NKS STATUS
Source **T**erm **A**nd **T**iming **U**ncertainty in **S**evere accidents

Sergey Galushin

Anders Riber Marklund

Vysus Sweden AB, Nuclear Safety & Licensing

NKS-STATUS – Source terms

NRC Definition

- “*Types and amounts of radioactive or hazardous material released to the environment following an accident.*”
  - In this project we also consider timing of onset of major release.

Some observations motivating this study

- Differences in point of view regarding source terms (somewhat exaggerated):
  - Emergency responders: “Accidents either end well or not. For the latter case, we more or less assume the source term of the plant and focus on the question of when.”
  - Analysts: “There are tenths of thousands of different accident sequences for each plant – all leading to different source terms with almost unknown uncertainties or conservatisms.”

- Reluctancy to share source term estimates in real case (Fukushima) – perhaps due to the above.

=> Can we shine some light on the uncertainties and increase understanding of why source term estimates differ?

NKS-STATUS – Project background

- Assessment of the source terms related to severe accident scenarios is typically performed with integral plant response codes, such as MAAP, MELCOR or ASTEC. These assessments are subject to uncertainty in the accident scenarios (aleatory) and in modeling of phenomena (epistemic).

- Typically, source term assessments are performed for a limited set of accident scenarios, using point-estimate values of epistemic uncertain parameters (user defined sensitivity coefficients in the models, and modelling parameters) in the codes.

- Furthermore, such analyses typically do not consider the effect of epistemic uncertainty on interactions between physical phenomena and transient accident scenarios, i.e. when physical phenomena (and associated epistemic uncertainty) can significantly affect the course of the accident progression.

NKS-STATUS – Project Goal

- The main goal of the NKS-STATUS project is to generate a body of knowledge regarding the uncertainty in the magnitude of fission products released to the environment in case of an accident in a Nordic nuclear power plant, as well as provide valuable insights into the effect of different types of uncertainty on source term predictions, which can be used in PSA and emergency planning.

- The project includes (*Phase 1 activities*):
  - *review of the safety design of Swedish and Finnish BWR designs;*
  - *review of the PSA and identification of the risk significant scenarios to be considered in the study;*
  - *identification of epistemic modelling parameters that can have significant effect on the magnitude and timing of fission products release to the environment for the considered scenarios;*
  - *best estimate and bounding assessments of combinations of selected scenarios and parameters;*
  - analysis of the sensitivity and uncertainty in source term predictions.

The NKS-STATUS project started in January 2021 and is planned for 3 years.

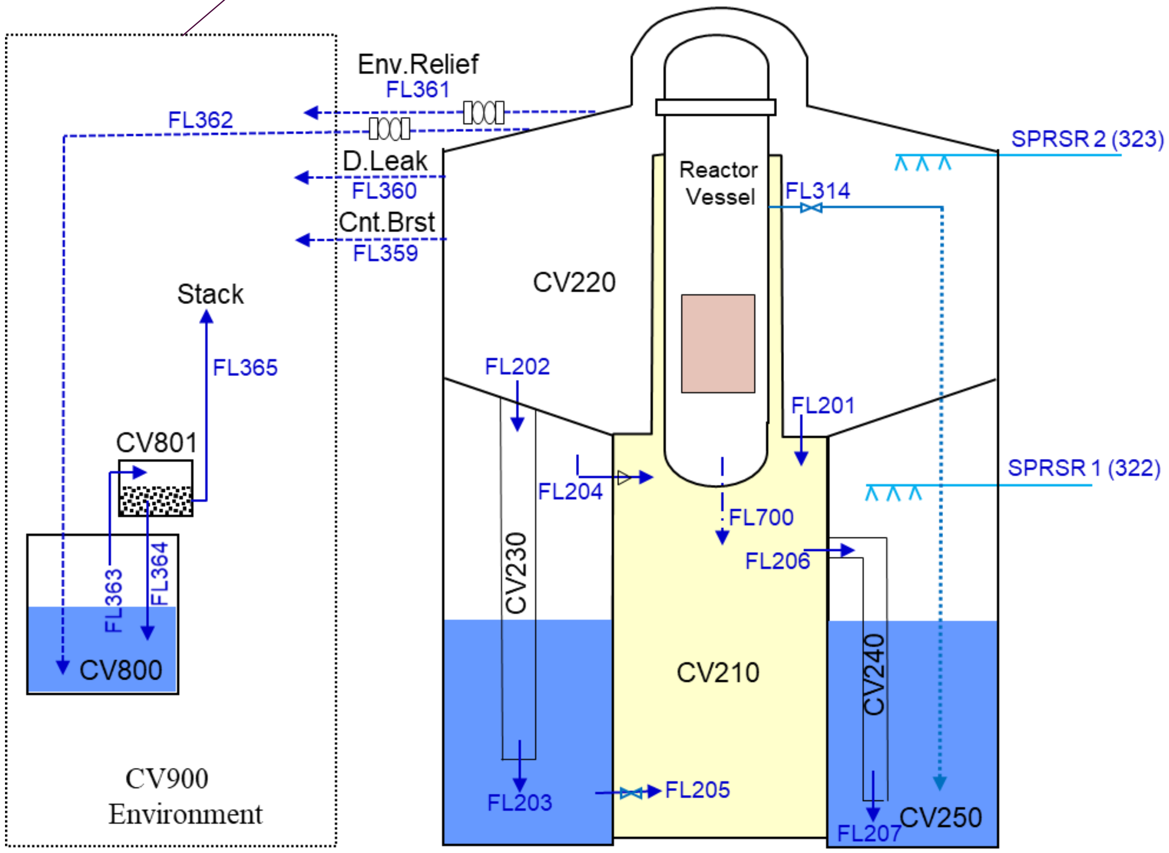
For Vysus Group, the work is supported both by NKS, SSM and internal funds.

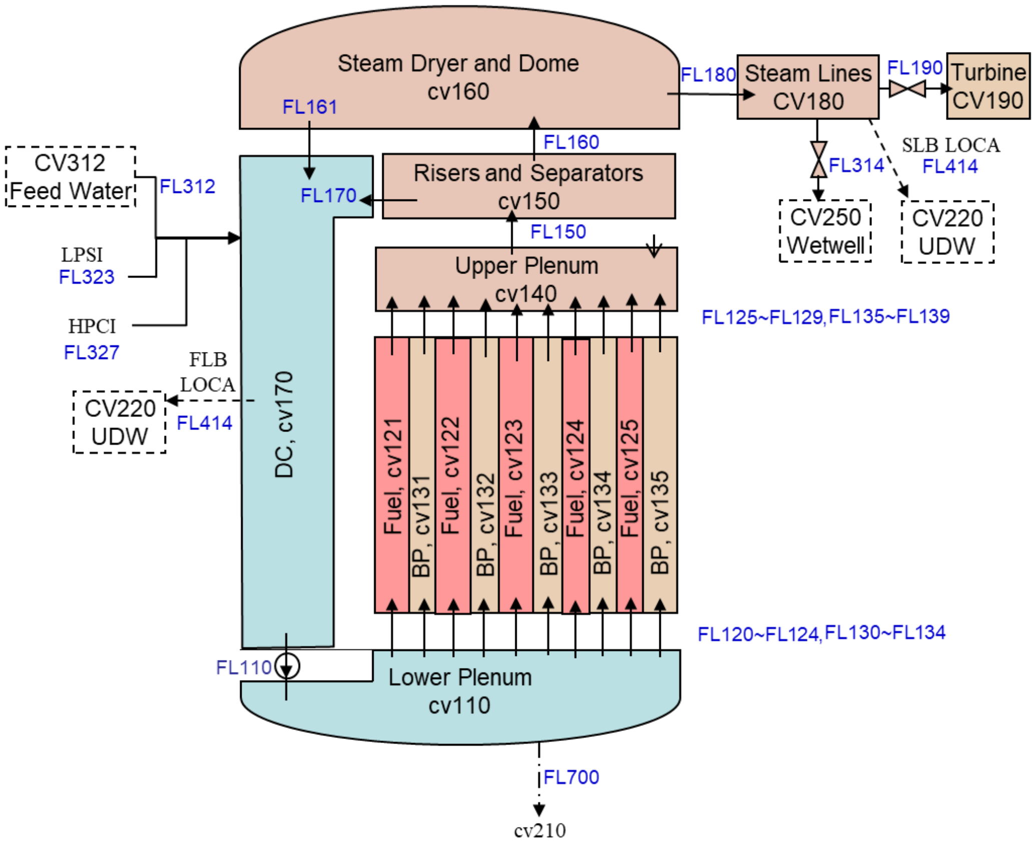
NKS-STATUS – Participating organizations

- Vysus Sweden AB, Sweden (VG), Project coordinator
- Technical Research Centre of Finland, Finland (VTT)
- Swedish Radiation Safety Authority, Sweden (SSM)
- Royal Institute of Technology, Sweden (KTH)
- Norwegian Radiation and Nuclear Safety Authority, Norway (DSA)

NKS-STATUS – Nordic Boiling Water Reactor in MELCOR

Multi-venturi scrubber system (MVSS) used in Swedish plant configuration.



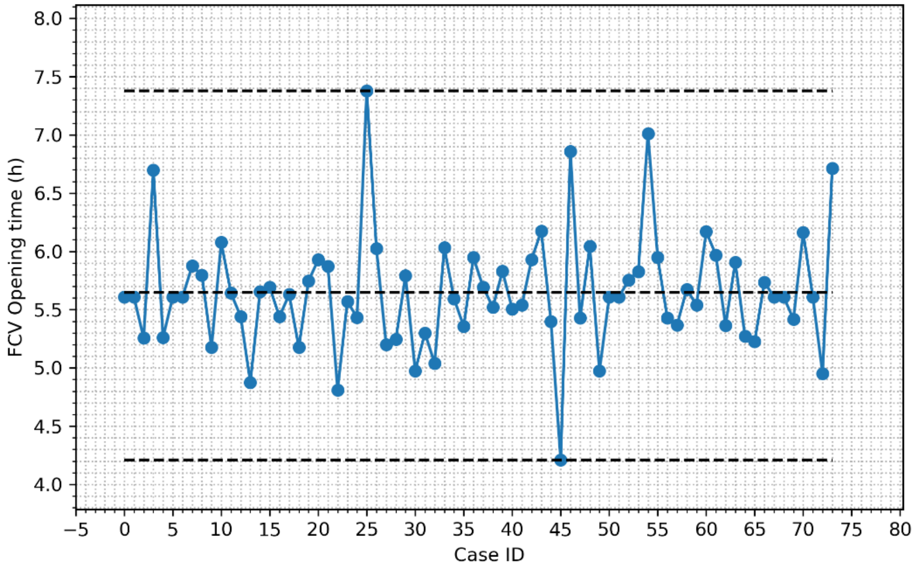


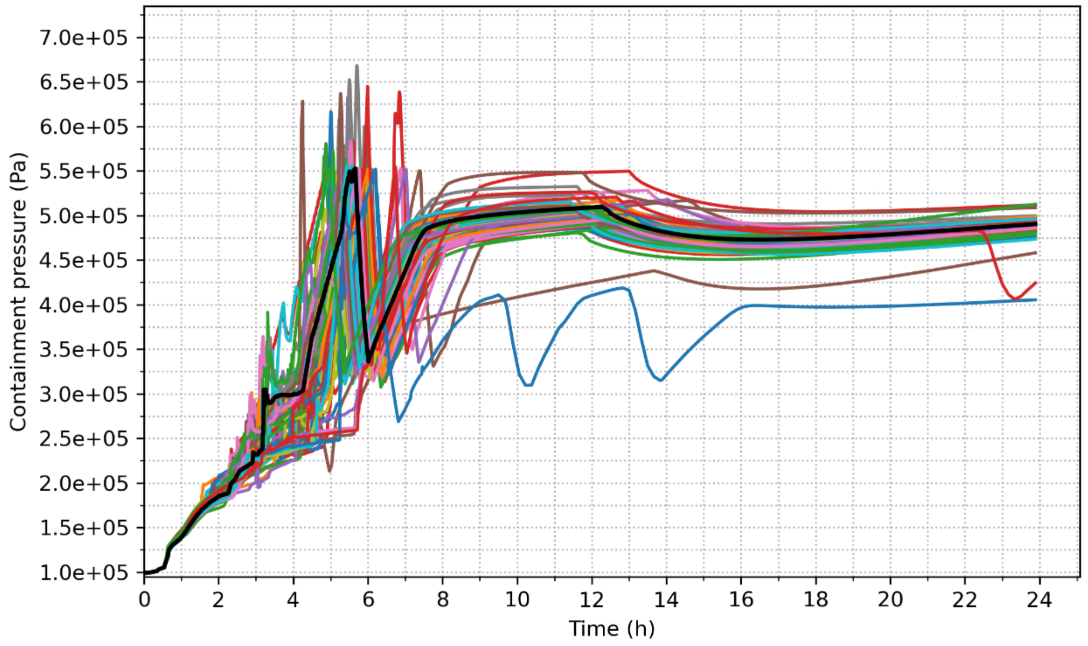
Bounding results (Unmitigated SBO, FP release via MVSS)

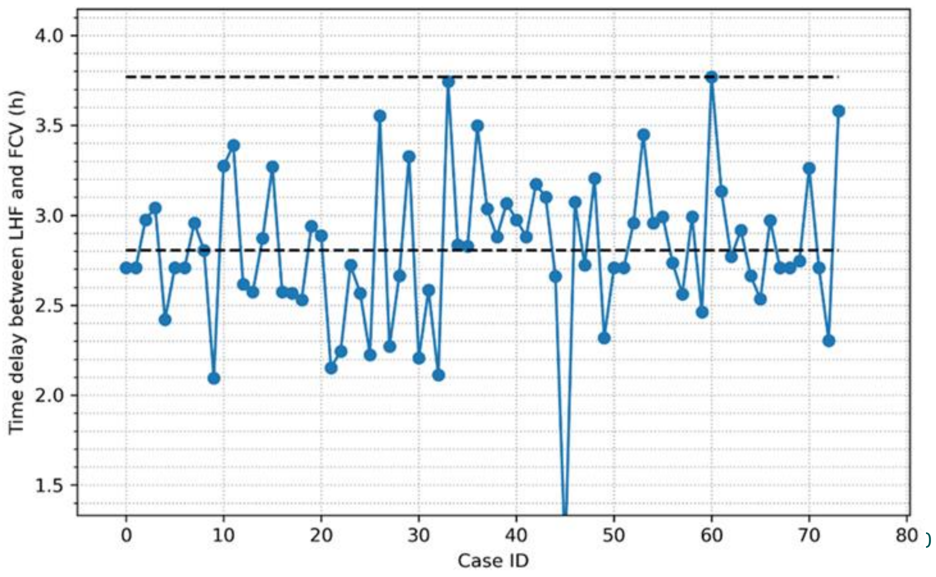
Containment pressure trend and MVSS opening time for 74 MELCOR simulations considering BE, max/min values of MELCOR code modelling parameters identified in Task 3.

- In most of the cases MVSS opens ~20000 sec (5.5 hours) after initiating event.
- The earliest time for MVSS opening ~15000 sec (4.2 hours) after initiating event.
- In all scenarios MVSS opens ~1.5-3.7 hours after vessel lower head failure.

Case 0 – is the reference (best estimate) case (black curve).



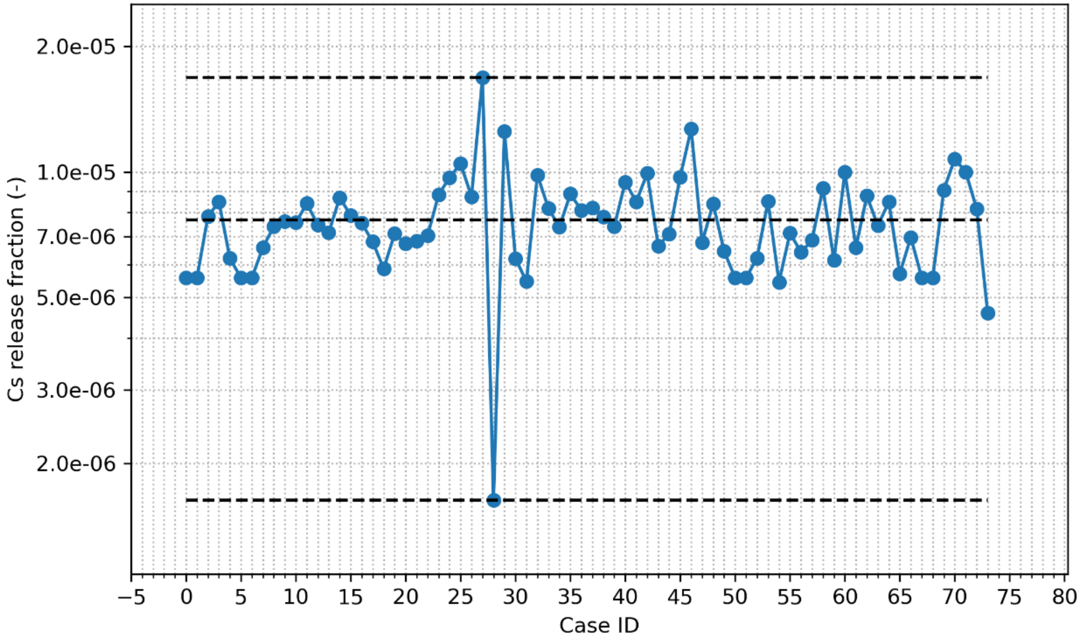




Bounding results (FP release via MVSS in case of SBO/LB-LOCA)

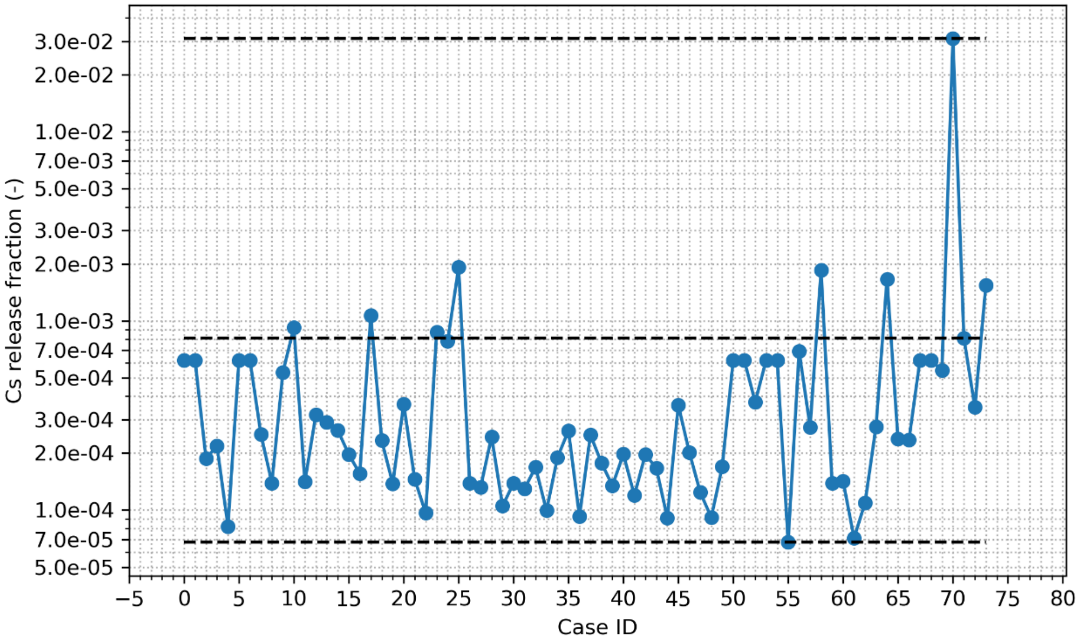
Unmitigated SBO:

- Cumulative environmental release fraction of Cs after ~24 h is ~8.E-6 (Diffuse leakage + release via MVSS).
- Most of the Cs released from the fuel is deposited in the suppression pool.



Unmitigated LB-LOCA:

- Cumulative environmental release fraction of Cs after ~24 h is ~8.E-4 (Diffuse leakage + release via MVSS).
- Quite significant release in Case 70 (IDEJ = 1)
  - IDEJ - Mode of debris ejection from the vessel

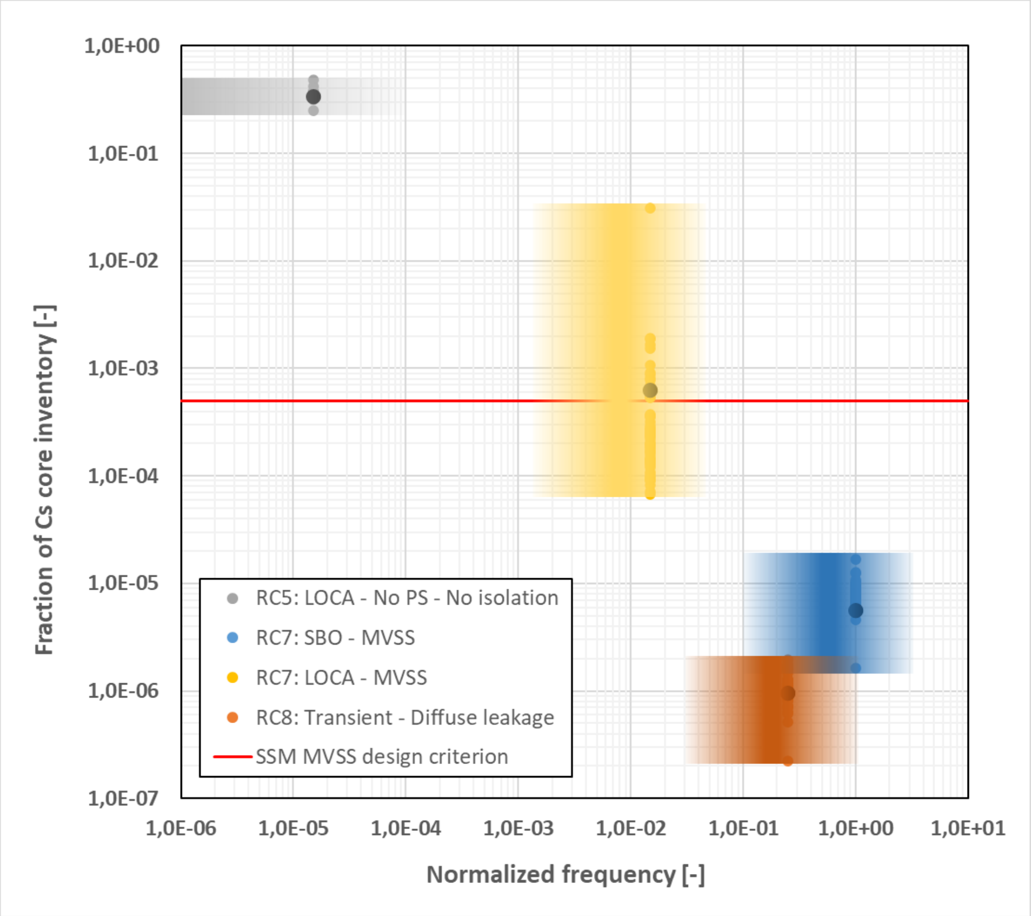


Summary of VG results

X-axis: Typical frequency results and uncertainties from PSA L2, normalized to RC7 frequency.

Y-axis: Fraction of core inventory of Cs including preliminary ranges from NKS STATUS

- RC5: LB-LOCA with failed pressure suppression function and failed isolation of unfiltered venting line.
  Large early release
- RC7: SBO with failed independent sprays.
  Filtered MVSS release
- RC7: LOCA with failed sprays.
  Filtered MVSS release
- RC8: Transient with safety systems recovery before RPV failure (recovery after 2 h after IE).
  Diffuse leakage (=intact containment)



Tuomo Sevón
Ilona Lindholm
Sara Ojalehto

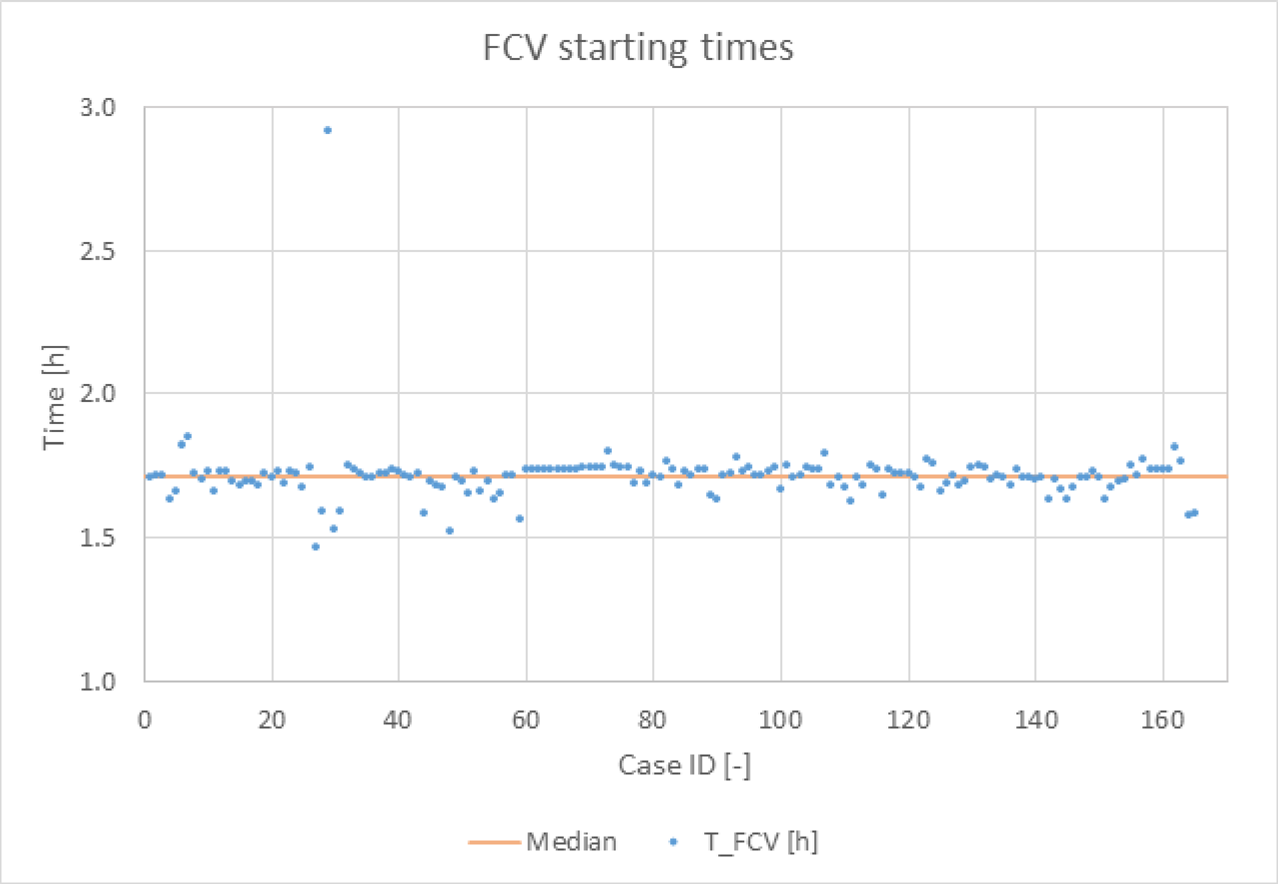
VTT results

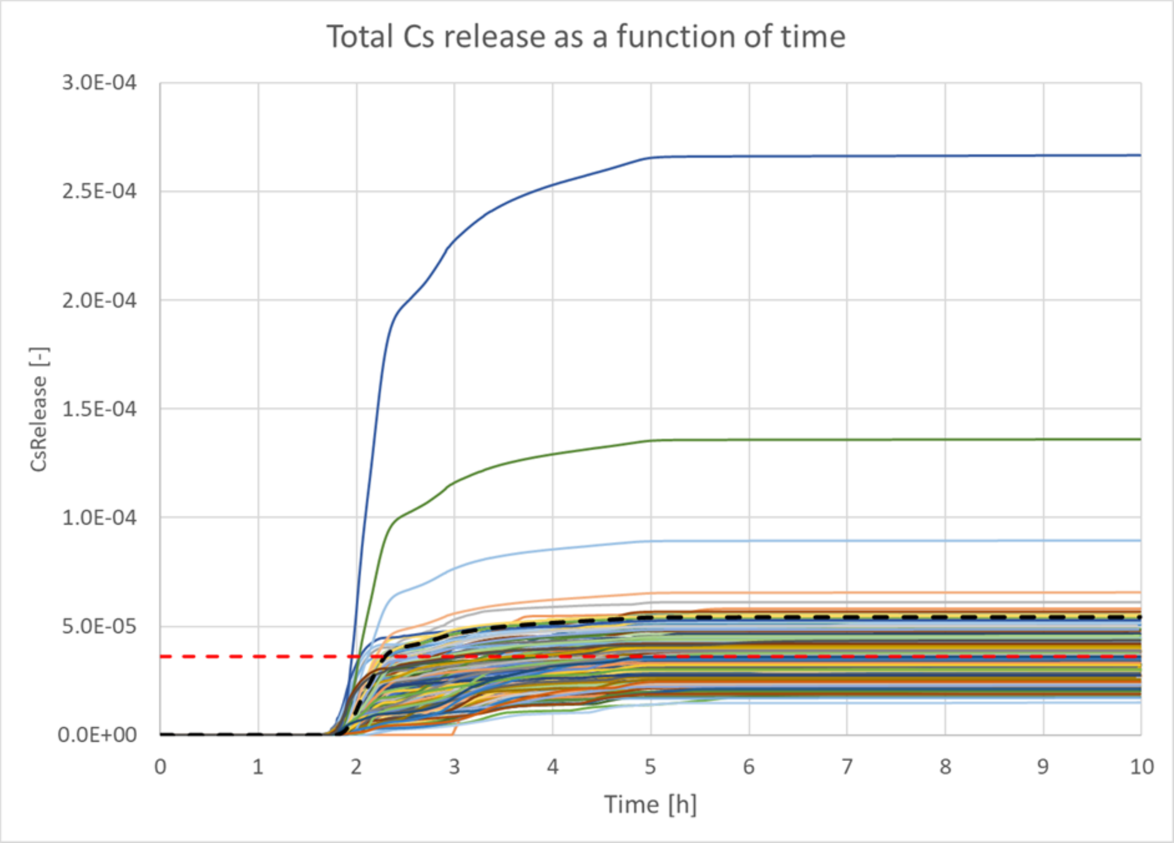
01/06/2022 VTT – beyond the obvious

VTT simulations

- VTT studied a station black-out scenario with filtered containment venting (FCV).
  - The accident is initiated by loss of all AC power.
  - The rupture disk in FCV was assumed opening at the time of RPV melt-through.
- Two figures of merit were studied: the starting times of filtered containment venting and the total cesium release during the simulated 10 hours.
- The simulations consisted of one reference case and on average four variations per each parameter.

VTT results





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VTT results

- Apart from a few exceptions, the effect of parameter variations on the FCV opening times appeared to be small.
- Unexpectedly, the cesium release was lower in almost all the cases compared to the reference case.
  - This was thought to be caused, at least partially, by molten core – concrete interaction (MCCI) that was observed occurring irregularly in some cases, including the reference case. In those cases, the hydrogen production increased the flow rate through the filtered venting system, resulting into higher cesium releases and thus obscuring the effect of parameter variations.
  - In order to obtain comparable results, MCCI will be switched off in the next phase of the project.
- The cesium releases were also observed changing irregularly between the variants of most parameters.
  - This highlights the need for a large number of calculations and a statistical analysis in order to properly investigate the effect of parameter variations on the simulation results.

NKS STATUS Project
KTH Contribution

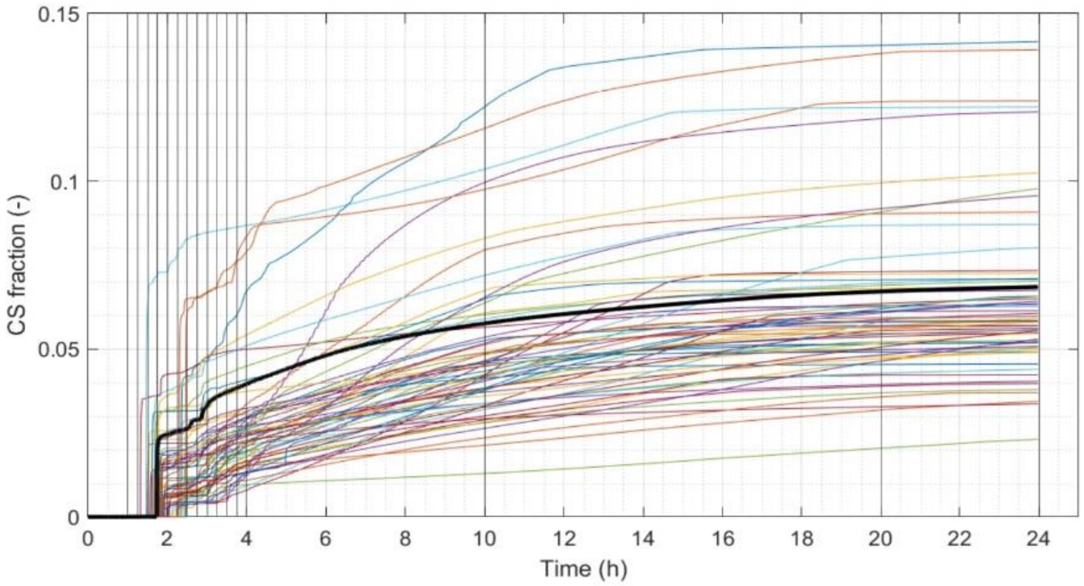
Pavel Kudinov
Dmitry Grishchenko
Govatsa Acharya
Division of Nuclear Engineering
Royal Institute of Technology (KTH)
Stockholm, Sweden

KTH Results

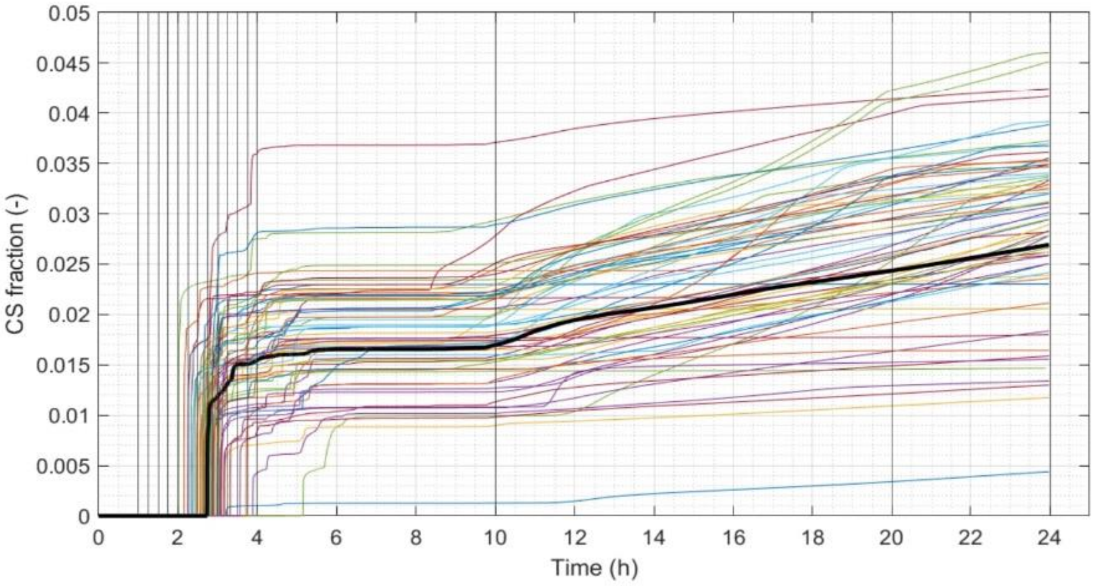
- KTH has studied two accident scenarios:
  - Large release in case of containment failure due to ex-vessel phenomena at RPV melt-through (RC4):
    - Initiated by LB-LOCA.
    - Initiated by SBO.
  - Containment failure assumed at the time of RPV melt-through.

Results – Cs Release

- LOCA



- SBO



- Black line indicates the reference case.
- It is seen that Cs release is almost an order of magnitude higher in case of LOCA than SBO.
- This may be due to larger release of fission products along with evaporating steam.
- It is also observed that in case of LOCA, only a few cases lead to larger release than the reference case, while the release is uniformly spread on either side of the reference case.

Summary

- Bounding analysis has been performed.
- The parameters that have significant effect on the results (Cs and I2 core inventory, timing of lower-head failure) were identified.
- Sensitivity and uncertainty analysis are to be performed in the second phase of the project.

Outlook: NKS-STATUS - Phase 2 (2022)

- The goal of the second phase of the project will be evaluation of the sensitivity of the magnitude of the fission products release in different accident scenarios (aleatory uncertainty) to the variability in deterministic modelling parameters (epistemic uncertainty), identification of the major contributors to the uncertainty, as well as quantification of the uncertainty in the results.
- The work will include a review of available literature, development and implementation of the algorithms for sensitivity analysis and uncertainty quantification with MELCOR code.
- The sensitivity and uncertainty calculations with MELCOR code will be performed for the accident scenarios identified in the first phase of the project for both the Swedish and Finnish plant configurations.
    - Additional dedicated codes and tools will be used to address uncertainty in specific severe accident phenomena, which are either not modelled or over-simplified in MELCOR code, such as ex-vessel steam explosion and debris coolability (e.g. the ROAAM+ tool developed at KTH).
- Insights regarding the impact of the results on the analysis of off-site consequences and emergency preparedness and response will be provided. Furthermore, this work will include assessment of available literature as well as relevant new methods concerning source term estimation for containment bypass sequences.

Vysus Group

Thank you