Radionuclide Transport and Dose Assessment for EIA and EP&R Frameworks for Modular Reactors

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PIANOFORTE EUROPEAN PARTNERSHIP FOR RADIATION PROTECTION RESEARCH
CATAPULT

NERIS Workshop – 28-30 April 2026

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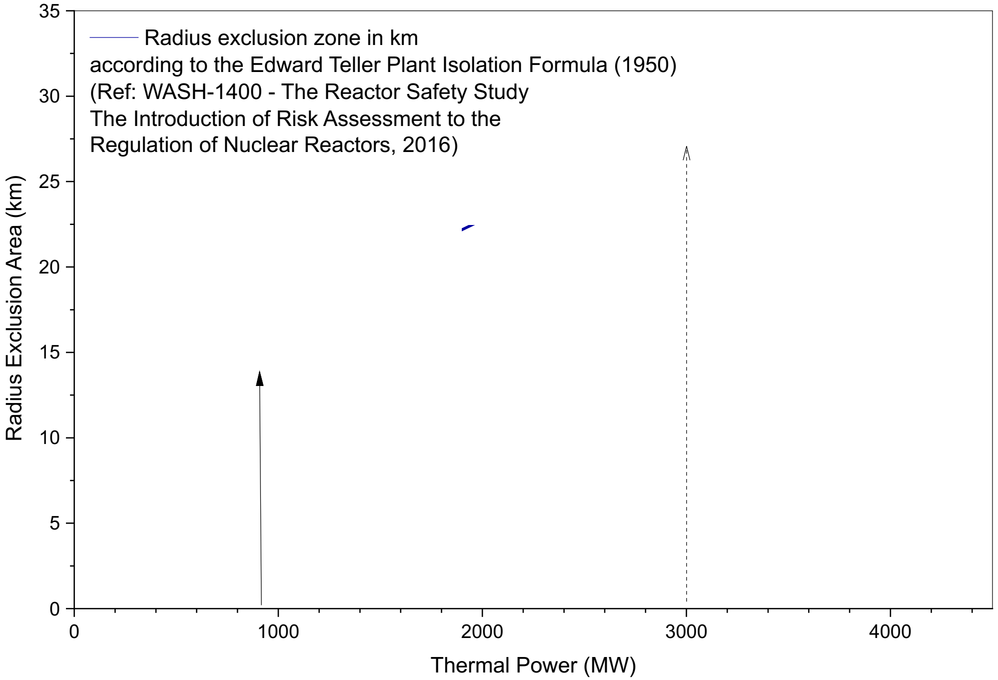
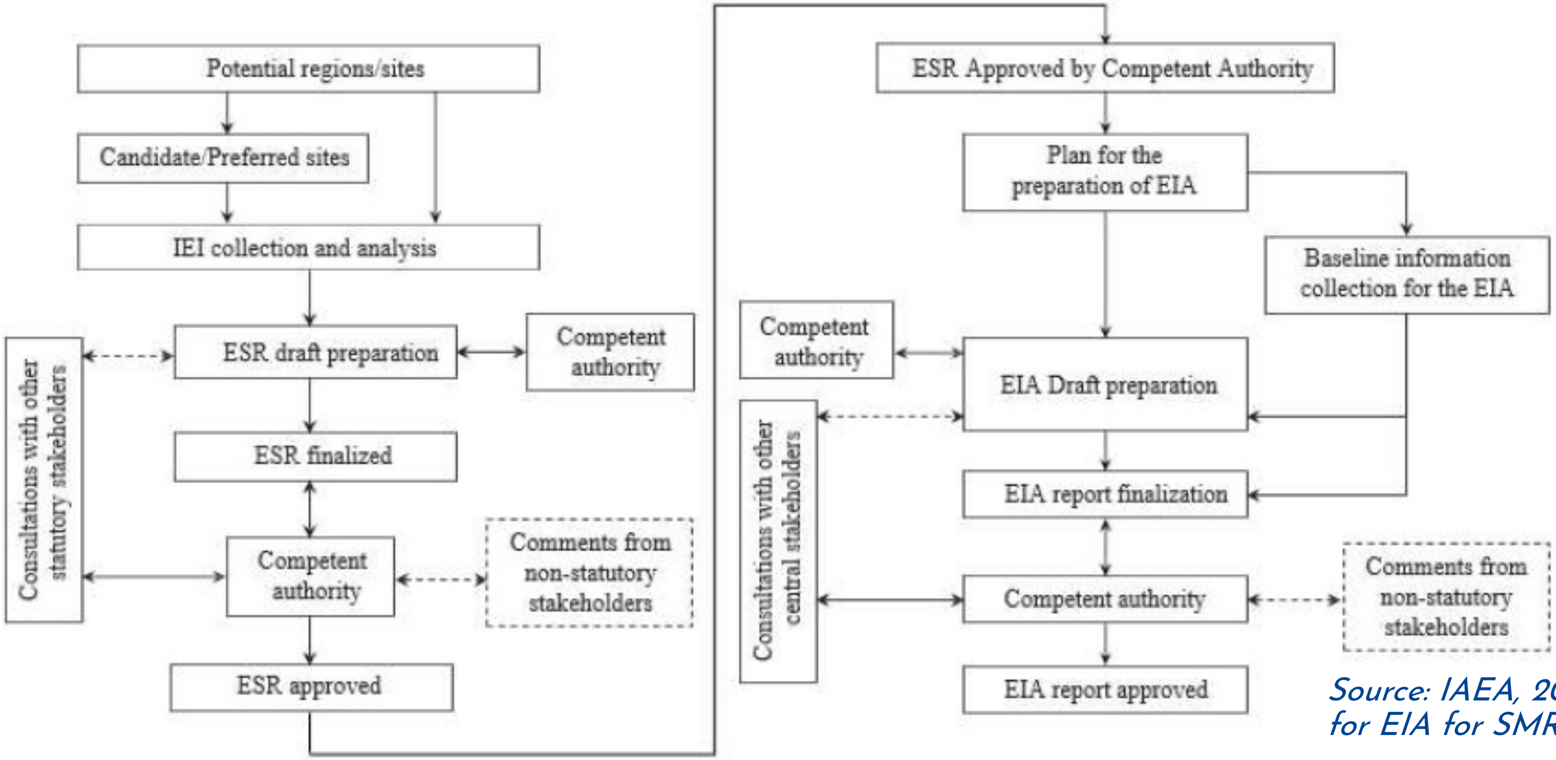
Introduction

- Improving/adapting the environmental transport (WP2) and the dose impact modelling (WP3)
- Delivering an analysis framework tailored to the needs of modular reactors and their typical site locations to guide end-users in the selection of computational models/ methodologies needed for EIA and EP&R (Emergency Planning Zones)



Research conducted by WP5 members (2025-2026) : Perko T., M. Martell.

EIA flowchart: analyses as part of Catapult WP5 research



Source: IAEA, 2020, Considerations for EIA for SMRs

Research conducted by WP5 members (2025-2026) : Perko T., M. Martell.

EIA flowchart: study by CATAPULT WP5

Two expert workshops with professionals involved in EIA processes (N= 23)

- to identify key differences between EIAs for large nuclear power plants and SMRs,
- mapping stakeholders across different EIA stages and
- to co-create a simplified EIA flowchart for SMRs

Research conducted by WP5 members (2025-2026) : Perko T., M. Martell.

Results: EIA for SMRs vs. traditional NPP as identified during the workshops

⚖️No SMR-specific EU law → projects fall under the existing nuclear framework

🧩 Harmonised design vs. local reality → site-specific assessments need to be maintained

⏱️ Same process, different pace → complexity can shape timelines

🔬 Impacts = source term, not size → radiological releases determine risk

🚚 Transport matters → modular delivery introduces a new EIA dimension

👥 New players/stakeholders emerging → start-ups, vendors & host sites are reshaping roles

Research conducted by WP5 members (2025-2026) : Perko T., M. Martell.

Results: What should be specifically considered in the EIA Report - as highlighted during the workshops?

🧪 Technology-specific scope → radionuclides and source terms need to be identified per SMR design

🔌 Infrastructure integration → grid connection and waste logistics need to be evaluated, especially on new sites

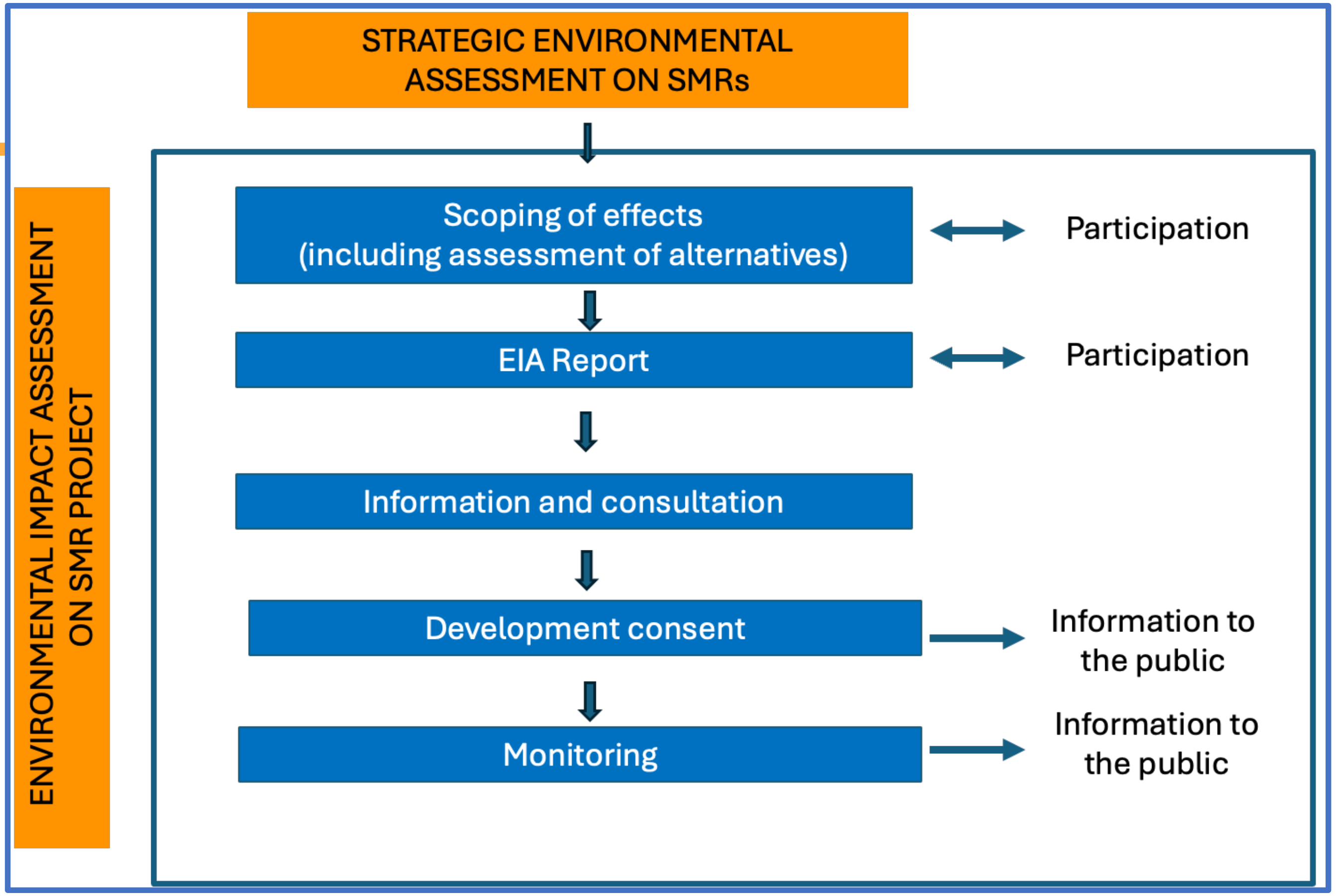
🔁 Alternatives assessment → energy options, SMR designs, and siting choices can be compared

🏭 Diverse deployment settings → integration in industrial and near-residential contexts extends beyond traditional nuclear sites

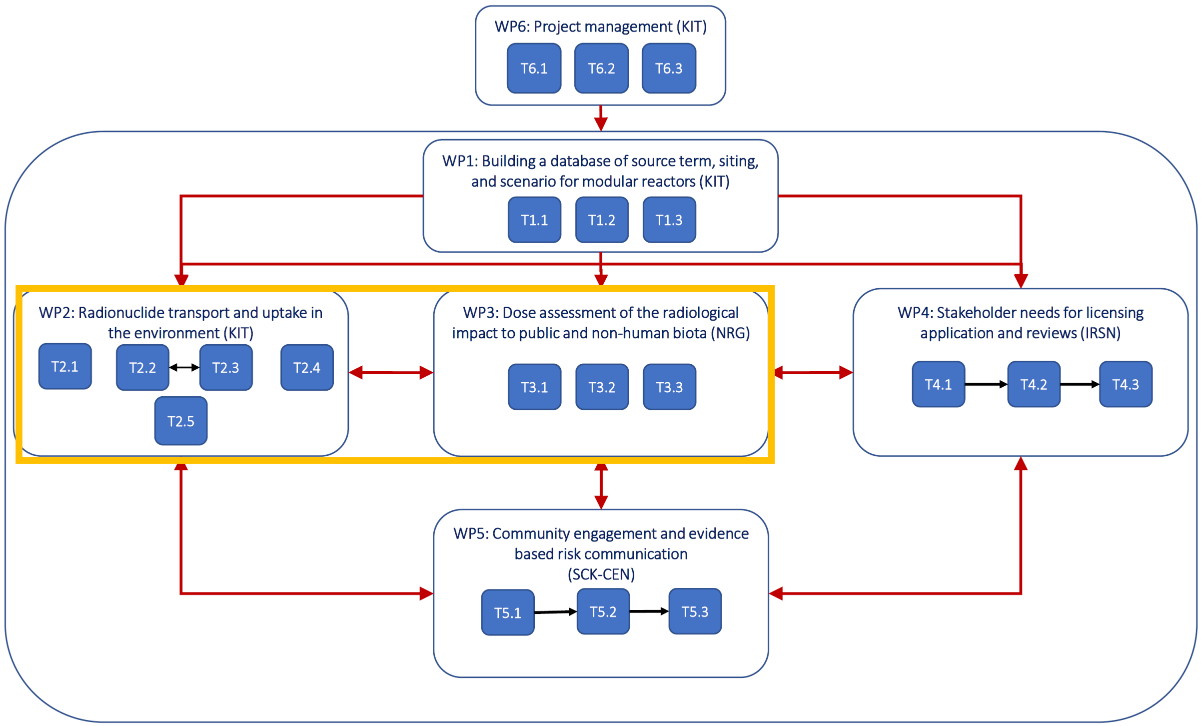
🏗️ Legacy site considerations → non-radiological impacts from previous use need to be assessed

📅 Estimated timeline → completion can be expected in ~12 months

EIA flowchart



WP2 and 3 strongly connected



Radionuclide transport and uptake in the environment (WP2)

Objectives:

- Adaptation and enhancement of state-of-the-art atmospheric and aquatic radionuclide transport and dispersion as well as food chain models
- Evaluation of the modelling for radionuclides so far not considered
- Integrated analyses: A systematic review of the simulation results aiming at drafting an end-users guidance by comparing the performance of the existing and adapted models.

Dose assessment of the radiological impact to public and non-human biota (WP3)

Objectives:

- Perform a dose study to evaluate present dose models for humans and wildlife based on stakeholder needs, and
- identify deficiencies that provide input for a work plan on future development.
- Use the findings from the dose study for a graded approach, and provide recommendations on aspects to be considered in the dose assessment (EIA & EP&R)

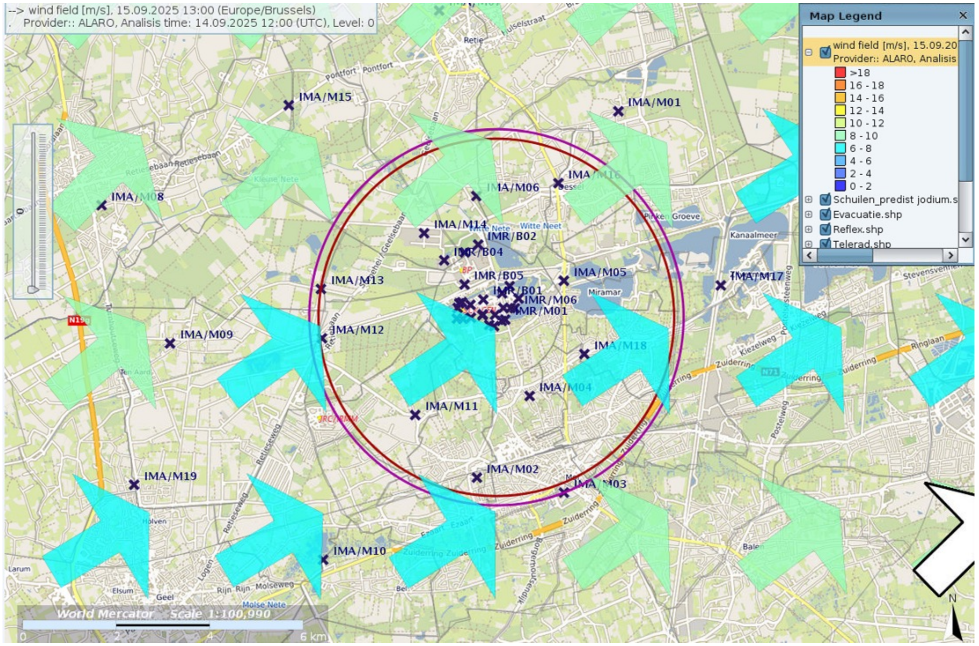
WP1 output = input WP2/WP3

- Very detailed source terms are collected for the selected technologies
  - High resolution in time (about 100 sec steps)
  - Multiple nuclides (about 20+)
- Postprocessing is expected: cluster the time intervals, can all nuclides be used with the models?

- Study locations are selected
  - Urbanised (FI, Vallila, Helsinki)
  - Urbanised (NL, Gelderland), Industrial (NL, Stein, Limburg), and Natura 2000 (NL, Region of North Holland)
- High resolution geo data is collected (files, links to resources)
  - Elevation
  - Building information
  - Landuse

Meteorological data

- SCK CEN: high-resolution numerical weather data (1.3 km/1 hour): AROME from RMI /Alternative: hourly IFS data from ECMWF at 0.1° (the highest available resolution of the operational forecast).
- STUK: historical forecast data from a meteo model covering the whole Scandinavia
  - High resolution in space, very suitable for the local scale calculations
- Long period of meteo data will be aquired (1+ year)



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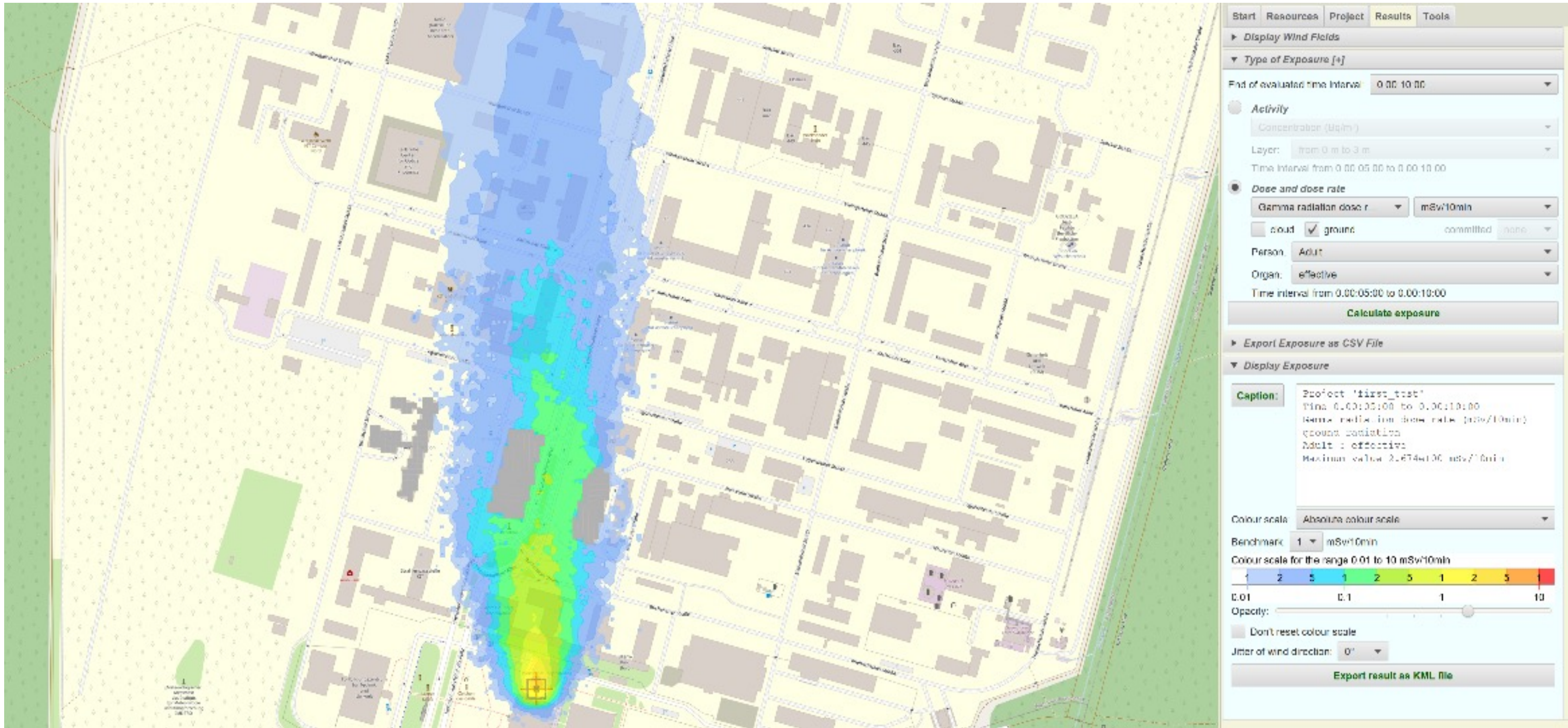
Dispersion models - atmospheric, LASAIR

- LASAIR - high resolution lagrangian particle atmospheric dispersion model for calculations in the urban environments
- The model uses explicit building information to reconstruct local wind field
  - OpenStreetMap as default, alternative sources are possible
  - A plain xml file per building with polygon coordinates and height
- First setup and calculations for a test site at KIT are successful

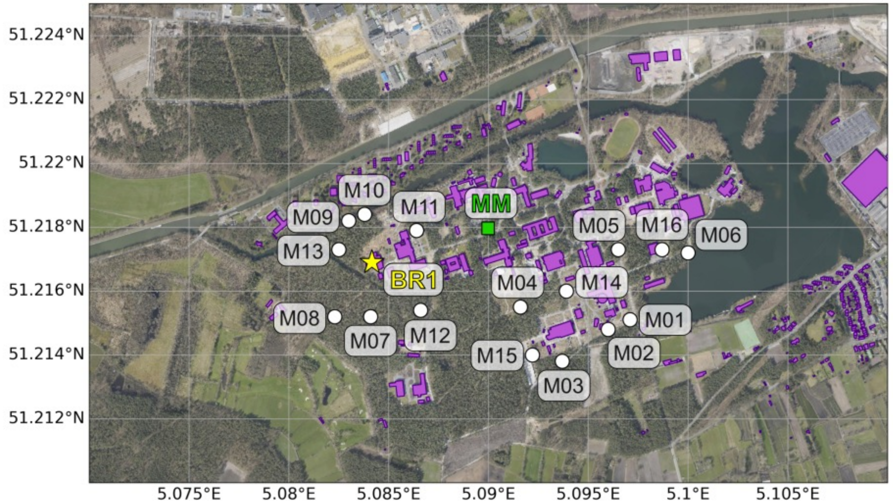
Dispersion models - atmospheric, LASAIR



Dispersion models - atmospheric, FLEXPART

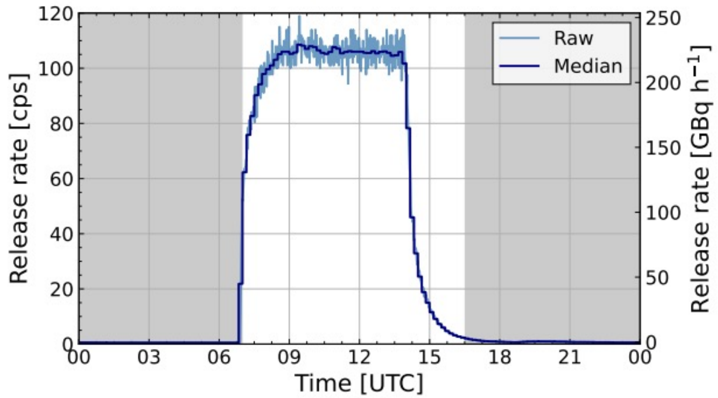
- FLEXPART - lagrangian particle atmospheric dispersion model usable for different scales from local to regional to global
- Elevation is taken from meteo files
- The model does not explicitly need the building info. Possible representation of the buildings by changing mesoscale parameters (roughness)
- Custom landuse - possible if resources allow (e.g. Copernicus data)

Atmospheric impact: can we just apply the models used in the past - dispersion of reactor-released ^{41}Ar on the near range in complex environment: a model intercomparison study using real data



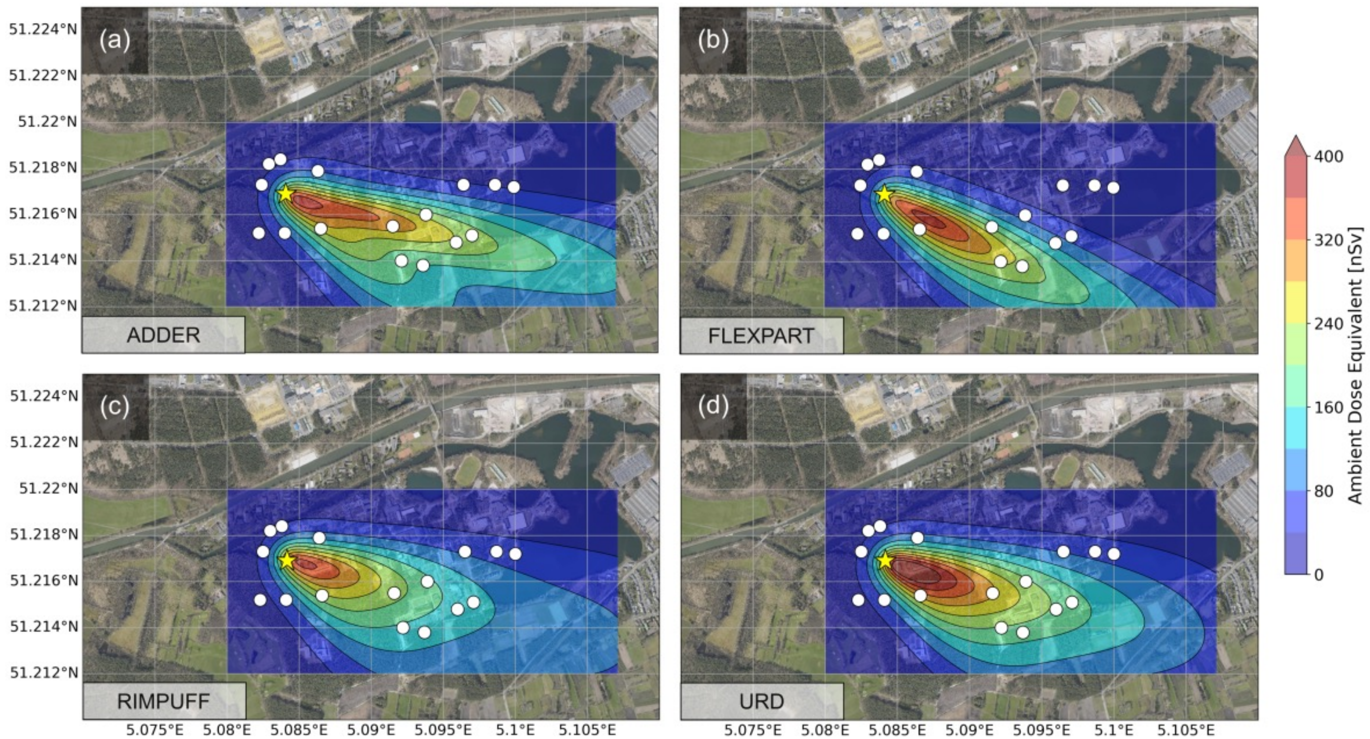
SCK CEN site showing building footprints (purple), BR1 (yellow star), detector locations (white dots) and meteorological mast (green square)

Meteorological data	Atmospheric dispersion model
10' on-site data from weather mast	ADDER (Bi-Gauss), RIMPUFF (Puff), URD (Puff, BLD)
Numerical weather prediction data (ECWF)	FLEXPART (Particle)



Stack release rate of the BR1 for 9 July 2014

Time-integrated ambient dose equivalent is consistent among ADDER, FLEXPART, RIMPUFF and URD



Time-integrated ambient dose equivalent [nSv] for (a) ADDER, (b) FLEXPART, (c) RIMPUFF and (d) URD. Maxima are similar across ADDER (383 nSv), FLEXPART (375 nSv) and RIMPUFF (371 nSv) and around 20% higher for URD (460 nSv). Yellow star: BR1 stack; white dots: detector locations

Lüdemann et al., 2025: "Atmospheric dispersion of reactor-released ^{41}Ar on the near range: a model intercomparison study". Submitted for publication in J HazMat.

Dispersion models - aquatic

- NRG: Dynamic hydraulics and aquatic dispersion models
- ASNR: Box model as a part of SYMBIOSE system
- SCK CEN: Basic model for the preliminary estimates on how the size of a water body would affect the concentrations in water as a consequence of the direct release / atmospheric deposition

- Source term information required:
  - Direct release to water – limited data for SMRs (Scaling, NuScale data)
  - 2D deposition field [Bq/m2] from an atmospheric dispersion run

Dose assessment for the public (NRG)
Source to Receptor Narrative and Model Scenarios

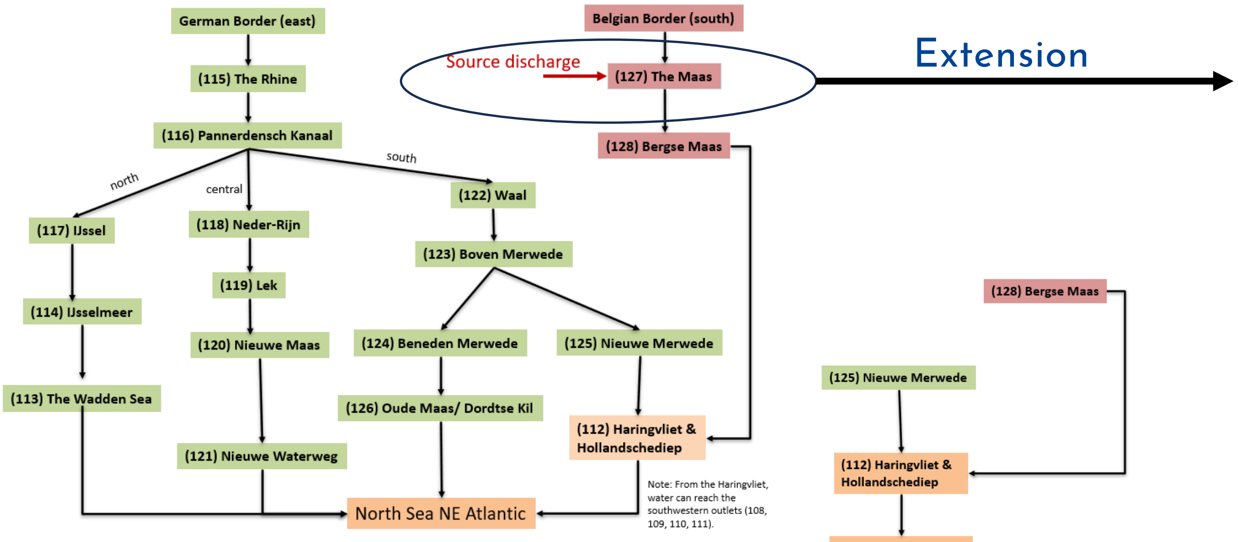
With POSEIDON-R we will track radionuclides from release to human exposure.

- First the source: liquid effluent or soil run-off enters the river
- Transport occurs through river flow and dispersion, with some contaminants binding to suspended sediments.
- Exposure happens when aquatic plants and fish absorb contaminants, eventually reaching people who consume local foods.
- External exposure occurs from contaminated shorelines or sediments, while internal exposure includes ingestion and inhalation of resuspended particles.
- Doses are then calculated.

There will be four scenarios:

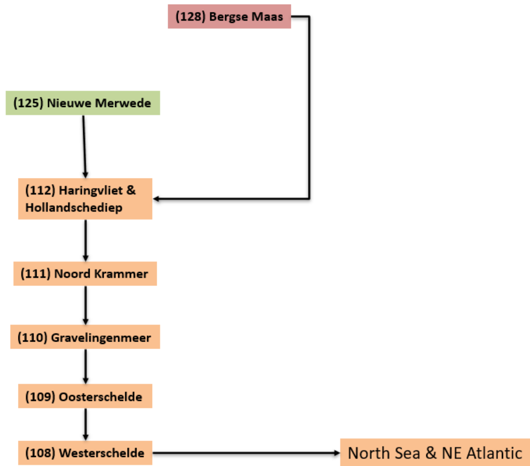
- Baseline with only ambient radioactivity (can also assume 0)
- Routine operations with continuous discharge and long-term build-up
- Design-Basis Accident with a short, high-concentration pulse to test downstream dispersion (e.g. yearly discharge in one week)
- Environmental Stress cases, where drought tests maximum concentration due to low flow and floods test sediment resuspension, increasing inhalation and external exposure risks. (Q10/Q50/Q90 Meuse flows)

Compartmental model



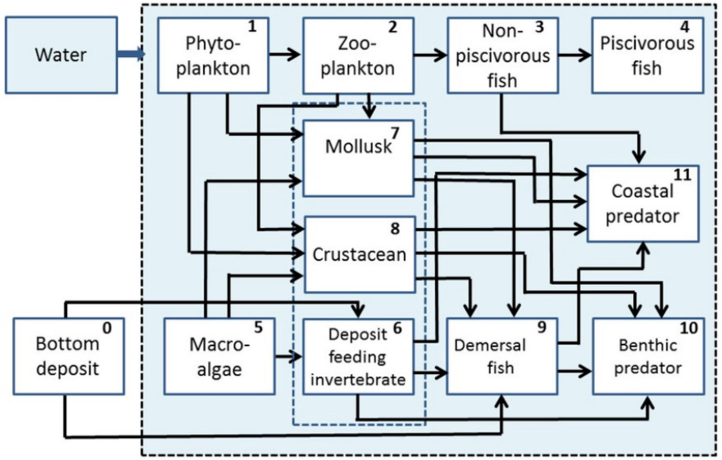
10/20 microcompartments, in the vicinity of the discharge point – To be decided later

To model the water exchanges we will use TELEMAC



Poseidon-R compartmental model

BURN food chain model (marine)

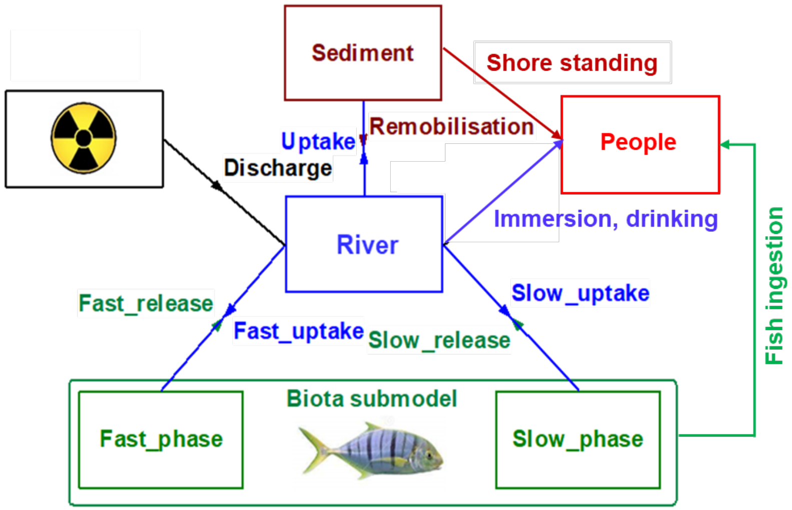


Biota in the Maas, so the model can be used, modifications may be required

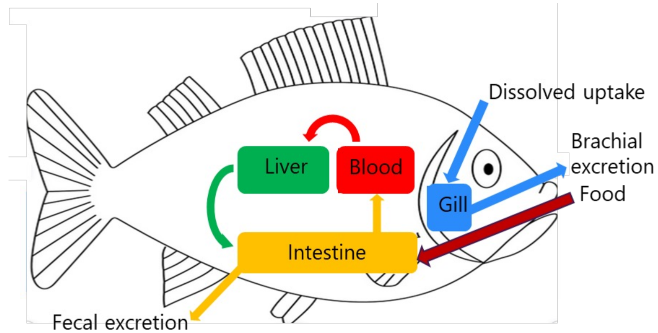
- Phytoplankton, the base of the river's food web: Diatoms, Green algae
- Macrophytes / Macro-algae (e.g. water mosses)
- Zooplankton, seasonally important, feeding on diatoms and green algae.
- Deposit-feeding invertebrates, e.g. Worms
- Mollusks: Snails, Freshwater mussels
- Crustaceans: Freshwater shrimp, Crayfish
- Non-piscivorous fish: Roach, Bream,, Chub, Barbel
- Piscivorous fish: Pike, Perch, Zander
- Migratory species: Atlantic salmon, European eel
- Demersal fish: Bottom-oriented species inhabiting deeper or slower zones
- Benthic predators: Large predatory invertebrates (dragonfly larvae, beetle larvae)
- Bottom-feeding predatory fish

Dose assessment for non-human biota (SCK CEN)
Foodweb model for aquatic biota

- Impact of potential liquid releases (smaller river systems, specific locations, specific radionuclides, …)
- Adaptation of D-DAT model and parameterization for SMR radionuclide impacts (including tritium and other radionuclides) in an aquatic foodweb



Schematic of the existing D-DAT model



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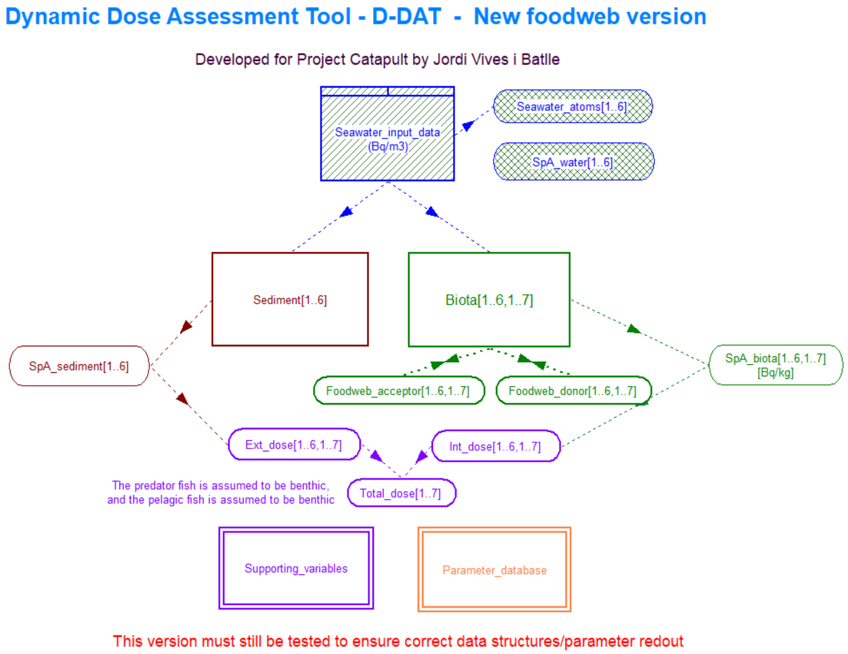
Foodweb model for aquatic biota

- Approach based on ingestion and assimilation rates for the fish, crustaceans, molluscs, algae and plankton
- The model is first coded in ModelMaker
- To combine it with dynamic dispersion modelling: an advanced Python version will be developed that will become the biota assessment tool for this project
- Model parameterized with detailed literature review data
- Sensitivity analyses: foodweb on/off, chemical form tritium and release characteristics (source term versus size of river) – Direct release or release via deposition



Symbiose sensitivity analyses by ASNR

SYMBIOSE → Uncertainties due to scenario → Uncertainties due to parameter values

Case Studies & Modelling

Case Studies
WP1, WP2, WP3

- Provide key modelling elements to balance issues at stake

Foods Concentrations
WP2

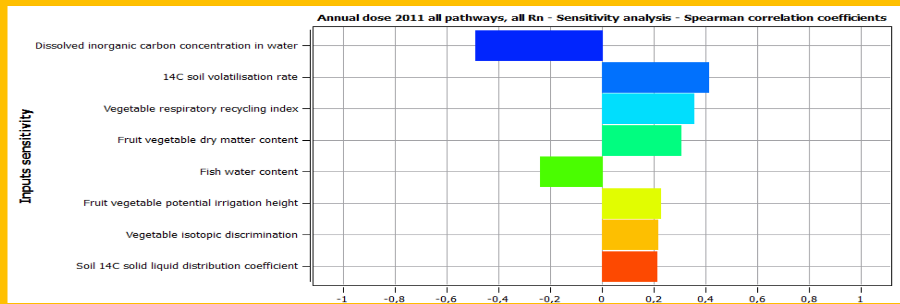
- Concentrations in foods vs Maximum Permitted Levels

Dose Assessment
WP3

- To identify priority requirements regarding doses

***SYMBIOSE** Sensitive analyses*

- To propagate parametric and scenario uncertainties
- All impacts (workers of nearby industries, public, non-human biota), and all exposure pathways will be compared



Spearman correlation coefficients

Evaluation of dose results, identification of deficiencies and specification of model needs for future developments

- Findings from the dose calculations will be analyzed and compared in a systematic manner considering results from the **different models, site locations, exposure conditions and their variations.**
- On the basis of WP4, the findings from the dose assessment will be used for **prioritization**.
- The prioritization will feed into **a graded approach**, which will provide recommendations - with differentiation to site location and reactor type - on the aspects (scenarios, pathways, radionuclides, etc.) that are to be considered in the dose assessment.
- **Deficiencies in EIA and EP&R** found will be used to **propose a work plan** for future developments.