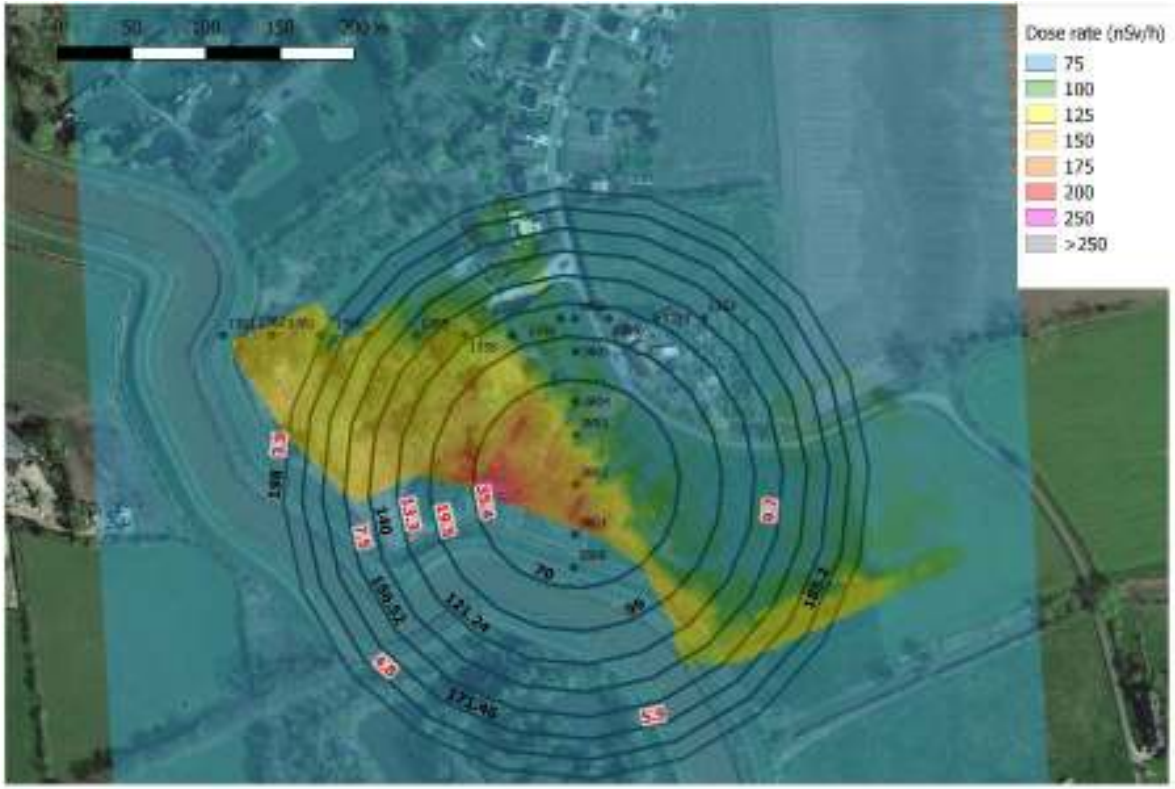


Foot campaign
(June 2016)

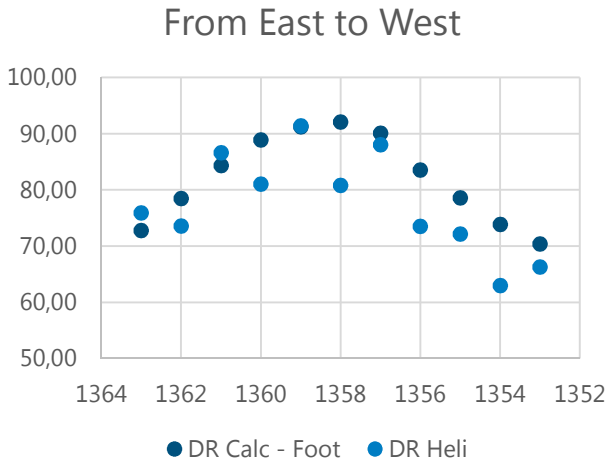
Aerial Gamma ray survey
(May 2016)

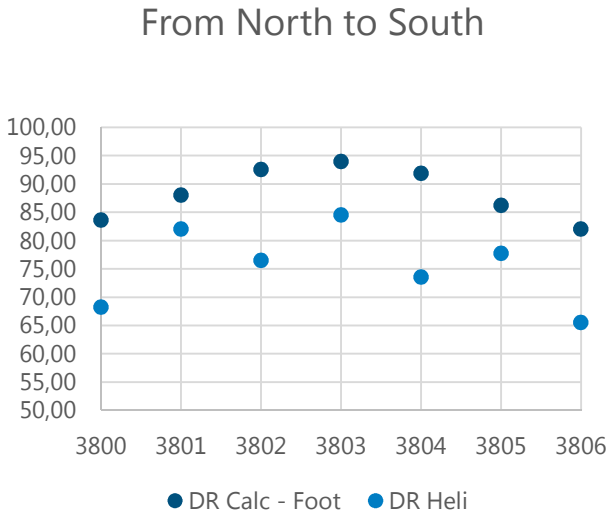


Spatial resolution



Aerial view of gamma ray survey (circles) on top of dose rate from foot campaign.
The red numbers next to each circle represents the relative (in percent) contribution of that shell to the aerial gamma-ray signal.
In this way it is possible to correlate dose rate measured on the ground with dose rate from aerial survey (see graphs on the right)



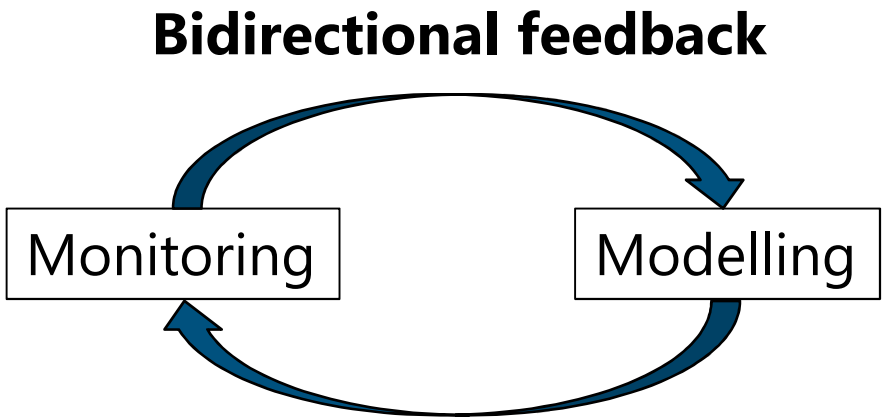


Survey of city
Car borne survey (around 1 day for part of small city)

Guidelines on joint use of monitoring and model results

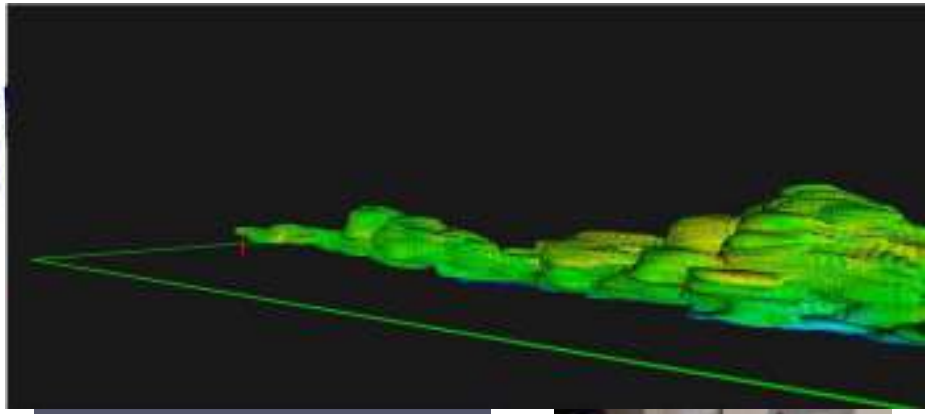
- Input: Monitoring strategies using WP1 scenarios
- Applicability of the proposed monitoring strategies into current DSS
- Harmonisation of monitoring strategy and modelling tools

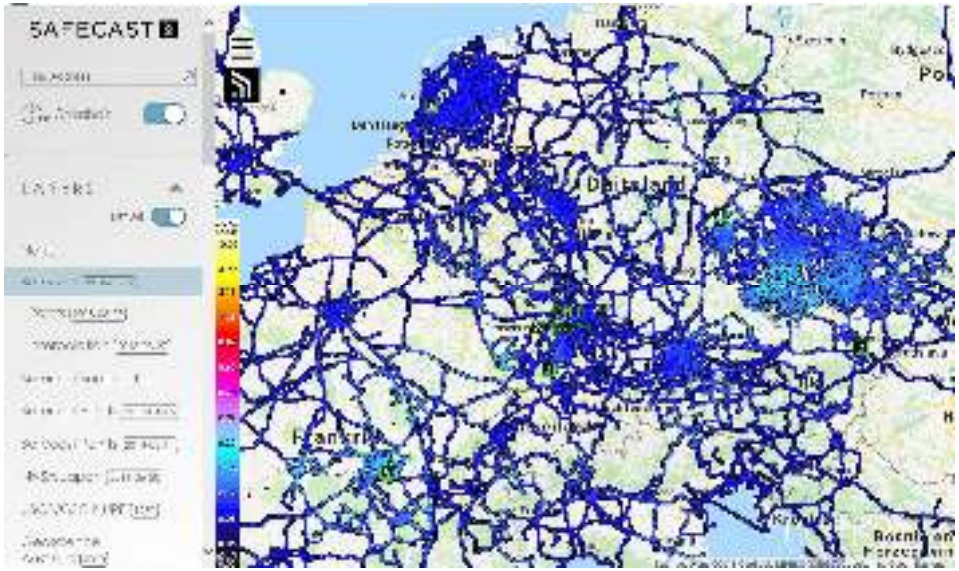
➔ Guidelines on joint use of monitoring and model results



Conclusions

- ✓ More robust monitoring strategies for nuclear emergency response and recovery are required
  - ✓ to serve models for impact assessment (especially real-time assessments)
  - ✓ models should be able to cope with monitoring data
- ✓ Gaps versus new challenges (new technologies)
- ✓ Big data versus specific and quality data (fusion of both)





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Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL