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The Source term and Siting CATAPULT database

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PIANOFORTE EUROPEAN PARTNERSHIP FOR RADIATION PROTECTION RESEARCH

CATAPULT

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Co-funded by the European Union

The Database

- Providing the necessary data for dose impact and the environmental transport studies

- **Three generic modular reactors**
  - Water-cooled SMR (submerged containment, 60 Mwe)
  - Lead-cooled ALFRED-like (125 MWe)
  - Gas-cooled HTR-like (200 Mwth)

- Characteristics of **four selected sites**

Database of the Source Terms

- **No extensive integral evaluations** of ST planned in CATAPULT → focus on the project on EIA and EP&R modelling and Social Sciences and Humanities Activities

- The **database based on first order estimates** (nominal and accident conditions)
  - Evaluation of fuel inventories
  - Available analyses by means integral codes
  - Application of release fractions to the initial inventory (open literature, reports)

- The database is a **living** source of information through the project

Water-cooled advanced modular reactor Source Term

- Fuel inventories at different burn-up (20, 30, 40, 50, and 60 MWd/kgU) computed by CASMO (developed by Studsvik)

- **Nominal conditions** (atmospheric release)

- **Severe accidents** (atmospheric release)
  - Derived by large uncertainty analysis on PWR KONVOI (MBLOCA) – 5 STs
  - Directly evaluated for a generic SMR (LOCA+SBO) by means of the ASTEC code (developed by ASNR) – 2 STs

- **Effluent release**

Water-cooled advanced modular reactor
Atmospheric release in Nominal Condition

- Release fractions from 100 Mwe PWR-type SMR applied to the fuel inventory at 20 MWd/kgU (considered representative of a core load at the equilibrium)

Nuclide	Release fraction	Source Term [Bq/y]	Nuclide	Release fraction	Source Term [Bq/y]
Kr-85m	3.30E-04	1.964E+13	**Te-132**	3.30E-10	8.910E+07
Xe-133	3.30E-04	1.317E+14	**Ba-139**	8.26E-10	2.974E+08
I-131	3.30E-04	9.176E+08	**Ba-140**	8.26E-10	2.874E+08
I-132	4.96E-09	1.366E+09	**Sr-90**	8.27E-10	1.464E+07
I-133	4.95E-09	1.970E+09	**Mo-99**	8.25E-10	2.978E+08
I-134	4.95E-09	2.237E+09	**Ru-106**	3.29E-10	2.346E+07
I-135	4.95E-09	1.866E+09	**Rh-105**	3.31E-10	5.097E+07
Rb-88	4.95E-09	2.046E+05	**Y-90**	8.27E-10	1.480E+07
Cs-134	8.25E-10	1.450E+07	**Y-91**	8.25E-10	2.285E+08
Cs-137	8.24E-10	1.774E+07			

P. M. Udiyani et al 2018 J. Phys.: Conf. Ser. **962** 012035

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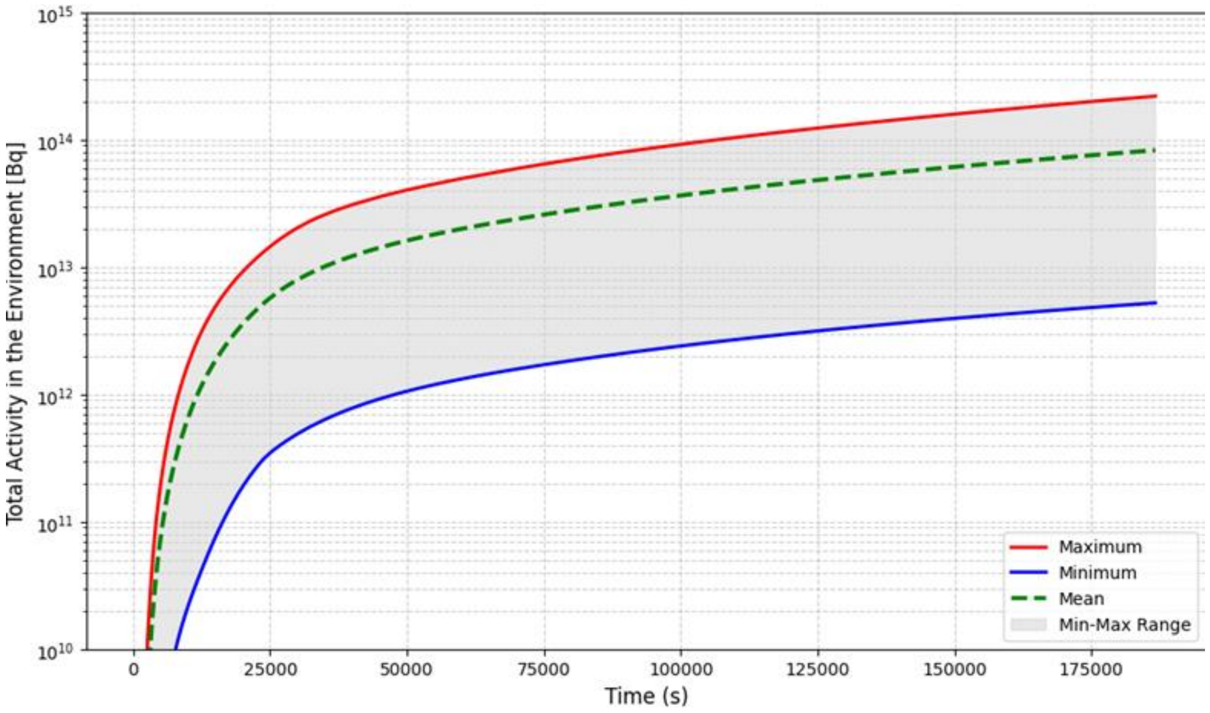
Water-cooled advanced modular reactor Atmospheric release in Severe accident conditions

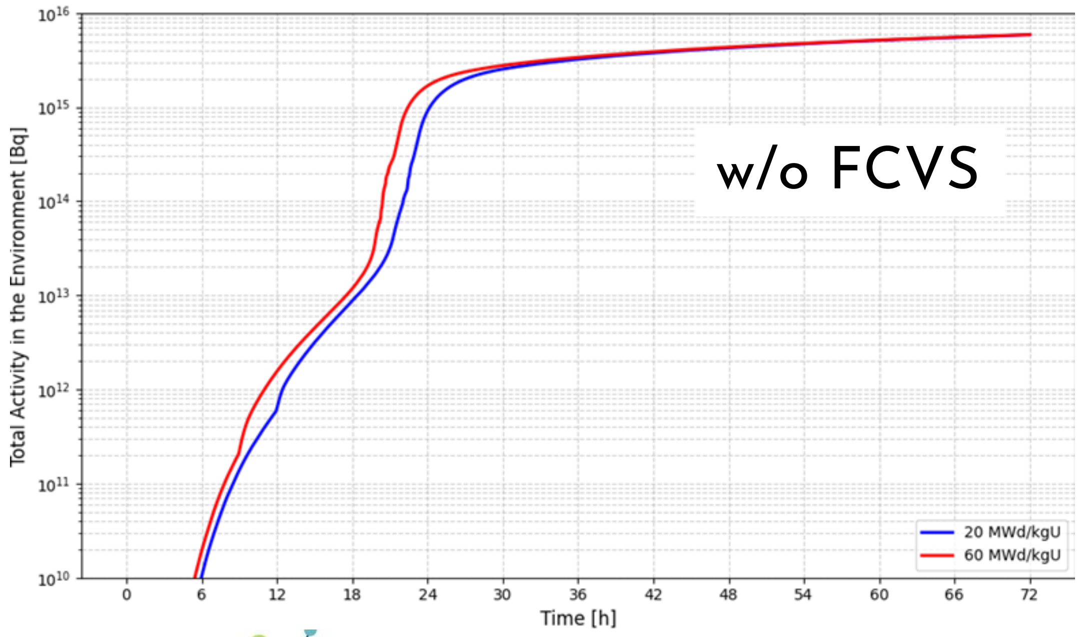
- 600 postulated MBLOCAs in a generic PWR KONVOI-1300 NPP computed by ASTEC

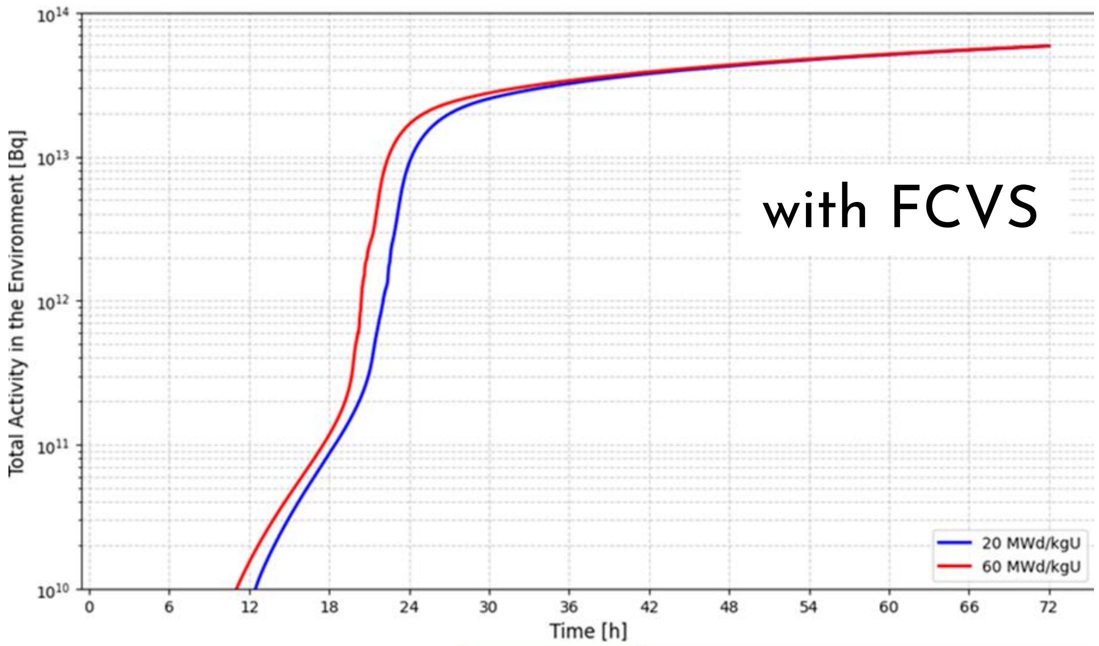
- **Max, Min, Mean** release rates computed and applied to the fuel inventory at **20, 40, and 60 MWd/kgU**



Water-cooled advanced modular reactor Atmospheric release in Severe accident conditions

- ASTEC analyses for a generic SMR (SBLOCA+SBO) with and w/o FCVS for fuel inventory at 20 and 60 MWd/kgU
- Source term for Cs-134, Cs-137, I-131, I-132, I-133, Kr-85, Xe-133, Xs-133M, Xe-135, and Ru-103





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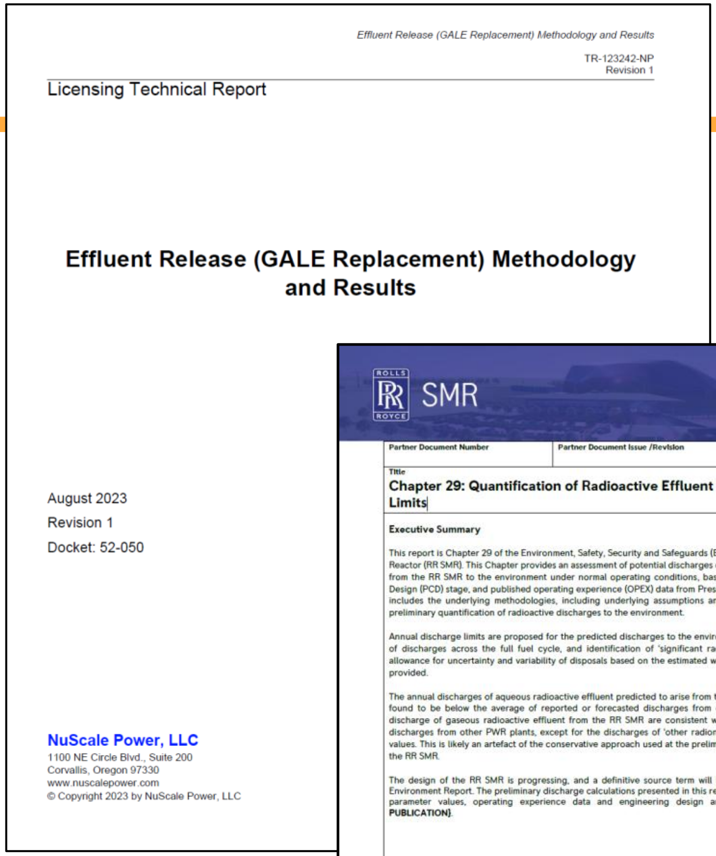
Water-cooled advanced modular reactor Effluent release

- https://www.nrc.gov/docs/ML2330/ML23304A359.pdf
- https://gda.rolls-royce-smr.com/assets/documents/documents/revised---rr-smr-e3s-case-chapter-29--quantification-of-radioactive-effluent-discharges-and-proposed-limits-gda-website-jm-redactions-check-(002)_ssx.pdf


Effluent Release (GALE Replacement) Methodology and Results

TR-123242-NP
Revision 1

Licensing Technical Report

Effluent Release (GALE Replacement) Methodology and Results

August 2023
Revision 1
Docket: 52-050

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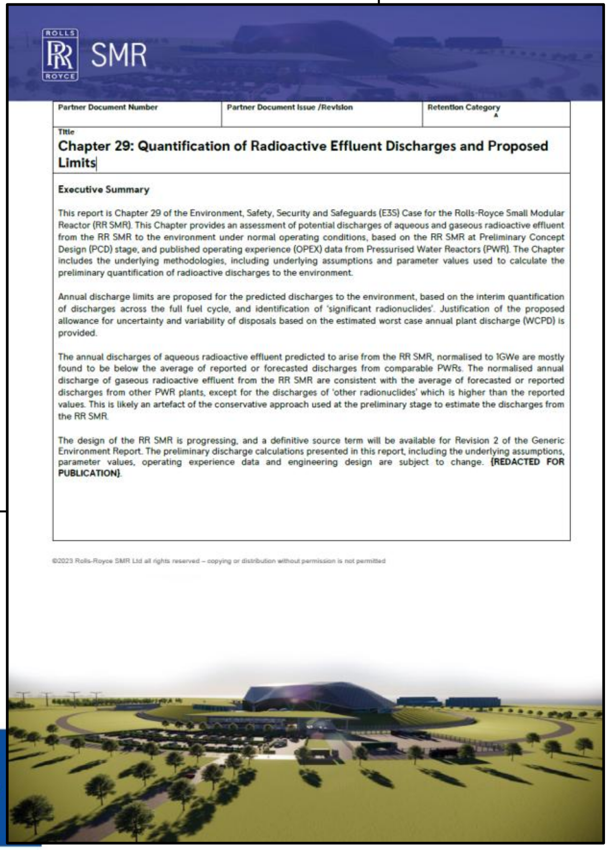

SMR

Partner Document Number	Partner Document Issue /Revision	Retention Category
		A

Title
Chapter 29: Quantification of Radioactive Effluent Discharges and Proposed Limits

Executive Summary

This report is Chapter 29 of the Environment, Safety, Security and Safeguards (E3S) Case for the Rolls-Royce Small Modular Reactor (RR SMR). This Chapter provides an assessment of potential discharges of aqueous and gaseous radioactive effluent from the RR SMR to the environment under normal operating conditions, based on the RR SMR at Preliminary Concept Design (PCD) stage, and published operating experience (OPEX) data from Pressurised Water Reactors (PWR). The Chapter includes the underlying methodologies, including underlying assumptions and parameter values used to calculate the preliminary quantification of radioactive discharges to the environment.

Annual discharge limits are proposed for the predicted discharges to the environment, based on the interim quantification of discharges across the full fuel cycle, and identification of 'significant radionuclides'. Justification of the proposed allowance for uncertainty and variability of disposals based on the estimated worst case annual plant discharge (WCPD) is provided.

The annual discharges of aqueous radioactive effluent predicted to arise from the RR SMR, normalised to 1GWe are mostly found to be below the average of reported or forecasted discharges from comparable PWRs. The normalised annual discharge of gaseous radioactive effluent from the RR SMR are consistent with the average of forecasted or reported discharges from other PWR plants, except for the discharges of 'other radionuclides' which is higher than the reported values. This is likely an artefact of the conservative approach used at the preliminary stage to estimate the discharges from the RR SMR.

The design of the RR SMR is progressing, and a definitive source term will be available for Revision 2 of the Generic Environment Report. The preliminary discharge calculations presented in this report, including the underlying assumptions, parameter values, operating experience data and engineering design are subject to change. **{REDACTED FOR PUBLICATION}**.

(courtesy of M. Constantin, RATEN)

Lead-cooled advanced modular reactor

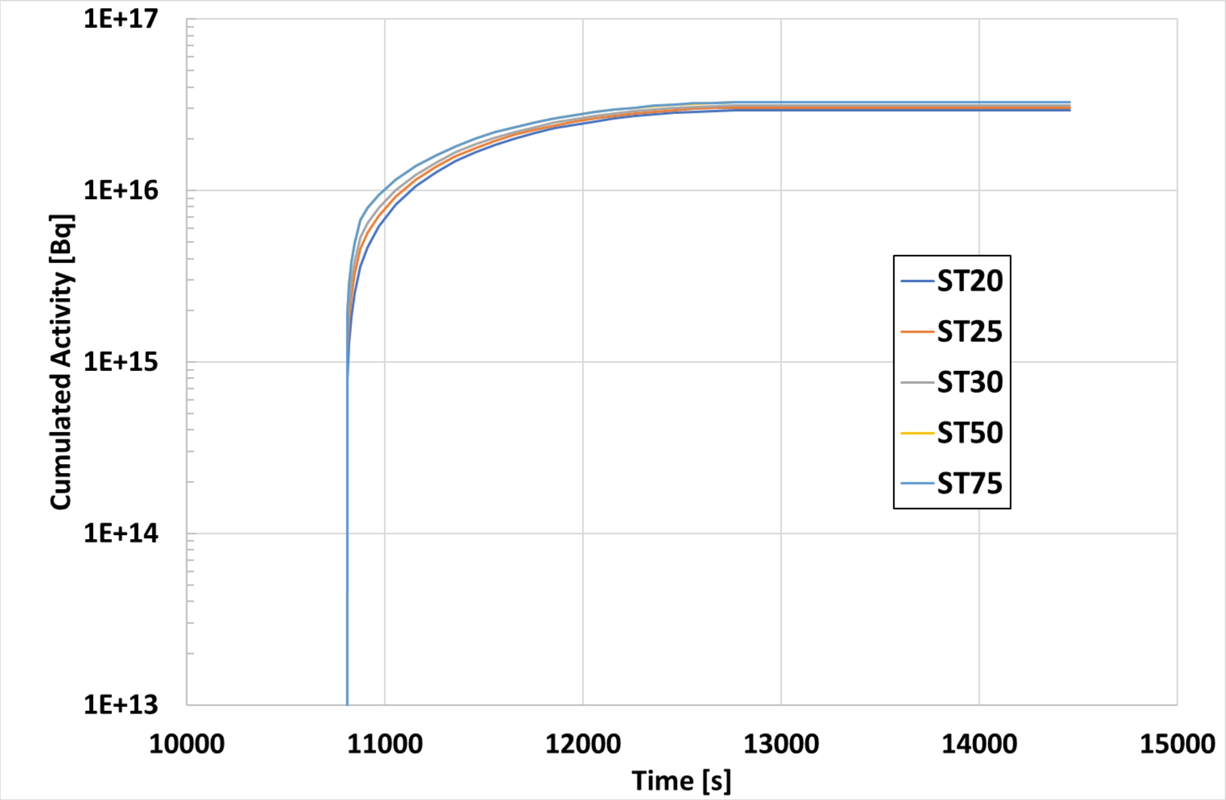
- ALFRED demonstrator
- Fuel inventories at different burn-up (20, 25, 30, 50, 75 MWd/kgU) computed by SERPENT
- Source terms for severe accident initiated by a flow blockage for a fuel assembly with local hot spots and cladding failure
  - ASTEC + Fission product transport method + release from the fuel rods, NUREG-1465

(courtesy of M. Constantin, RATEN)

Lead-cooled advanced modular reactor Atmospheric release in Severe accident conditions

- **Source term for fuel inventory at 20, 25, 30, 50, 75 MWd/kgU**

- Source term for Kr-78, Kr-85, Xe-133, Xe-134, Xe-135, Xe-136, Cs-134, Cs-135, Cs-136, Cs-137, Sr-89, Sr-90, I-129, I-130, I-131, I-135, Rb-86, Rb-87, Se-79, Sb-124, Sb-125, Sb-126, Te-123, Te-127, Te-128, Te-129, Te-130, Te-132



Gas-cooled advanced modular reactor

- Derived by a single 250 MWth pebble bed HTGR module with 700°C reactor coolant outlet temperature (INL) – fuel inventory rescaled by power
- Fuel inventory: TRIstructural ISOtropic (TRISO) fuel in cylindrical compacts, stacked in prismatic graphite blocks*
- Source terms for
  - Nominal condition
  - Severe accidents (three scenarios considered)

*Lowry, P. (October 2012). Scoping analysis of source term and functional containment. Idaho National Laboratory, Idaho, USA: INL/EXT-11-24034 Revision 2.

Gas-cooled advanced modular reactor Atmospheric release in Nominal Condition

- 50% and 95% upper bound values of the attenuation factors

- Uncertainty distribution for each safety barrier taken into account, e.g., heavy metal contamination, SiC coating defects, fuel particle kernel, graphite, and building

Nuclide	Source term (50%) [Bq]	Source term (95%) [Bq]
Xe-133	4.470E+11	4.470E+12
Kr-85	2.344E+09	2.344E+10
Kr-88	2.282E+11	2.282E+12
I-131	2.466E+11	2.466E+12
I-133	4.440E+11	4.440E+12
Te-132	3.345E+11	3.345E+12
Cs-137	4.168E+09	2.084E+12
Cs-134	4.689E+09	2.344E+12
Sr-90	5.210E+11	6.946E+12
Ag-110m	8.658E+12	8.658E+13
Ag-111	9.102E+14	9.102E+15
Sb-125	2.898E+08	2.898E+11
Ru-103	4.440E+09	1.480E+11
Ce-144	2.874E+09	9.581E+10
La-140	4.026E+09	1.342E+11
Pu-239	5.742E+04	5.742E+06

Lowry, P. (October 2012). Scoping analysis of source term and functional containment. Idaho National Laboratory, Idaho, USA: INL/EXT-11-24034 Revision 2.

Gas-cooled advanced modular reactor Atmospheric release in Severe accident Condition

- Scenario - loss of the He forced cooling
  - loss of heat transport and shutdown cooling
  - sudden He depressurization in the He pressure boundary
  - venting the reactor building

Short-term release [Bq]		Long-term release [Bq]	
50% confidence	95% confidence	50% confidence	95% confidence
2.979E+12	4.673E+14	1.111E+13	1.616E+15

- Short-term release assumed lasting many hours
- Long-term release: the core heat-up is postulated to heat-up for 50 hours, followed by the release of fission products lasting for the next 40 hours

Lowry, P. (October 2012). Scoping analysis of source term and functional containment. Idaho National Laboratory, Idaho, USA: INL/EXT-11-24034 Revision 2.

Gas-cooled advanced modular reactor Atmospheric release in Severe accident Condition

- Scenario - steam generator tube break followed by water ingress
  - reactor trip
  - loss of heat transport and shutdown cooling
  - water ingress
  - isolation of both the main steam and feedwater lines
  - over-pressurization of the He pressure boundary
  - venting the reactor building

Short-term release [Bq]		Long-term release [Bq]	
50% confidence	95% confidence	50% confidence	95% confidence
2.308E+14	9.279E+14	1.177E+13	9.729E+14

Lowry, P. (October 2012). Scoping analysis of source term and functional containment. Idaho National Laboratory, Idaho, USA: INL/EXT-11-24034 Revision 2.

Gas-cooled advanced modular reactor Atmospheric release in Severe accident Condition

- Scenario - very conservative (derived by former studies on the High Temperature engineering Test Reactor, HTTR)
- Source term of Xe-133, Kr-85, Kr-88, I-131, I-133, Te-132, Cs-137, Cs-134, Sr-90, Ag-110m, Ag-111, Sb-125, Ru-103, Ce-144, La-140

Nuclides group (elements)	Release fraction (%)
Noble Gases (Xe, Kr)	30
Iodine (I)	15
Cesium and Strontium (Cs, Te, Sr, Ba, Rb)	15
Antimony (Sb)	1.2
Molybdenum (Mo, Ru, Rh, Tc)	2.8
Cerium (Ce)	0.3
Lanthanides (La, Pr, Sm, Eu, Nb, Y, Nd, Zr, Pm)	0.1

Hummel, D., Chouhan, S., Lebel, L., & Morreale, A. (2020). Radiation dose consequences of postulated limiting accidents in small. Annals of Nuclear Energy 137.

(courtesy of A. Tacu, NRG Pallas, and P. Roivainen, STUK)

Typical SMR Site Characteristics

- Preferably located 100 m from sea/coast or adjacent to suitable surface water (river, reservoir) for cooling access
- Flat terrain with gentle slopes, outside flood zones and seismic faults
- Not located on protected habitat, aquifer recharge zones, wetlands, or contiguous to dense population
- Good access to infrastructure: roads, rail, transmission lines, and low-risk surrounding industrial sites

GDA Step 2 of the Rolls-Royce SMR: fundamental assessment full report - GOV.UK

Geographical Considerations in Site Selection for Small Modular Reactors in Saskatchewan

(courtesy of A. Tacu, NRG Pallas, and P. Roivainen, STUK)

Database of the Sites

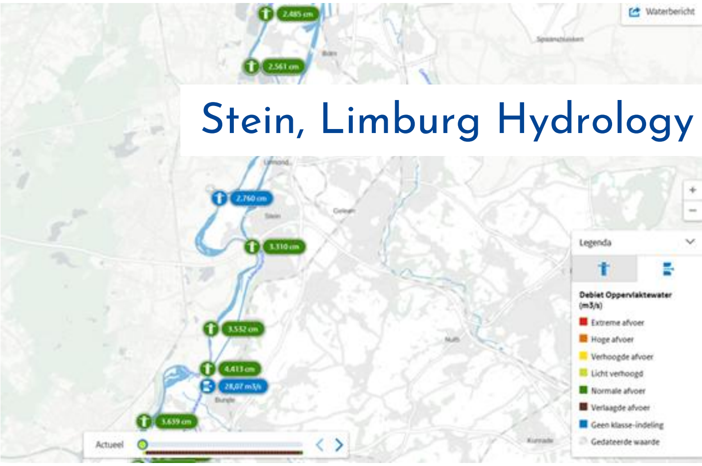
- Four sites
  - **Industrial site** next to heavy/chemical industry (Stein, Limburg, Netherlands)
  - **Urbanized site** - close to both urban and industrial zones (Arnhem, Gelderland, Netherlands)
  - **Natura2000 site** - Petten (Netherlands)
  - **Urbanized site** for district heating (Helsinki, Finland)

- Quite detailed and extensive set of information sources (websites, maps, tables) has been collected and implemented in the database

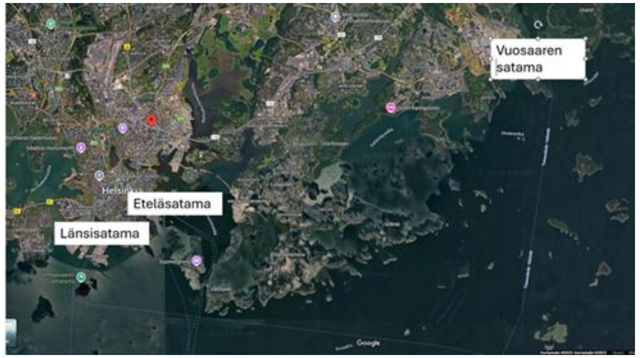
(courtesy of A. Tacu, NRG Pallas, and P. Roivainen, STUK)

Database of siting: status

- Information collected related to
  - Population
  - Buildings
  - Geology
  - Hydrology
  - Ecology, flora, fauna
  - Maps, e.g., LiDAR datasets of the City of Helsinki
  - Marin traffic
  - Risks



Marine Traffic in the Helsinki ports



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Summary and Outlook

- The CATAPULT database of source term and siting has been assessed and going to be employed for the planned dose impact and the environmental transport studies
- The database is fully documented
- The database is a **living** document, namely under continuous extension, e.g.:
  - ^{3}H and ^{14}C release (UNSCEAR 2024 Report, United Nations, 2025)
  - Exploitation is going on → working teams on environmental science, radiation dosimetry, and nuclear operation and regulatory compliance (cross-fertilization!)
  - Source term in nominal condition in a generic Lead-cooled reactor
  - Effluent release in Gas- and Lead-cooled reactors

Co-funded by the European Union