BVS-ABR

Comment protéger la population en cas de rejets radioactifs dans l'environnement ?

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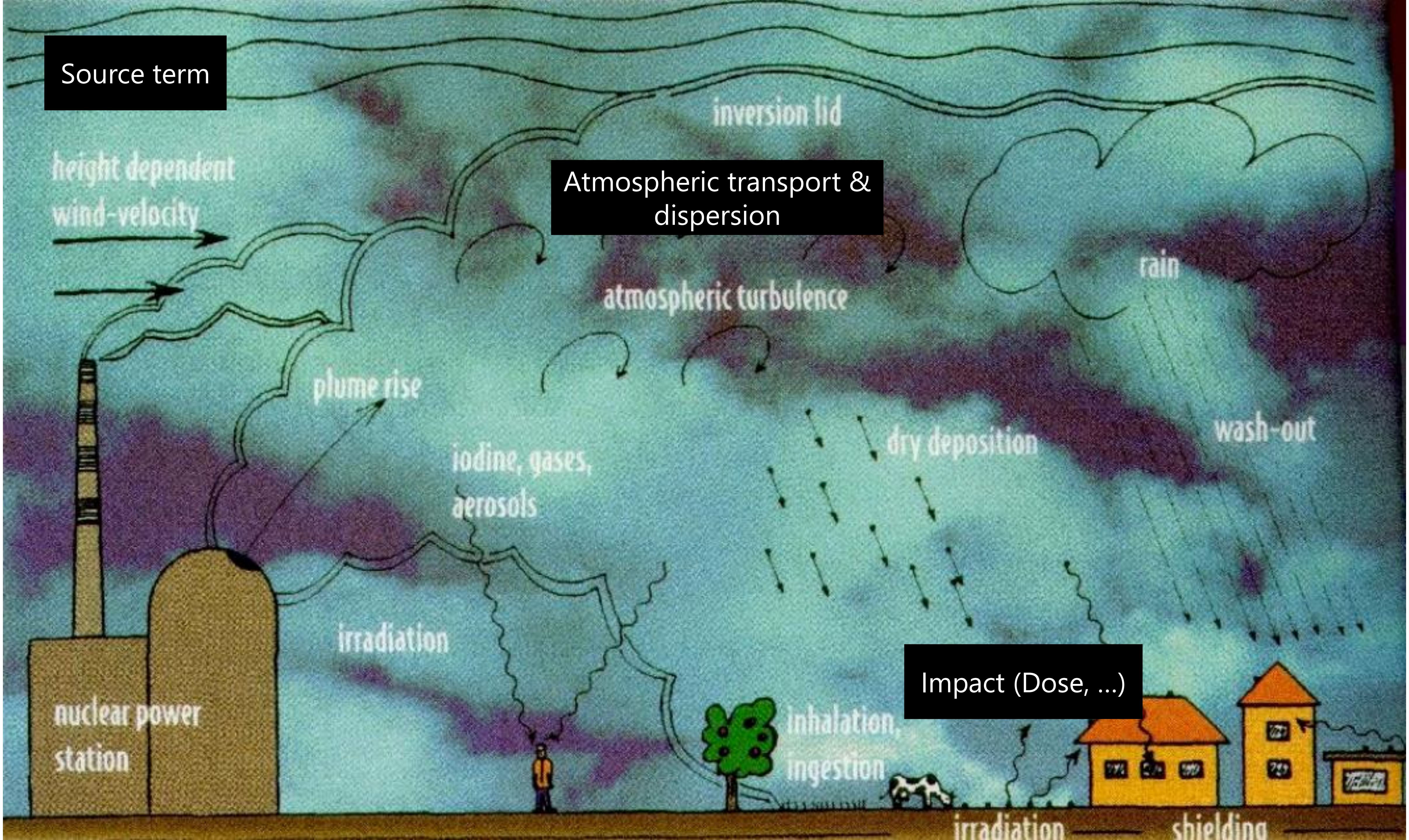
# Modelling of atmospheric releases of radioactivity from nuclear accidents

**Johan Camps**
**Belgian Nuclear Research Center (SCK CEN)**

johan.camps@sckcen.be

sck cen



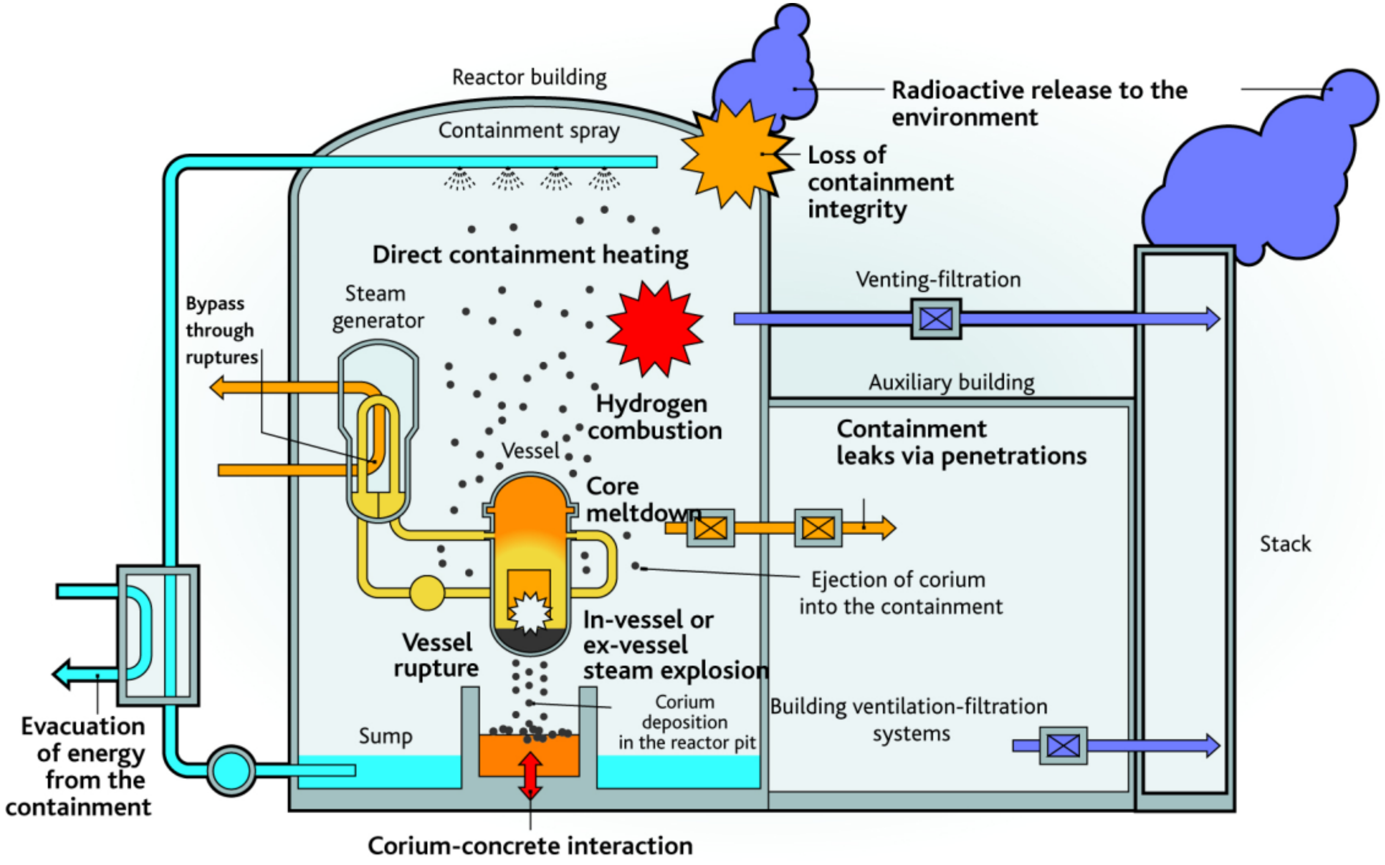
Source term
height dependent
wind-velocity
inversion lid
Atmospheric transport &
dispersion
rain
atmospheric turbulence
plume rise
wash-out
dry deposition
iodine, gases,
aerosols
irradiation
Impact (Dose, ...)
nuclear power
station
inhalation,
ingestion
irradiation
shielding

# Content

1. Source term of an NPP accident
2. Atmospheric transport & dispersion (meteorological data – models)
3. Some examples:
   - Exposure pathways (hypothetical accident Tihange)
   - Impact of an accident in one of the Ukrainian NPPs
   - Hypothetical accident Gravelines
4. Outlook in atmospheric modelling

# Source term NPP

- Inventory of reactor (burn-up, time after reactor shut down, spent fuel, …).
- During a severe NPP accident (core melt), a large amount of radioactive substances can be released from the fuel.
- There are various removal processes which will reduce the concentration of radioactive particles in the containment atmosphere.
- Duration, magnitude, composition and timing of the release to the environment, should it occur, is called the **source term.**



# Source term: different groups of radionuclides

- Noble gases:
  - Xe-133, Xe-135, Kr-isotopes
- Iodine isotopes:
  - I-131, I-132, I-133, I-135
  - Chemical form: $I_2$, Organic, Aerosol (can change during transport)
- Aerosols:
  - Cs-137, Cs-134
  - Sr-90
  - Pu-isotopes

But also: location, height, heat content, … of release

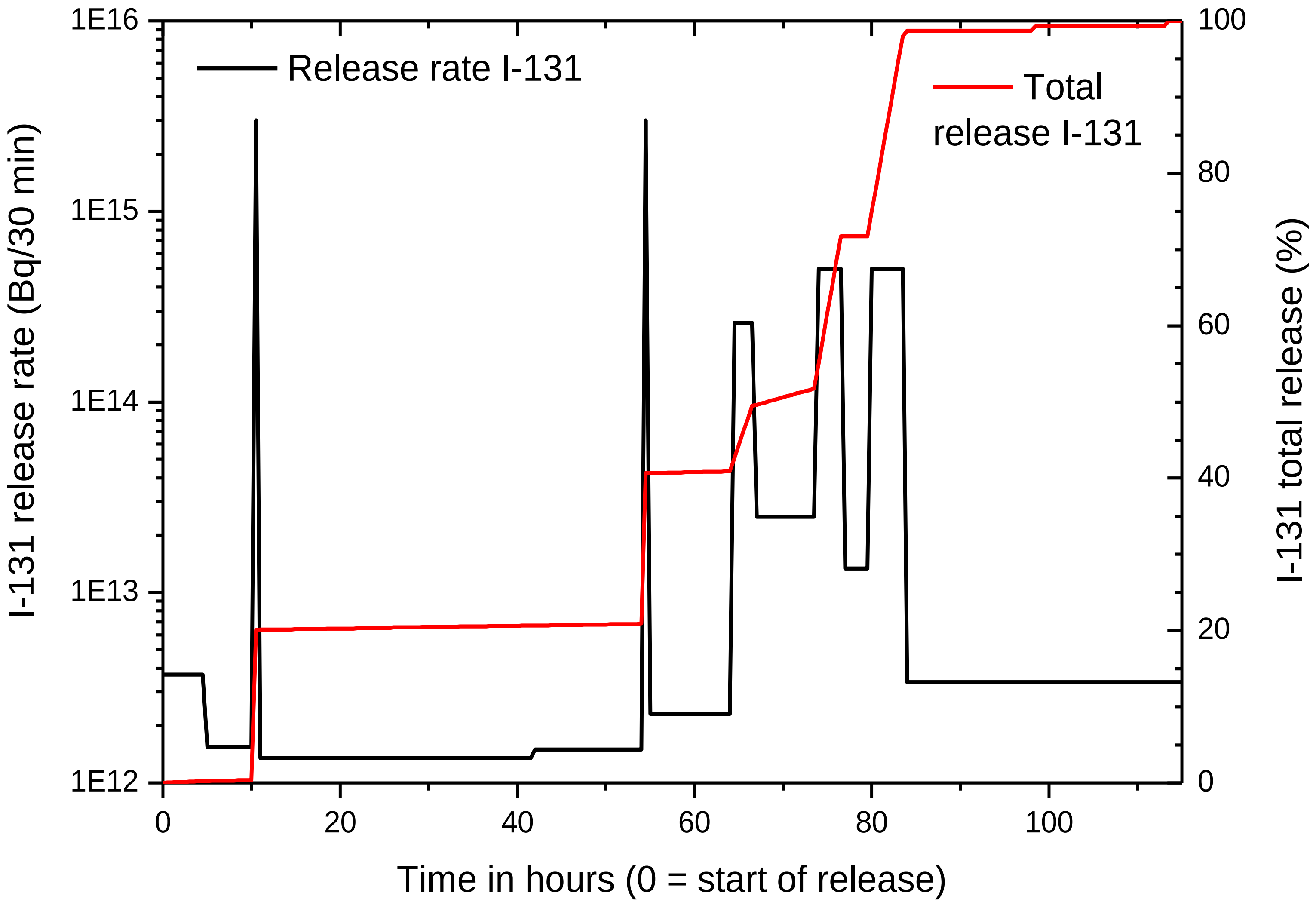
Differences:
- released fractions of inventory (volatility)
- dry and wet deposition during atmospheric transport (and consequently depletion)
- Exposure pathways

# Example actual total source terms

- 1 PBq = $10^{15}$ Bq

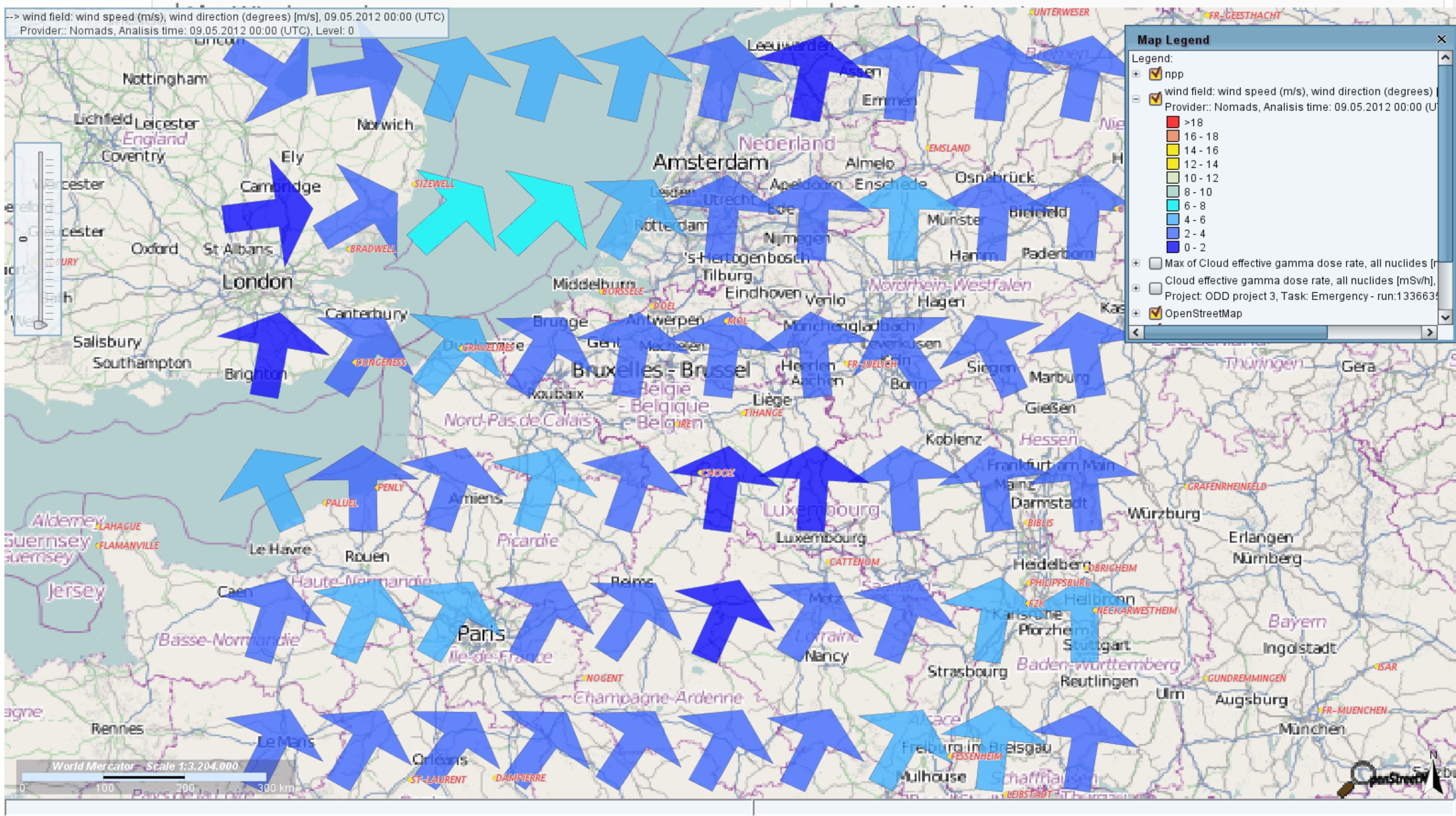
| | Three Mile island | Chernobyl | Fukushima |
|---|---|---|---|
| Xe-133 (5 days) | 370 PBq | 6 500 PBq | 11 000 PBq |
| I-131 (8 days) | $5 \times 10^{-4}$ PBq | 1 800 PBq | 160 PBq |
| Cs-137 (30 years) | - | 85 PBq | 15 PBq |
| Cs-134 (2 years) | - | 52 PBq | 18 PBq |
| Sr-90 (29 years) | - | 8 PBq | 0.14 PBq |
| Pu-238 (88 years) | - | $1.5 \times 10^{-2}$ PBq | $1.9 \times 10^{-5}$ PBq |

# Example: detailed I-131 source term Fukushima



# Atmospheric transport and dispersion


- Atmospheric conditions
  - Wind field
  - Turbulence
  - Convection
  - ....
- Terrain:
  - surface roughness
  - topography
  - ...
- Modelling: scale!



# Dispersion

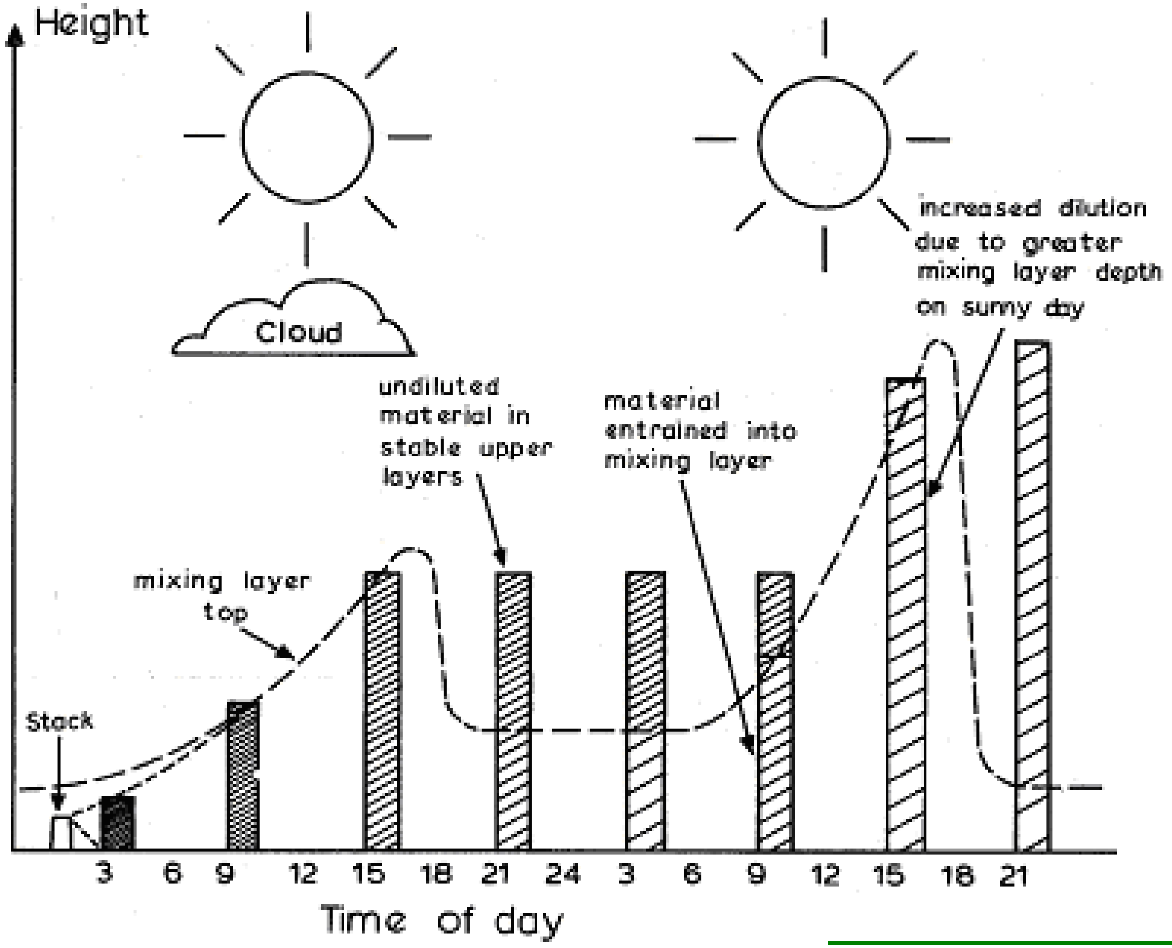
- Atmospheric turbulence

Neutral conditions

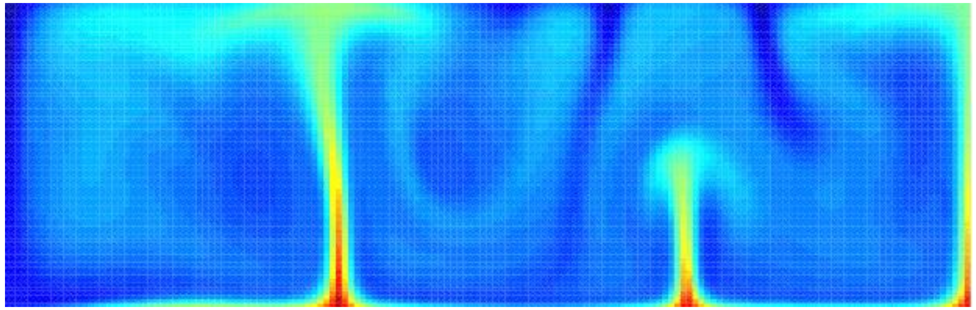
Very unstable conditions

Very stable conditions

# Transport and dispersion at long range




+ convection:
Particles move from the planetary boundary layer into the free troposphere



**Typical values for the mixing height**

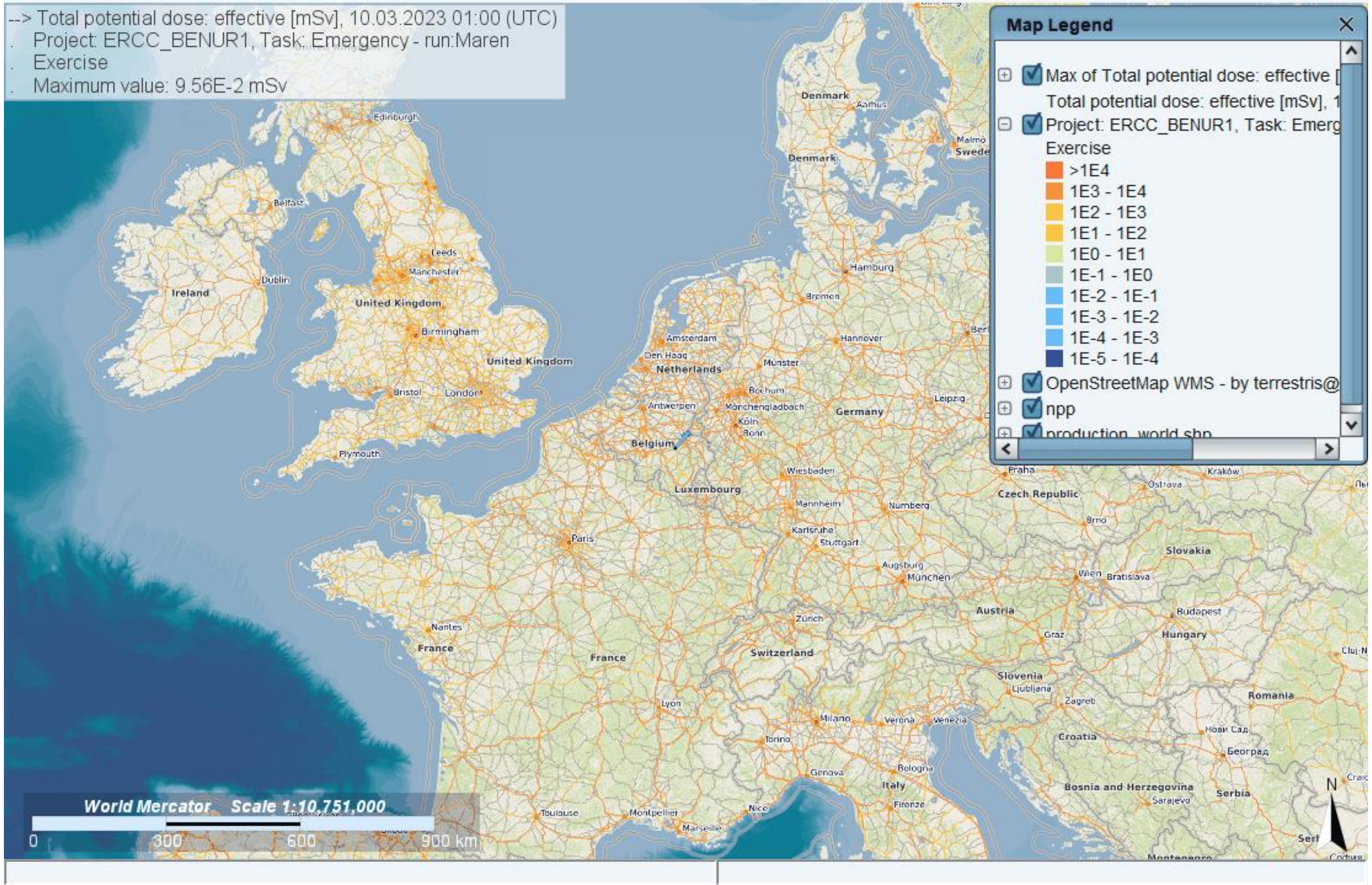
| Stability | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| $Z_i$ [m] | 1300 | 900 | 850 | 800 | 400 | 100 |

# Example: hypothetical accident scenario Tihange NPP – exposure pathways

- JRODOS calculation with following input data:
  - numerical weather data (prediction from NOAA) starting from 10 March 00:00
  - source term in which 1.6E16 Bq noble gases, 1.2E15 Bq iodine and 8.0E14 Bq aerosols will be released over a time period of 24h.
  - Simulation duration: 4 days
  - Limited to 800 km

# Total effective dose (inhalation, cloud shine, ground shine)

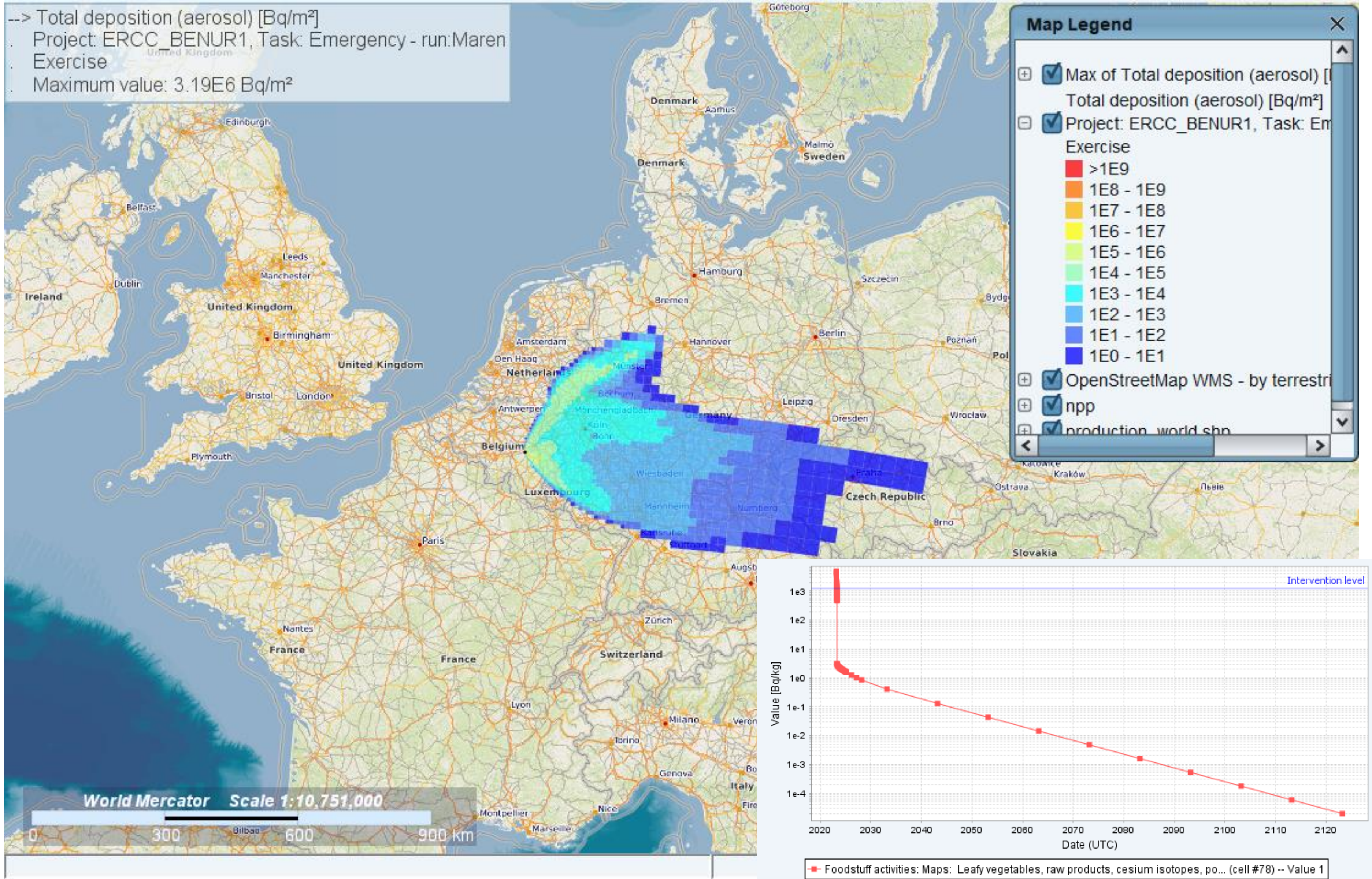
This scenario would give some direct countermeasures such as stable iodine prophylaxis for children up to 4 km



# Ground contamination Cs-137 (Bq/m²)

Potential direct food countermeasures can range up to a distance of 60 km (Cs-137)

(first year, direct deposition)



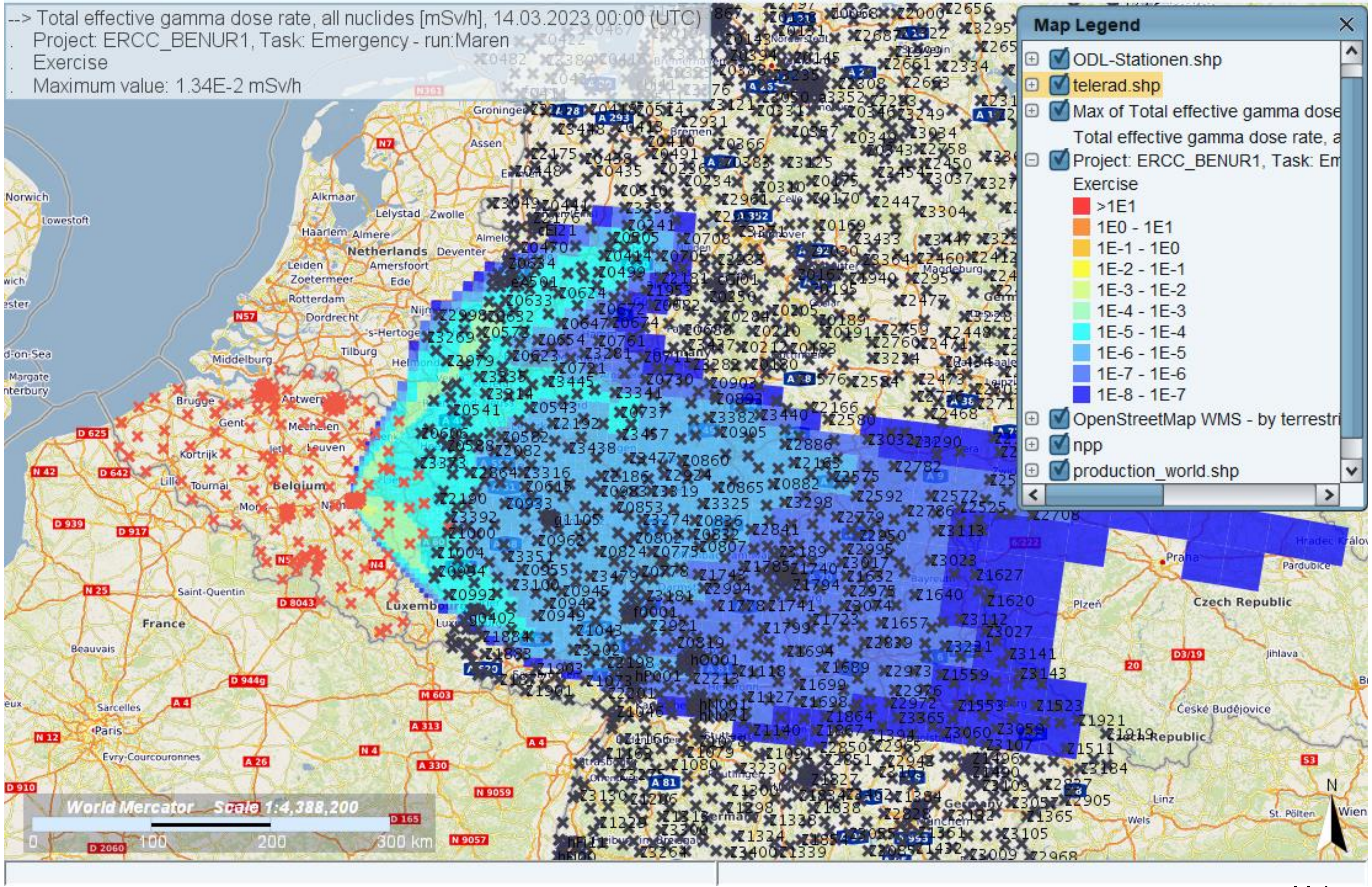
# Dose rate early warning stations (Belgium & Germany)

**Summary:**

Noble gases: only exposure during cloud passage

Iodine: Dominates effective dose from cloud (inhalation) passage/Thyroid dose (esp. children) + food chain (short term)

Cs137/Cs134: food chain (longer term) + ground shine (20-100 mSv/y)

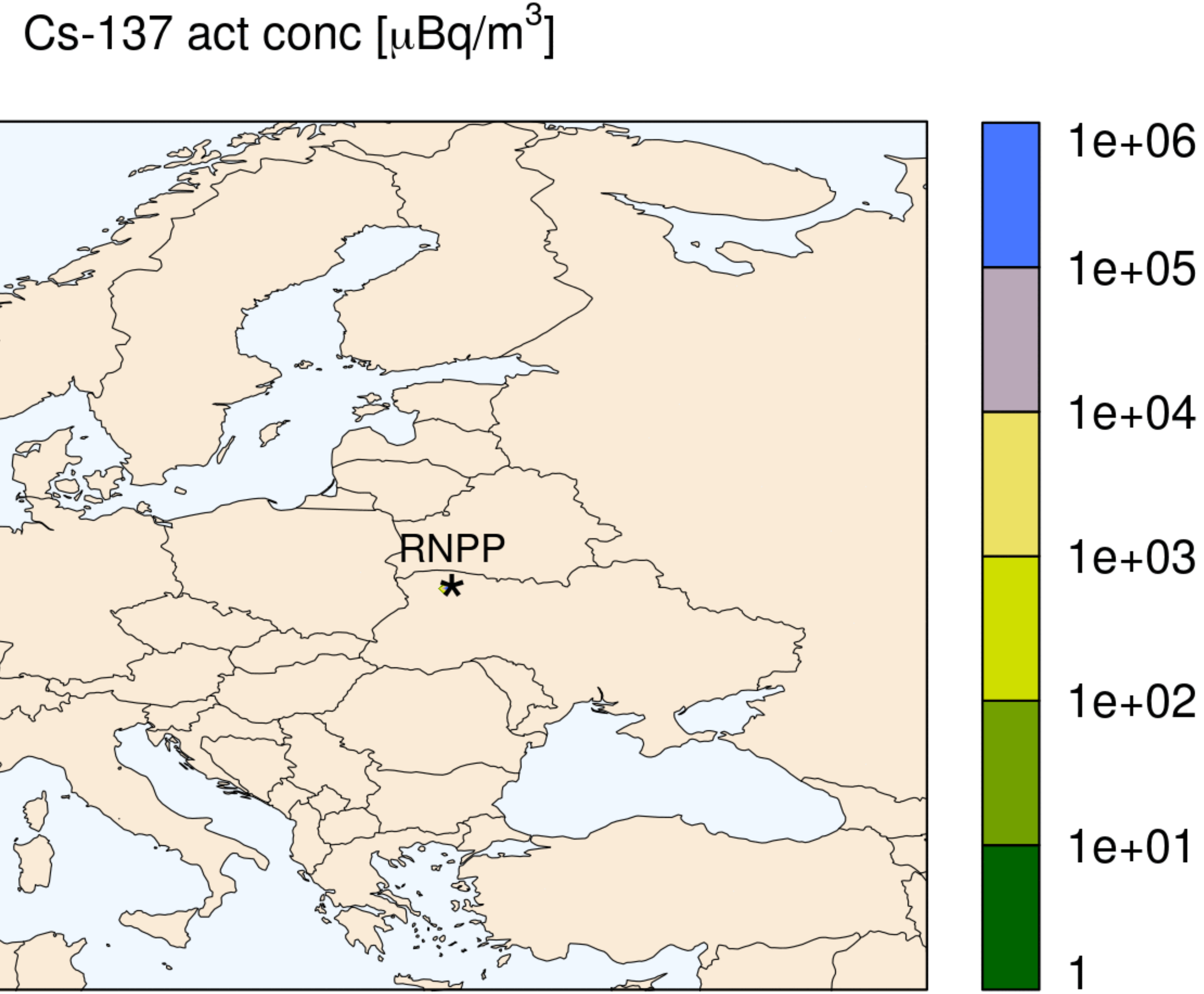


# Example: potential impact from a hypothetical release from a Ukrainian NPP (on Western Europe)

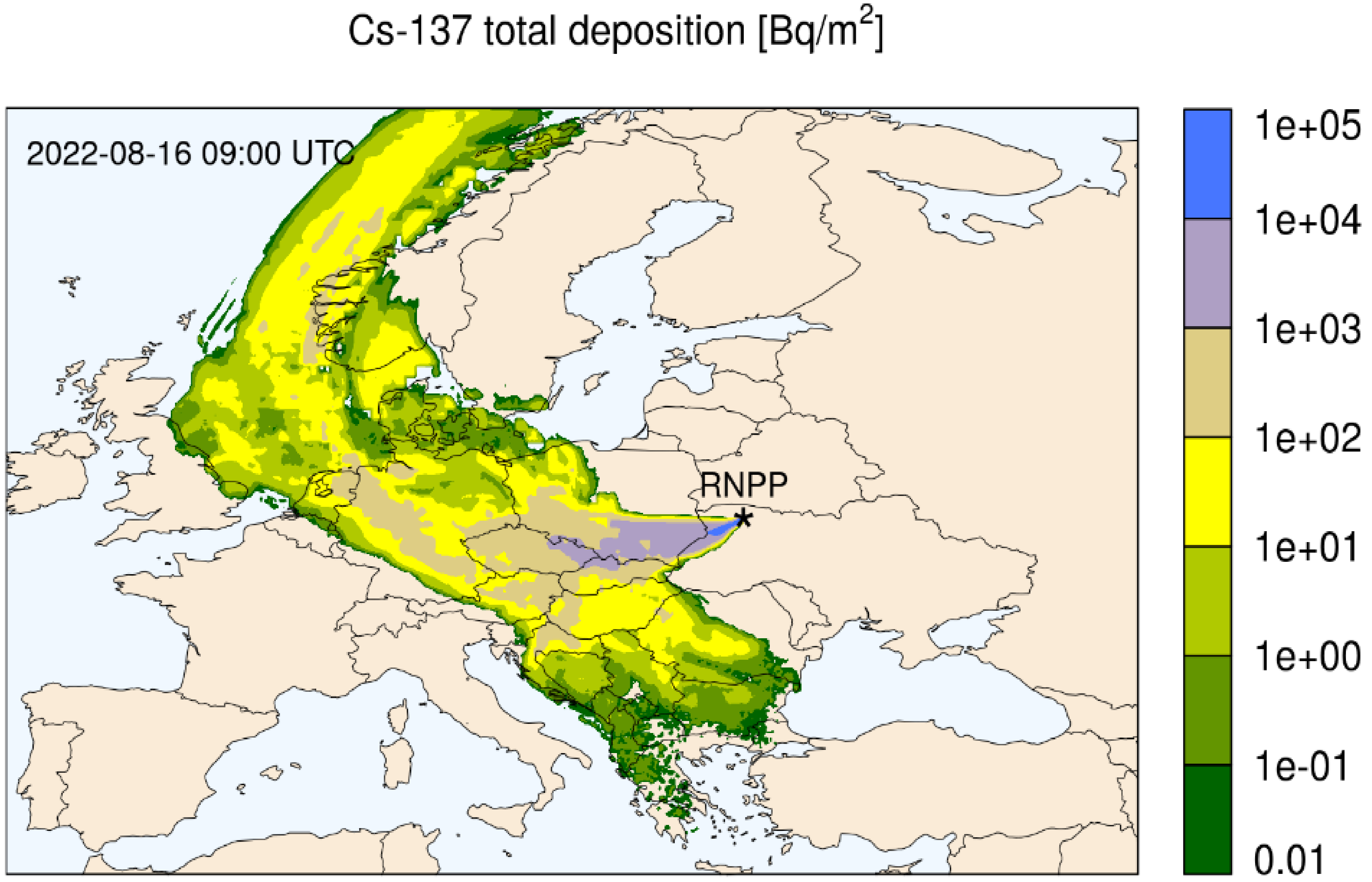
Calculation set-up

- Lagrangian stochastic particle model *Flexpart*, coupled with archived numerical weather data from the ECMWF Forecasts provided by the RMI
- Simulations for the 4 NPP locations in Ukraine
- 6 hour release of
  - A “passive” air tracer (noble gas – no deposition –depletion): Xe133, Xe135
  - I131
  - Cs137
- Total of 6000 simulations: 500 release moments x 3 radionuclide species x 4 locations

# Example – Rivne NPP (unit source term)



**Rivne NPP**
**(1 PBq Cs137)**

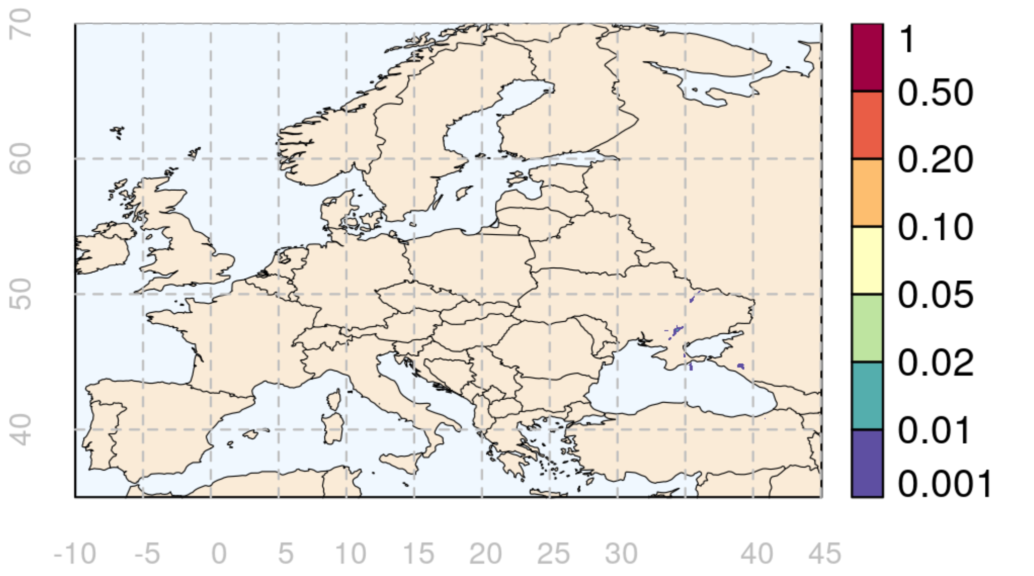


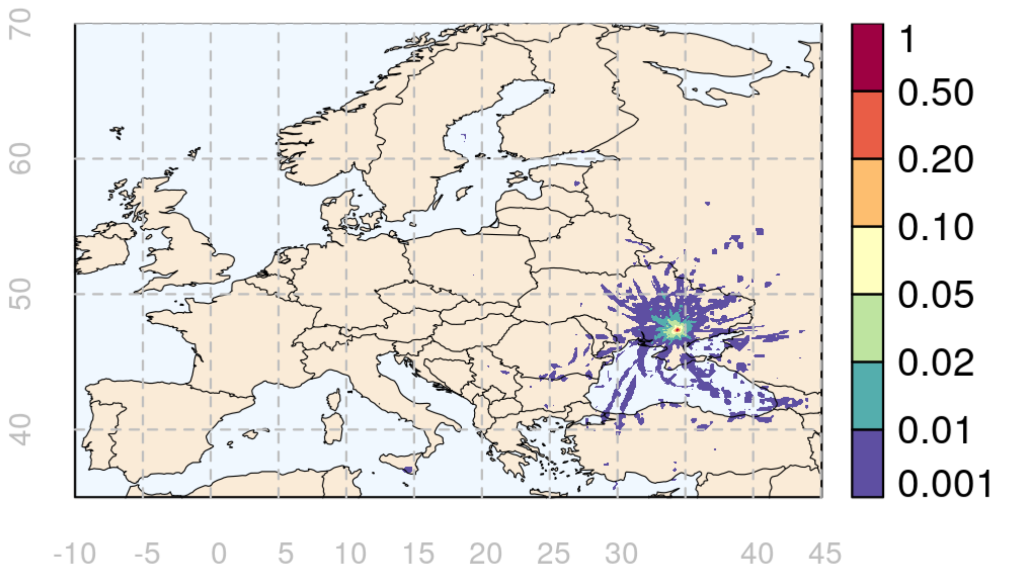
# Output of simulation: an answer to three questions

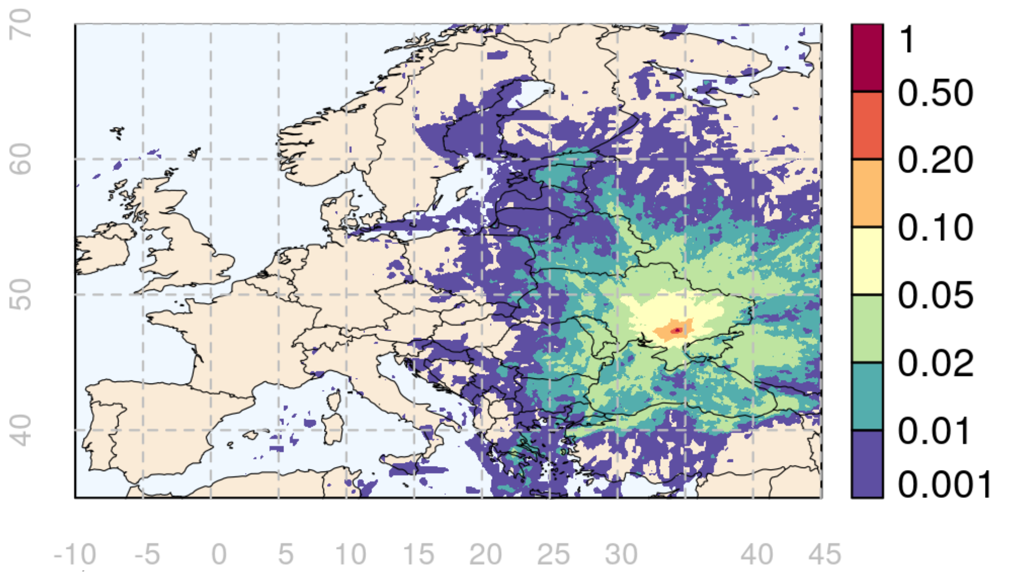
- Assuming a hypothetical Cs-137 release, which area could face a potential impact on the food chain?
- Assuming a hypothetical I-131 release, which area could face a potential impact on the food chain?
- Assuming a hypothetical release of radioactive noble gases, in which area could the plume be detected by early warning gamma dose rate monitoring stations?

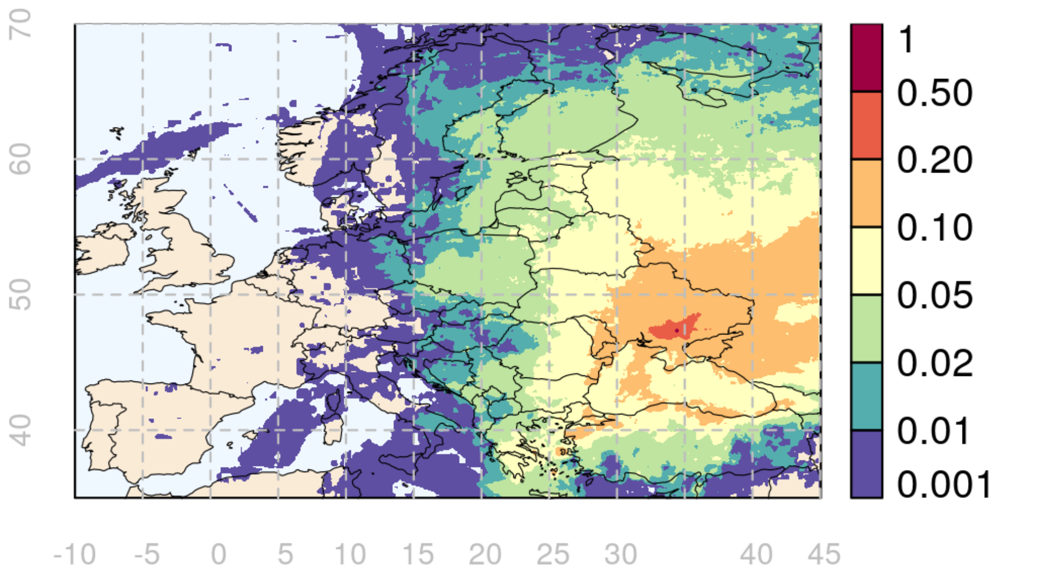
→ Plots as a function of source term released

# Zaporizhzhia NPP
# Cs137



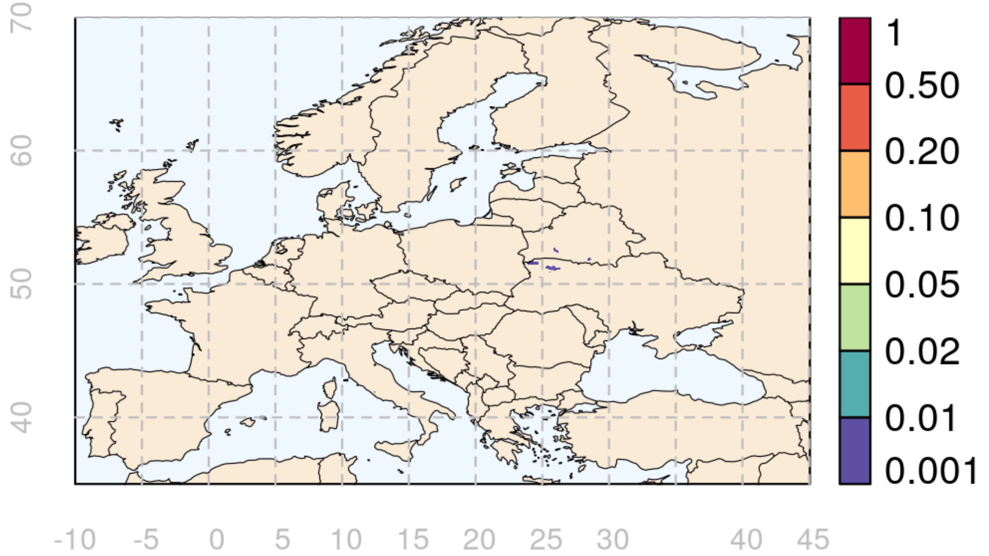



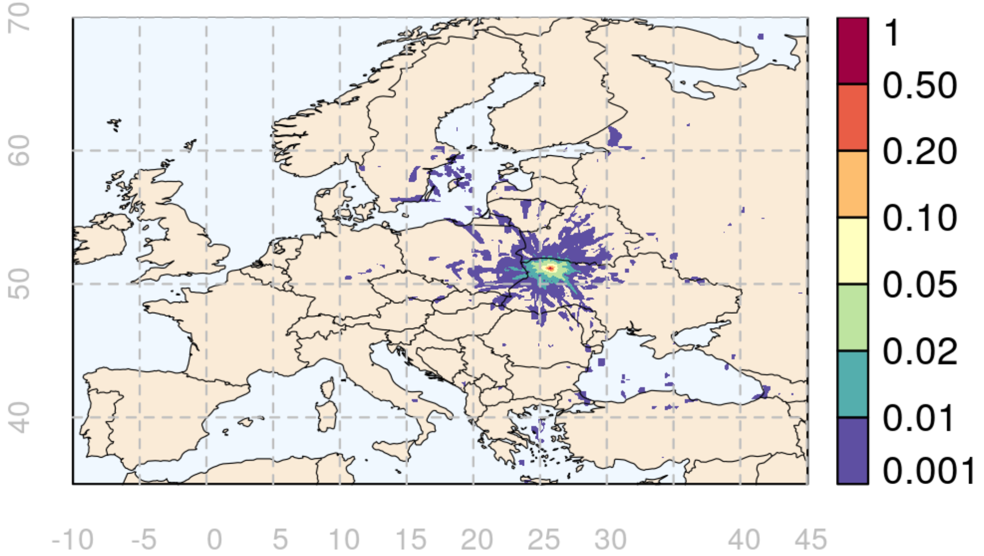



# Rivne NPP
# Cs137

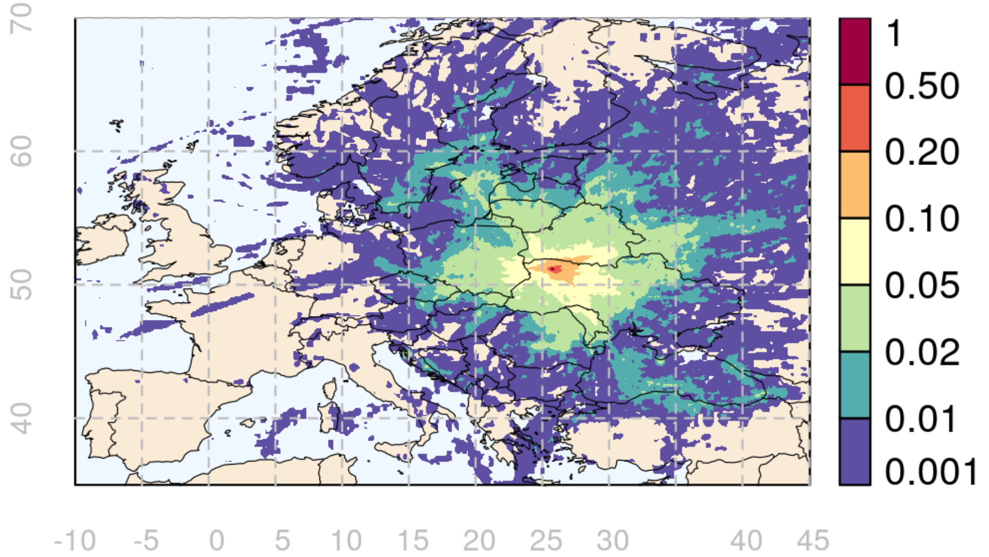
**RNPP - 0.1 PBq - Probability of total deposition > 10kBq/m²**



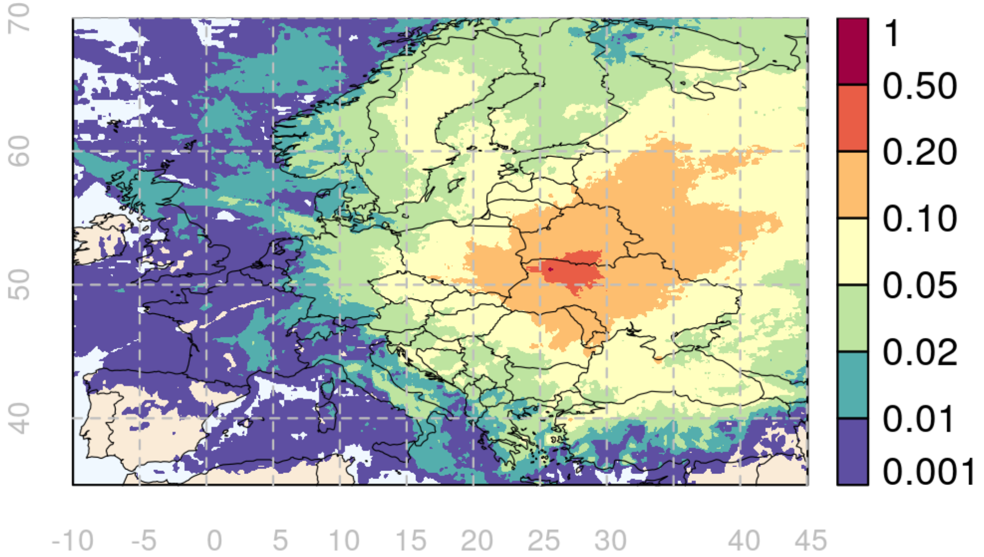

**RNPP - 1 PBq - Probability of total deposition > 10kBq/m²**




**RNPP - 10 PBq - Probability of total deposition > 10kBq/m²**

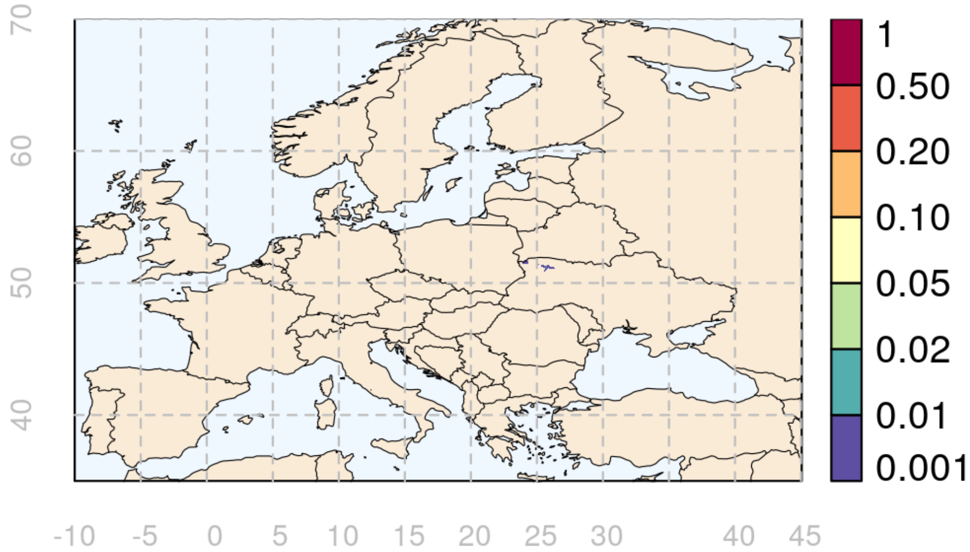



**RNPP - 100 PBq - Probability of total deposition > 10kBq/m²**

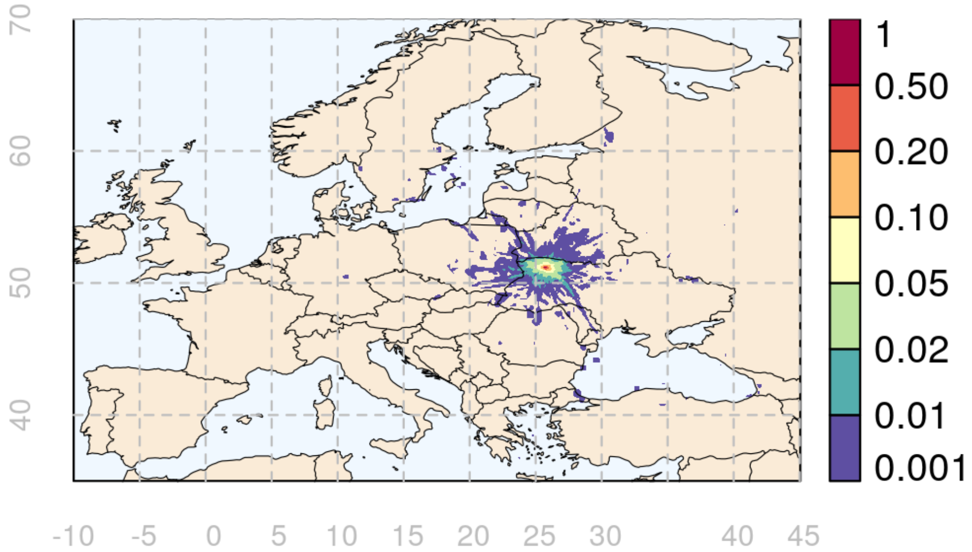


# Rivne NPP
# I131

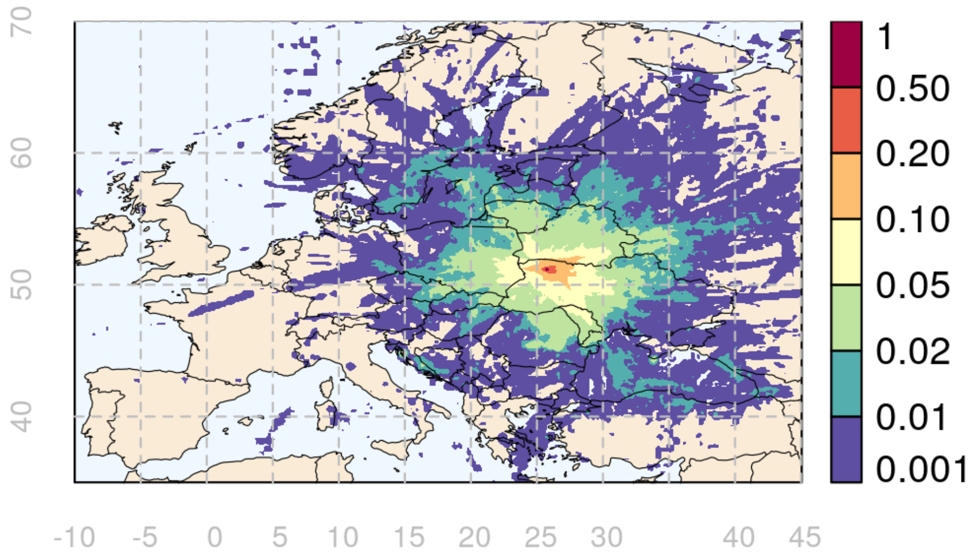
RNPP - 0.1 PBq - Probability of total deposition > 10kBq/m²



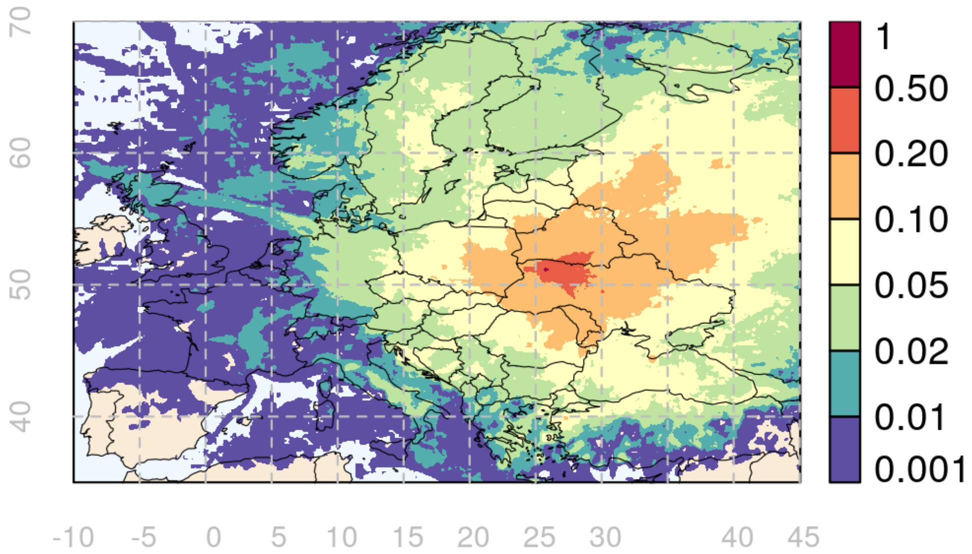

RNPP - 1 PBq - Probability of total deposition > 10kBq/m²



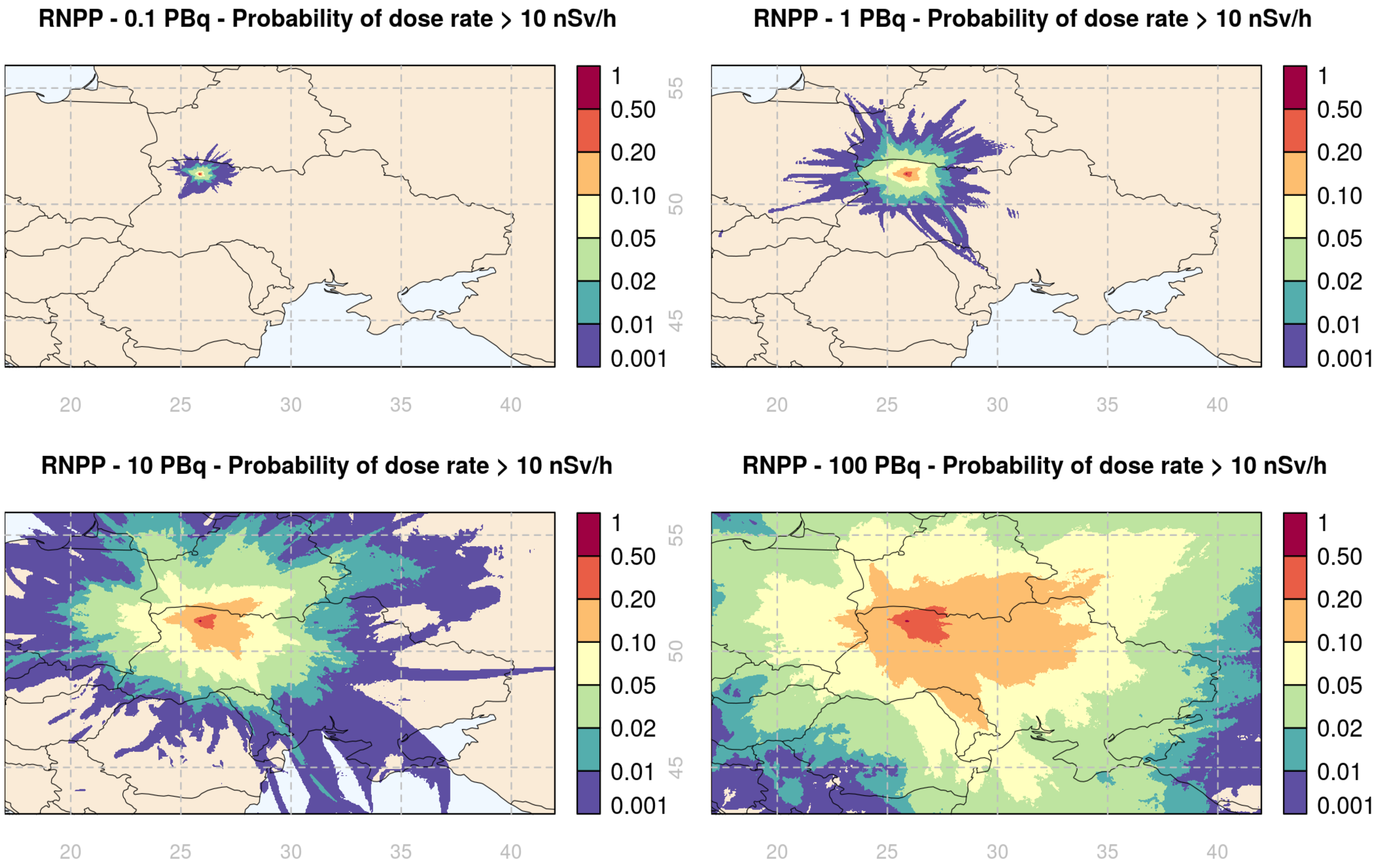

RNPP - 10 PBq - Probability of total deposition > 10kBq/m²




RNPP - 100 PBq - Probability of total deposition > 10kBq/m²

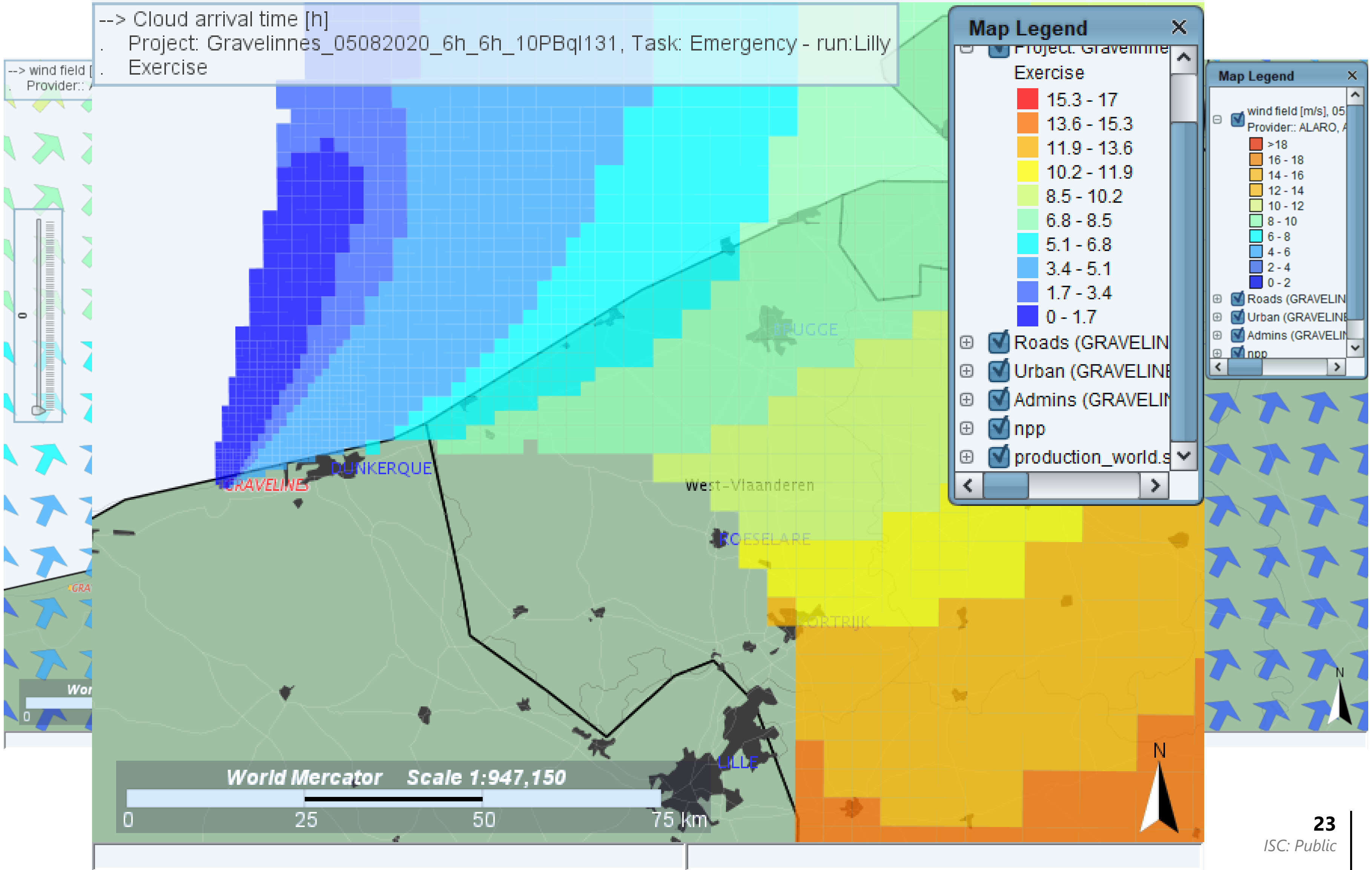


## Rivne NPP
## Dose rate
## noble gases
## (Xe133, Xe135)



# Example: case study of hypothetical accident Gravelines

- Sea breeze
- High resolution NWP data required
- ALARO (IRM)



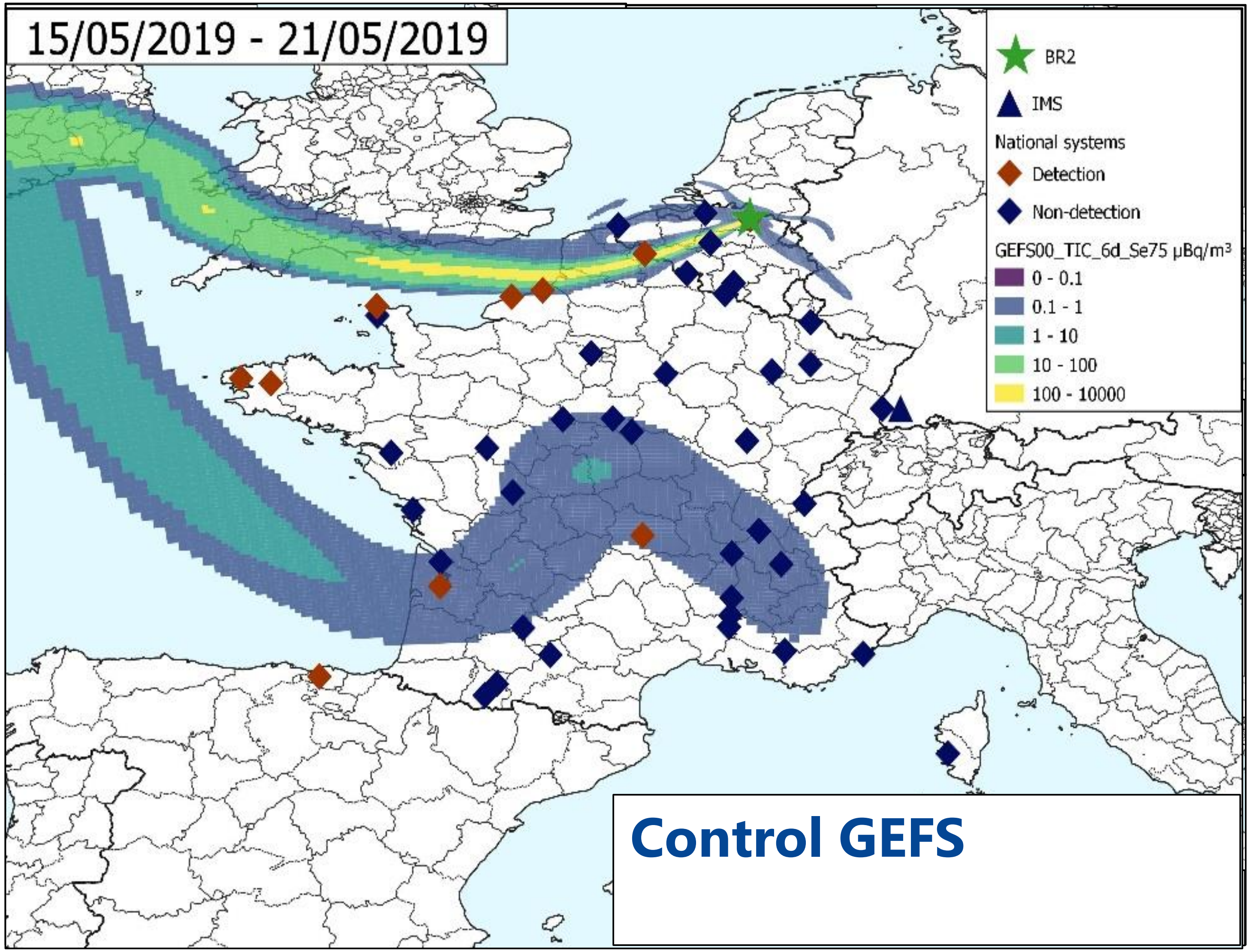
# Outlook: meteorological ensembles

Example: anomalous release of Se-75 from BR2 (SCK CEN) – May 2019

Ultra-low level radioactivity sampling stations in France and Spain picked-up the Se-75 release

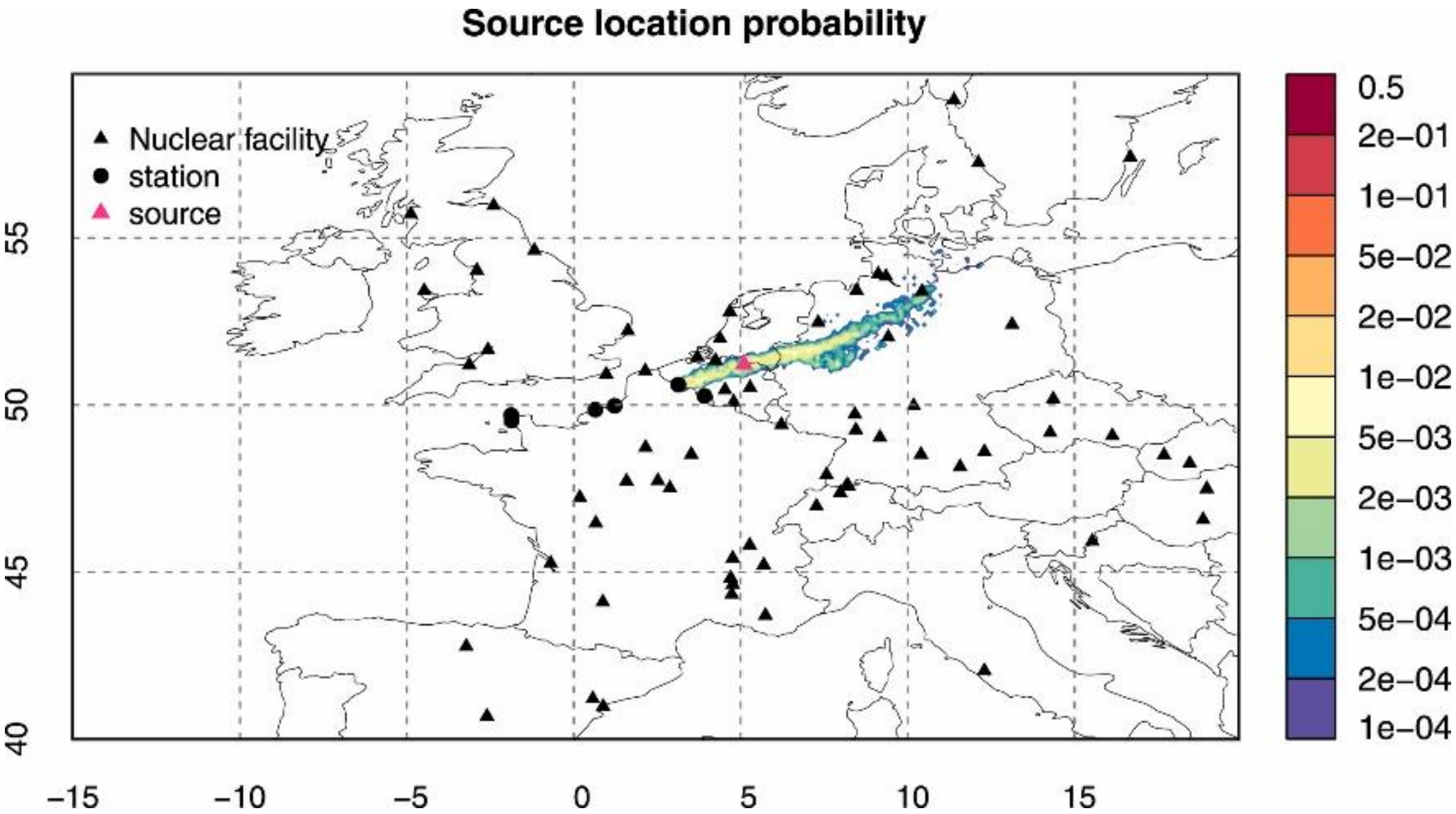
JRODOS simulation with GFS weather data:
1/ Control forecast
2/ Ensemble members (4 out of 20 are shown)

→ Assessment of meteorological uncertainty




C. Gueibe, NERIS workshop 2021

# Outlook: source term estimation Se-75 release




Fixed location (BR2): Estimated[1]

2.36 - 14.63 GBq

Release start 07:24 - 13:30 UTC
Release end 13:49 – 17:51 UTC

(all 95% credibility)

'Real' source term and start and stop[2]:

14.9 GBq, 13:10-14:10 UTC

[1]Pieter De Meutter, Ian Hoffman, Bayesian source reconstruction of an anomalous Selenium-75 release at a nuclear research institute, Journal of Environmental Radioactivity, Volume 218, 2020
[2]J.P.K.W. Frankemölle, J. Camps, P. De Meutter, P. Antoine, A.W. Delcloo, F. Vermeersch, J. Meyers, Near-range atmospheric dispersion of an anomalous selenium-75 emission, Journal of Environmental Radioactivity, Volume 255, 2022

# Conclusions

- Source term, and especially the exact evolution of the releases, is probably the biggest unknown in the assessment of the impact of a NPP accident
- Ensembles can give good idea of atmospheric modelling uncertainties (and discriminate between situations/locations with low and higher uncertainty)
- Importance to combine atmospheric transport and dispersion modelling with measurements to assess the situation
  - Importance for off-site estimation of source term (especially in situation in which information from plant can be expected to be limited)
- Preparedness phase: atmospheric modelling is an excellent tool to study the potential impact and the probability of exceeding certain thresholds

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**SCK CEN**
Belgian Nuclear Research Centre

Foundation of Public Utility

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