MELCOR 1.8.6 Simulation of Severe Accidents Simultaneously Ongoing in the Reactor Core and in the Spent Fuel Pool of the VVER-1000 Type of Reactor

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Simultaneous SAs in the RPV and SFP

- **VVER-1000/320 (Temelin NPP)**
- **IE: SBO at the EOC**
  - **RPV** – 300 EFPDs
    - Total decay heat: **235.5 MW**
  - **SFP** – 340 days since ¼ of core unloaded + older FAs (several years)
    - Total decay heat: **1.261 MW**
- **H₂ mitigation system - PARs**
  - 27x NIS22 (SA)
  - 41x NIS44 (SA)
  - 22x Areva FR90/1-150 (DBA)
- **Spray operation**
  - 1. no spray, 2. CSS, 3. fire spray
- **Simulation duration: 10 days**
Sequencing calculations

- MELCOR: allows only for 1 set of parameters for the COR, DCH, RN etc.
- **2 integral** calculations of SAs:
  - reactor (RPV)
  - spent fuel pool (SFP)
- saving sources (EDF) of
  1. masses
  2. enthalpies
  3. FPs
- **1 stand-alone** calculation of the CTMT response considering the saved sources
1. Integral calculation of SA in RPV

- EDF package
  - ASCII/binary data files
2. Integral calculation of SA in SFP

- EDF package
  - ASCII/binary data files
3. Stand-alone calculation in CTMT

- EDF package
  - ASCII/binary data files
**Issue: FP source (inventory & decay heat)**

- **MELCOR: user input for FPs (DCH)**
  
  **RPV:**
  
  ```
dchnem0300 'Cs' 275.032281
  dchnem0301 0.0 56332.0 0.0018 56323.0 0.028 56195.0 0.142 55658.0
  ```

- **initial inventory**
- **decay heat history**

- **Only 1 DCH input set allowed!**

- **FPs for CTMT *stand-alone* calculation – DCH input for:**
  
  1. **SFP** (sources of $M$ and *DCH* of FPs from the *integral* SFP simulation are **correct**)
     
     - FP sources from the *integral* RPV simulation are
     
     1. left as they are => *mass* is correct, *decay heat* is too low
     2. multiplied by an *appropriate factor* => *mass* is too high, *decay heat* is correct
  
  2. **RPV** (sources of $M$ and *DCH* of FPs from the *integral* RPV simulation are **correct**)
     
     - FP sources from the *integral* SFP simulation are
     
     1. left as they are => *mass* is correct, *decay heat* is too high
     2. multiplied by an *appropriate factor* => *mass* is too low, *decay heat* is correct
FP source – *appropriate factor (max. release)*

\[ \frac{DCH_{RPV\_class\#\_@max\text{-}release}}{DCH_{SFP\_class\#\_@max\text{-}release}} \]

*Example:* release of class #2 – alkali metals (Li, Na, K, Rb, Cs, Fr, Cu)

RPV *integral* analysis:

\[ t = 3.84 \text{ h} \]
FP source – *appropriate factor (ratio)*

- \( \frac{DCH_{\text{RPV,cl#2}}}{DCH_{\text{SFP,cl#2}}} \)

**Example:** release of class #2 – alkali metals (Li, Na, K, Rb, Cs, Fr, Cu)

**RPV integral analysis:**

- \( t = 3.84 \text{ h} \)
- \( DCH_{\text{RPV,cl#2}} = 1114 \text{ W/kg} \)
- \( R = \frac{1114}{351.5} = 3.17 \)

**SFP integral analysis:**

- \( t = 340 \text{ d} \)
- \( DCH_{\text{SFP,cl#2}} = 351.5 \text{ W/kg} \)
RPV model – FAs & FPs distribution

![Diagram of RPV model with radial and axial levels, showing distribution of FAs and FPs.](image)
RPV model – overall nodalization
RPV model – CVs + core cells
RPV model – core cells + FU
RPV model – core cells + FU + CL
RPV model – core cells + FU + CL + SS
RPV model – core cells + NS
SFP model – situation

B02

B01  B03

0.721 MW  0.540 MW
SFP model – FAs distribution (B02)
SFP model – FAs distribution (B01)
SFP model – FAs distribution (B03)
## SFP model – FPs distribution

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### Radial ring # [-]

- B02: 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00
- B01: 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00
- B03: 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00, 0.00E+00
SFP model – overall nodalization
### SFP model – CVs + core cells

| 9184 mm | 20 |
| 8844 mm | 19 |
| 8627 mm | 18 |
| 8522 mm | 17 |
| 8335 mm | 16 |
| 8080 mm | 15 |
| 7825 mm | 14 |
| 7570 mm | 13 |
| 7315 mm | 12 |
| 7060 mm | 11 |
| 6805 mm | 10 |
| 6550 mm | 9  |
| 6295 mm | 8  |
| 6040 mm | 7  |
| 5785 mm | 6  |
| 5523 mm | 5  |
| 5220 mm | 4  |
| 5002 mm | 3  |
| 4947 mm | 2  |
| 4642 mm | 1  |

| 4047 mm | 20.7 m |
| 2022 mm |       |
| 1424 mm |       |

**B02**

**B01**

**B03**
SFP model – core cells + FU
SFP model – core cells + FU + CL
SFP model – core cells + FU + CL + SS
SFP model – core cells + NS
SFP model – core cells + CN
Detailed CTMT model (138 CVs)

- +6.6 m
- +13.2 m
- +16.8 m
- +19.4 m

- +25.7 m
- +33.6 m
- +36.9 m

reactor hall section
RPV accident progress: 0.05 h (1/11)

- Situation right after reactor shutdown – intact core, full water inventory
RPV accident progress: 1.67 h (2/11)

- Water level decrease due to boil-off, still before PC depressurization
Onset of core components degradation, right after PC depressurization (water inlet)
RPV accident progress: 2.85 h (4/11)

- Water inventory make-up thanks to HAs, high void fraction visible (intensive boiling)
RPV accident progress: 3.81 h (5/11)

- Water inventory already boiled off, massive debris formation
RPV accident progress: 4.50 h (6/11)

- Core debris relocation, molten pools formation
RPV accident progress: 4.63 h (7/11)

- Debris relocation into LP – right after core support plate collapse
RPV accident progress: 5.03 h (8/11)

- Debris and metallic molten pools within LP, no remaining water
RPV accident progress: 7.35 h (9/11)

- Debris, metallic and also oxidic molten pools within LP
RPV accident progress: 8.38 h (10/11)

- Material relocation from LP – right after RPV LH failure
RPV accident progress: 228 h (11/11)

- End of calculation – last remnants of debris gone from LP
SFP accident progress: 0.0 d (1/4)

- Initial SFP state shortly after the IE
SFP accident progress: 7.4 d (2/4)

- Ongoing FAs uncovery in the B01 pool
SFP accident progress: 9.1 d (3/4)

- Further decrease of water level in the B01 pool
• End of calculation – $H_2$ production start in B01, FAs in B03 start to uncover
CTMT response: pressure

~ units of days

~ hundreds of kPa

no spray

fire spray

CSS
CTMT response: temperature (in RH)

- No spray
- Fire spray
- CSS

~ lower hundreds of °C

~ units of days
CTMT response: $\text{H}_2$ concentration (in RH)
CTMT response: Shapiro diagram (in RH)

σ criterion (FA) – fulfilled just after RPV melt-through in the tunnel connecting GA301 to GA302

λ criterion (DDT) – not fulfilled

- no spray
- fire spray
- CSS
Conclusions (RPV + SFP)

- **Simulation of simultaneous SAs in RPV & SFP is feasible**
  - using the MELCOR *EDF* module *and*
  - properly defining sources into the CTMT of
    - mass
    - enthalpy
    - FP

- **Attention must be paid to DCH module definition**
  - in order to obtain correct FP *masses* or *decay heat*

- **Careful scenario definition – timing**
  - EOC – more conservative from the point of view of FPs in the core
  - BOC – better concurrence of SAs expected
Conclusions (other matters)

- **MCAP-2015 opened issues**
  - CORijjDX record
    - PD axial relocation through *intact CN/levels with DX=1.0*; VFALL influence
  - LH/penetration failure
    - Logical CF defined as ICFLHF does *not* trigger failure
  - Differed restart
    - Calculation is not the same when restarting from MELRST
  - PD/MP2 mass oscillation
    - Unrealistic & unphysical switching between *particulate debris/metallic molten pool*

- **HSs sequencing during 1.8.6 => 2.1 conversion (film tracking)**
  - M 1.8.6 – “donor” and “acceptor” defined explicitly for HSs
  - M 2.1 – “donor” and “acceptor” stem from HSs ordering
  - **But!** SNAP re-orders the HSs according to their numbers, which may be in contradiction with the film flow direction
Thank You for Your Attention