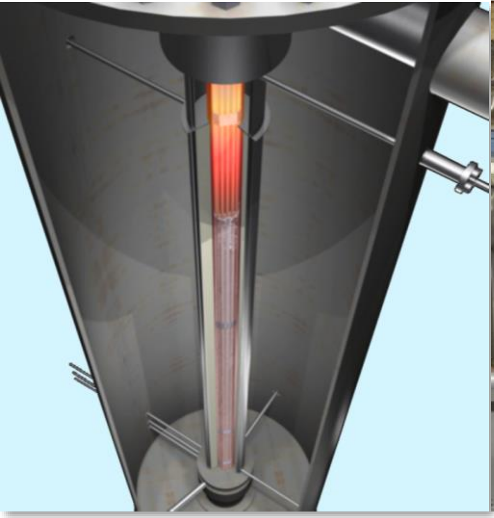
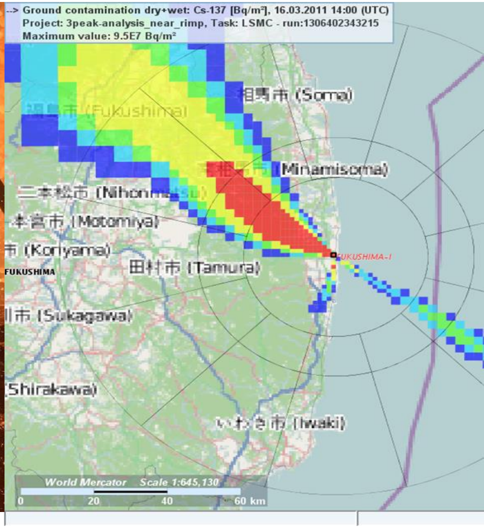
Karlsruhe Institute of Technology

30th NENE 2021
September 6 - 9
BLED-SLOVENIA
International Conference Nuclear Energy for New Europe

EMPLOYMENT OF THE ASTEC CODE IN THE SEVERE ACCIDENTS RESEARCH ACTIVITIES AT KIT

Fabrizio Gabrielli, Victor Hugo Sanchez-Espinoza, A. K. Mercan, Walter Tromm





KIT Strategy for SA codes (1/2)

- Fukushima accidents showed necessity for
  - Re-evaluating accident analysis methods, SAMGs, and plant status
  - Improving the numerical simulation tools
  - Codes extension and V&V
  - V&V of SA codes ← Experiments
  - Support to the development of SA codes ← Experiments

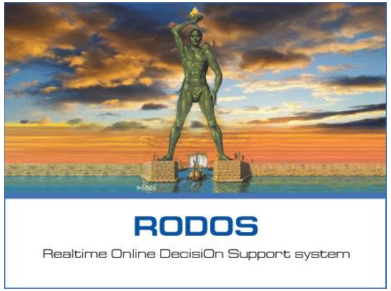
- Coupling with other codes, e.g. MELCOR/GASFLOW, ASTEC/JRODOS
  - Evaluation of the Radiological Source Term
  - Application of U&S methods to SA codes, e.g. URANIE, SUNSET, DAKOTA, in-House tools ← Experiments
  - Applications of SA Codes for SAMs assessment
  - Use of High Performance computing (HPC)
- Education and Knowledge preservation/dissemination (PhDs and Master programs)

KIT Strategy for SA codes (2/2)

- ASTEC
  - Co-developer for IRSN
  - Plant applications
  - U&S
- MELCOR
  - Plant applications
  - Code benchmarking
  - U&S (planned)
- Validation against KIT Experiments
  - QUENCH, LIVE, MOCKA, HYKA

Radiological Source Term

- **Emergency Management**
  - **JRODOS (KIT)**

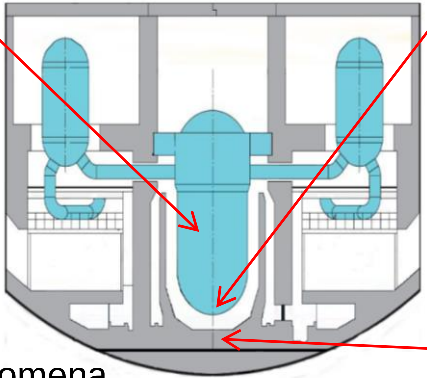


Development of Severe Accident Codes and JRODOS integral part of reactor safety research at KIT

Large scale test facilities at KIT

Core coolability and debris cooling

QUENCH



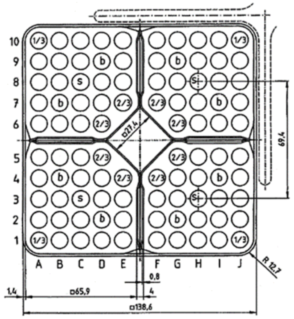
In-vessel melt retention

MCCI

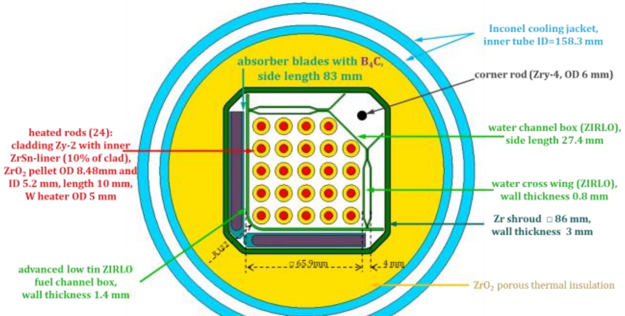
Containment phenomena

Validation: QUENCH-20

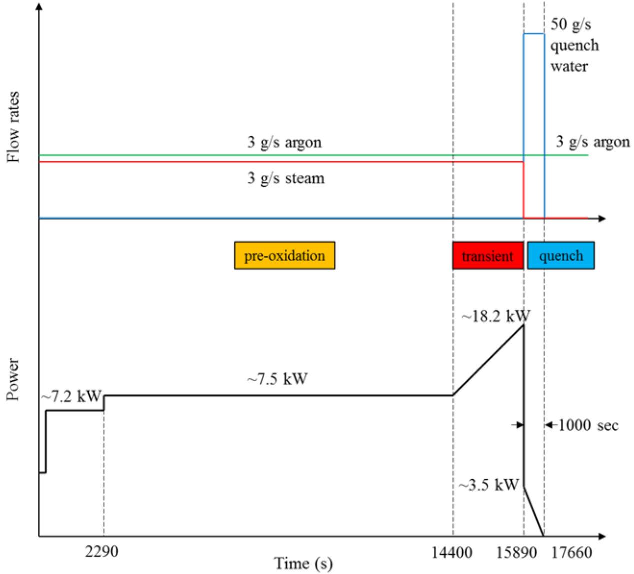
- Oxidation and H2 generation during reflooding of a ¼ BWR pre-oxidised bundle.



SVEA-96 Optima-2 fuel bundle

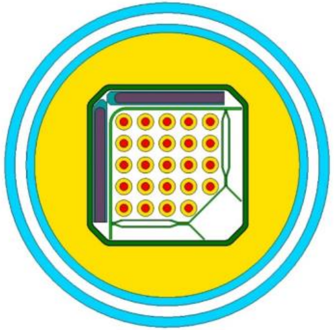


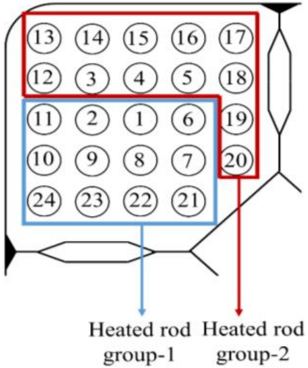
Geometrical parameters:
- bundle pitch 12.898 mm;
- outer diameter of claddings 9.84 mm;
- thickness of claddings 0.605 mm;
- absorber blades: thickness 8.05 mm
- cladding length 2500 mm
- absorber and cannel box lengths 1600 mm

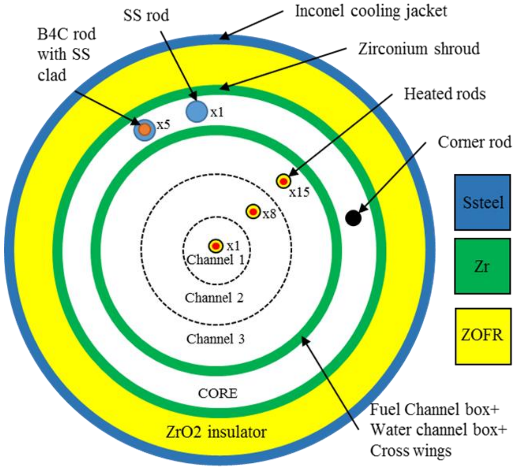


ASTECv2.2_b Model of QUENCH-20

- Geometry of the test difficult to be modelled
- HT Radiation model to be developed

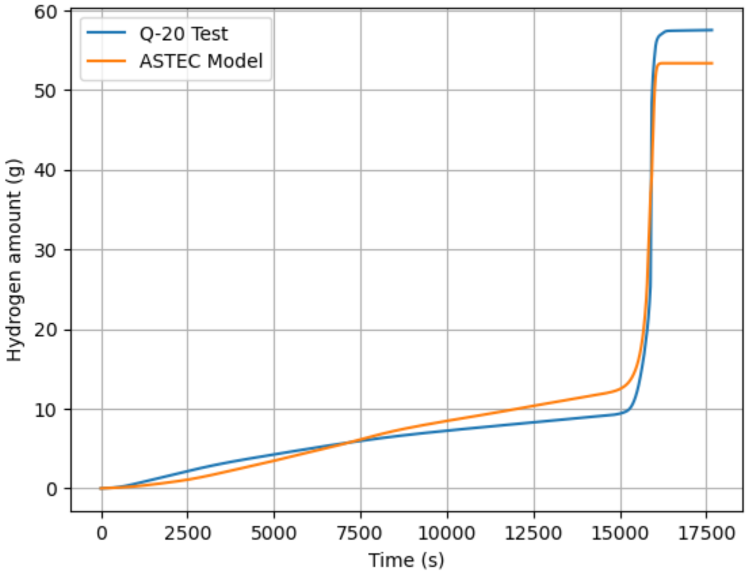






- Canister, shroud, and absorber blades represented as cylindrical structures in ICARE.
- Heated rods in ASTEC-model are described one by one in order to assess the power levels correctly in each channel.
- Zircaloy-4 MDB data employed

Results for QUENCH-20: H2 Production



	Experiment	ASTECv2.2_b
Total H2 (g)	**57.4**	**53.4**
H2 from B_4C Oxidation (g)	**10**	**9.48**

Evaluation of the ST during Selected Severe Accident Scenarios in a generic KONVOI NPP

- Evaluation of the Source Term in NPPs
  - Severe Accident integral codes (Application, Development, V&V)
  - Emergency Management

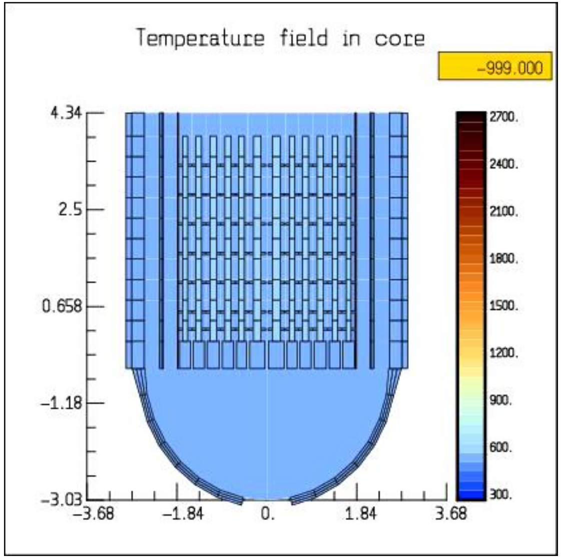
- EU Management and Uncertainties of Severe Accidents (MUSA) project
  - The ASTEC/URANIE platform employed at KIT for generic KONVOI NPP
- WAME Project (in cooperation with Framatome Erlangen and financed by BMWi)
  - PhD work: development of a novel real-time program system to improve decision making in severe accident events in nuclear power plants
  - Internal/external measurement data and ST database computed by ASTEC/FSTC, generic KONVOI NPP being used
  - Application of ASTEC/JRODOS to SAs in VVER-1000

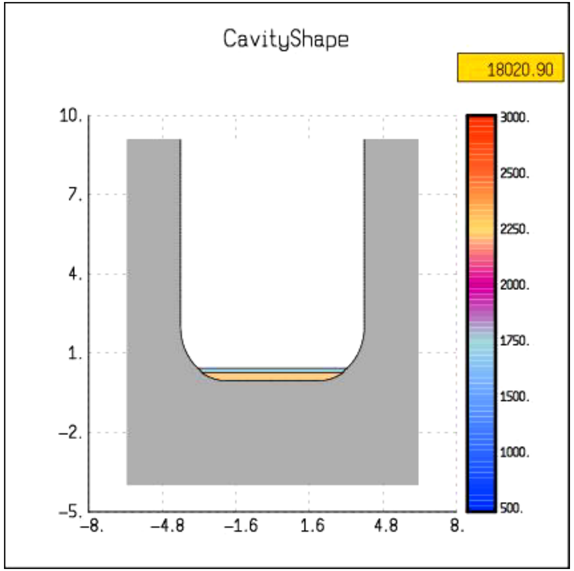
Severe Accident Scenarios Investigated

- MBLOCA (12”) and SBLOCA (2”)
  - Break of the cold leg @t=0 s
  - SCRAM if Primary pressure <132 bar or containment overpressure > 30 mbar
  - Emergency Core Cooling System (ECCS) activated if two of the following three conditions are fulfilled: containment overpressure >30 mbar, RCS pressure <110 bar or pressurizer liquid level< 2.30 m
  - Main Coolant Pumps (MCPs) coasted down and the pressure regulation in the pressurizer is switched off
  - Activation of the Emergency Feed Water System (EFWS) when the liquid level of one SG falls below 4.50 m
  - HPIS (SBLOCA) and LPIS (MBLOCA) activated (T_gas in the primary > 650 °C) up to the tanks are empty → entering the SA
- MBLOCA (12”) and SBLOCA (2”) +SBO
  - AC loss @t=0 s
  - As above but only accumulator discharge available

Results

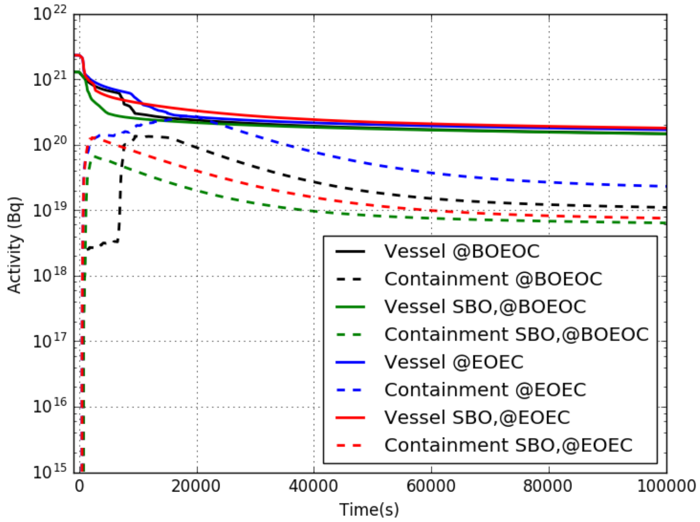
- For each scenario:
- Two fuel inventories employed @BOEC and @EOEC (effect of difference decay heat and initial FP inventory on the ST)
- ASTEC V2.2_b version employed



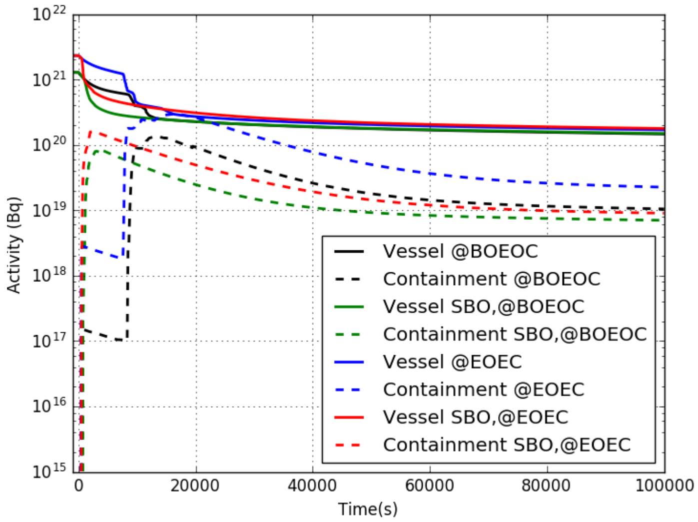


Results: Activity in the Core and in the Containment

MBLOCA



SBLOCA



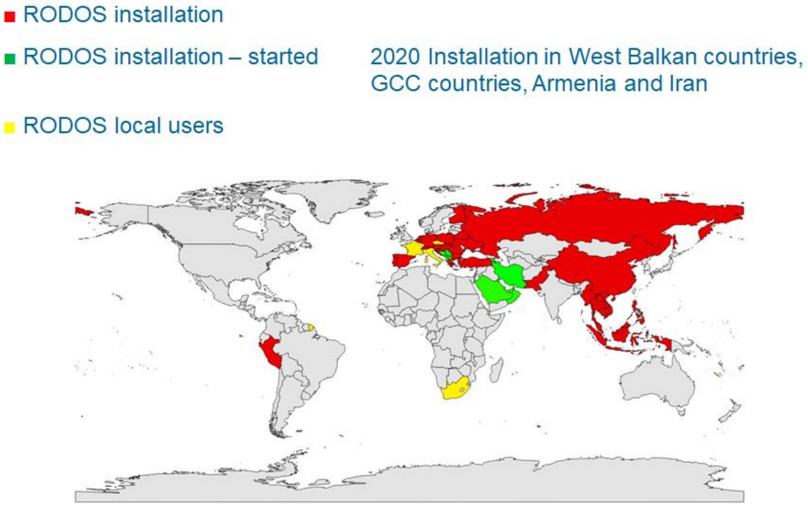
- Significant amount of the activity in the vessel transported to the containment.
- Effect of different inventories seems to be dominant.

ASTEC/JRODOS Analysis for a generic VVER-1000 NPP

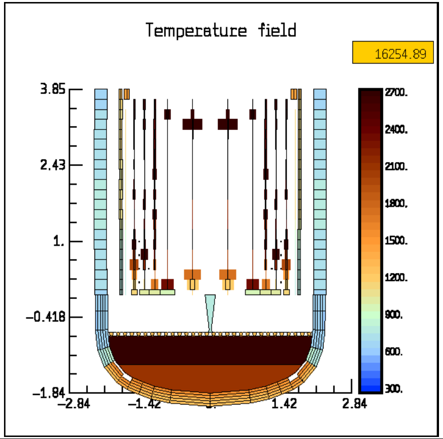
- ASTEC: Severe accident modelling of VVER-1000
  - In-vessel phenomena
    - Loss of water inventory
    - Oxidation and hydrogen generation
    - Loss of safety barriers
  - Ex-vessel phenomena
    - MCCI process
    - Gas generation and containment gas inventory change
    - Basemat rupture
  - FP release and transport estimation
    - FP release from vessel to primary
    - FP transport to the containment
    - FP release to the environment
- JRODOS: Radiological dispersion
  - Release history and inventory
  - Weather and site information
  - Total deposition and dose rate

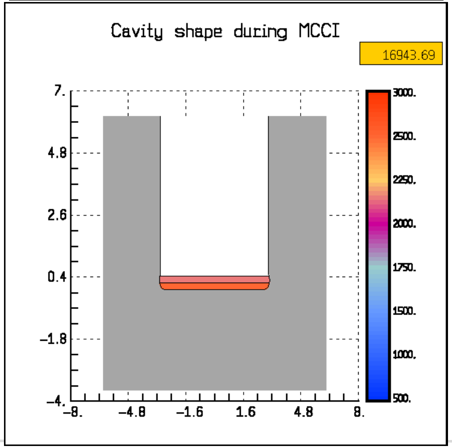
JRODOS (real time online decision support system)

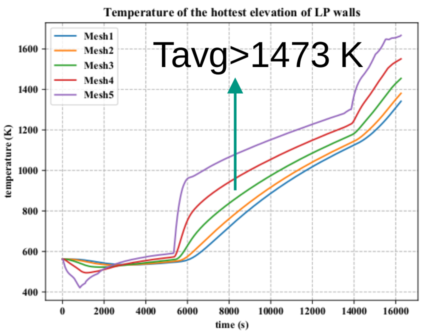
- JRODOS is used operational in many European countries and since more than 15 years in Germany
- It is installed – partly with the support of the European Commission – in about 40 countries worldwide
- Ongoing installations are in the ASEAN countries, six Gulf states, six West-Balkan states, Armenia and Iran



LBLOCA with SBO: RPV failure & sequence of events







Temperature of 4th axial mesh of LP

Parameter	ASTEC model
H2 mass produced during the in-vessel phase (kg)	357.62
H2 mass produced during the MCCI (kg)	641.51
Melted material mass at lowerplenum at in-vessel phase(t)	73.6
Produced aerosol mass during in-vessel phase (kg)	15354.7

Event Chronology	ASTEC model
Event	**Time(s)**
Opening of a break (850 mm)	0
Reactor Scram	0
MCPs are stopped	0
Turbine trip	1.6
Feedwater flows stop	5
Start of accumulators	12.9
Accumulator depletion	97.10
Core uncovery	517.31
Start of FP release	533.88
Start of structural material release	764.15
First material slump at LP	764.15
First slump of corium with FPs in lower plenum	827.72
Loss of water inventory	1693.82
RPV lower head failure	16254.8

Paths for the Fission products to reach the Containment

- Early: after fuel rod failure through the break

VESSEL → PRIMARY → SG-BOX → CONTAIN MENT

FP transport by carrier fluids

Deposition and retention of FPs

Release through the break

Dispersion inside the containment

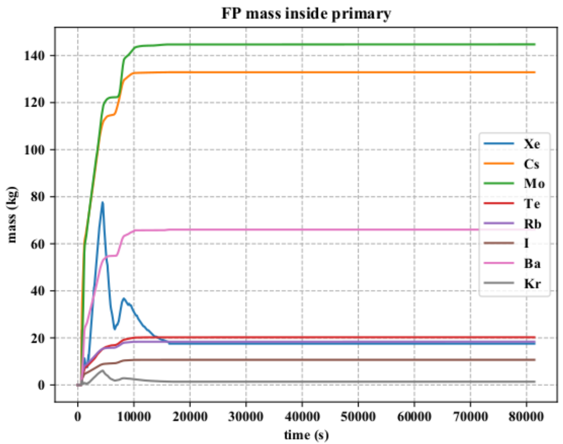
- Late: after the RPV failures

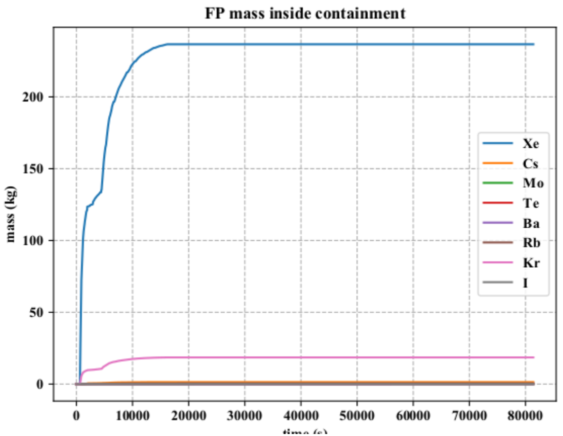
VESSEL → CAVITY → CONTAIN MENT

Vessel collapse

MCCI and gas generation

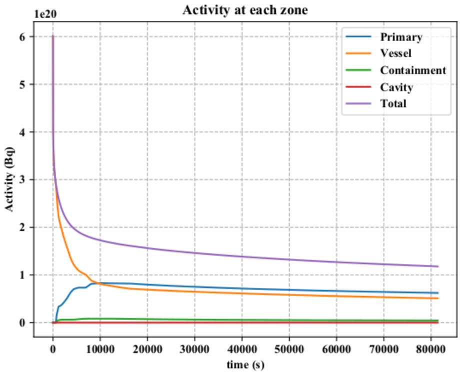
LBLOCA with SBO: Fission Products: at 80 000 s





Remarks:

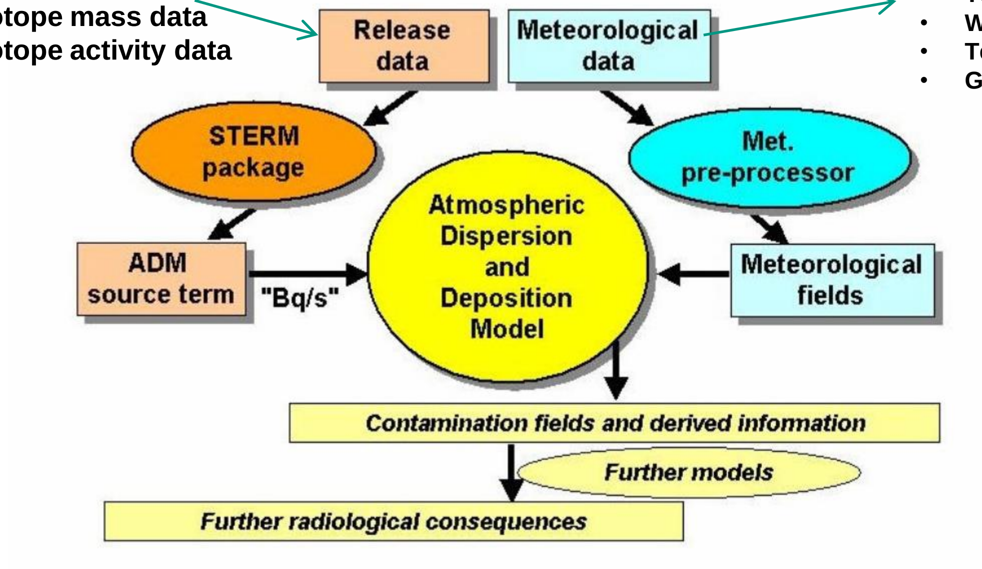
- Fission products mostly stay inside the primary circuit.
- After RPV fail, FP transported to cavity especially heavier elements such as Ba, Mo and Te.
- Most of the amount of lighter elements such as Rb, Cs and I have already retended before RPV failure.



VVER-1000: Radiological Dispersion by JRODOS

Supported by ASTEC
- Isotope mass data
- Isotope activity data

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

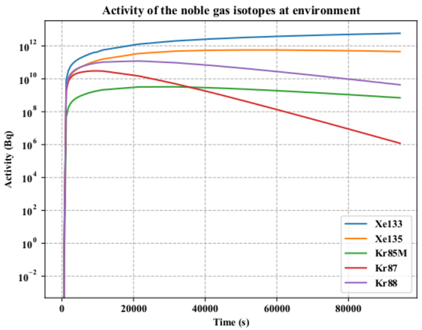


Remarks:
- JRODOS supports location data which include urbanization, population and vegetation data
- Additionally, code support countermeasure variants across world according to their regulations

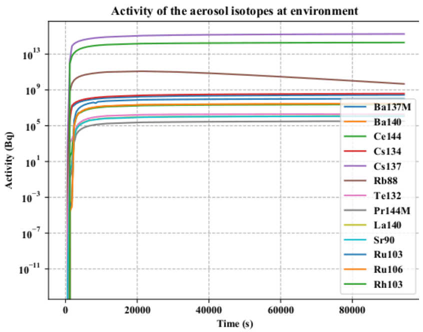
VVER-1000: Radiological Dispersion by JRODOS

Karlsruhe Institute of Technology

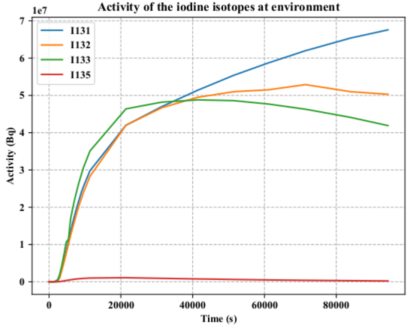
ASTEC OUTPUT → Mass of the isotopes released to the environment → (Radioactive decay calculations) → Activity of the isotopes released to the environment → (Daughter-parent data of some selected isotopes) → JRODOS INPUT



Noble gas activity (in log scale)



Aerosol particle activity (in log scale)



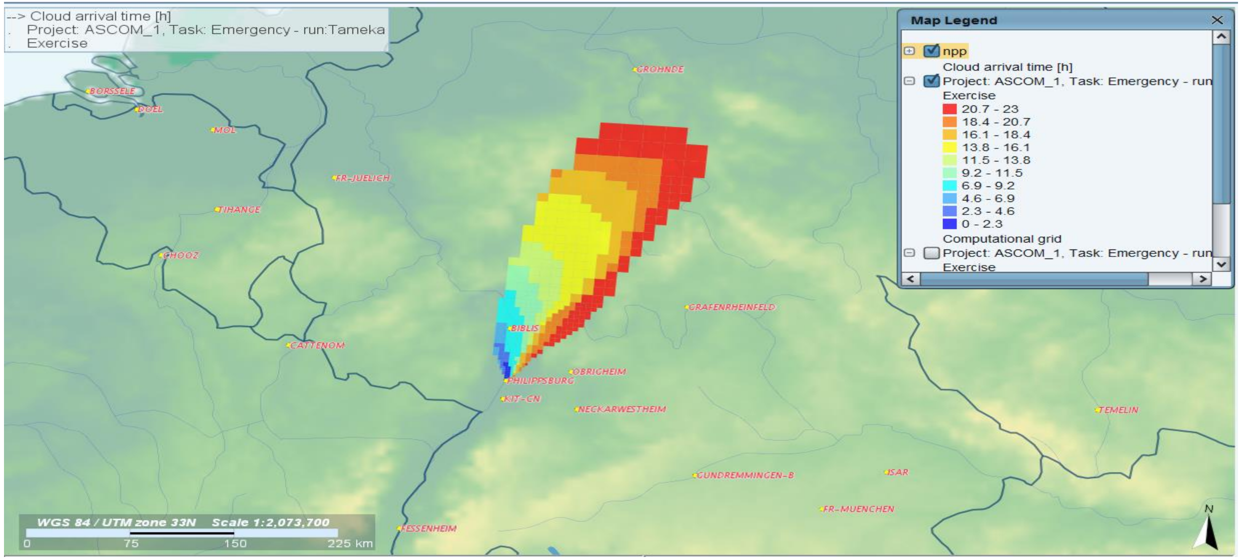
Iodine particle activity (in log scale)

Remarks:

- ASTEC output: released mass of the isotopes
- JRODOS requires activity of the isotopes
- Additionaly, some selected isotopes may require parent/daughter information.

VVER-1000: Radiological Dispersion by JRODOS

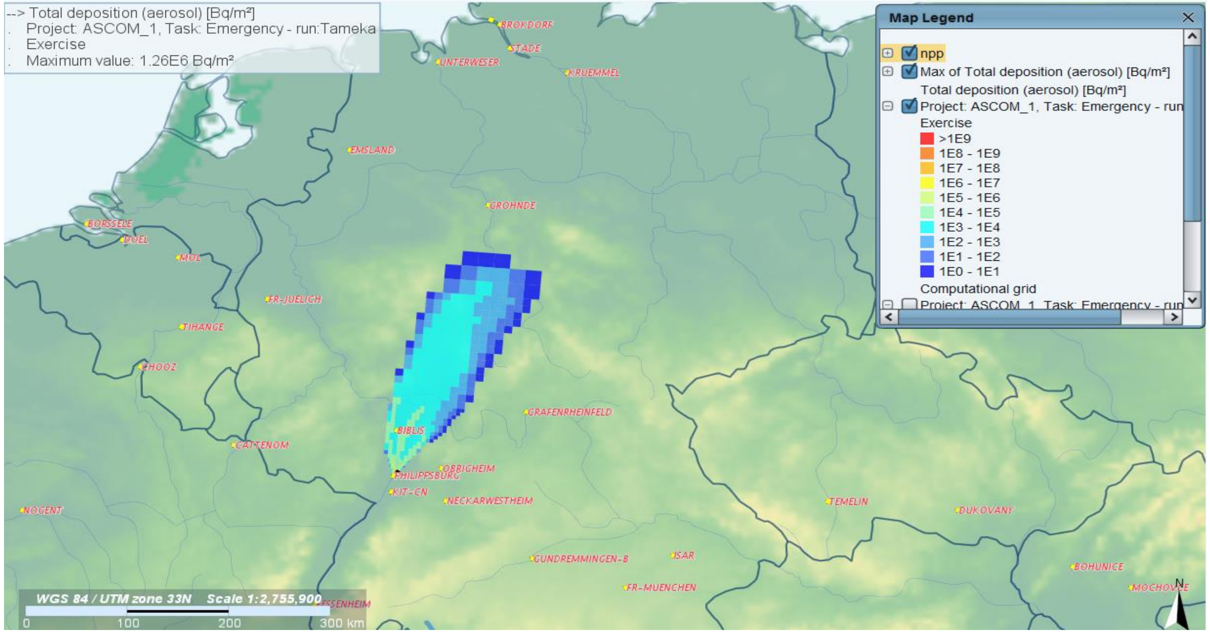
Karlsruhe Institute of Technology



Assumptions:

- Location of Philipsburg NPP is selected for accident location.
- Calculation range is set up to 200 km.
- Total of 23 h weather data is supported

VVER-1000: Radiological Dispersion by JRODOS

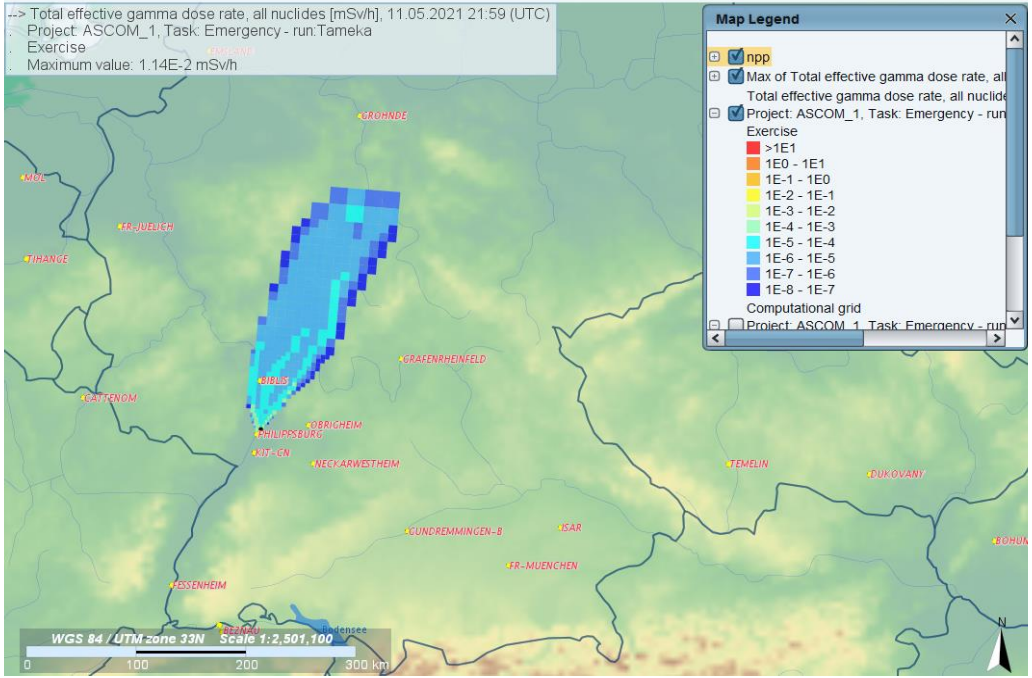


Total deposition:

- Max value of 1.26 MBq/m^2 is calculated for the deposition of aerosols
- Max deposition of iodine is calculated as 0.359 MBq/m^2

International Conference Nuclear Energy for New Europe 2021 September 6 - 9 BLED-SLOVENIA

VVER-1000: Radiological Dispersion by JRODOS



Total effective gamma dose :

- Total effective gamma dose from all nuclides is observed as 1.14E-2 mSv/hr at the first 2 km area.
- In 200 km range, values decreases between 1.E-5 to 1E-6 mSv/hr.

Summary and Outlook

Karlsruhe Institute of Technology

Evaluation of Selected Severe Accident Scenarios in generic NPPs

- Evaluation of the Source Term in NPPs
  - ASTEC Severe Accident integral code (Application, Development, V&V)
- VVER-1000 ASTEC model has been modelled. The sequence of events is obtained, and both in-vessel and ex-vessel phenomena are modelled
- Emergency Management: JRODOS input deck created and radiological dispersion calculated with the output of LBLOCA along with SBO accident for a selected location and time period.
- The ASTEC code shows a rather high stability
- The results provide important insights in view of the activities currently on-going:
  - UQ of the source term
  - Source term database assessment for the application of prediction tools
  - Verification of the latest ASTEC version release (v2.2.0) on-going