Karlsruhe Institute of Technology

Determination of the Radiological Consequences by means of JRODOS and JRODOS codes at a generic Akkuyu VVER-1000 plant unit

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Motivation

- Thesis objectives → assessment of source term (ST) → fission product (FP) dispersion during a severe accident (SA) in NPPs → quantification of uncertainties and sensitivity studies

- **A reliable, fast evaluation of the source term with determined uncertainties is essential to support.**
  - early emergency teams during an event
  - development of action plans for various scenarios

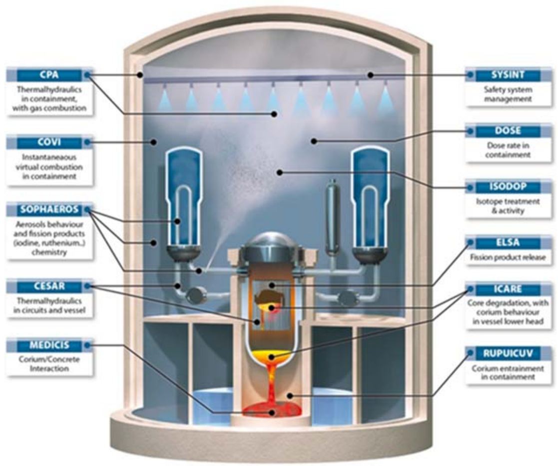
- **Reference** codes to be employed for assessing a database of STs during SA scenarios for VVER-1000
  - ASTEC-JRODOS → **A. K. Mercan, et al., 2022, Source term estimation and dispersion analysis of VVER-1000 reactor in case of LBLOCA along with SBO, ERMSAR2022, May 19-22, Karlsruhe.**
  - ASTEC-KATUSA → In progress
  - KATUSA/JRODOS → In progress

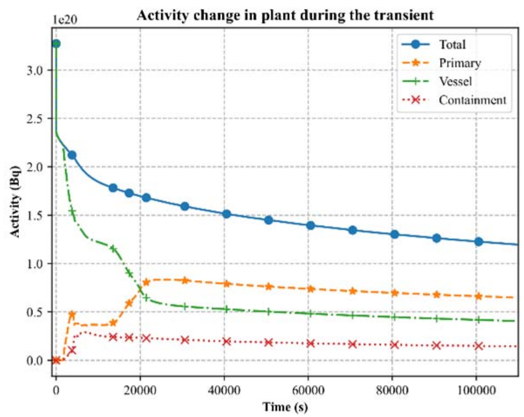
Strategy for Source Term Analyses

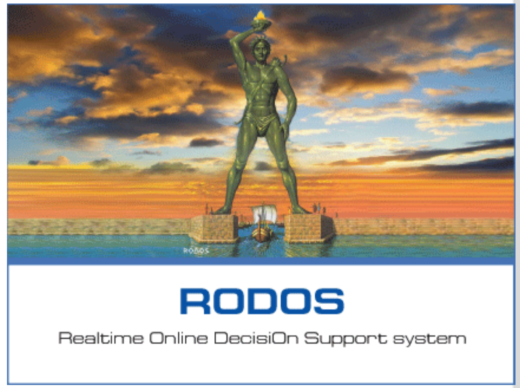
- **European reference Accident Source Term Evaluation Code (ASTEC)**, developed by IRSN and co-developed by KIT since 2020 → SA scenario analyses and ST evaluations.

- ASTEC results employed to analyze the FP dispersion in the environment by means of the **Java based Real-Time On-Line Decision Support system (JRODOS, KIT).**

Source Term







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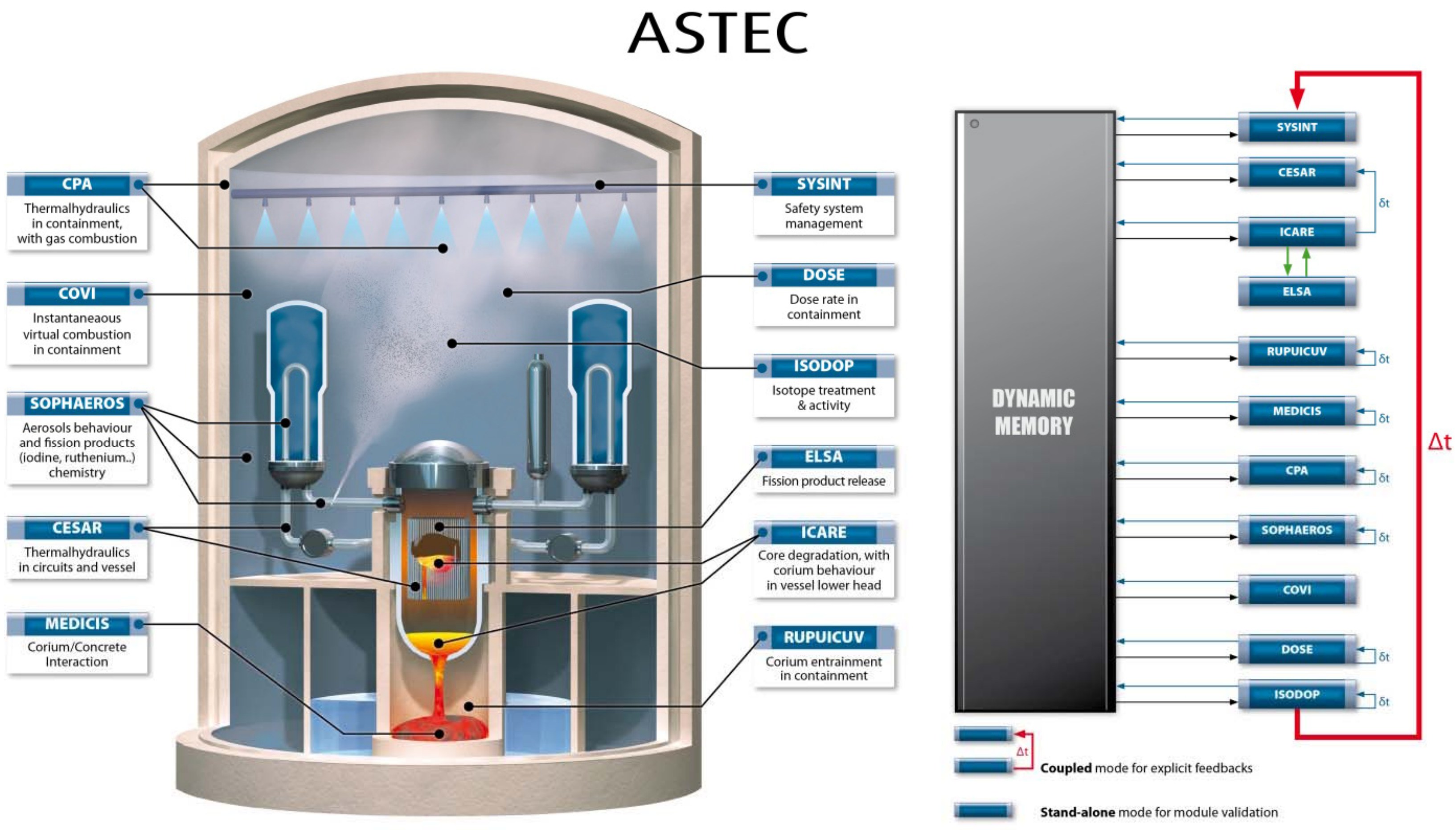
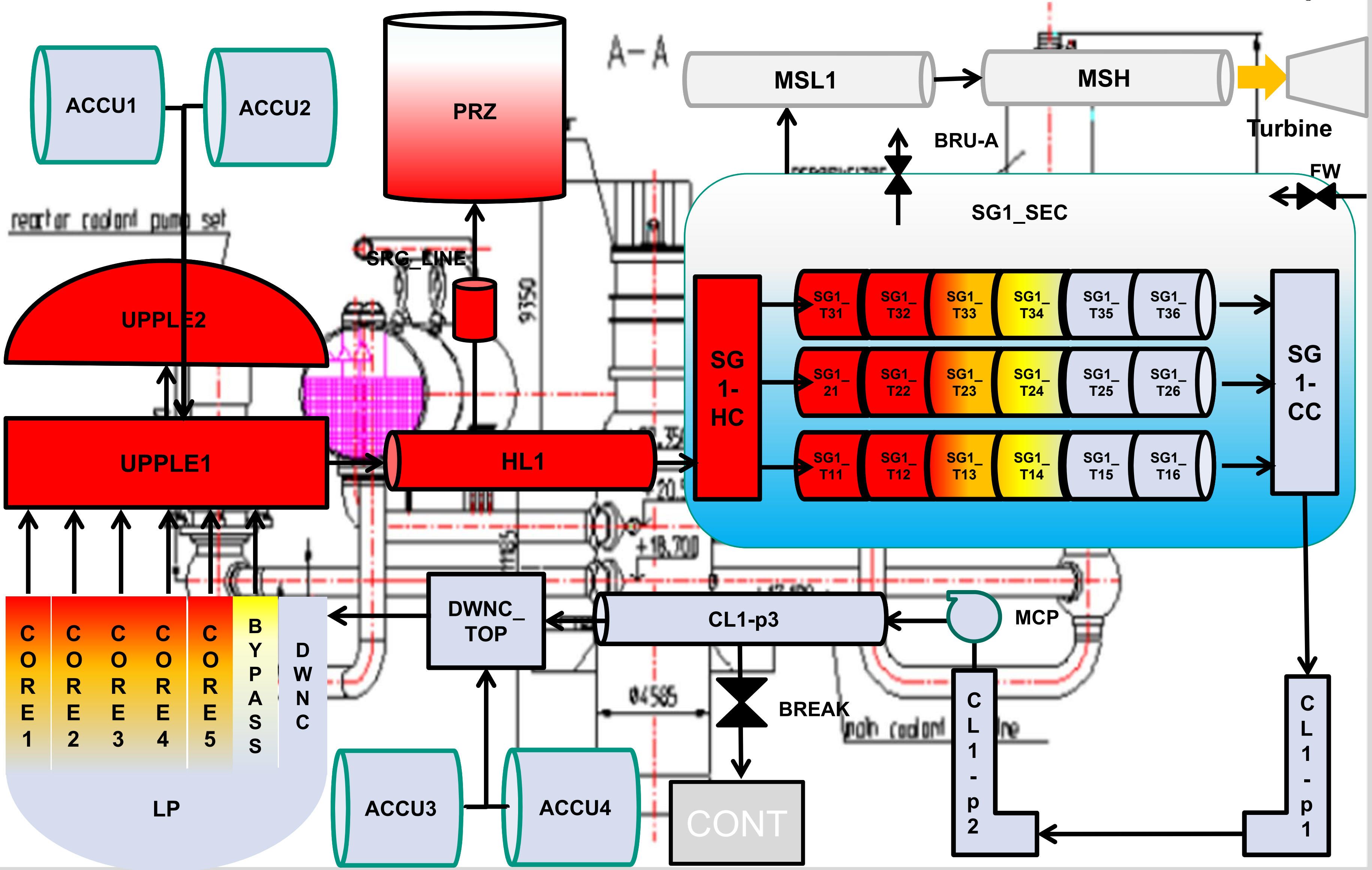
ASTEC: Integral Code



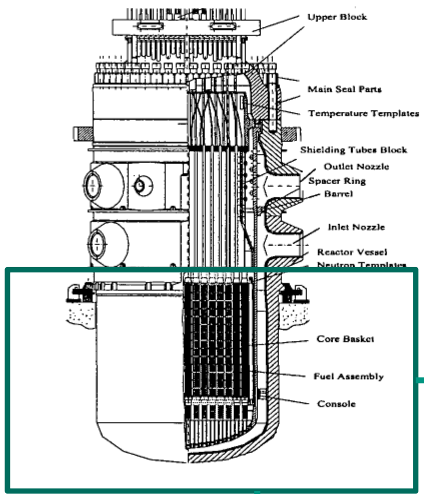
Structure of the ASTEC software and main modules

The ASTEC (Accident Source Term Evaluation Code) software system makes it possible to simulate all phenomena that take place during a water-cooled reactor meltdown accident, from the initiating event to the discharge of radioactive materials (called the "source term") out from the containment

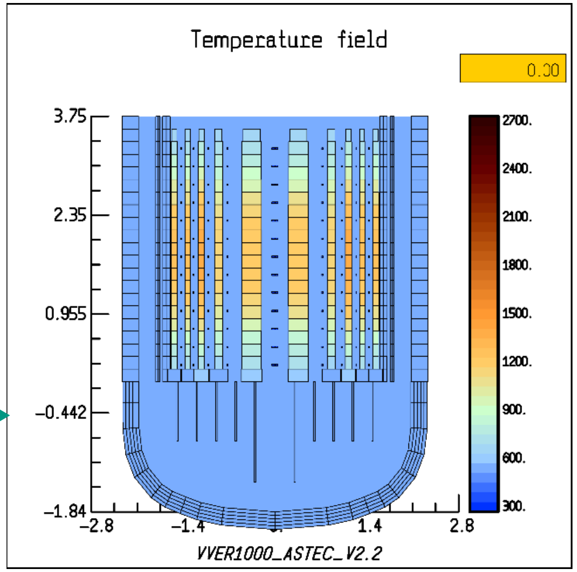
ASTEC: Primary & Secondary System Model



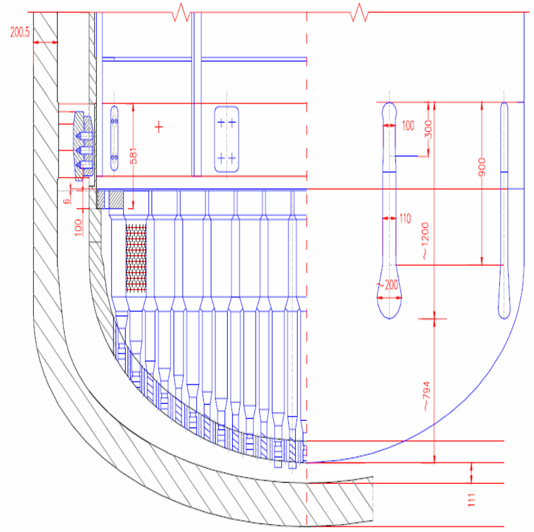
ASTEC:VVER-1000 RPV and Core



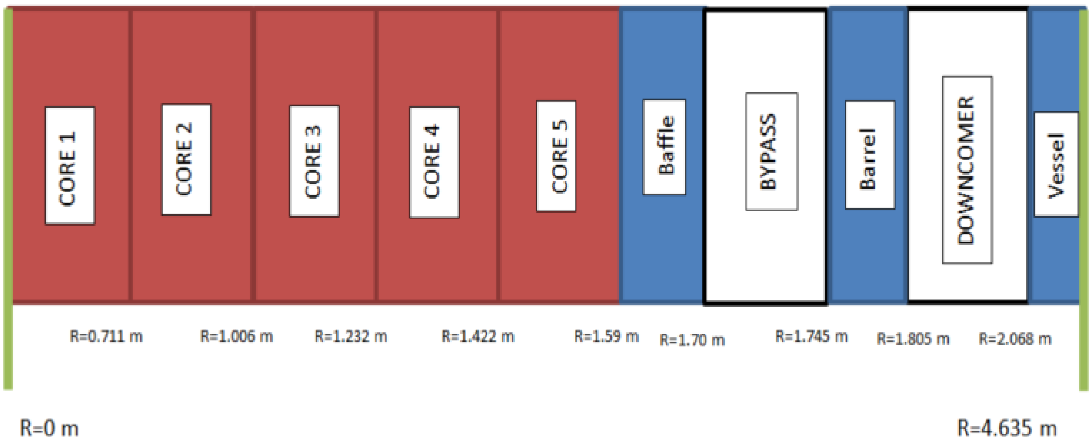
Reference vessel representation



ASTEC vessel representation

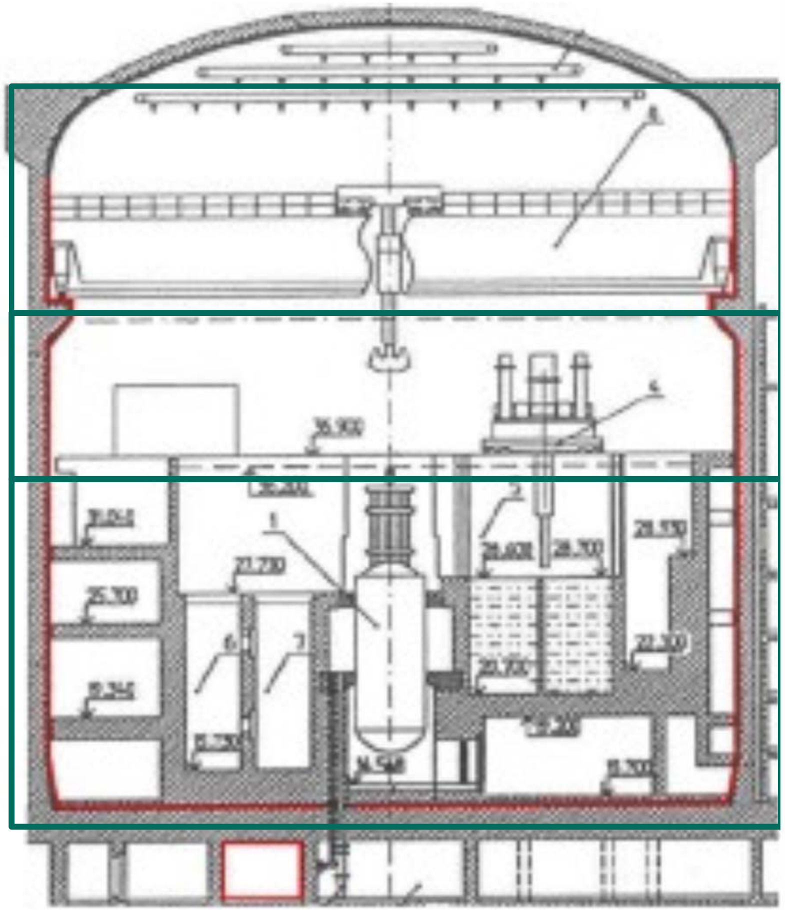


Reference lower plenum

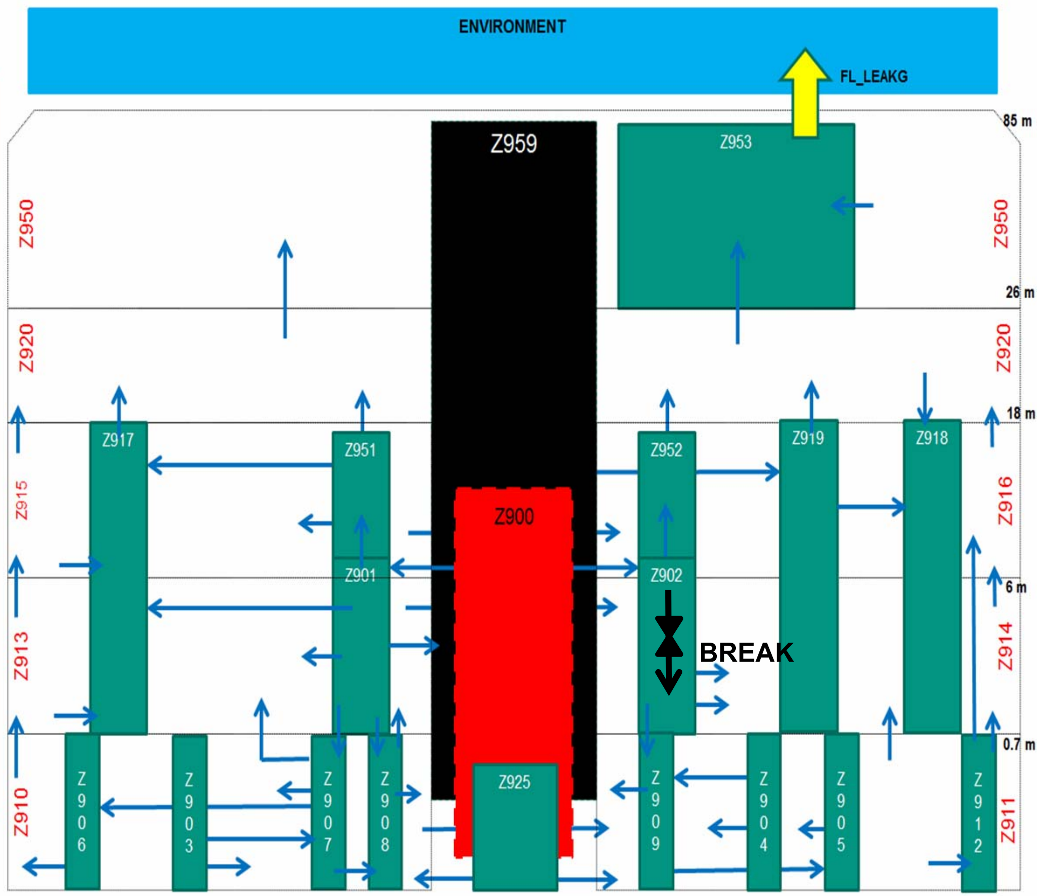


Parameter	Value
Pellet diameter (mm)	7.56
Clad diameter (mm)	9.1
Clad thickness (mm)	0.69
Fuel rod total lenght (mm)	3837
Fuel rod active lenght (mm)	3530
Fuel rod pitch (mm)	12.75

ASTEC: Containment model



VVER-1000 Containment



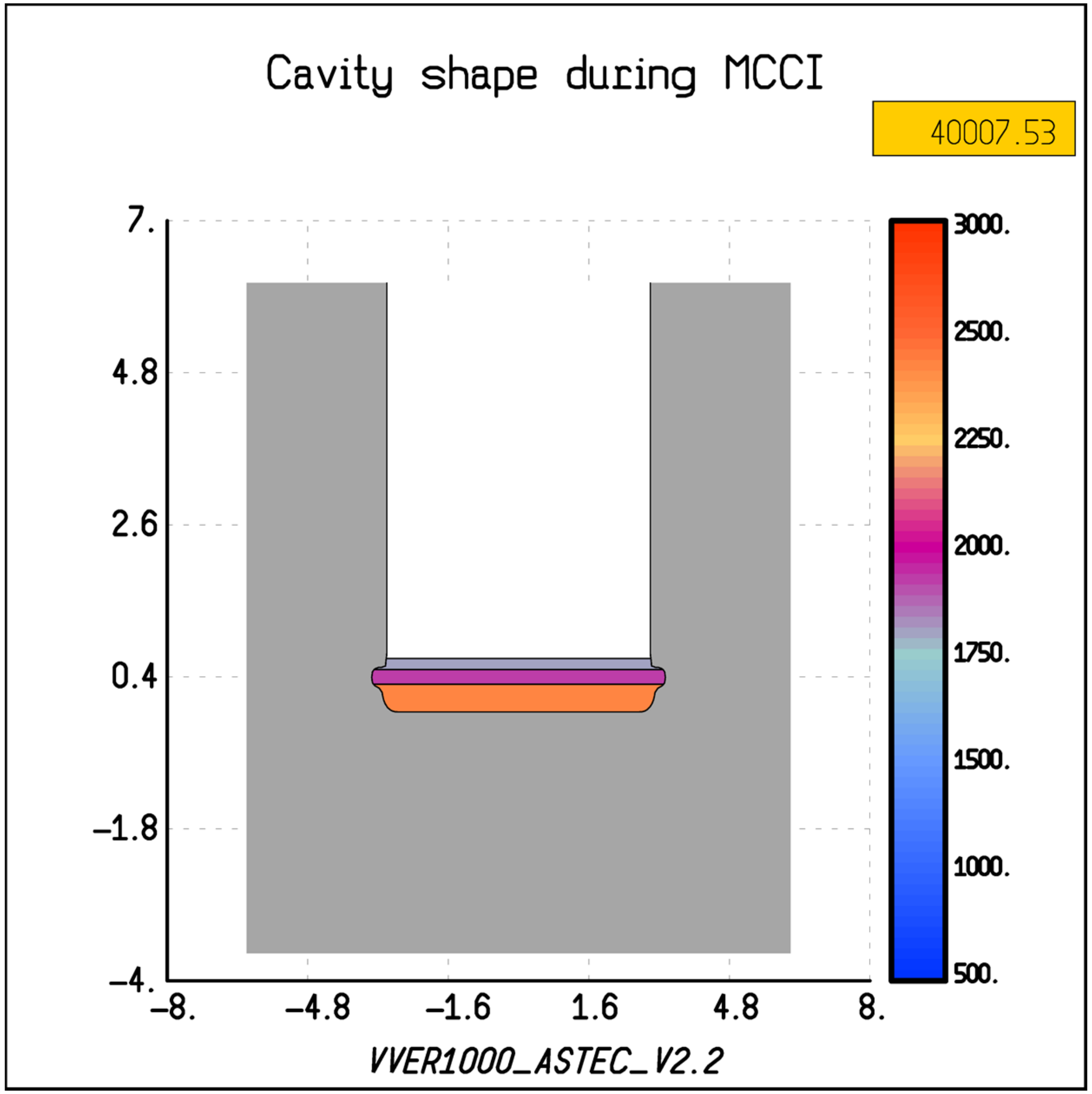
ASTEC: Containment Nodalisation

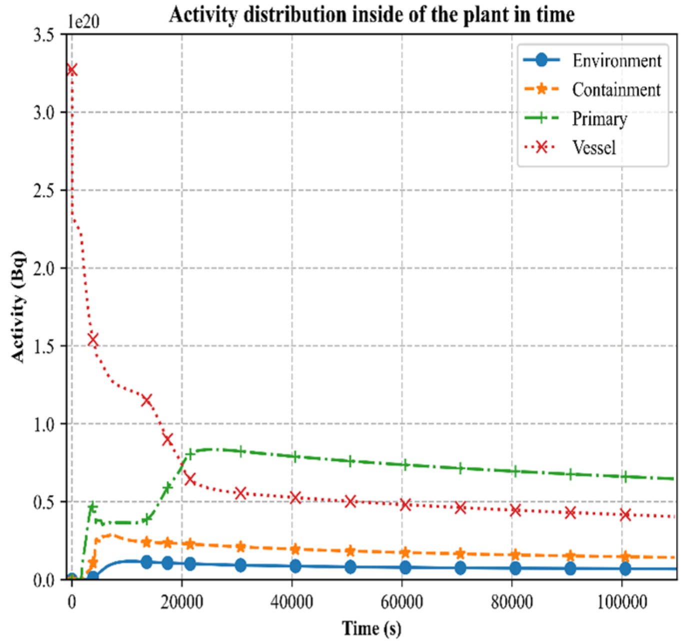
- **27 control volumes**
- **60 junction between volumes**
- **One junction to the environment for the leakage.**

LBLOCA on the hot leg with SBO /Best-Estimate Calculation (1/2)

- ASTEC Scenario:
  - Large break (850 mm) on hot leg between pump and downcomer
  - Assumption:
    - Coincident SBO:
      - i.e. no active ECCS available: LPIS, HPIS
    - Passive accumulators available when P < 5.9 Mpa.
    - SCRAM is given at time=0, Pump coast-down is at time=0
    - BRU-A valves are activated P > 8.29
    - Steam, hydrogen, xenon and kripton have been modelled as carrier fluid for FPs.
    - All modules of ASTEC (in-vessel, ex-vessel, FP transport) are activated.
    - Natural leakage to the environment
    - No filter activity
- JRODOS Scenario:
  - Winter weather conditions (15/01/2022-25/01/22)
  - Zapohorizhzhia-6 NPP
  - Early emergency applications with Germany limits
    - Sheltering when effective dose > 10 mSv, Evacuation when effective dose > 100 mSv
    - Thyroid pills when thyroid dose > 250 mSv for adults and thyroid dose > 50 mSv for chıldre´n
    - Relocation when effective dose > 30 mSv temporary, when effective dose > 100 mSv permanent

LBLOCA on the hot leg with SBO /Best-Estimate Calculation (2/2)





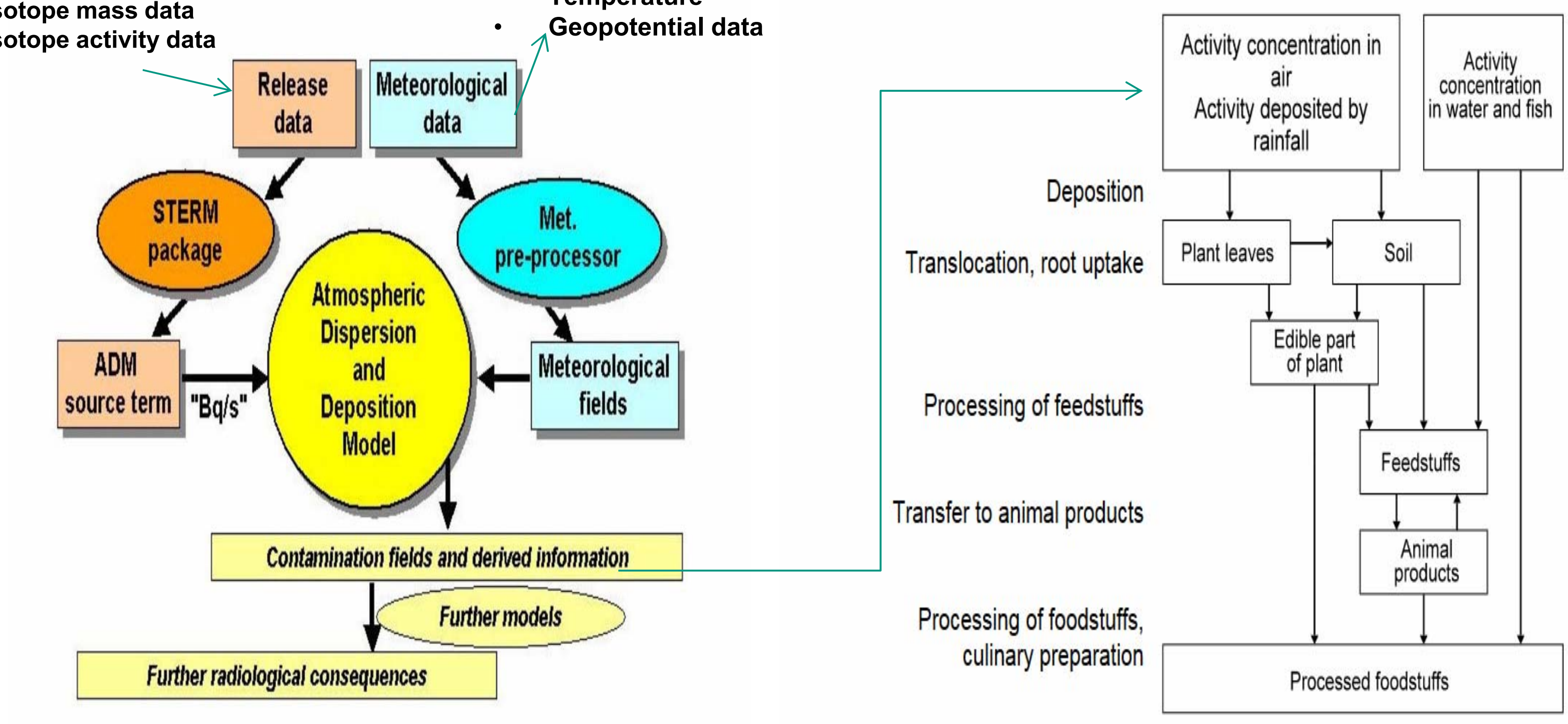
Remarks:

- Activity at the environment is 8.33 $x10^{18}$ Bq.
- Low retention of FPs!

VVER-1000: Radiological Dispersion by JRODOS: Calculation steps

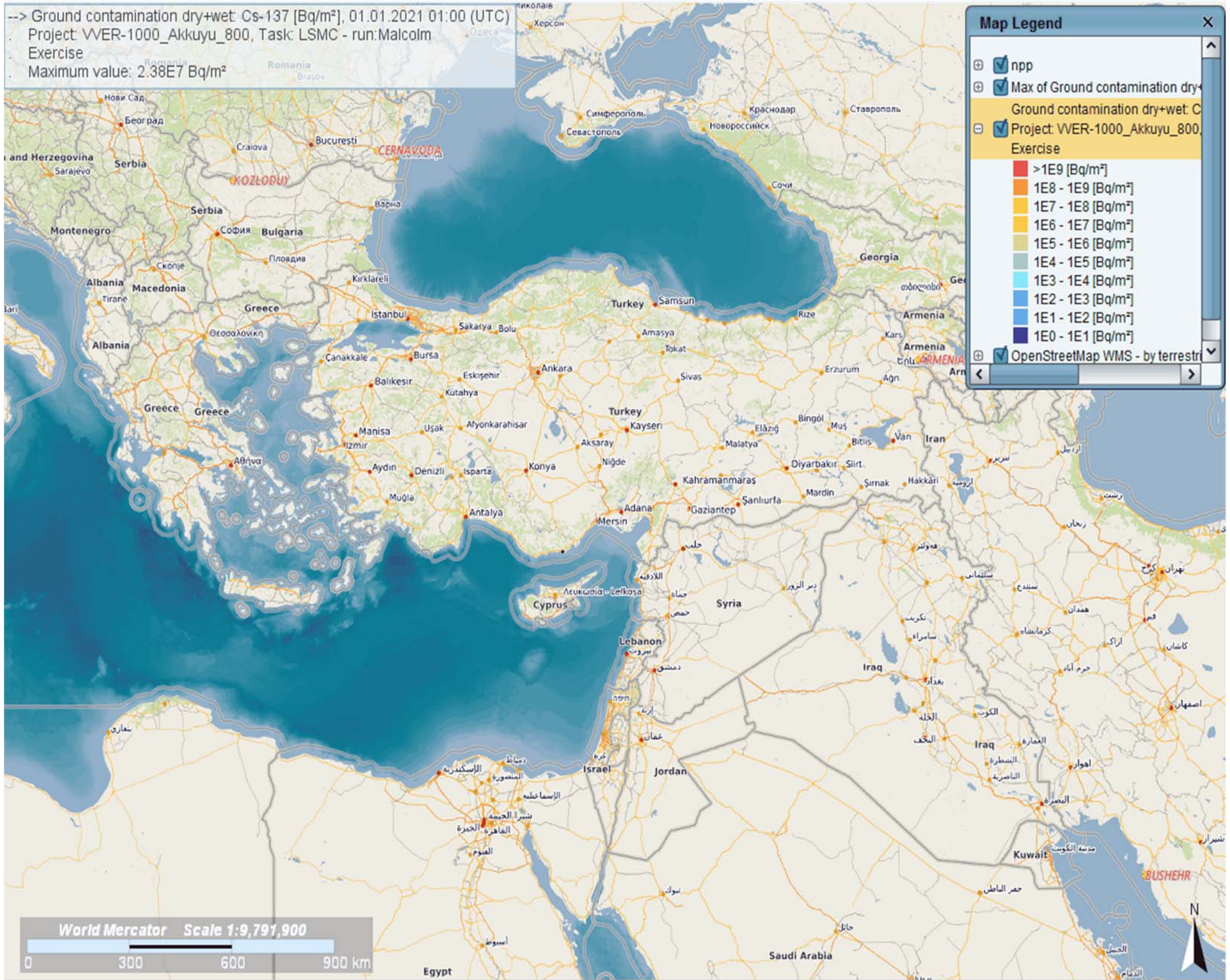
Supported by NOMAD
- **Total precipitation**
- **Wind speed**
- **Temperature**
- **Geopotential data**

Supported by ASTEC
- **Isotope mass data**
- **Isotope activity data**



Remarks:
- **JRODOS supports location data which include urbanization, population and vegetation data.**
- **By including release and meteorological data, the code calculate the contamination with various pathways.**
- **Additionally, code support countermeasure variants across world according to the their regulations**

JRODOS: Radiological Impact Analysis on VVER-1000 /Contamination over the Area by Cs-137

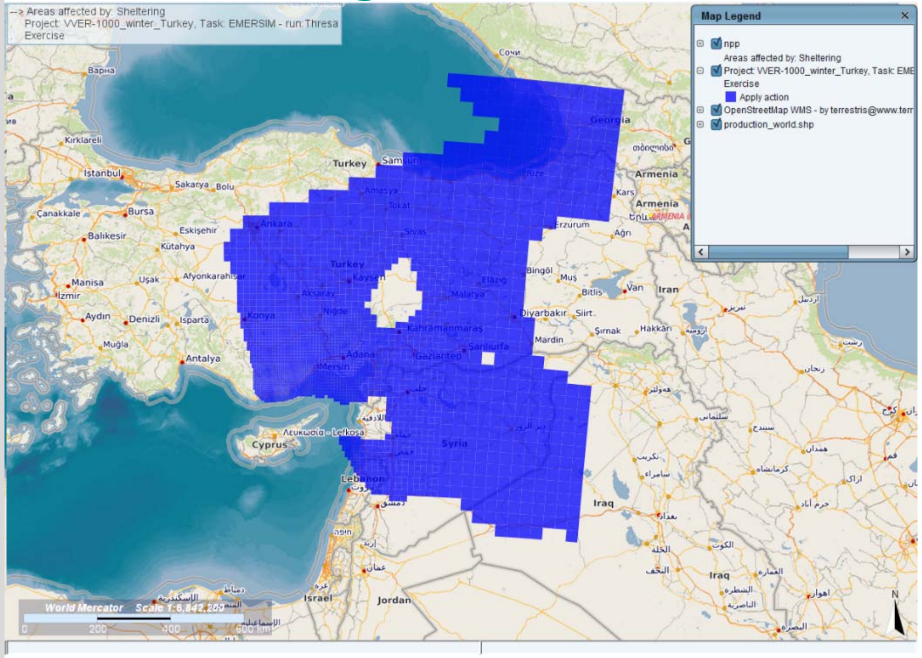


Remarks:

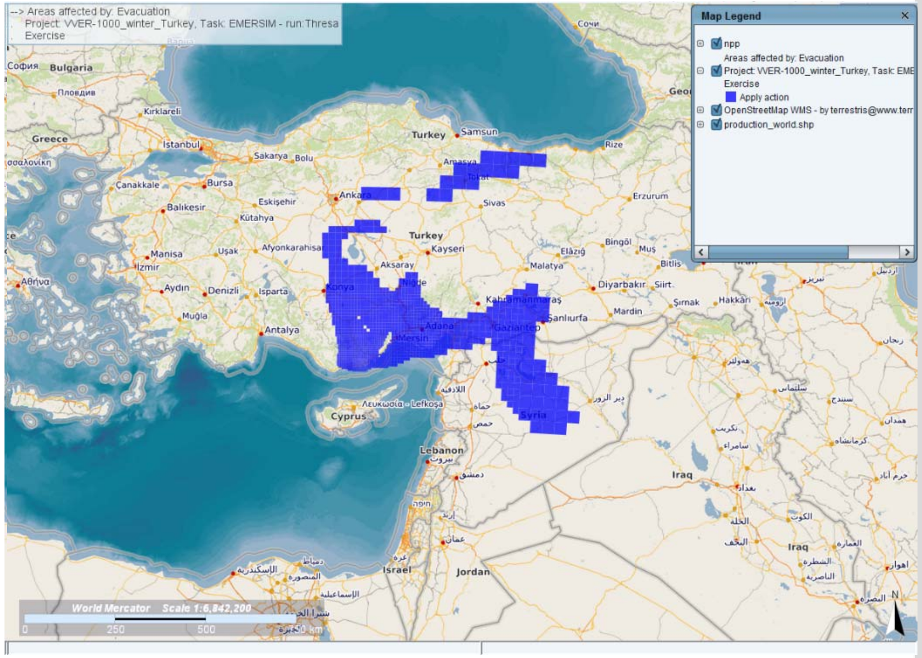
- Maximum contamination from Cs-137 is 247 $\mathrm{MBq/m^2}$
- Affected area is 2.55 $\mathrm{Mkm^2}$ and affected population is 202 M

15.5 $\mathrm{MBq/m^3}$ at Fukushima for Cs-137

JRODOS: Radiological Impact Analysis on VVER-1000 /Acute & Long term doses



Acute effective dose / Sheltering



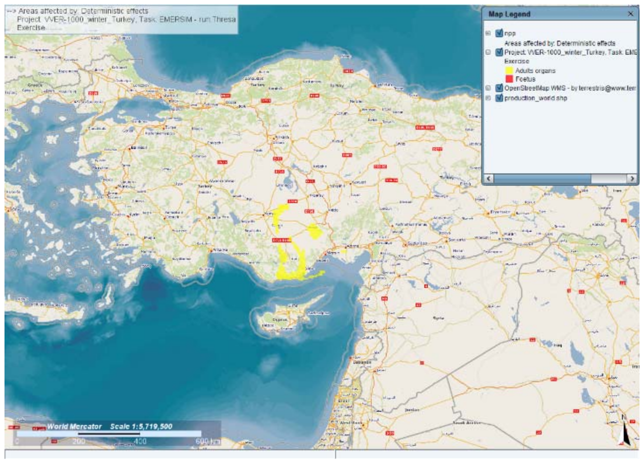
Effective dose after a year / Relocation

- Acute effective dose is over than annual limits
- 1 year doses show that sheltering and relocation is required!
- Deterministic effect on adults is observed

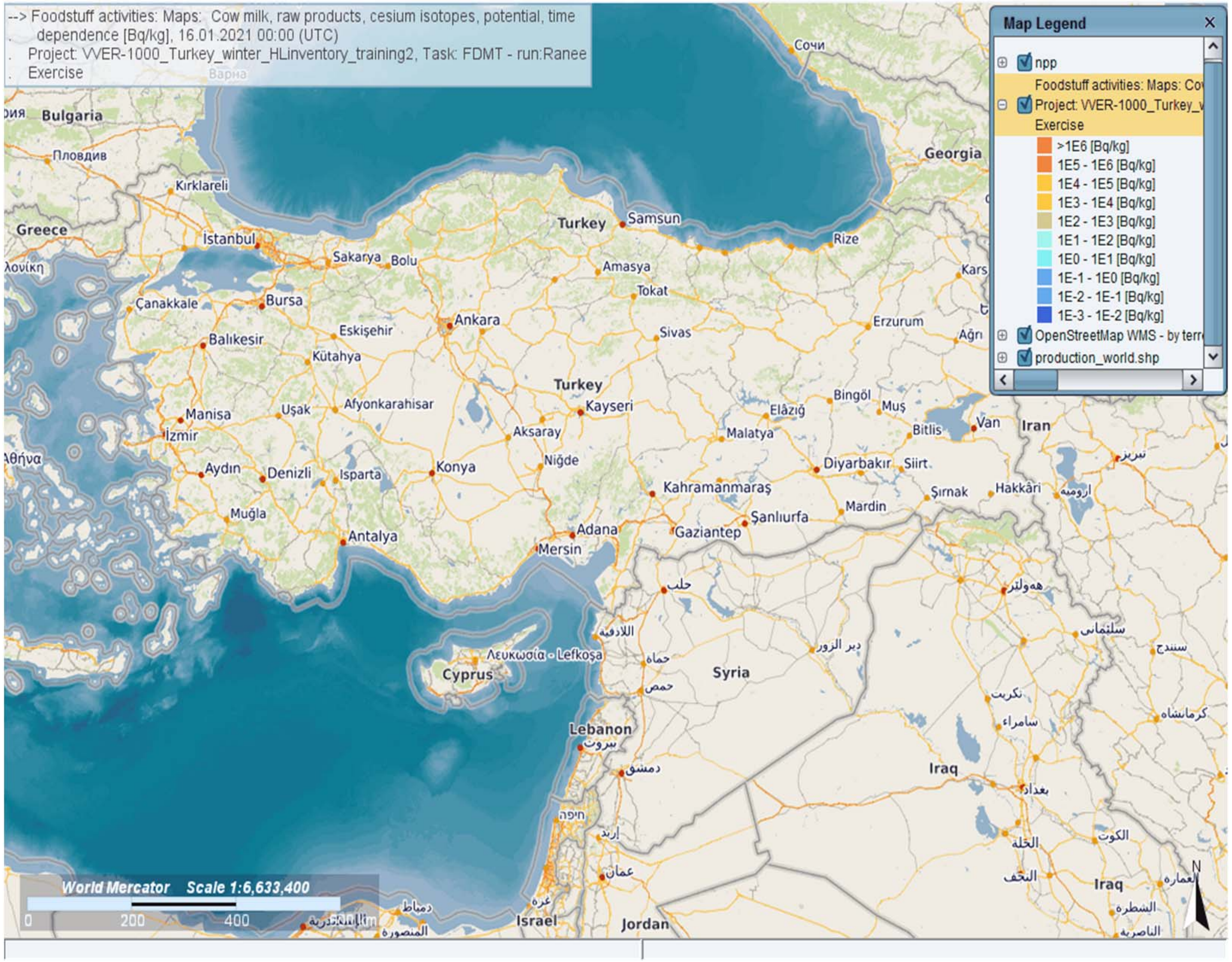
>1 mSv/year for public

>20 mSv/year for worker

Deterministic Effects



JRODOS: Radiological Impact Analysis on VVER-1000 /Activity concentration on Cow's Milk



Remarks:

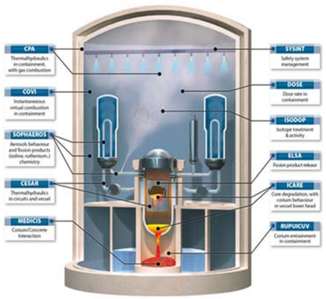
- Maximum concentration on cow's milk from cesium isotopes is 672 MBq/kg
- Long term effect!

1000 Bq/kg is limit for human consumption and international trade

Strategy for U&S

Development of in-house **Karlsruher Tool for Uncertainty and Sensitivity Analysis** (KATUSA) → **Uncertainty Quantification (UQ) of the ASTEC ST results** + determination of difference on activity levels released to the environment

Sampling → Multiple simulations → Collecting and filtering simulation results → U&S analysis



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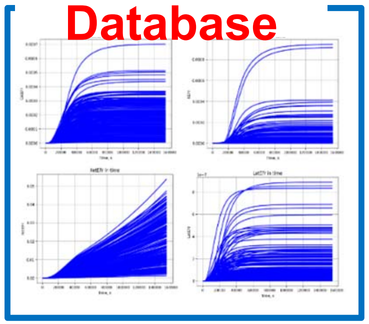
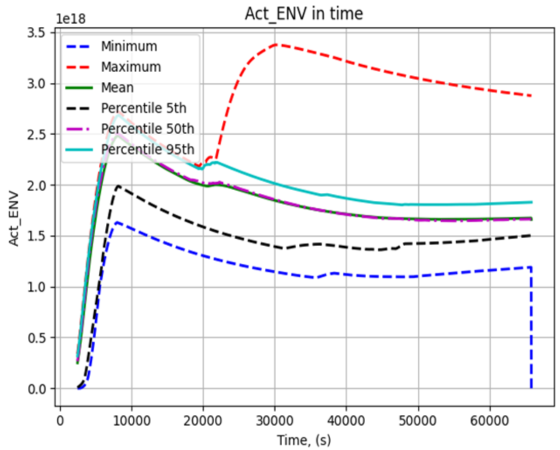
ST Training Database



ASTEC+UQ



Uncertainy Parameters & FOMs

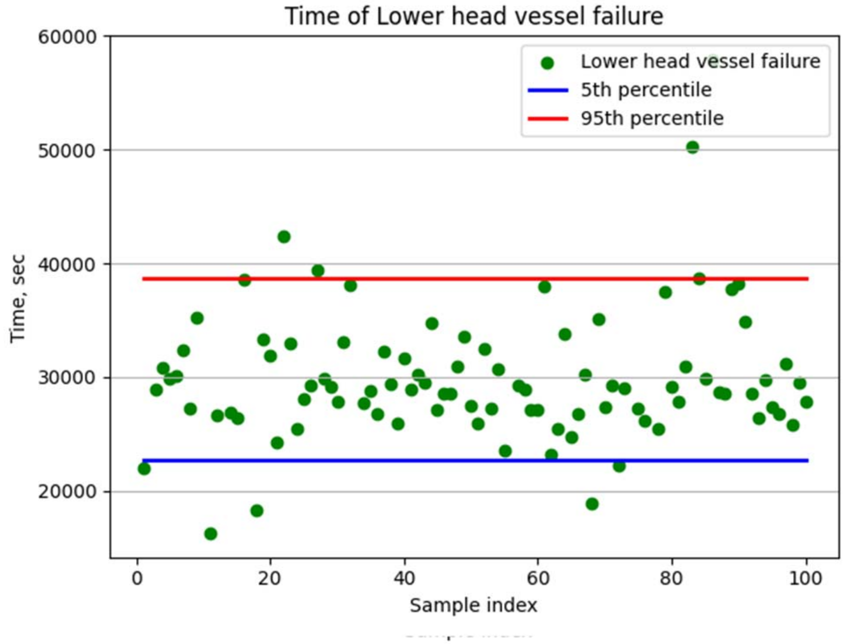
Parameter	Phenomena	Description	Reference Value	Variation Range	PDF
frho	Aerosol size, shape and thermal properties	**Particle mean density (kg/m^3)**	3000.	Min=2400. Max=3600.	Uniform
fspheat		**Particle mean specific heat (J/kg-K)**	840.	Min=672. Max=1008.	Uniform
fR_min		**Particle minimum radius (m)**	1.0E-08	Min=1.E-09 Max=2E-08 Mode=1.1E-08	Triangular
fR_max		**Particle maximum radius (m)**	2.0E-5	Min=5.E-06 Max=2E-05 Mode=1.99E-05	Triangular
fv_stks		**Shape factor relative to Stokes velocity**	1.0	Alpha=1.0 Beta=5.0 Min=1.0 Max=3.0	Beta
fTBEG	Hydrogen generation	**Temperature of oxidation begins (K)**	600.	Min=480. Max=1008.	Uniform
fTABLA		**Ablation temperature at cavity (K)**	1570.	Min=1256. Max=1884.	Uniform
f_leak	Leakage to the environment	**Containment leakage area (m^2)**	3.14E-02	Min=3.14E-02 Max=3.14E-01	Uniform

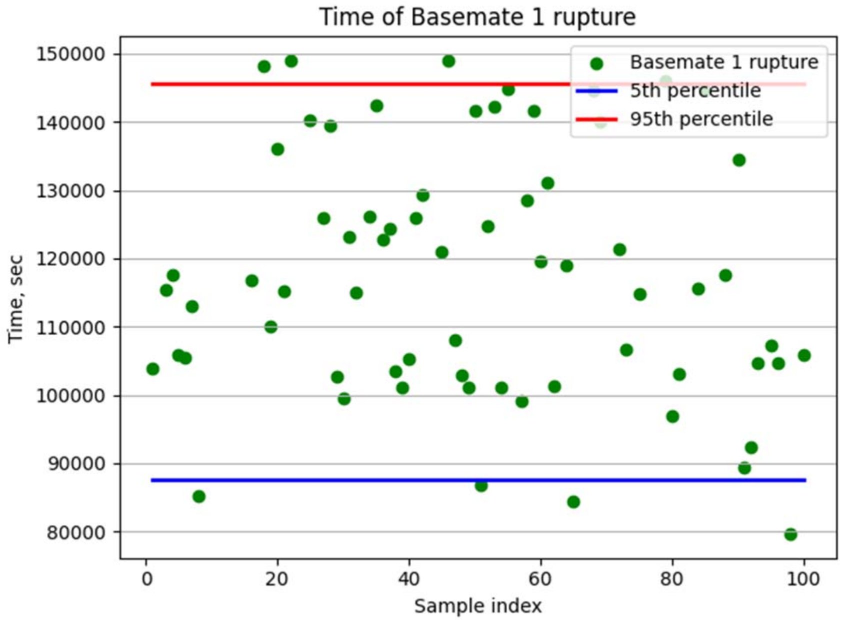
FOMs & Methodology

#	Figure-of-Merit
1	Total amount of FP and isotopes released in the primary circuit [kg]
2	Total amount of FP and isotopes in the containment [kg]
3	Total amount of FP and isotopes released to the environment [kg]
4	Total activity of the isotopes released to the environment [Bq]
5	Total activity of the isotopes in the containment [Bq]

- ASTEC v2.2_b Linux version is used
- 100 samples with LHS method
- 32 cores are used
- 6 failed calculation. These are not considered in U&S calculation.
- Wall-clock time= 4.5 $\text{x}10^4$ s
- Min, max and mean values are calculated.
- Confidence level = 95%

LBLOCA on the hot leg with SBO / Uncertainty & sensitivity analyses (1/2)

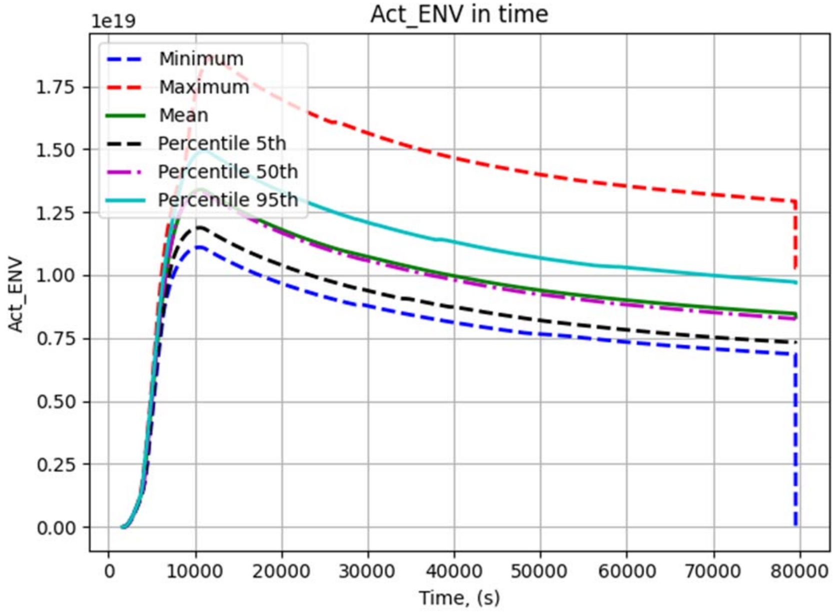


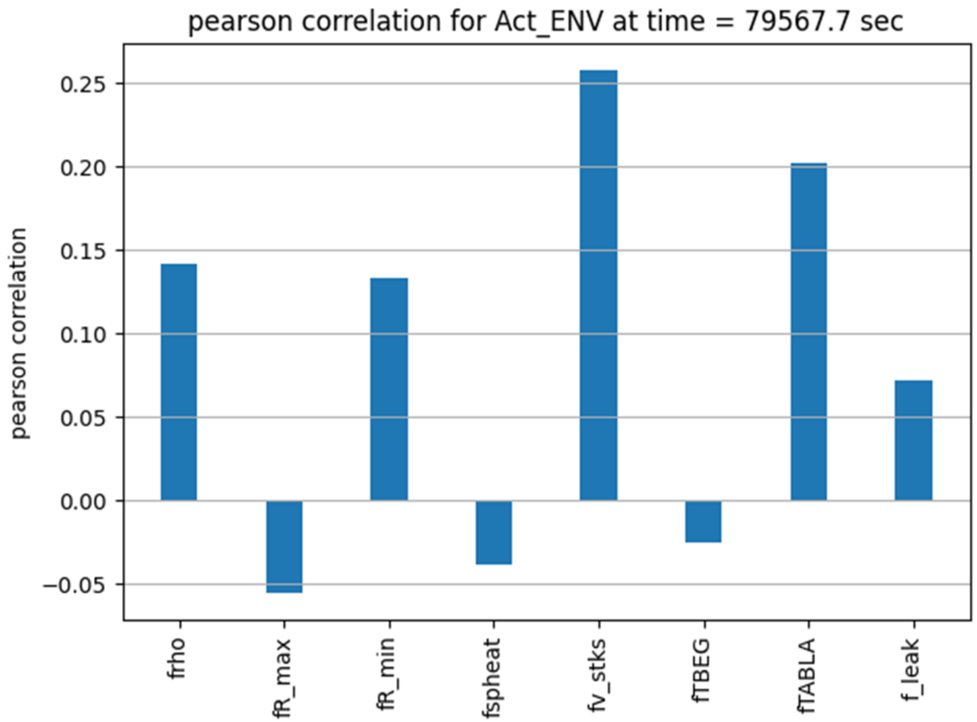


Remarks:

- Start of FP release time flactuates between 1560 s and 1590 s
- First total core uncovery spans between 5600 s and 7600 s.
- RPV failure can be observed between 23000 s and 39000 s.
- Finally, basemat rupture window is between 90000 to 14500s.

LBLOCA on the hot leg with SBO / Uncertainty & sensitivity analyses (2/2)

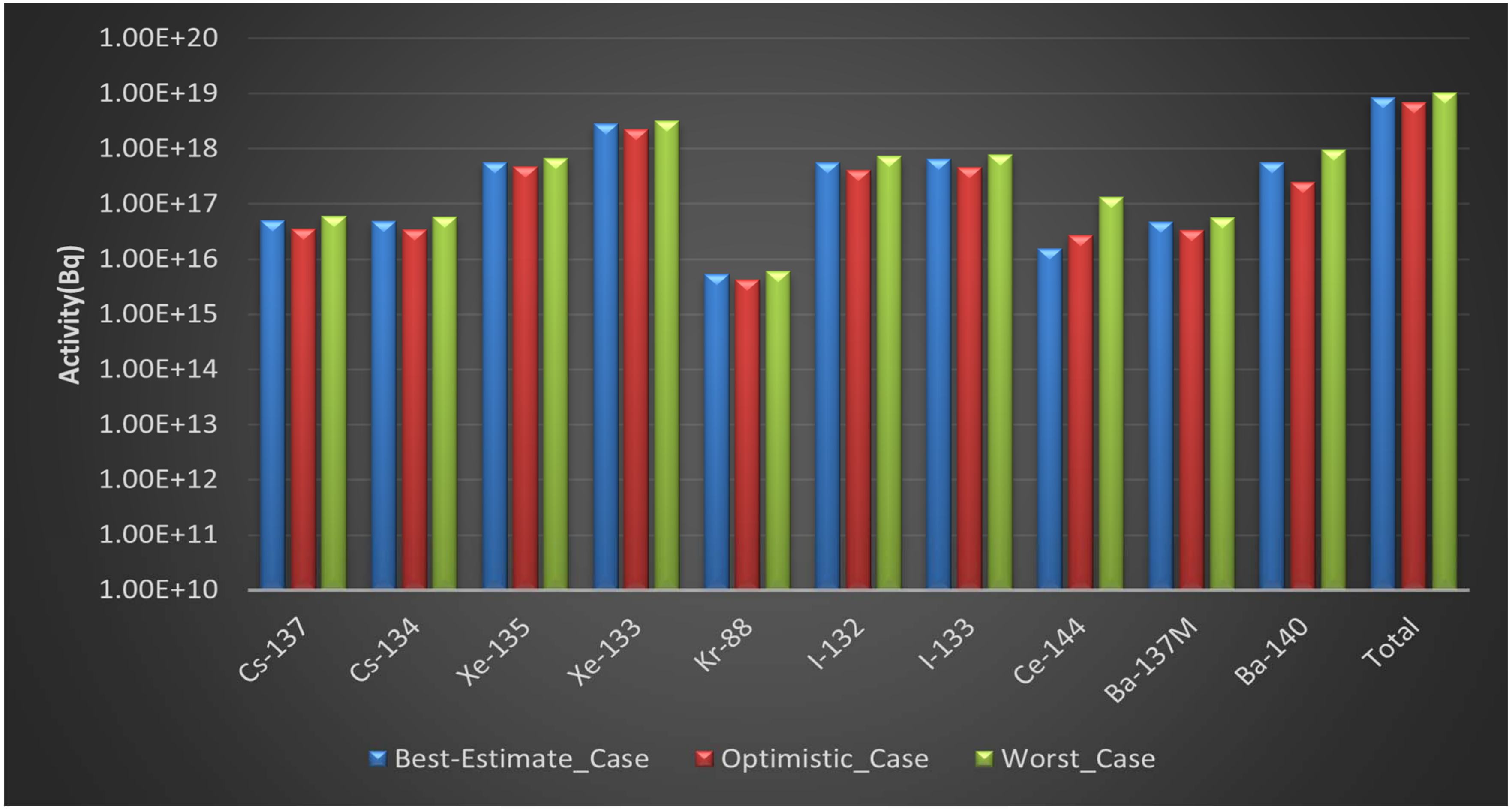




Remarks:

- Activity at the environment spans between 6.86$\mathrm{x}10^{18}$ Bq to 1.03 $\mathrm{x}10^{19}$ Bq at the end of transient.
- Stokes-velocity correction factor (fv_stks) impacts the activity at the environment at most at early stage. Stokes-velocity correction factor is also dominating factor at late stage
- Oxidation onset temperature (fTEB) at early stage and ablation temperature of the cavity(fTABLA) at late stage are the second contributers at their stages.

LBLOCA on the hot leg with SBO / Comparison of activity at different conditions



- Predicted level of activity between the from INES level 5.5 to INES level 5.7
- Difference can be observed on the low-volatile isotopes(Ce-144, Sr-90 etc.).

Summary & Outlook

Karlsruher Institut für Technologie

Summary:

- ASTEC-JRODOS platform is first-of-a-kind application to determine radilogical impact for the Akkuyu NPP site from the initiation of the severe accident to the estimation of radiological consequences. Findings can be summarized that:
  - 8.33×10^{18} Bq actvitiy can be released to the environment.
  - Total deposition is 11.5 $\mathrm{GBq/m^2}$ as maximum. Deterministic effects are observed.
  - Doses are far above the limits, doses under 1 mSv only be observed after 300 km.
  - Activity concentration for cow's milk reaches under 1000 Bq/kg after 30 years

- Based on uncertainty quantification of ASTEC using KATUSA, the following findings were obtained:
  - The most probable start of FP-release is between 1200 s any 1400 s
  - Most probable RPV-failure is between 15000 and 23000 s
  - Most probable time window for basemat rupture is from 80000 s. to 140000.
  - Activity released to the environment can be 2 times higher than in the best estimate case. Significant difference of low-volatile isotopes.
  - The most influencing parameters with the greatest impact on radiological source term are: Stokes-velocity correction at in-vessel phase and aerosol specific heat at late stage.

Outlook:

- Ensemble calculation by JRODOS to determine the impact of uncertainties in different weather conditions