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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UJV Rez

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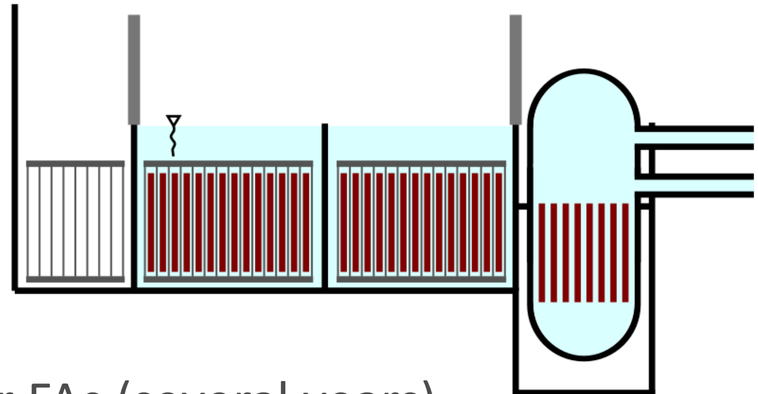
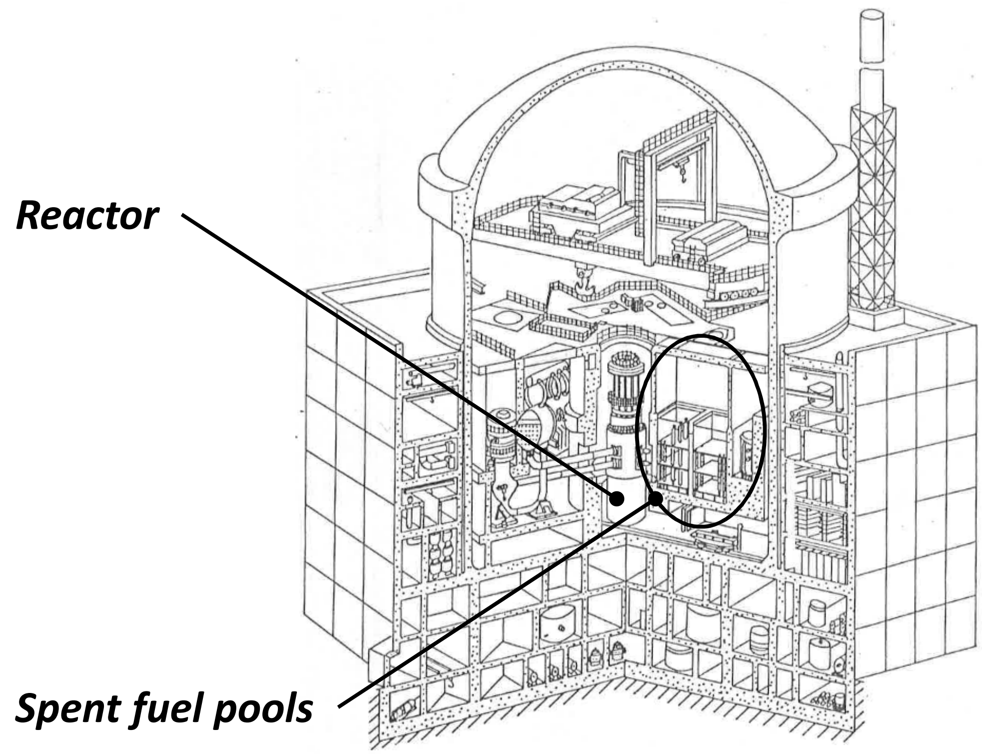
Simultaneous SAs in the RPV and SFP

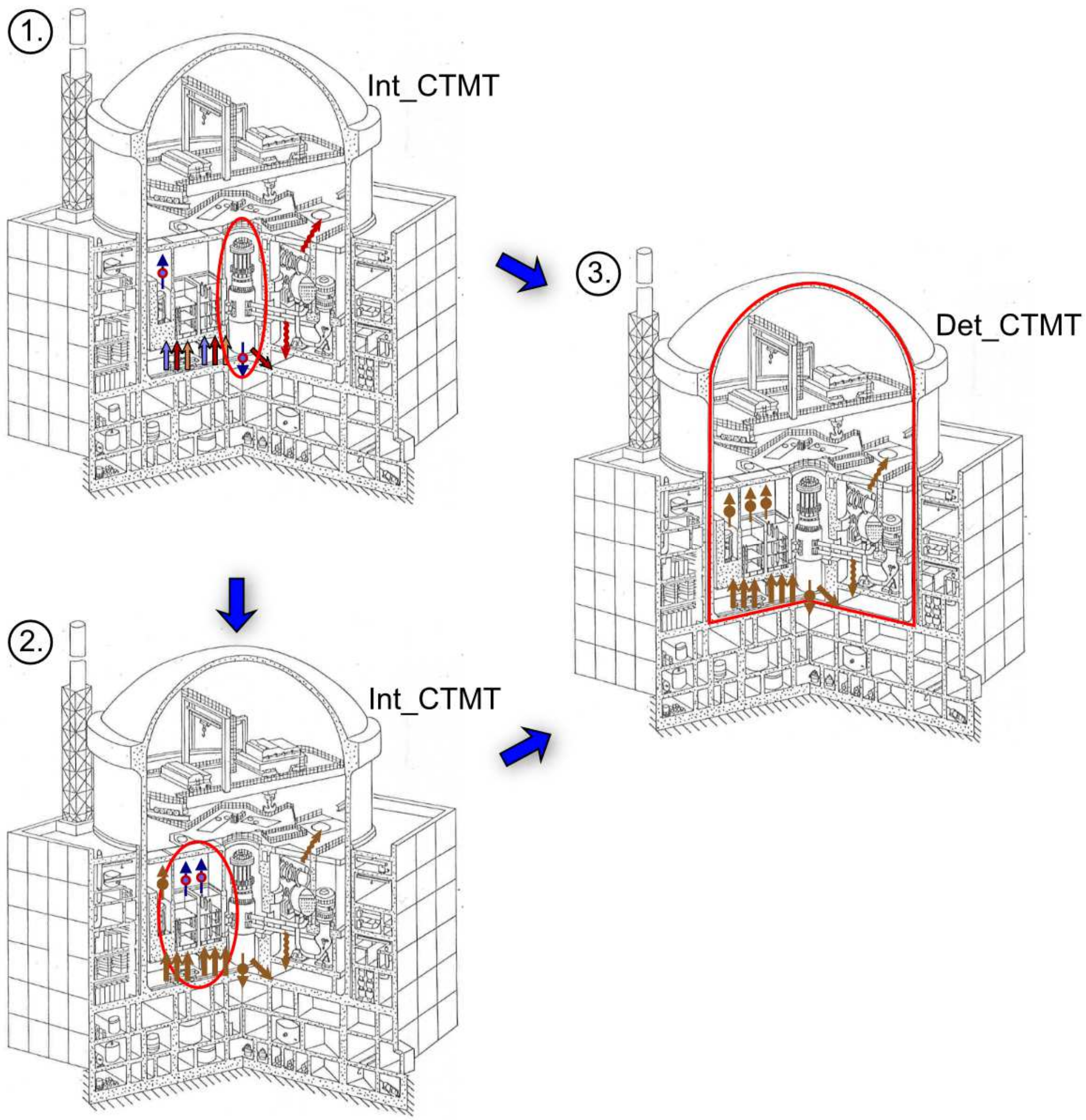


- **VVER-1000/320 (Temelin NPP)**
- **IE: SBO at the EOC**
  - **RPV** – 300 EFPDs
    - **Total decay heat: 235.5 MW**
  - **SFP** – 340 days since ¼ of core unloaded + older FAs (several years)
    - **Total decay heat: 1.261 MW**
- **H_2 mitigation system - PARs**
  - 27x NIS22 (SA)
  - 41x NIS44 (SA)
  - 22x Areva FR90/1-150 (DBA)
- **Spray operation**
  - 1. no spray, 2. CSS, 3. fire spray
- **Simulation duration: 10 days**



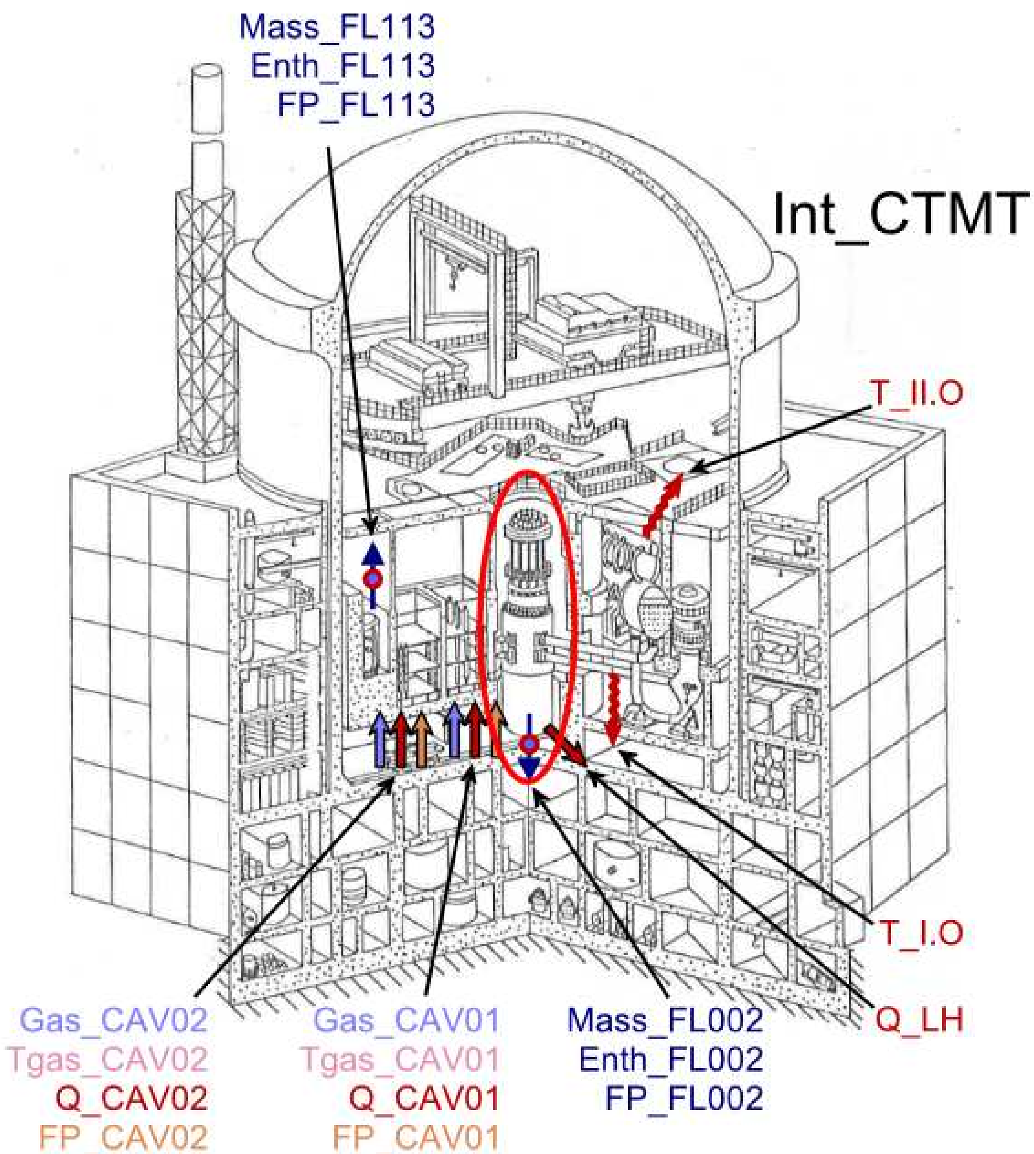
Sequencing calculations

- **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**



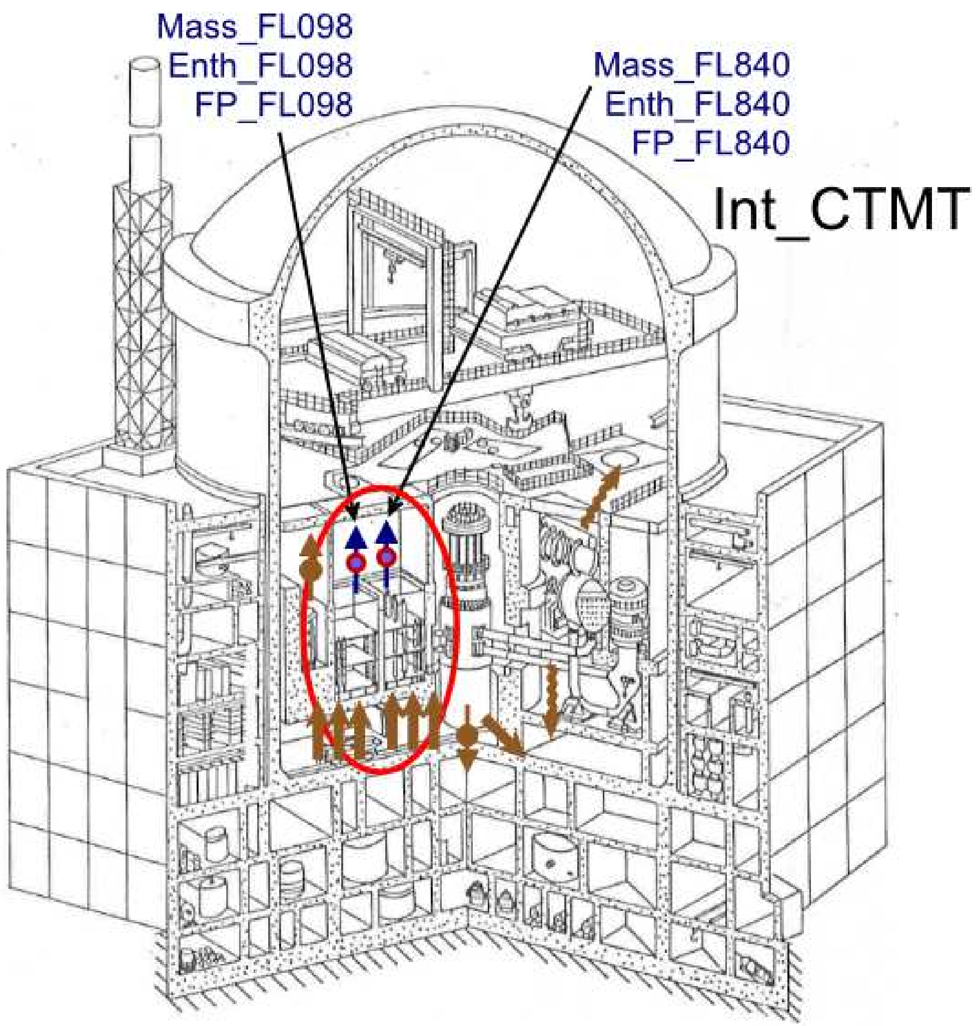
1. Integral calculation of SA in RPV

- **EDF package**
  - ASCII/binary data files



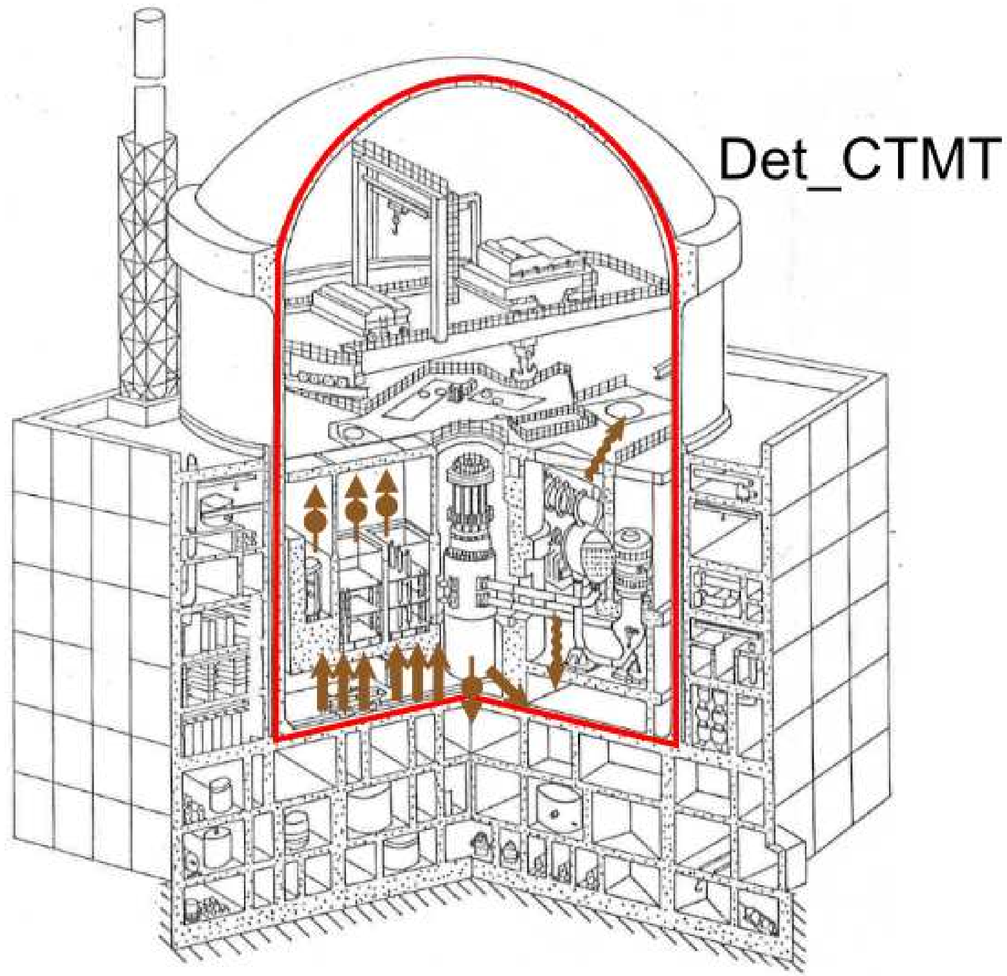
2. Integral calculation of SA in SFP

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

RPV:

```
dchnem0300 'Cs' 275.032281
dchnem0301 0.0 56332.0 0.0018 56323.0 0.028 56195.0 0.142 55658.0
```

IE: at SCRAM

SFP:

```
dchnem0300 'Cs' 705.373230
...
dchnem0349 28638169.452 397.16 29034540.786 396.15 29433636.323 395.13
```

IE: ~340 days from shutdown

- **Only 1 DCH input set allowed!**
- **FPs for CTMT *stand-alone* calculation – DCH input for:**

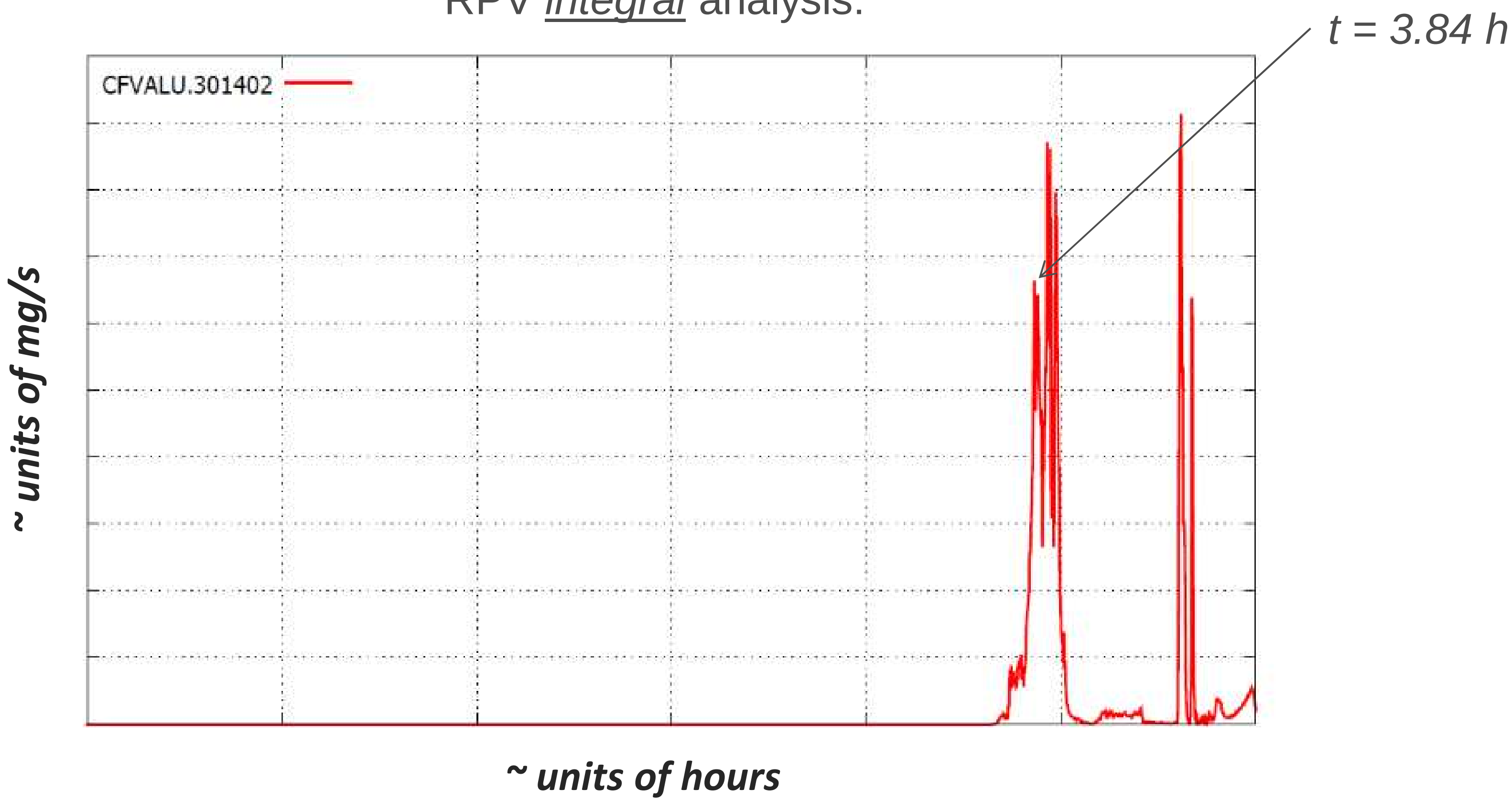
1. **SFP** (sources of ***M*** and ***DCH*** of FPs from the *integral* **SFP** simulation are **correct**)
   - FP sources from the *integral* RPV simulation are
     1. left as they are => ***mass*** is **correct**, ***decay heat*** is **too low**
     2. multiplied by an *appropriate factor* => ***mass*** 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)*

- $DCH_{RPV\_class\#\_@max\text{-}release}$ / $DCH_{SFP\_class\#\_@max\text{-}release}$

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

RPV *integral* analysis:

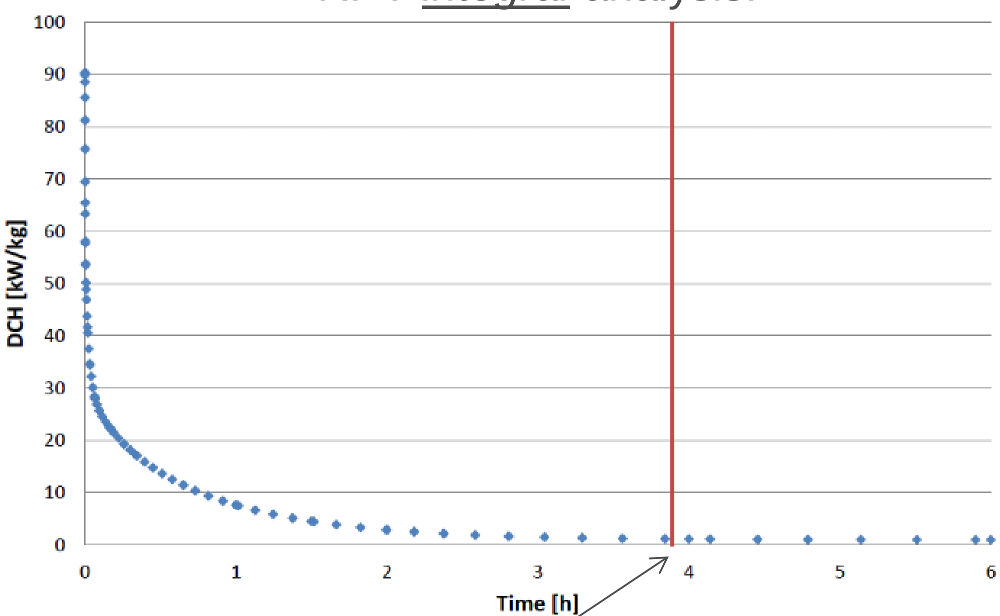


FP source – *appropriate factor (ratio)*

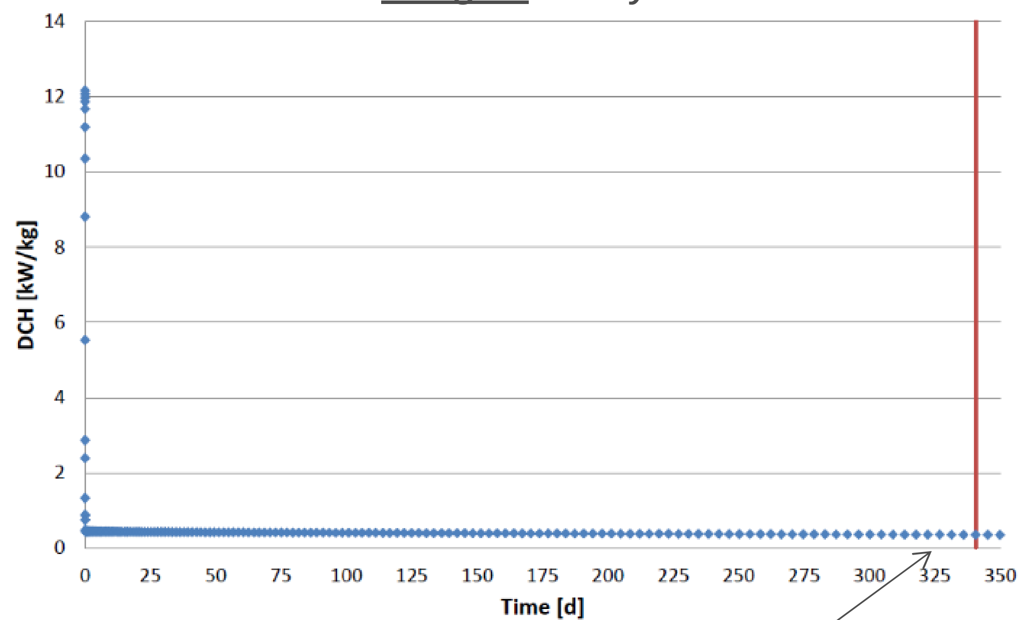
- $DCH_{RPV\_class\#\_@max\text{-}release}$ / $DCH_{SFP\_class\#\_@max\text{-}release}$

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

RPV *integral* analysis:



SFP *integral* analysis:



t = 3.84 h

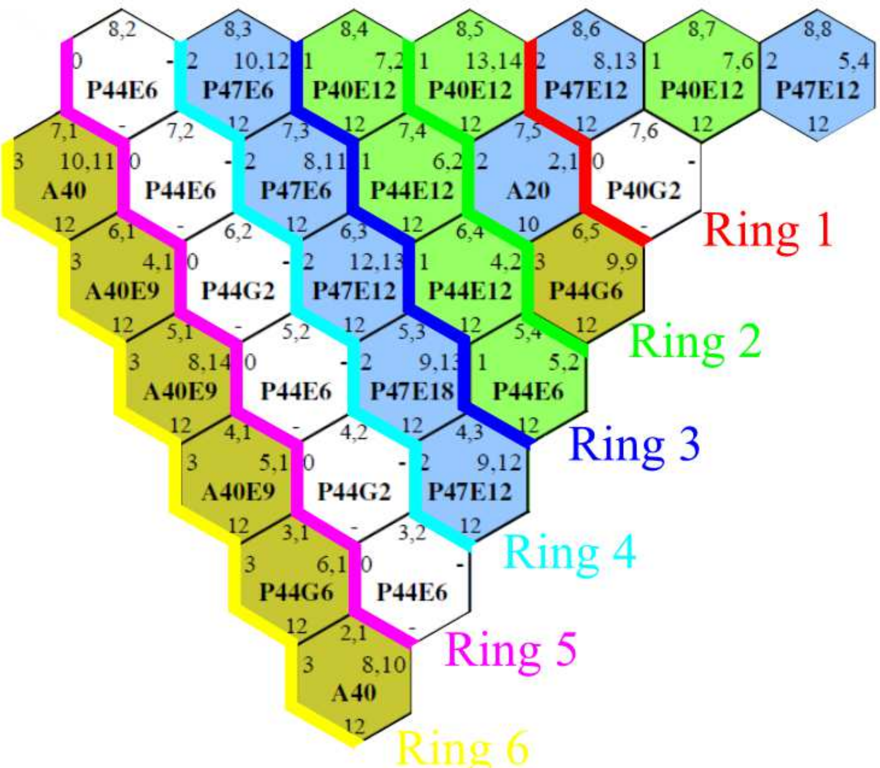
$DCH_{RPV,cl\#2}$ = 1114 W/kg

R = 1114/351.5 = 3.17

t = 340 d

$DCH_{SFP,cl\#2}$ = 351.5 W/kg

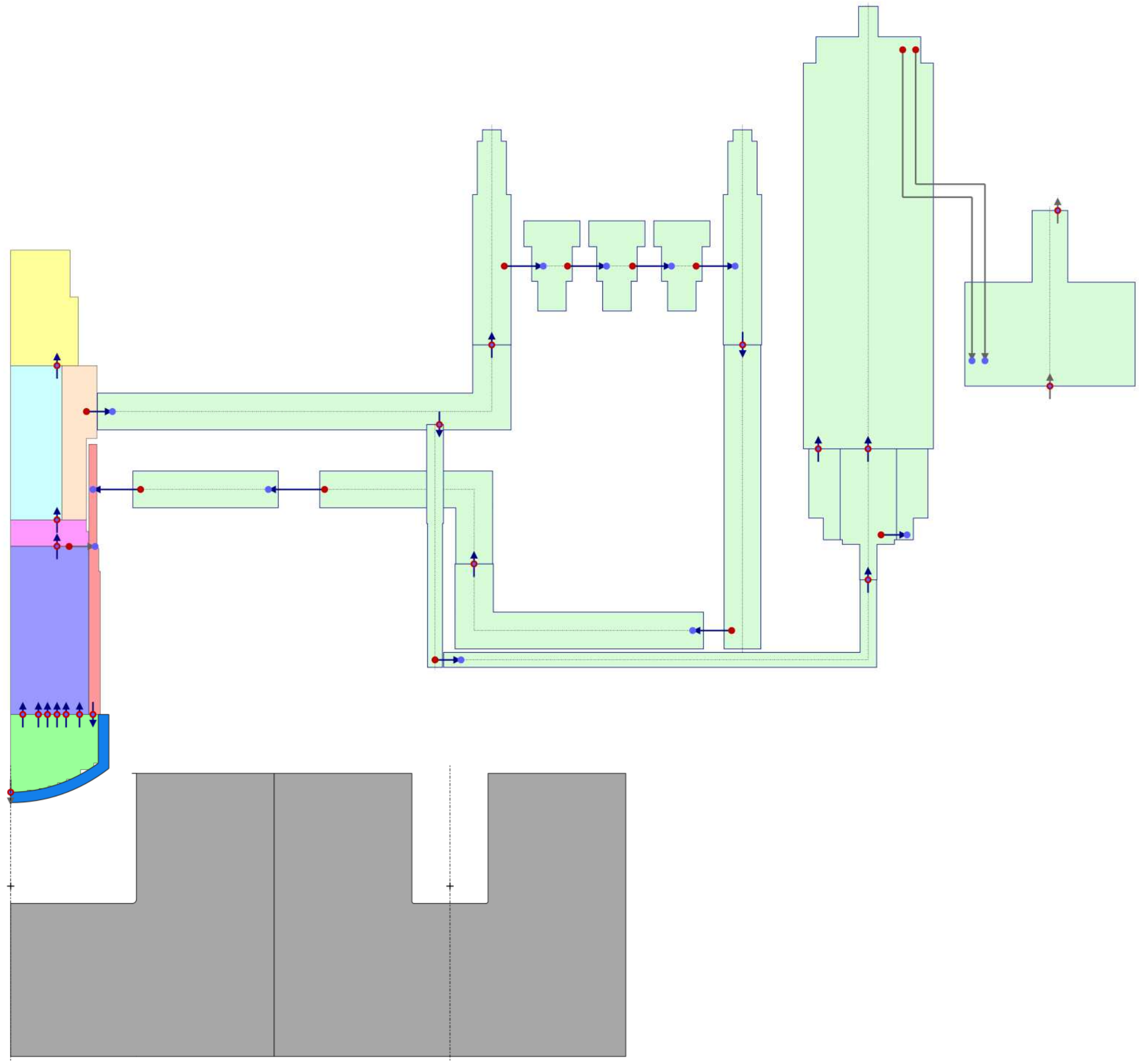
RPV model – FAs & FPs distribution



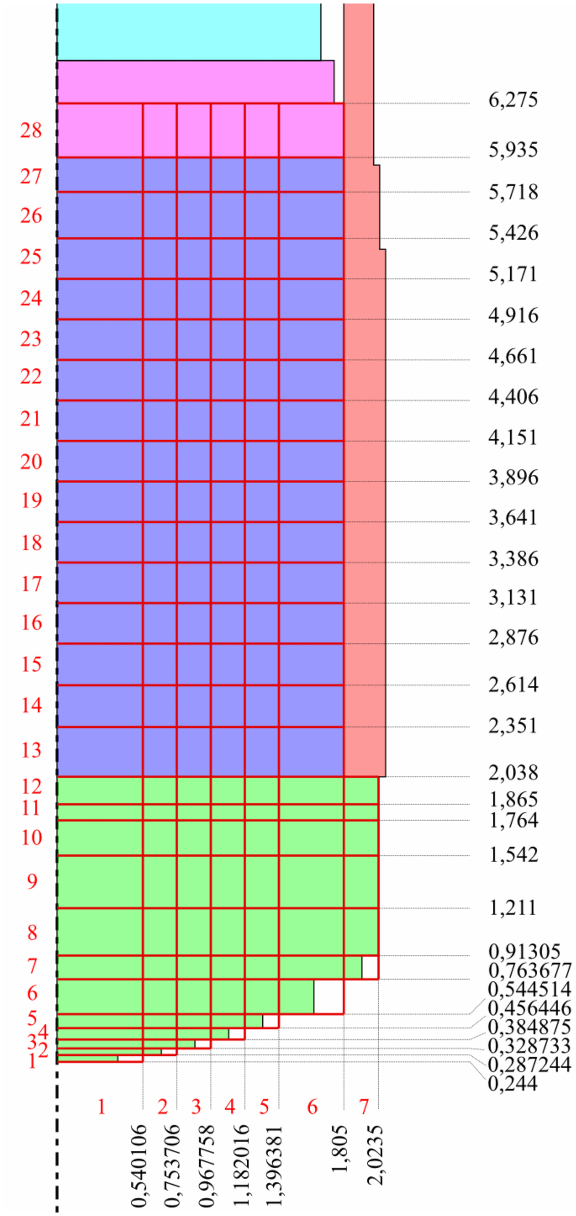
Radial ring # [-] (columns); Axial level # [-] (rows)

Axial level # [-]	1	2	3	4	5	6	7
28	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
26	4.46E-03	3.53E-03	5.75E-03	6.09E-03	9.59E-03	5.23E-03	
25	9.87E-03	7.81E-03	1.27E-02	1.35E-02	2.12E-02	1.16E-02	
24	1.11E-02	8.78E-03	1.43E-02	1.52E-02	2.39E-02	1.30E-02	
23	1.10E-02	8.72E-03	1.42E-02	1.51E-02	2.37E-02	1.29E-02	
22	1.05E-02	8.27E-03	1.35E-02	1.43E-02	2.25E-02	1.23E-02	
21	9.92E-03	7.85E-03	1.28E-02	1.36E-02	2.13E-02	1.16E-02	
20	9.47E-03	7.49E-03	1.22E-02	1.29E-02	2.04E-02	1.11E-02	
19	9.25E-03	7.32E-03	1.19E-02	1.26E-02	1.99E-02	1.09E-02	
18	9.27E-03	7.34E-03	1.20E-02	1.27E-02	1.99E-02	1.09E-02	
17	9.52E-03	7.53E-03	1.23E-02	1.30E-02	2.05E-02	1.12E-02	
16	9.90E-03	7.84E-03	1.28E-02	1.35E-02	2.13E-02	1.16E-02	
15	1.02E-02	8.10E-03	1.32E-02	1.40E-02	2.20E-02	1.20E-02	
14	9.52E-03	7.53E-03	1.23E-02	1.30E-02	2.05E-02	1.12E-02	
13	4.68E-03	3.71E-03	6.04E-03	6.40E-03	1.01E-02	5.50E-03	
12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
4	0.00E+00	0.00E+00	0.00E+00	0.00E+00			
3	0.00E+00	0.00E+00	0.00E+00				
2	0.00E+00	0.00E+00					
1	0.00E+00						

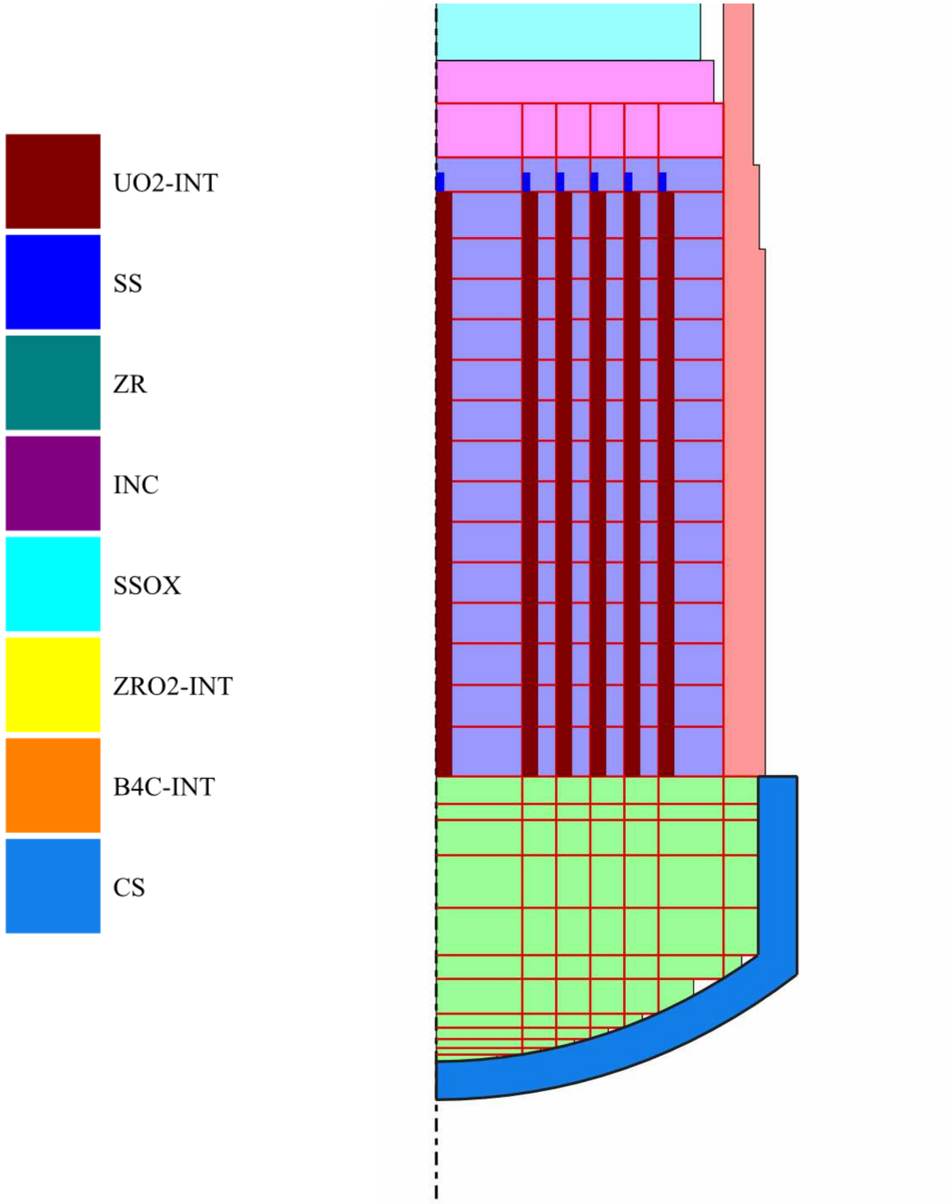
RPV model – overall nodalization



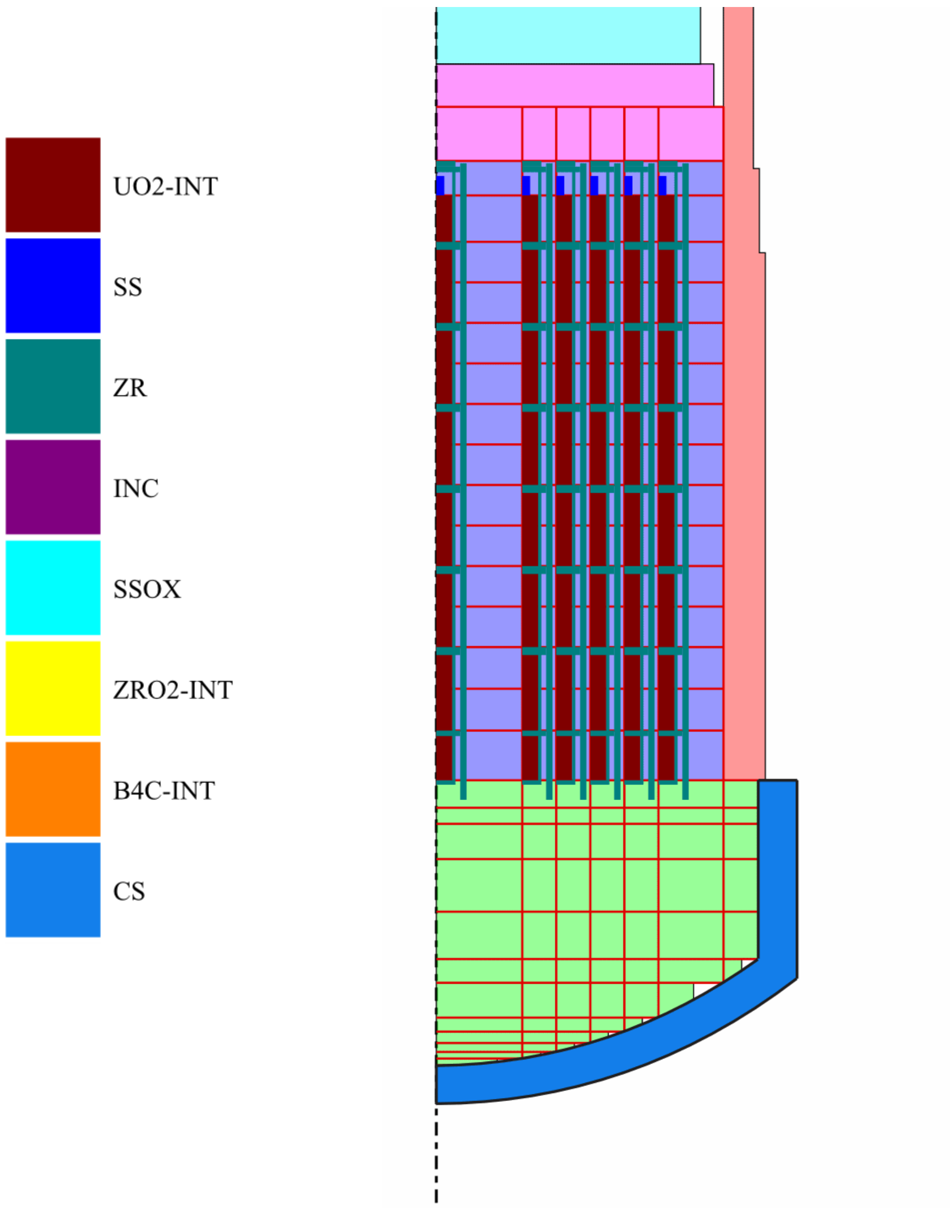
RPV model – CVs + core cells



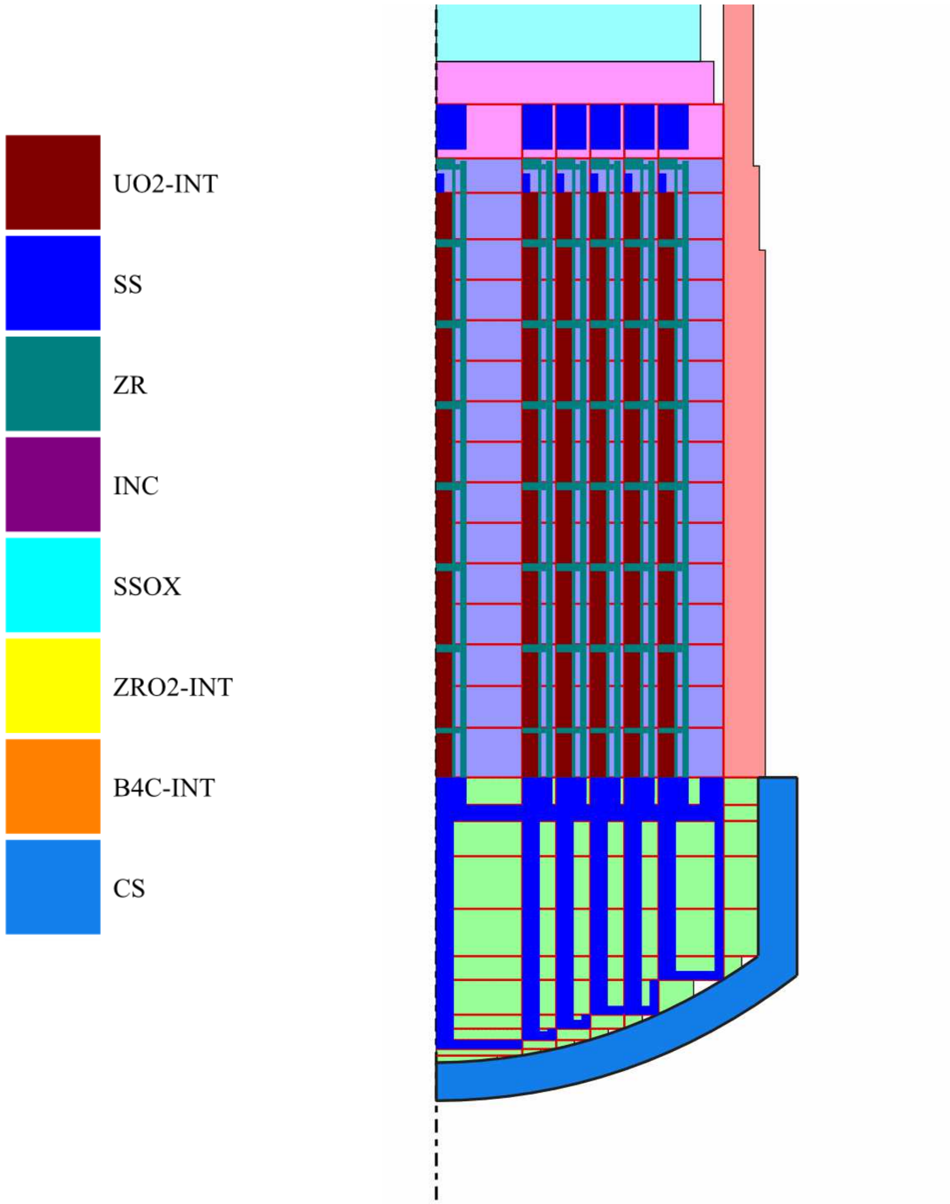
RPV model – core cells + FU



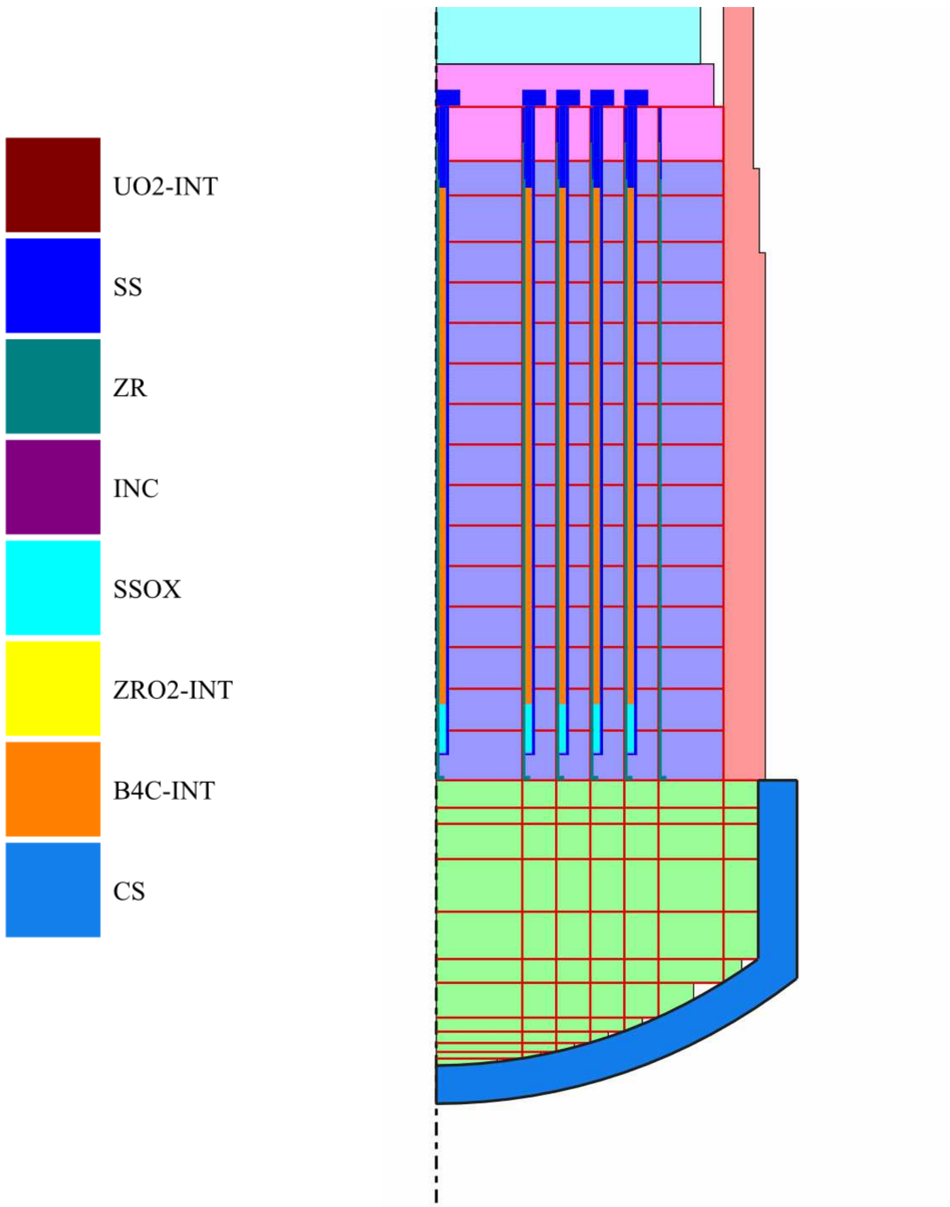
RPV model – core cells + FU + CL



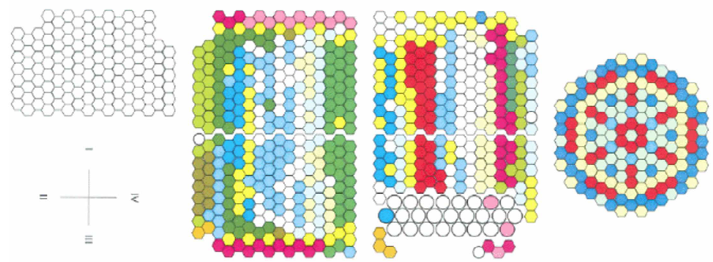
RPV model – core cells + FU + CL + SS

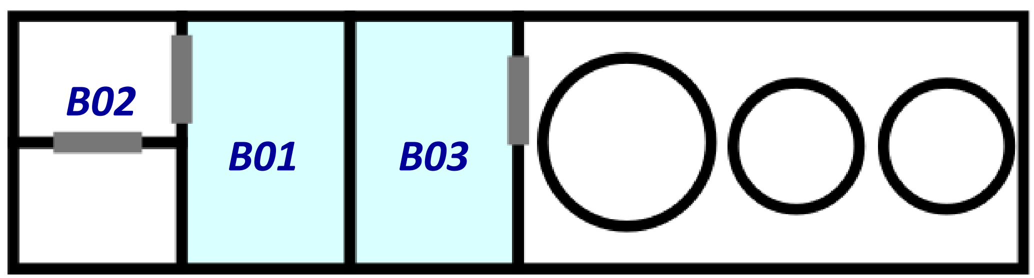


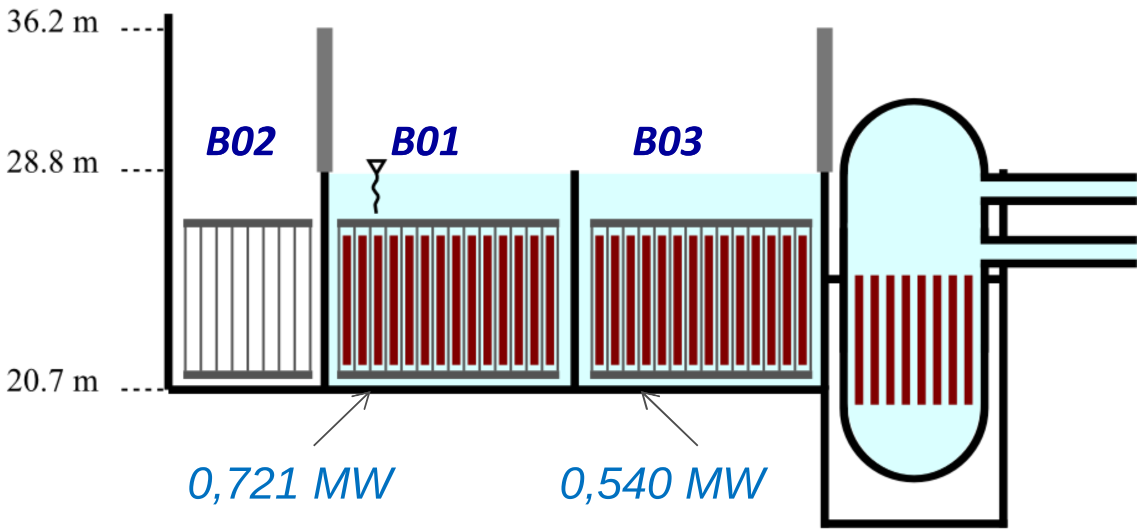
RPV model – core cells + NS



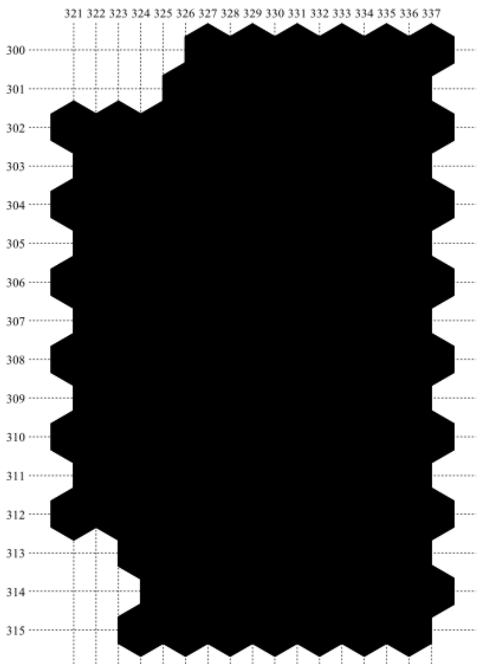
SFP model – situation

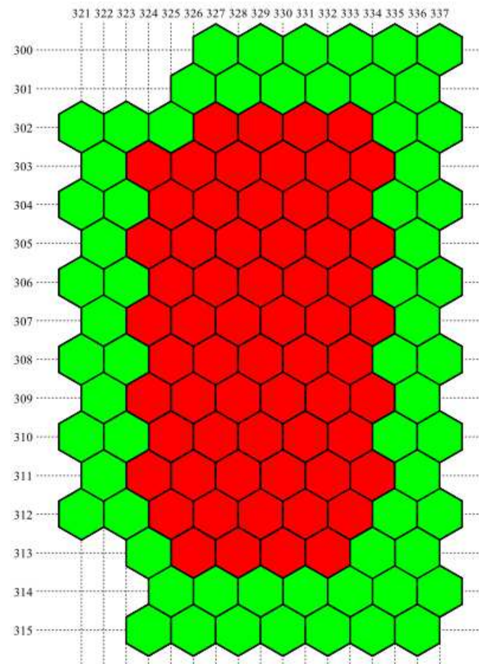


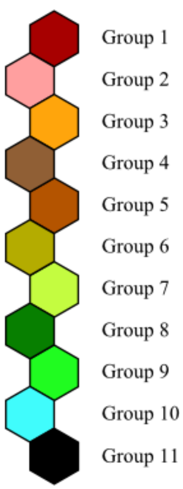


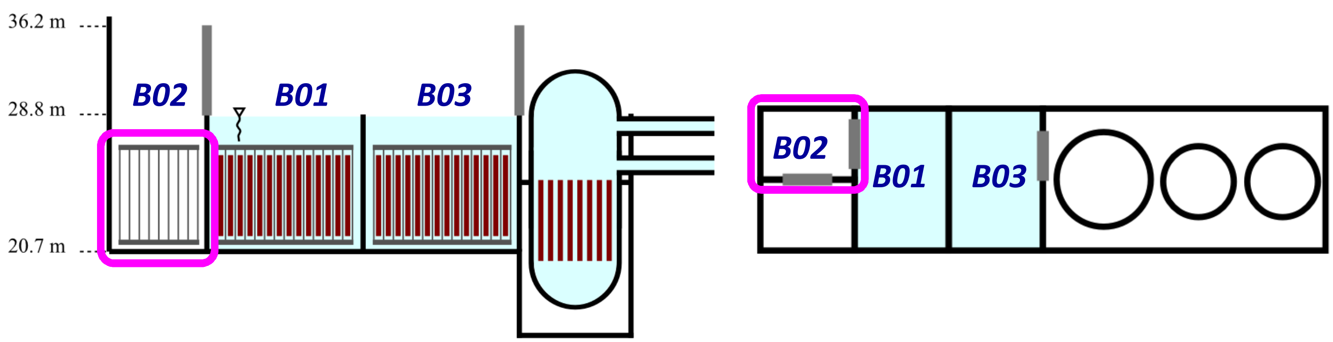


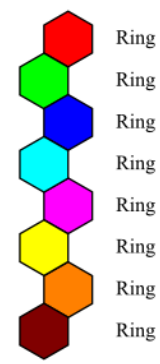
SFP model – FAs distribution (B02)



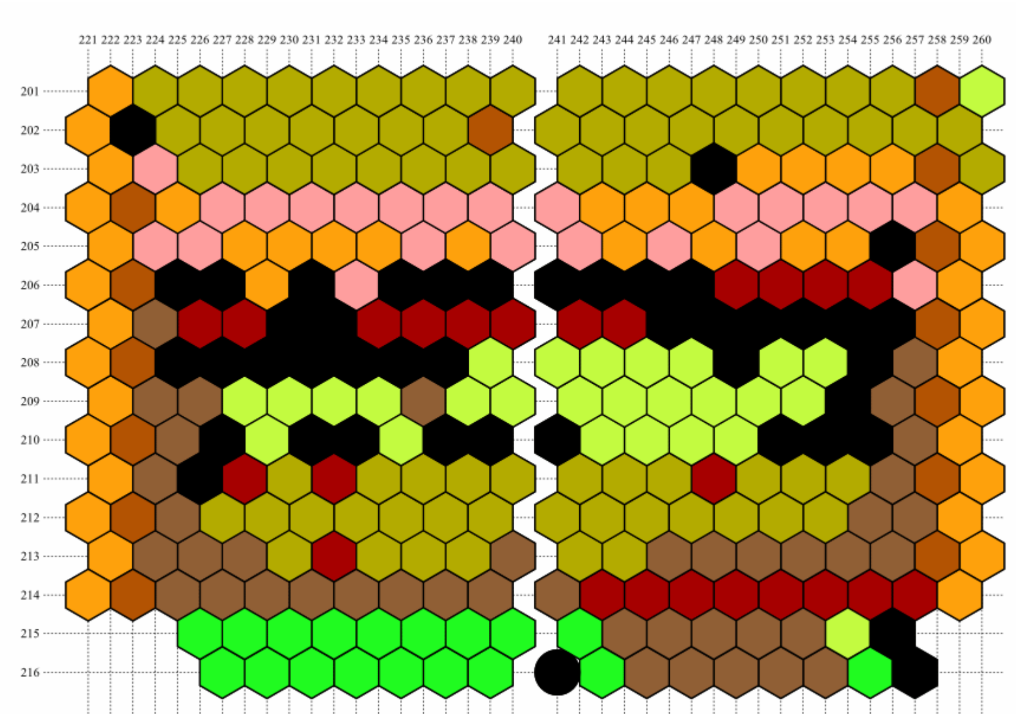


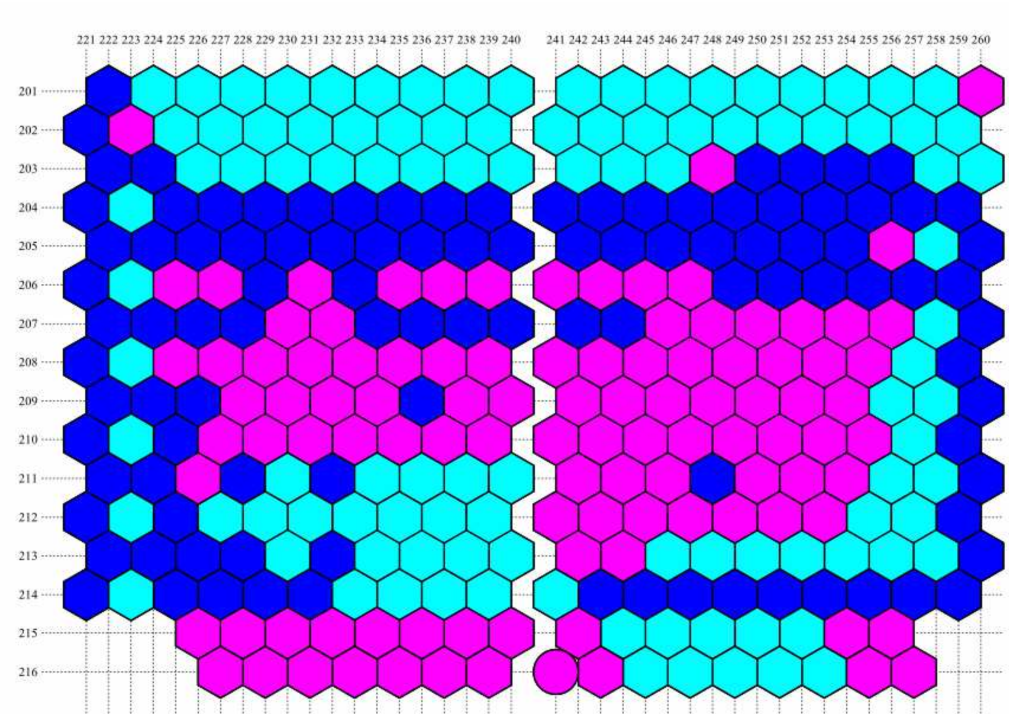


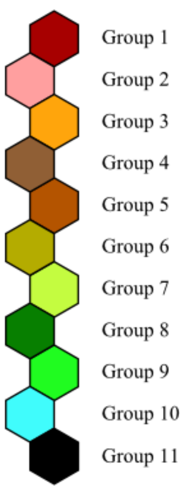


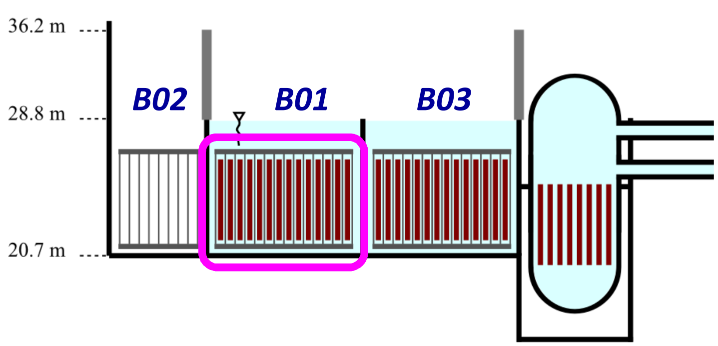


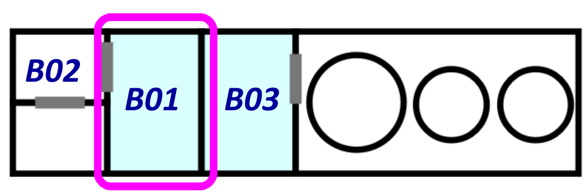
SFP model – FAs distribution (B01)

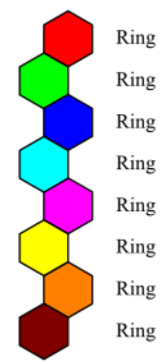




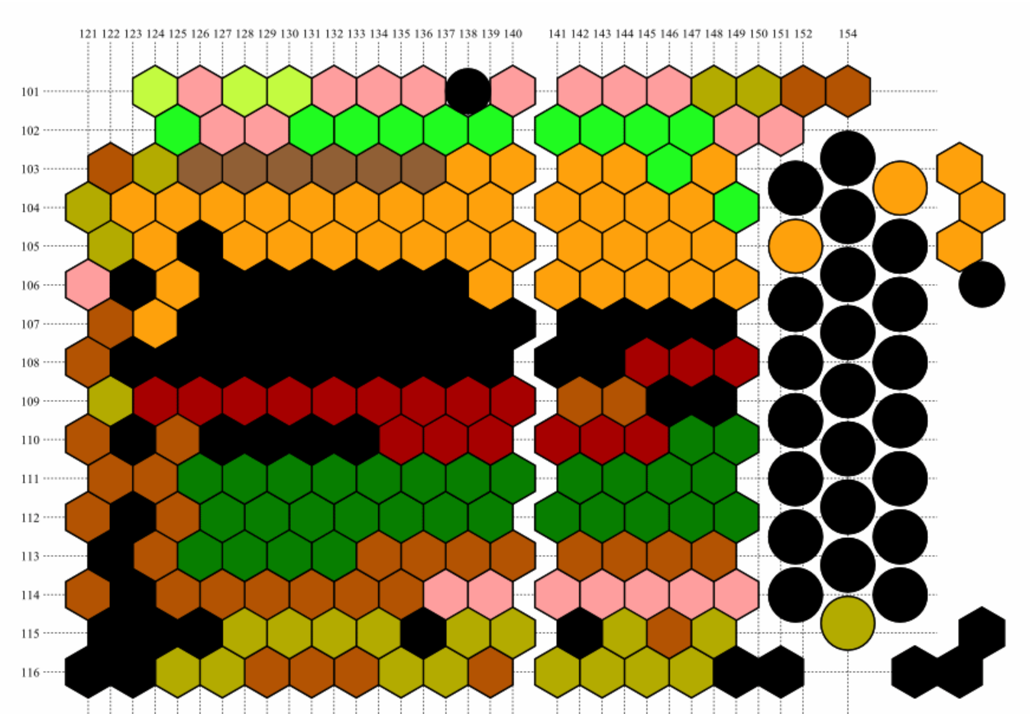


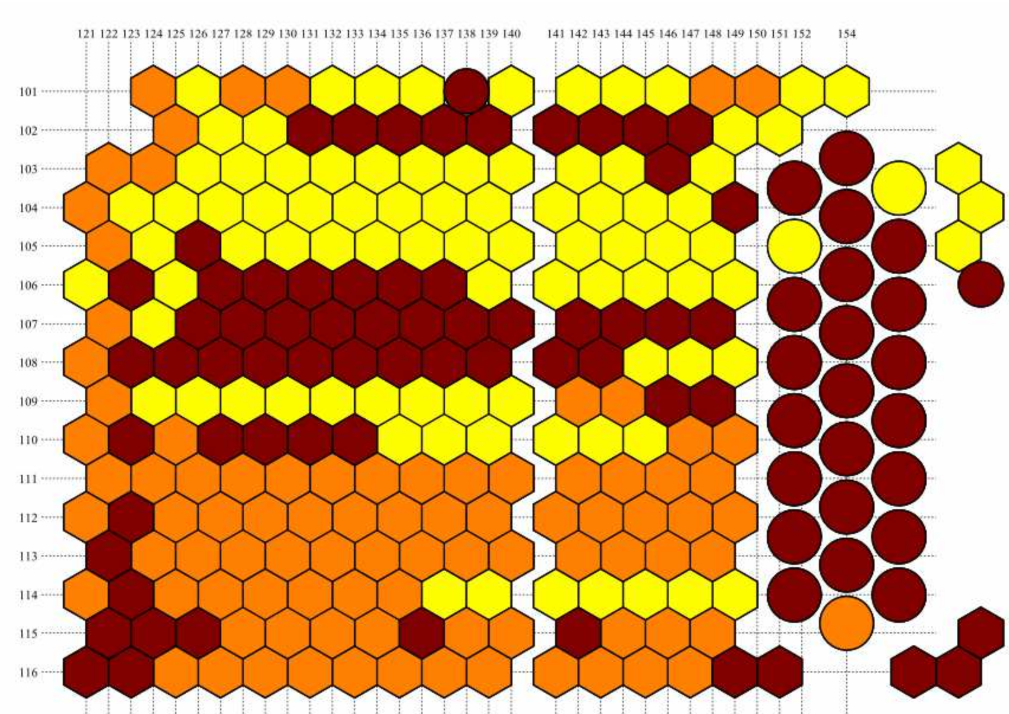


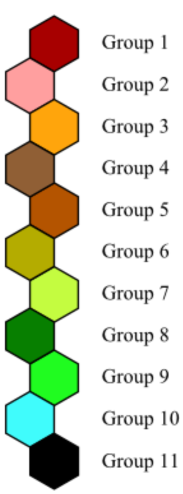


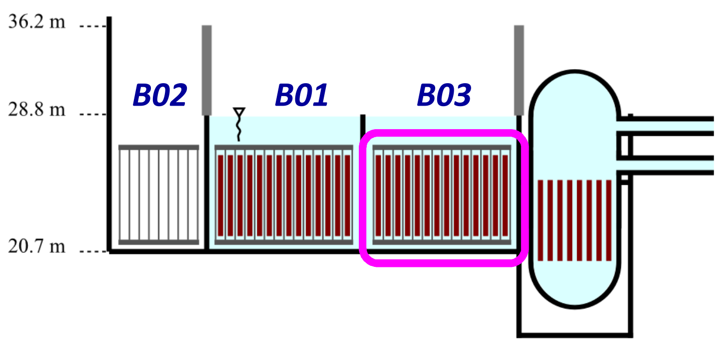


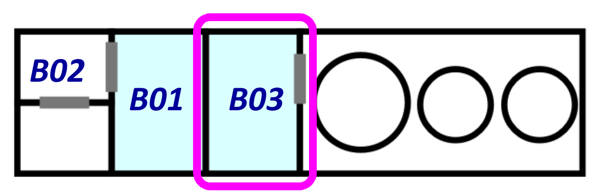
SFP model – FAs distribution (B03)

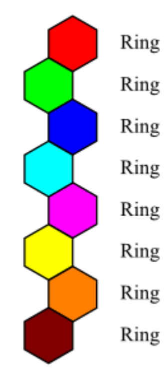










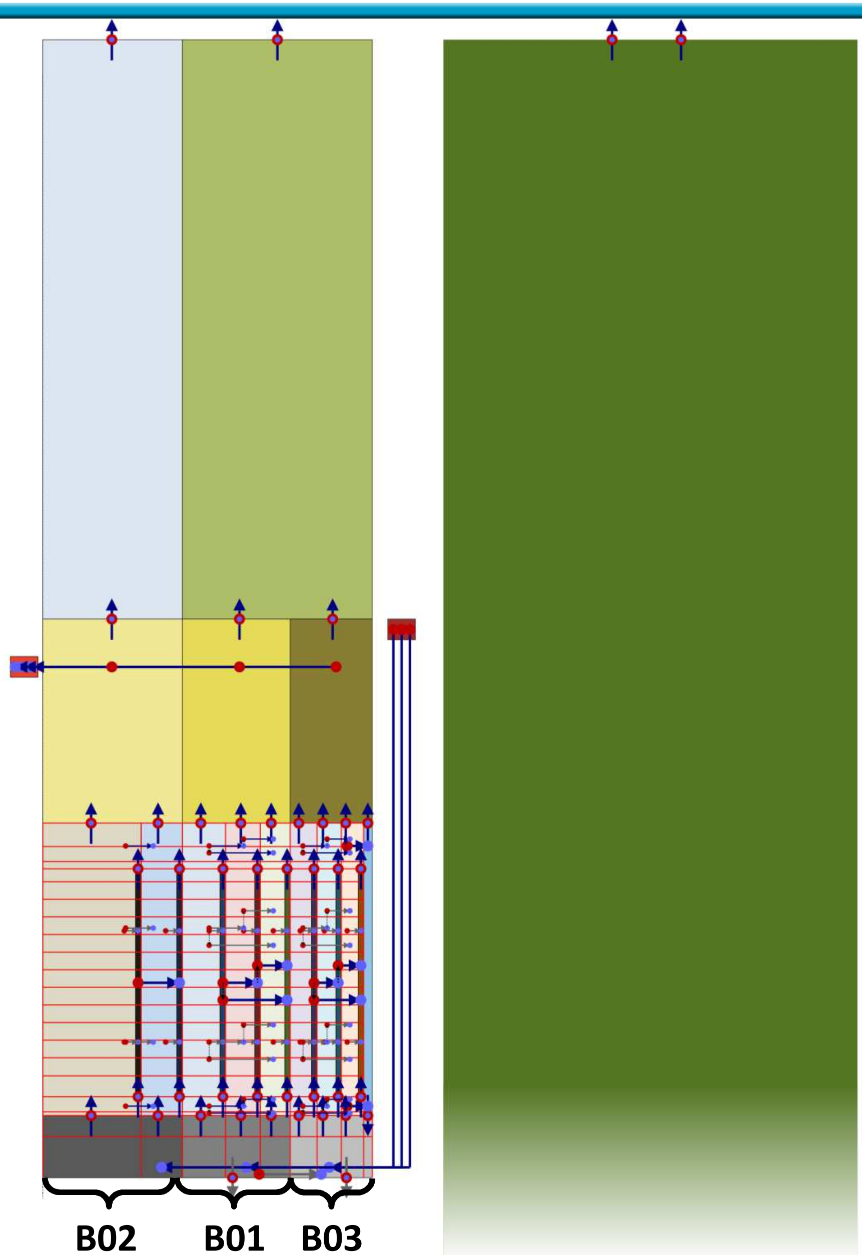


SFP model – FPs distribution

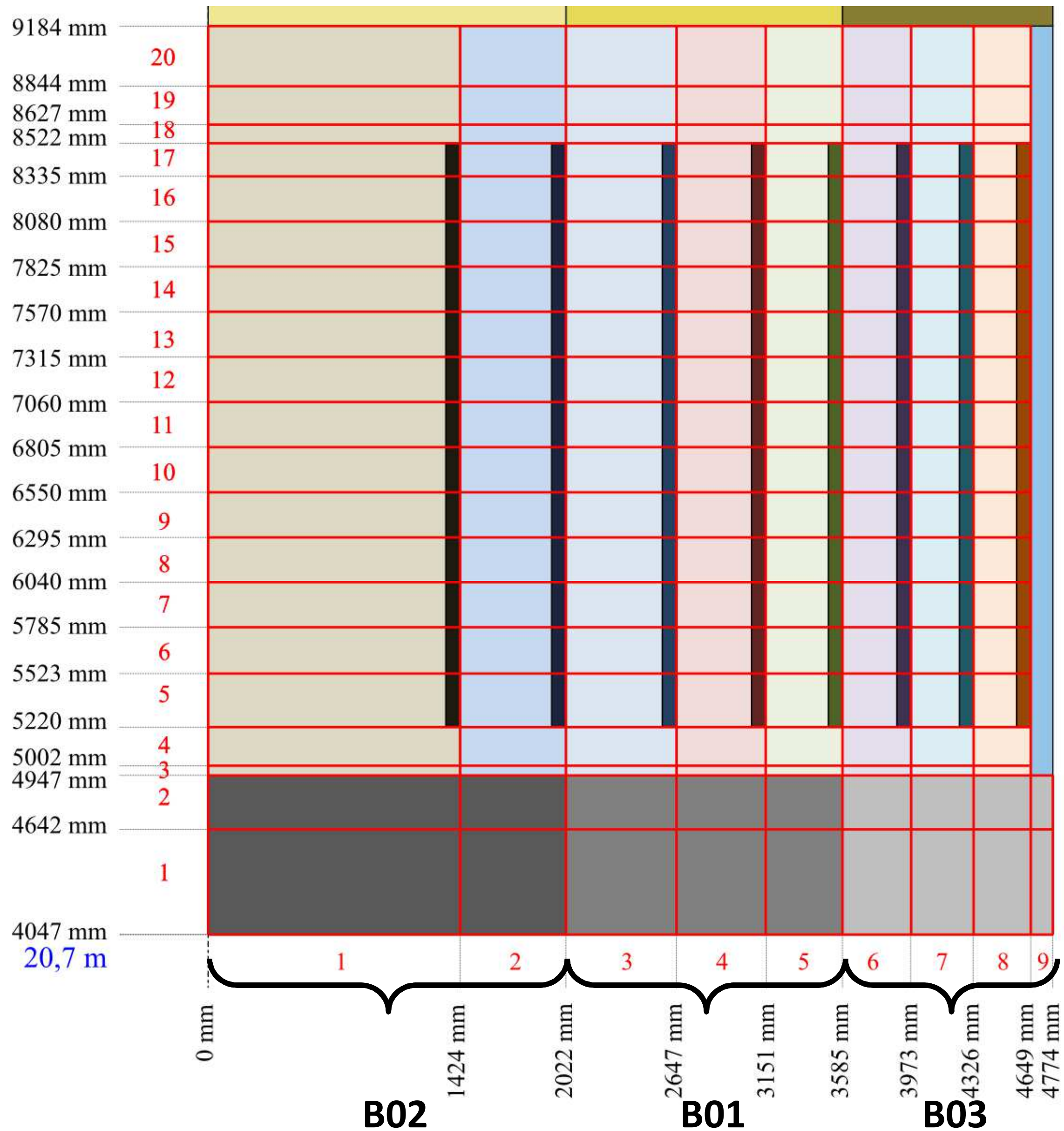
Radial ring # [-]

Axial level # [-]	1	2	3	4	5	6	7	8	9
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
18	0.00E+00	0.00E+00	1.18E-02	1.11E-04	3.09E-05	8.84E-03	6.77E-05	4.14E-06	
17	0.00E+00	0.00E+00	2.98E-02	2.81E-04	7.84E-05	2.24E-02	1.72E-04	1.05E-05	
16	0.00E+00	0.00E+00	4.17E-02	3.93E-04	1.10E-04	3.14E-02	2.40E-04	1.47E-05	
15	0.00E+00	0.00E+00	4.69E-02	4.41E-04	1.23E-04	3.52E-02	2.70E-04	1.65E-05	
14	0.00E+00	0.00E+00	4.61E-02	4.34E-04	1.21E-04	3.47E-02	2.65E-04	1.62E-05	
13	0.00E+00	0.00E+00	4.36E-02	4.10E-04	1.15E-04	3.27E-02	2.51E-04	1.53E-05	
12	0.00E+00	0.00E+00	4.12E-02	3.88E-04	1.08E-04	3.10E-02	2.37E-04	1.45E-05	
11	0.00E+00	0.00E+00	3.94E-02	3.71E-04	1.04E-04	2.96E-02	2.27E-04	1.39E-05	
10	0.00E+00	0.00E+00	3.85E-02	3.63E-04	1.01E-04	2.90E-02	2.22E-04	1.36E-05	
9	0.00E+00	0.00E+00	3.84E-02	3.62E-04	1.01E-04	2.89E-02	2.21E-04	1.35E-05	
8	0.00E+00	0.00E+00	3.94E-02	3.71E-04	1.04E-04	2.96E-02	2.26E-04	1.39E-05	
7	0.00E+00	0.00E+00	4.09E-02	3.85E-04	1.08E-04	3.08E-02	2.35E-04	1.44E-05	
6	0.00E+00	0.00E+00	4.20E-02	3.95E-04	1.10E-04	3.16E-02	2.42E-04	1.48E-05	
5	0.00E+00	0.00E+00	3.79E-02	3.57E-04	9.97E-05	2.85E-02	2.18E-04	1.34E-05	
4	0.00E+00	0.00E+00	2.05E-02	1.93E-04	5.40E-05	1.54E-02	1.18E-04	7.23E-06	
3	0.00E+00	0.00E+00	6.89E-03	6.49E-05	1.81E-05	5.18E-03	3.96E-05	2.43E-06	
2	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
1	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
	B02		B01			B03			

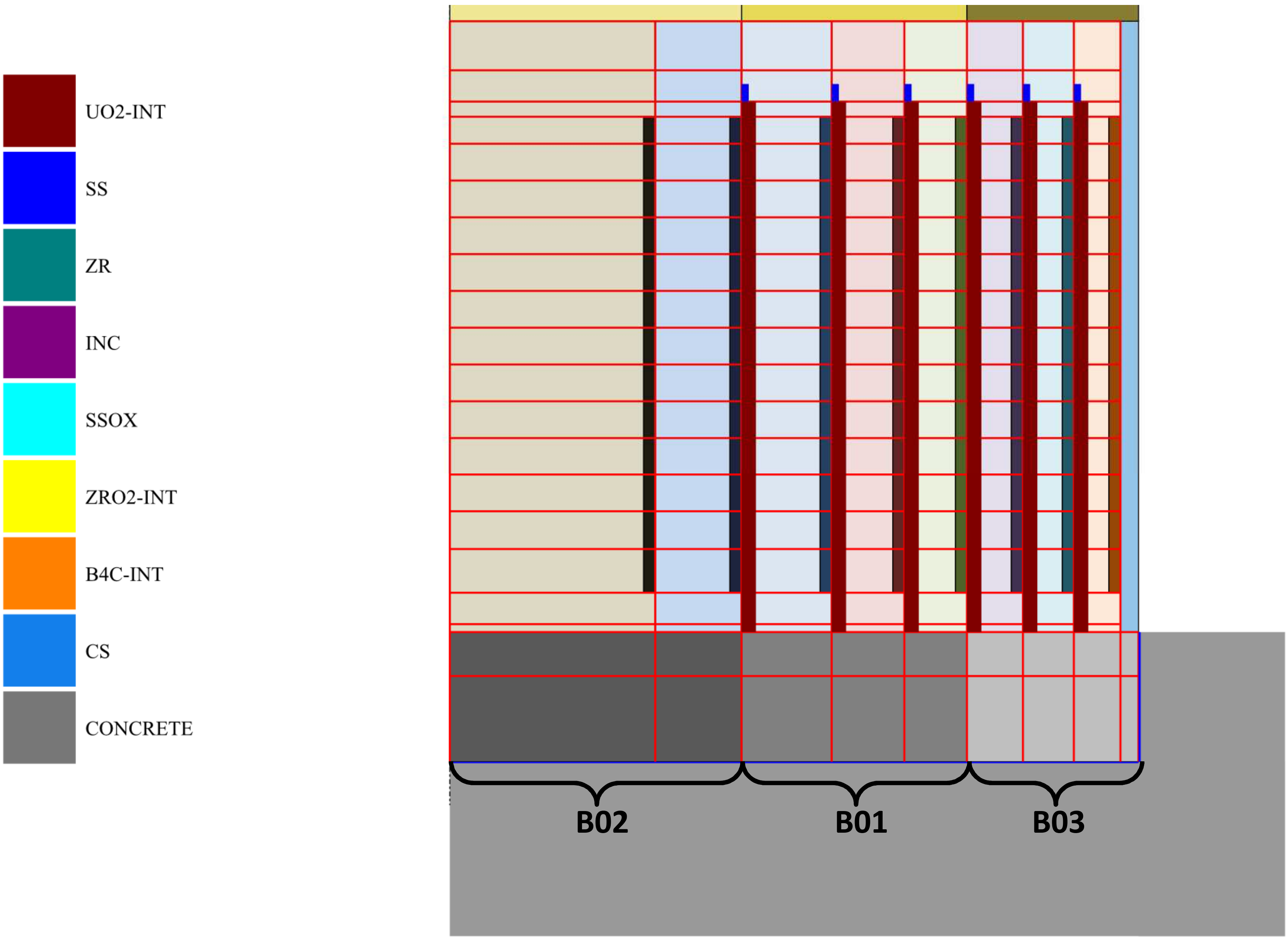
SFP model – overall nodalization



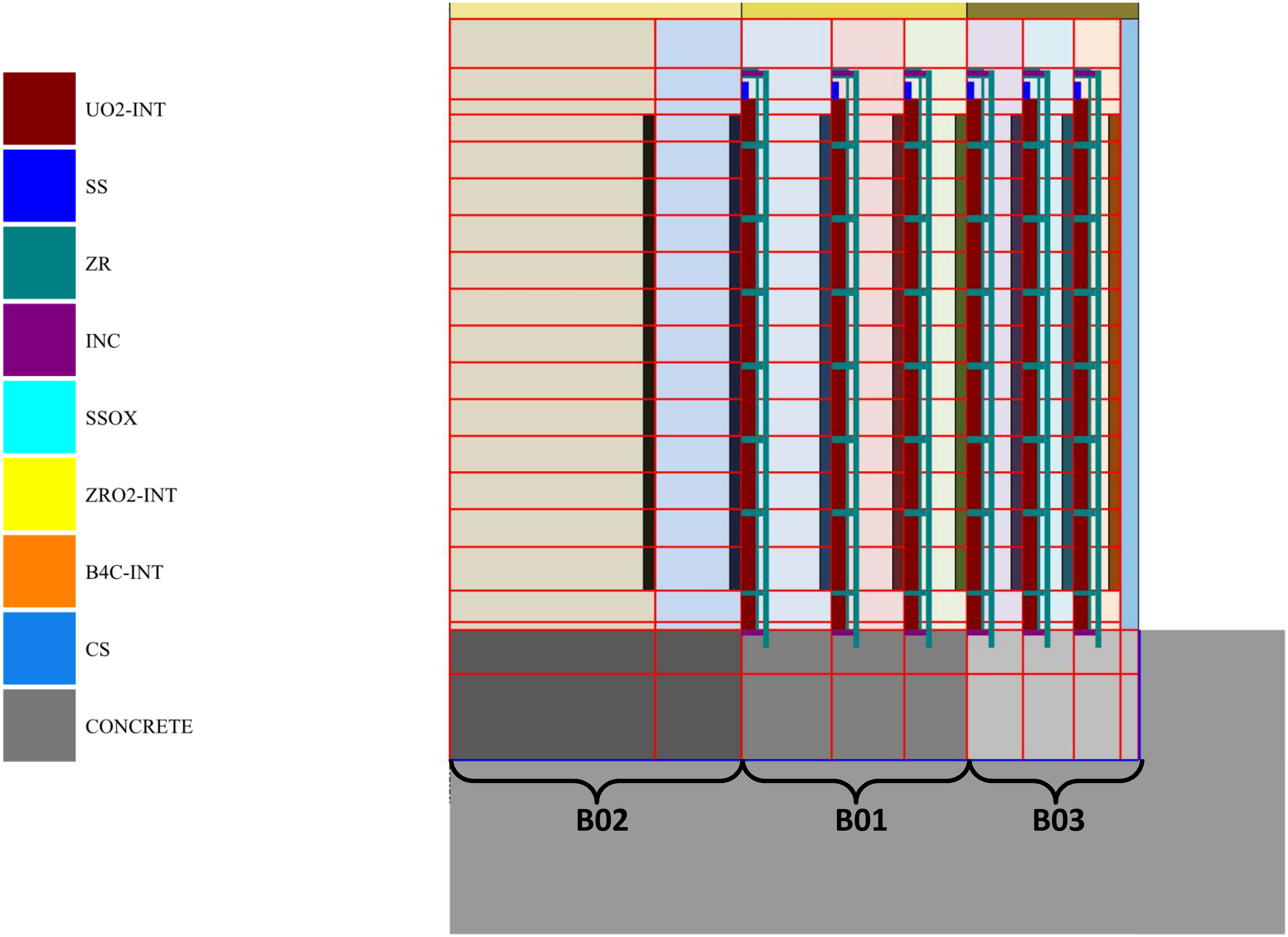
SFP model – CVs + core cells



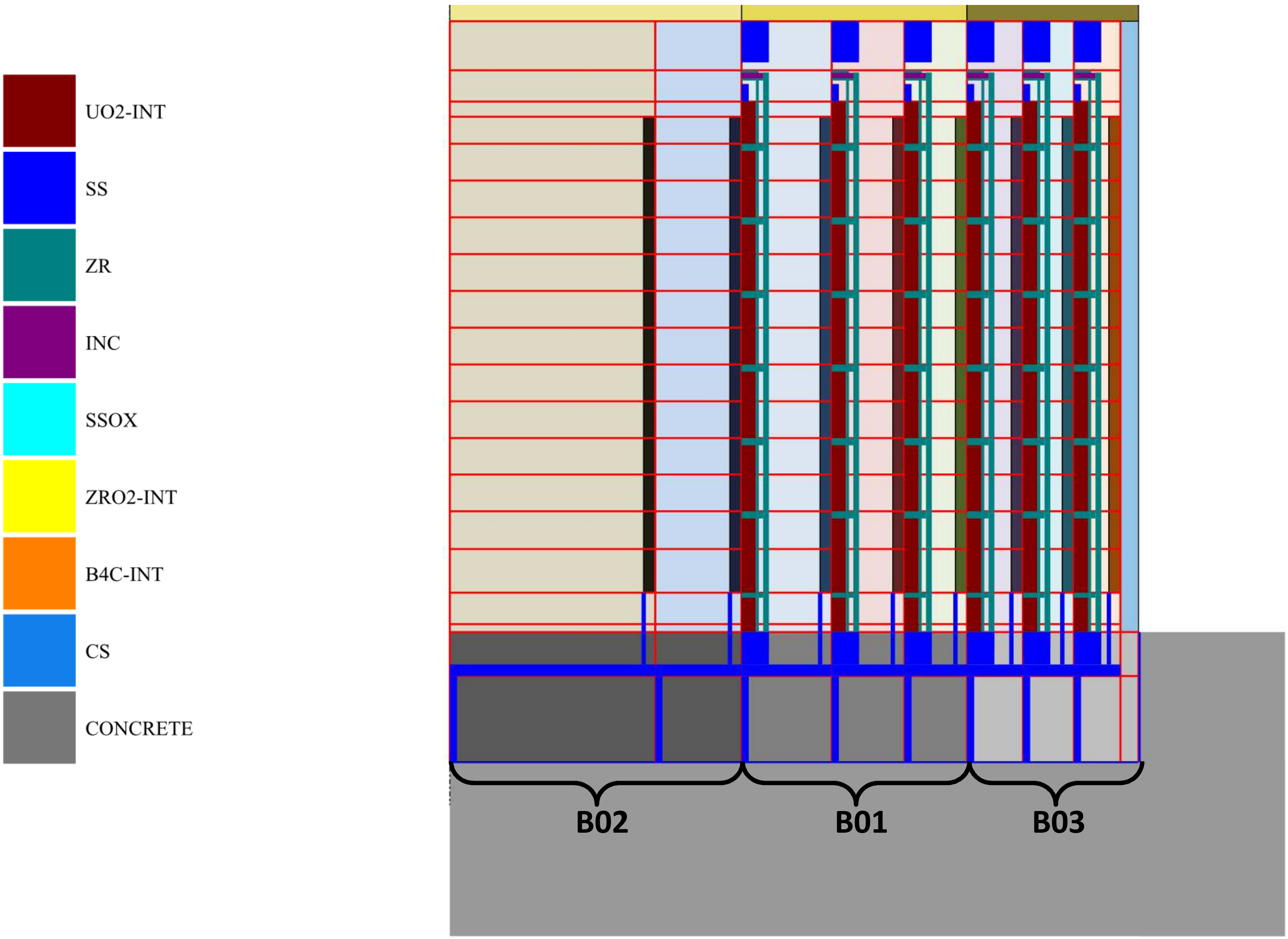
SFP model – core cells + FU



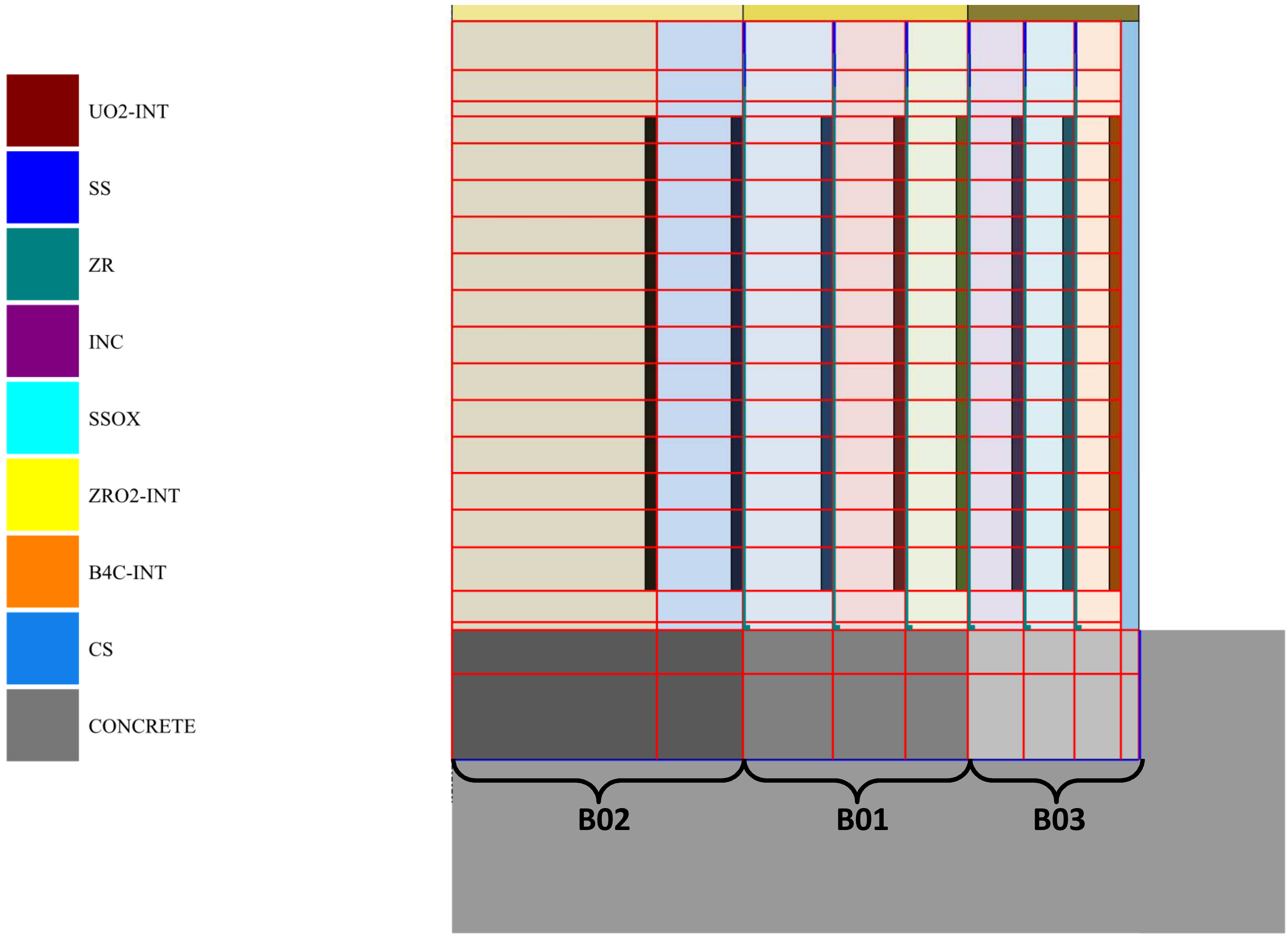
SFP model – core cells + FU + CL



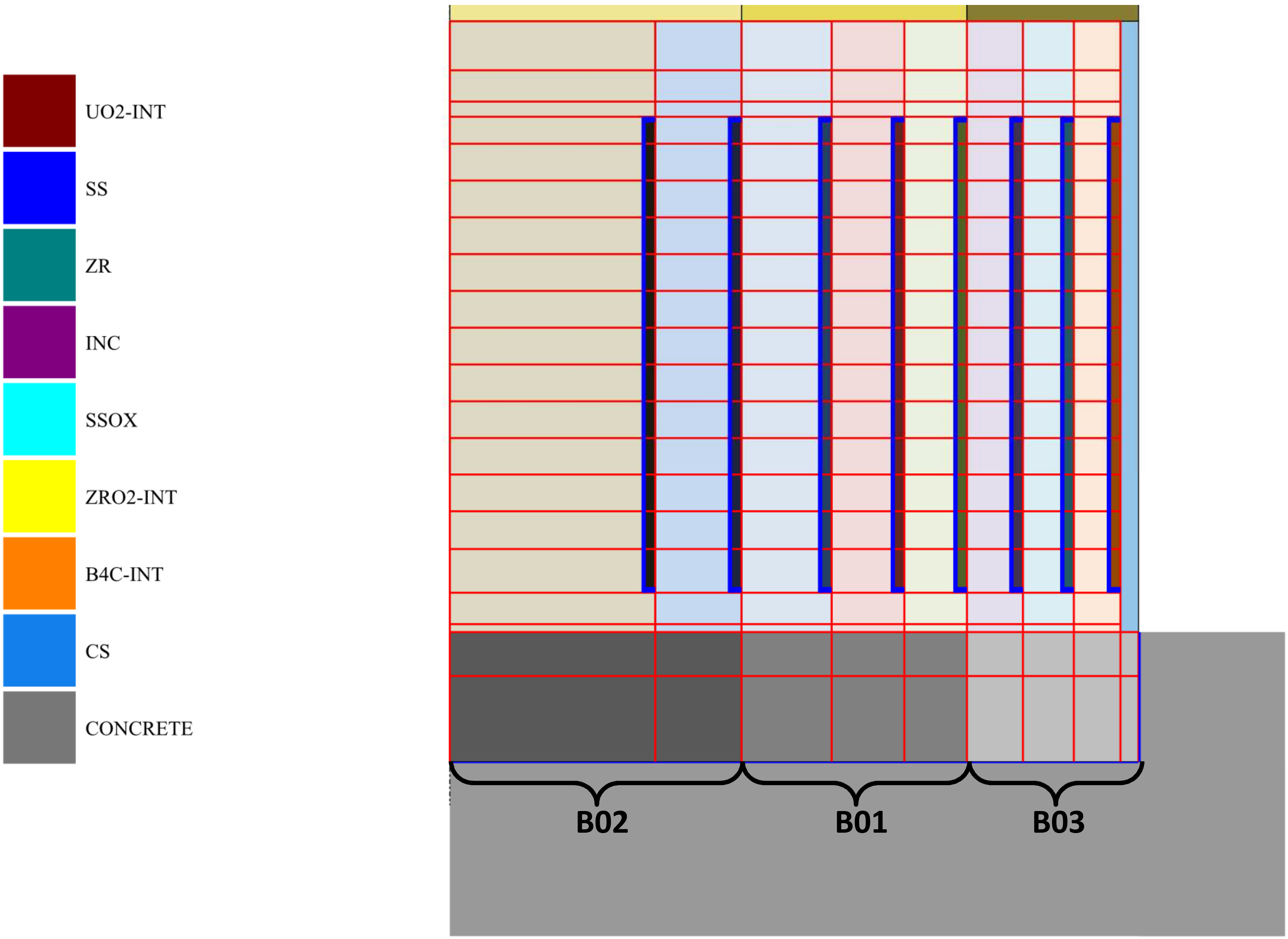
SFP model – core cells + FU + CL + SS



SFP model – core cells + NS

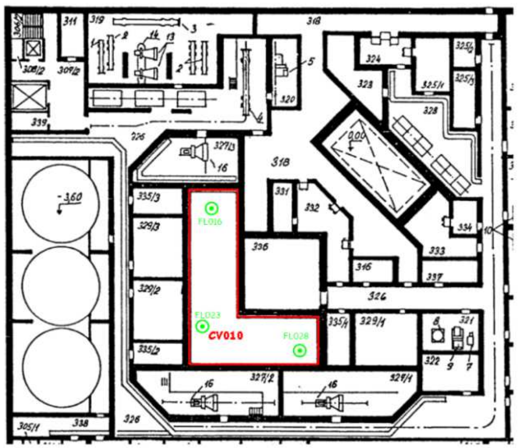


SFP model – core cells + CN

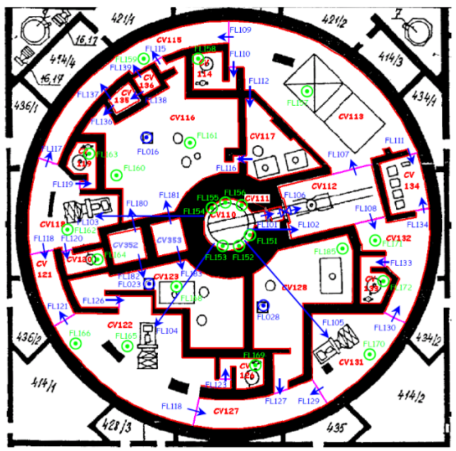


Detailed CTMT model (138 CVs)

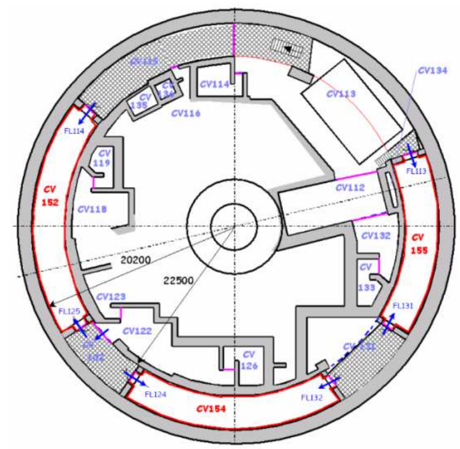
+6.6 m



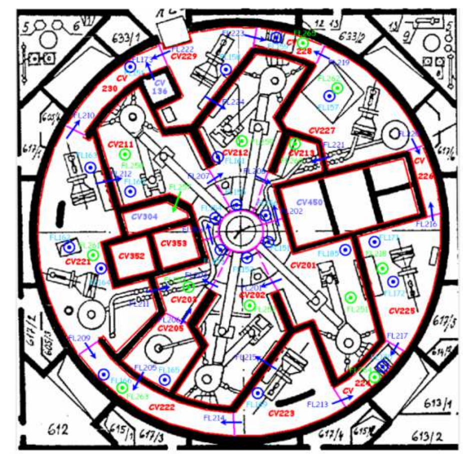
+13.2 m



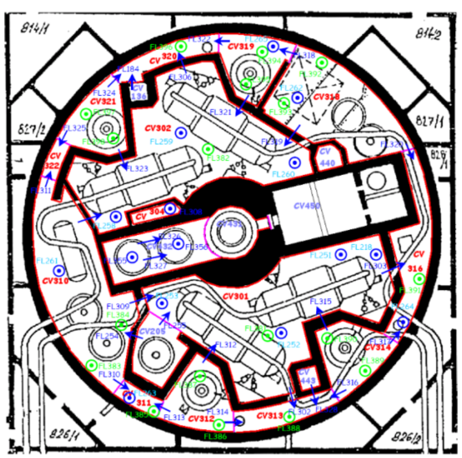
+16.8 m



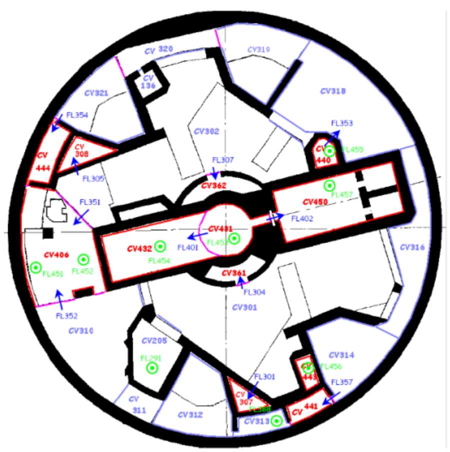
+19.4 m



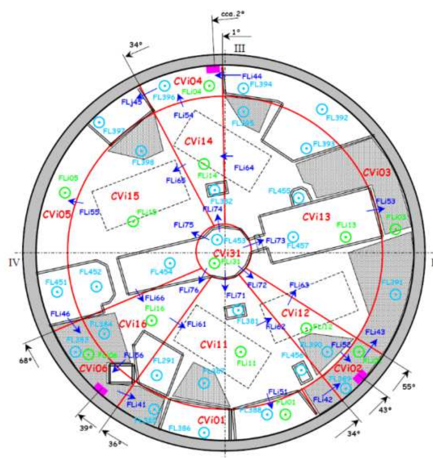
+25.7 m



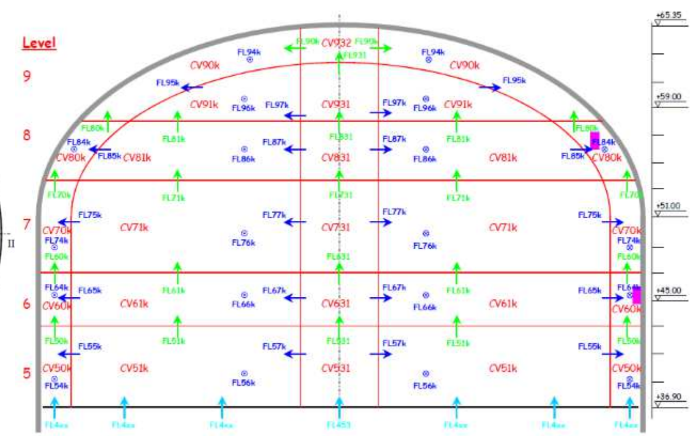
+33.6 m



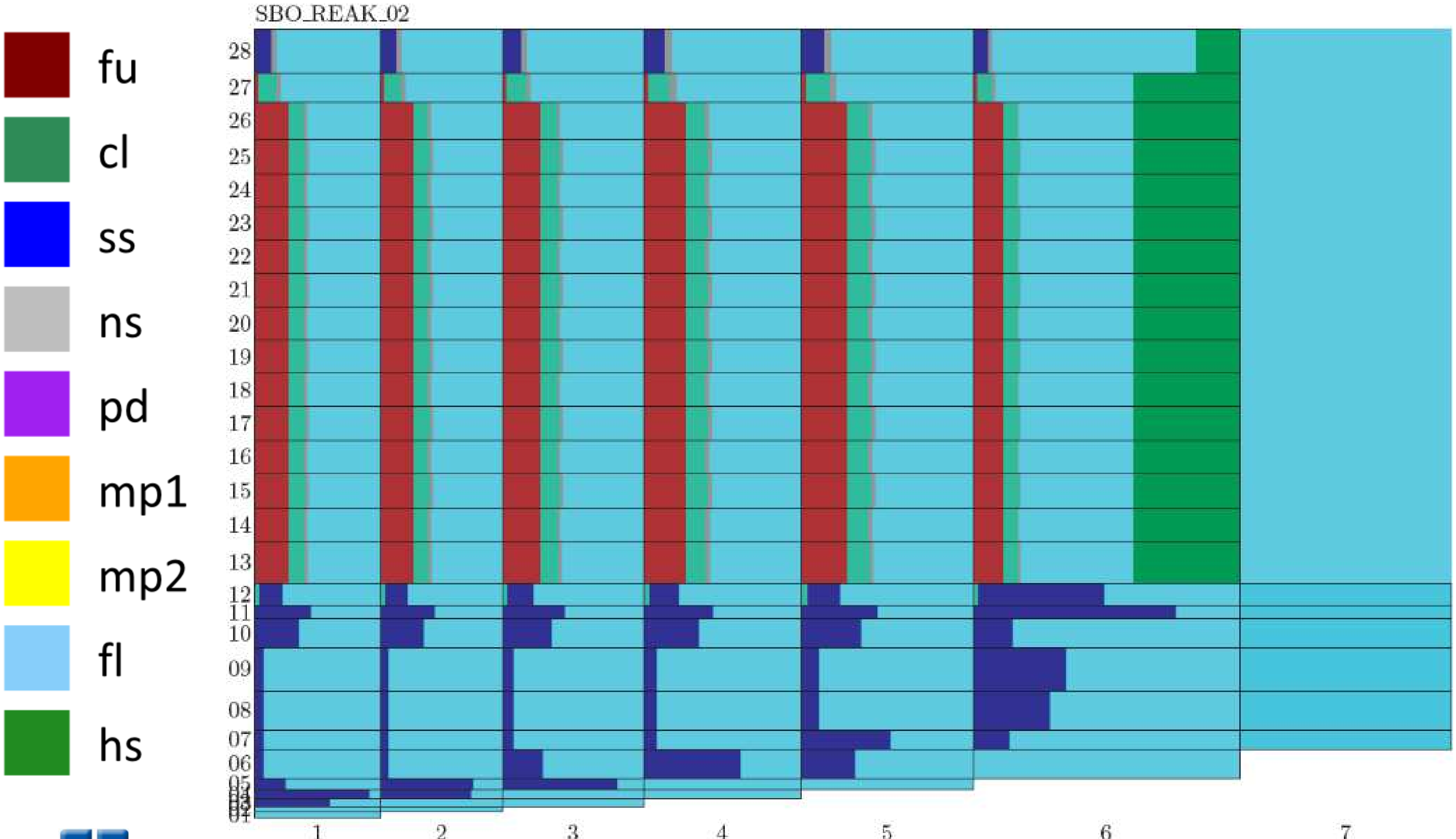
+36.9 m



reactor hall section

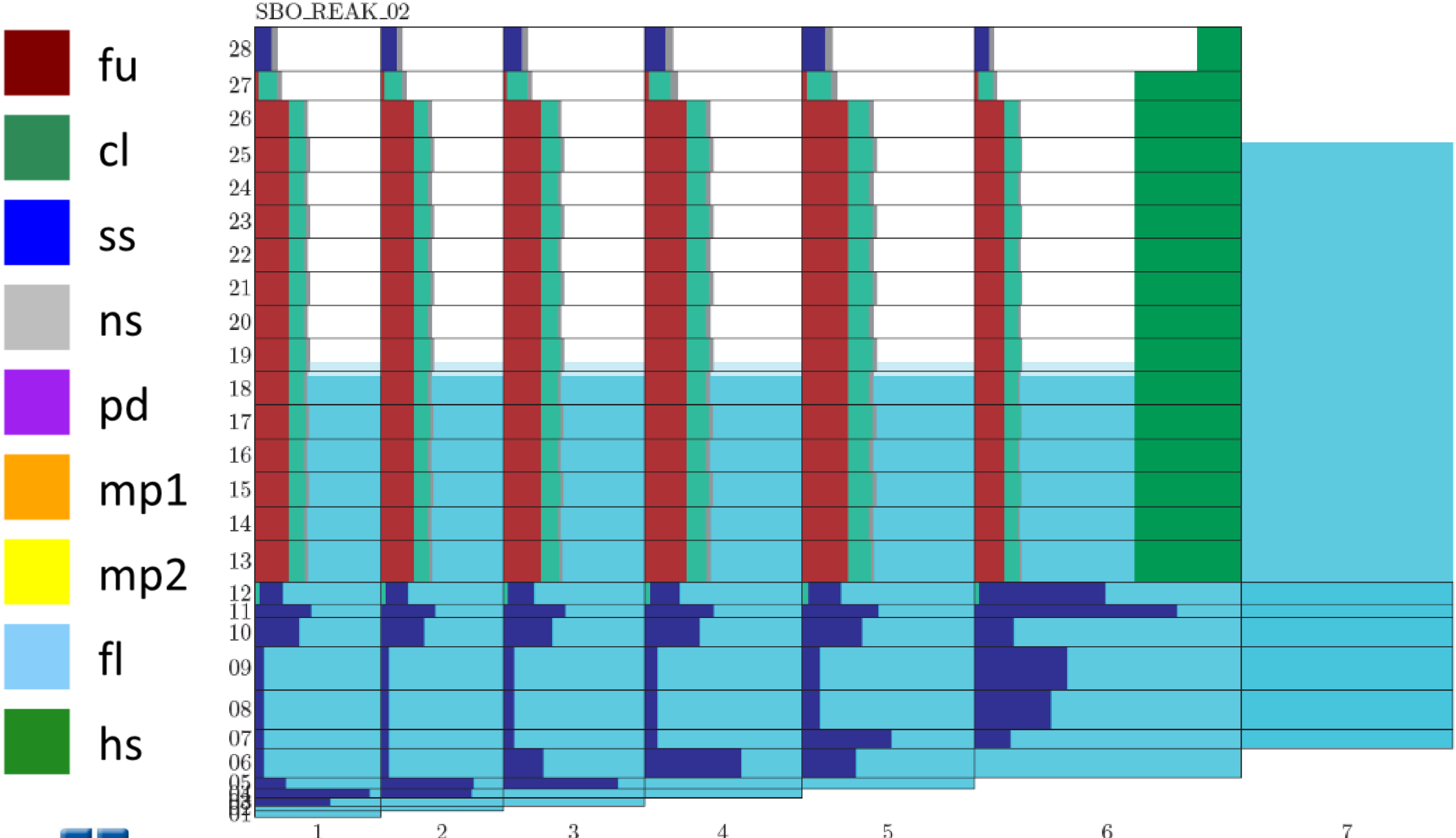


RPV accident progress: 0.05 h (1/11)



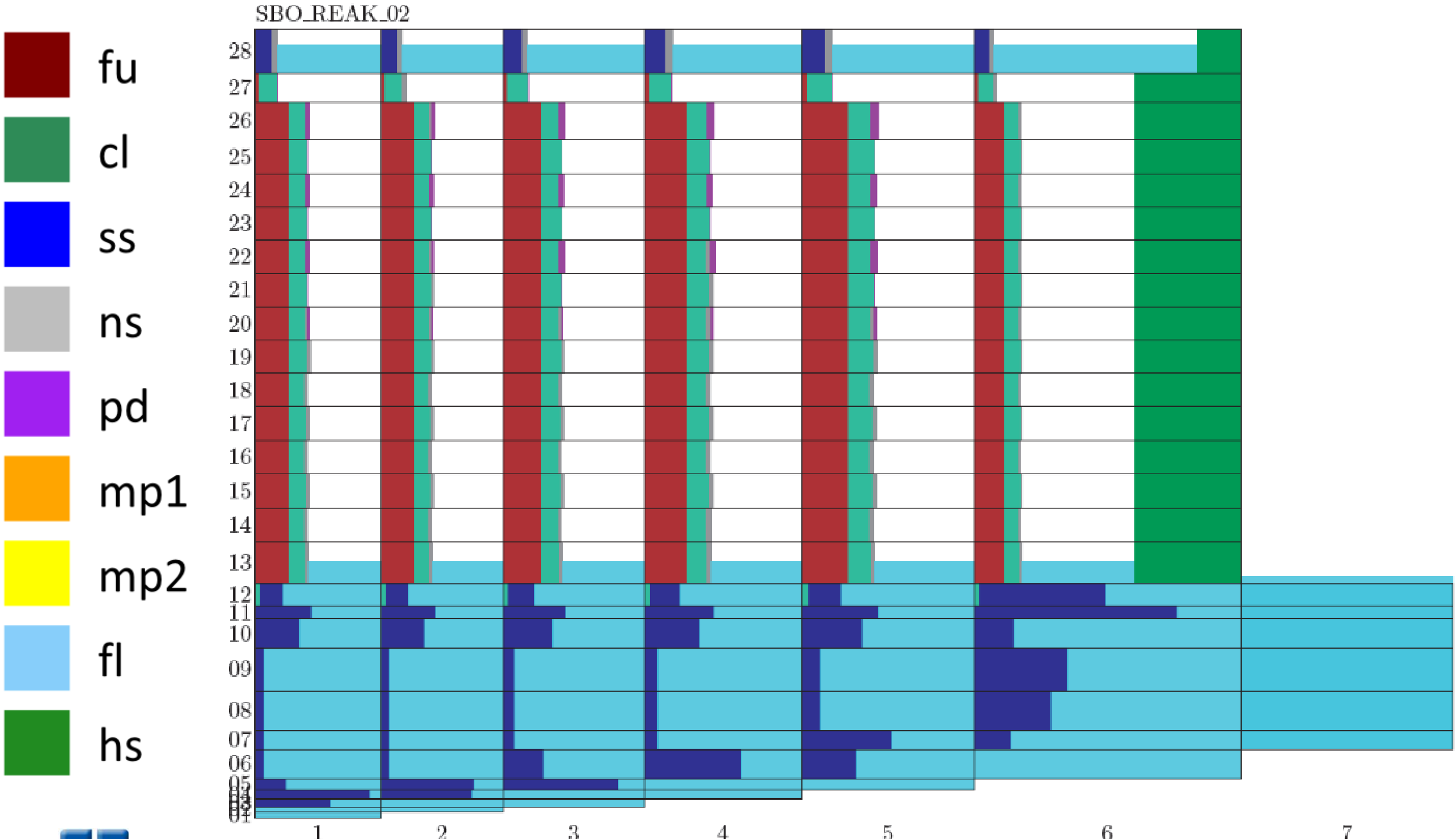
- *Situation right after reactor shutdown – intact core, full water inventory*

RPV accident progress: 1.67 h (2/11)



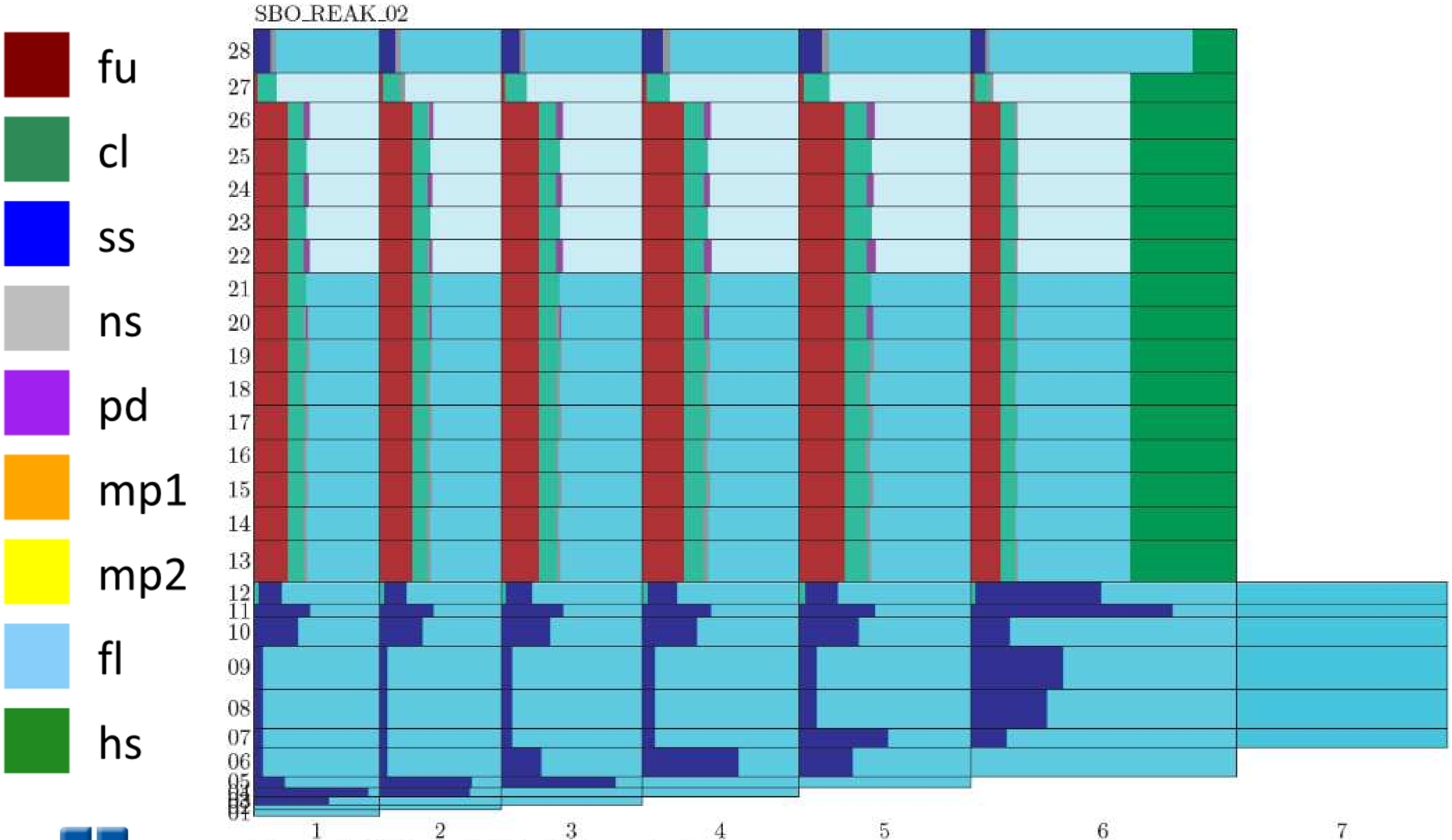
- *Water level decrease due to boil-off, still before PC depressurization*

RPV accident progress: 1.97 h (3/11)



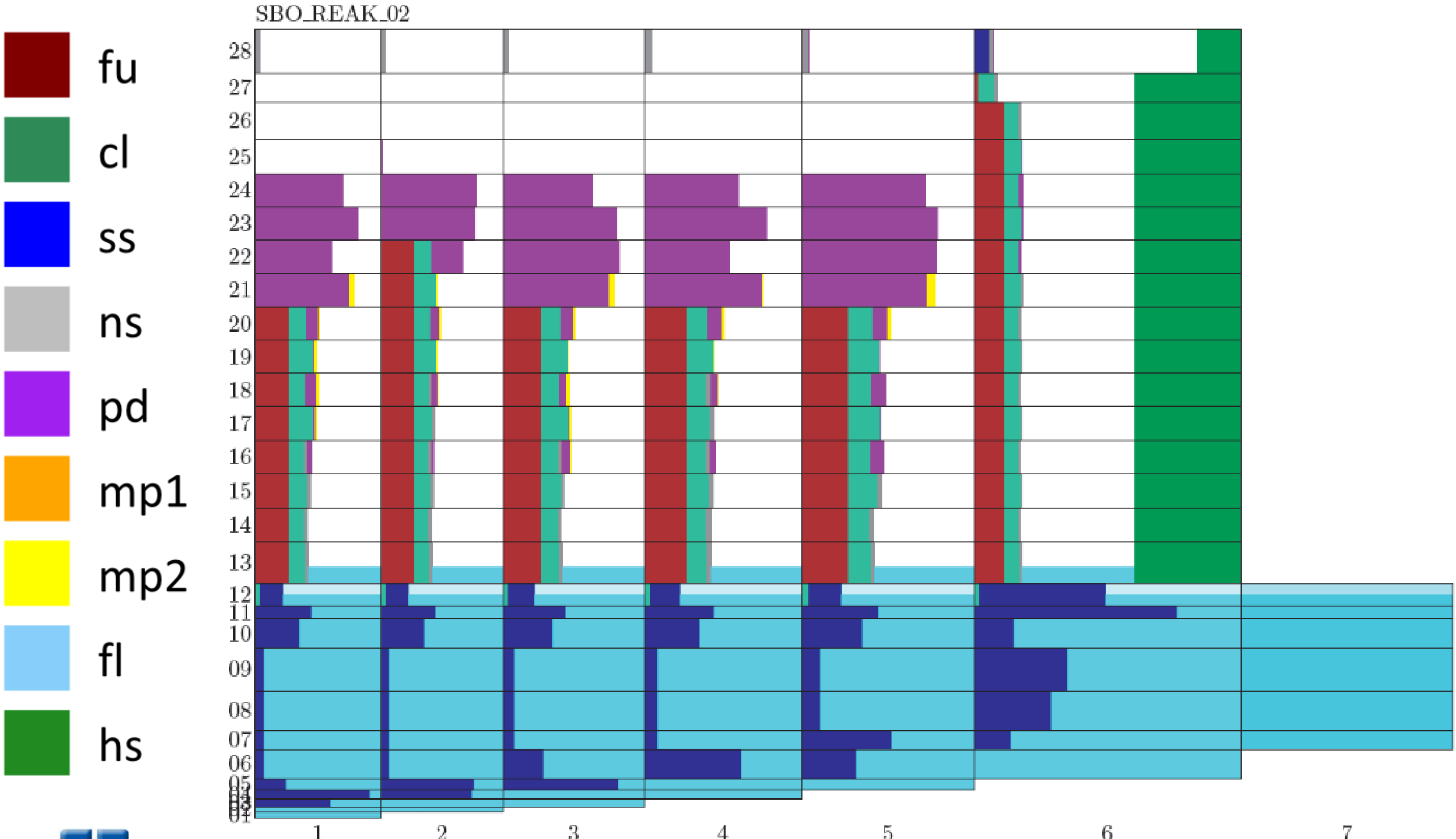
- *Onset of core components degradation, right after PC depressurization (water inlet)*

RPV accident progress: 2.85 h (4/11)



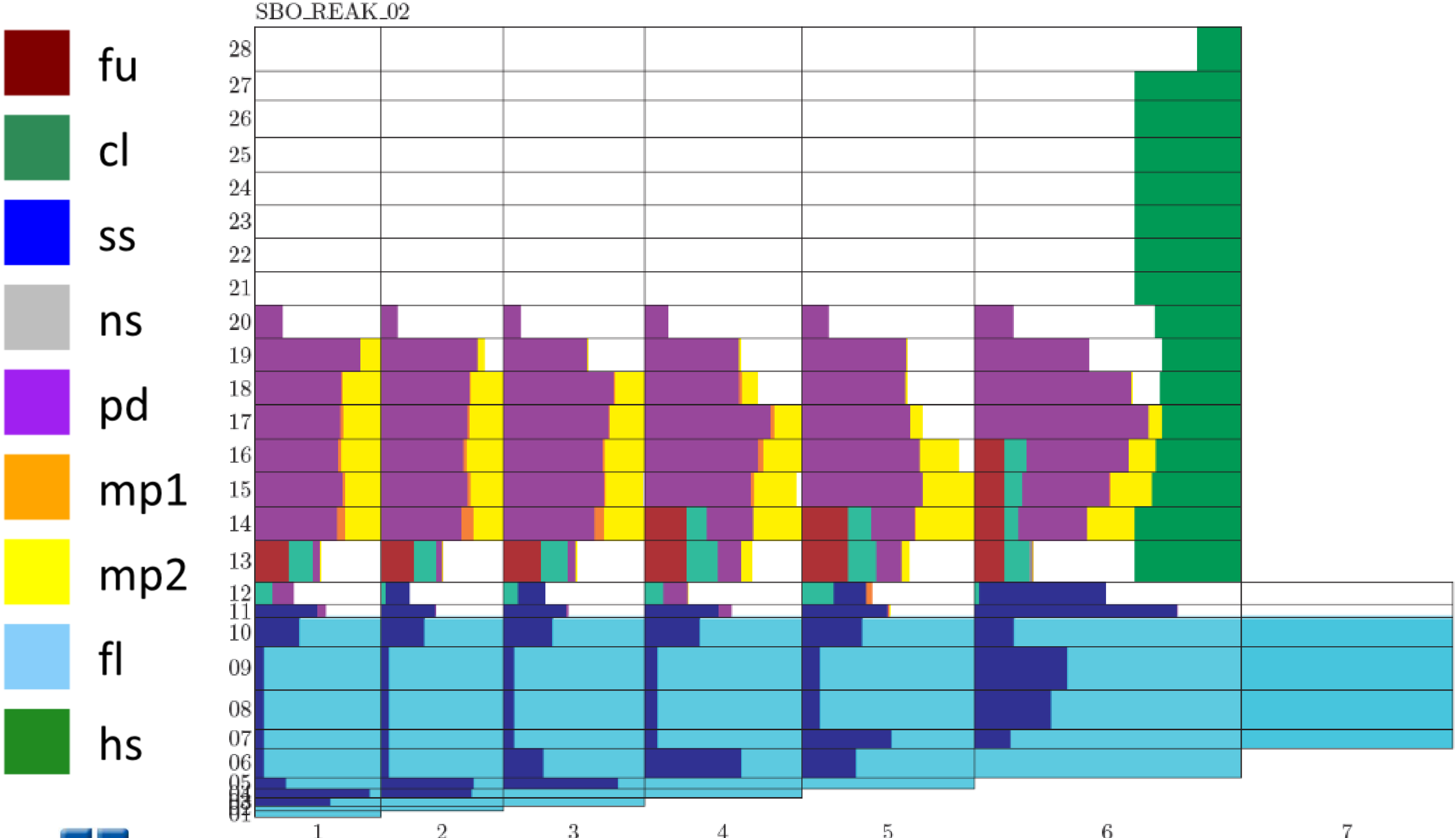
- *Water inventory make-up thanks to HAs, high void fraction visible (intensive boiling)*

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*

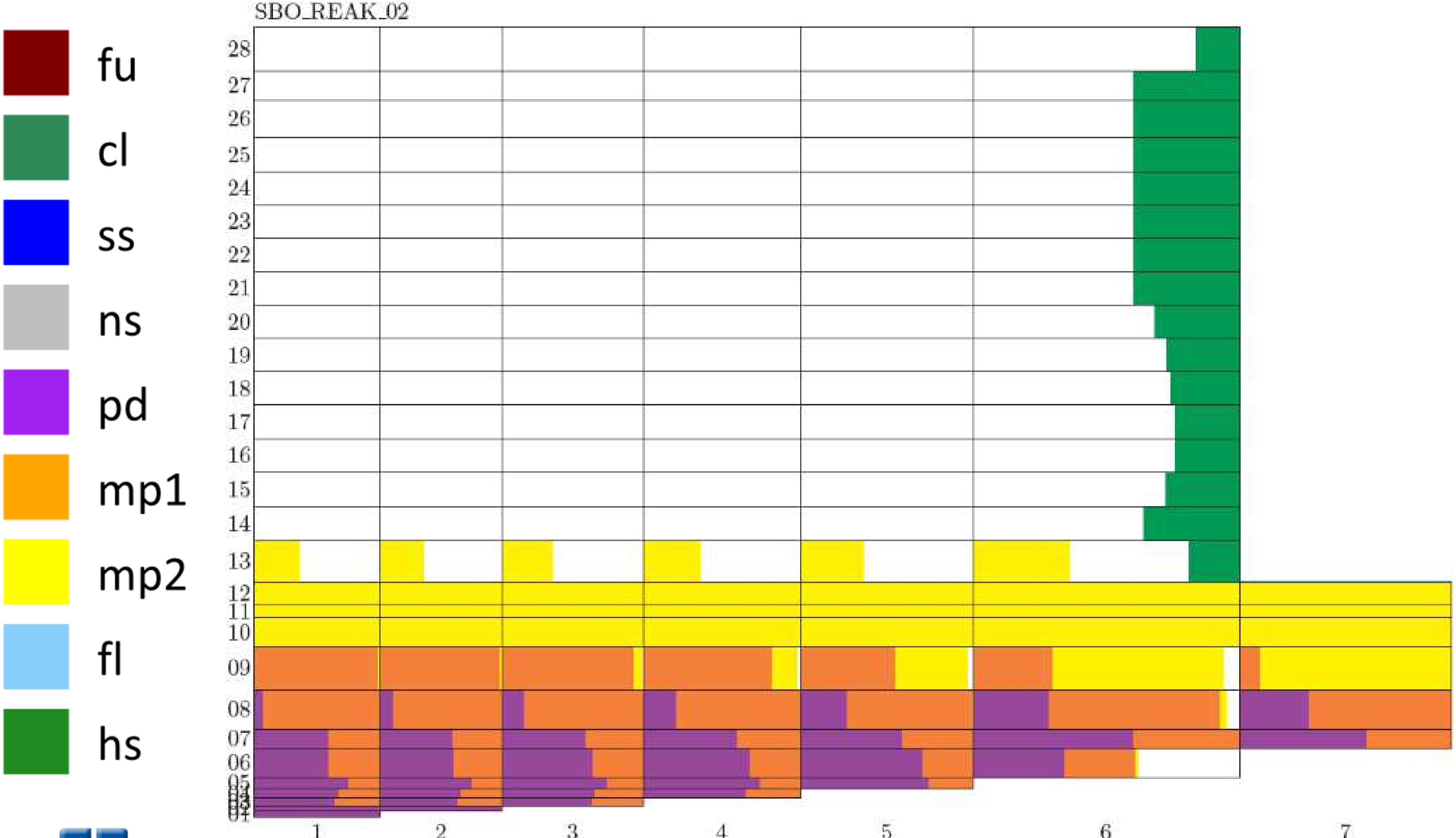
RPV accident progress: 4.63 h (7/11)

- *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*

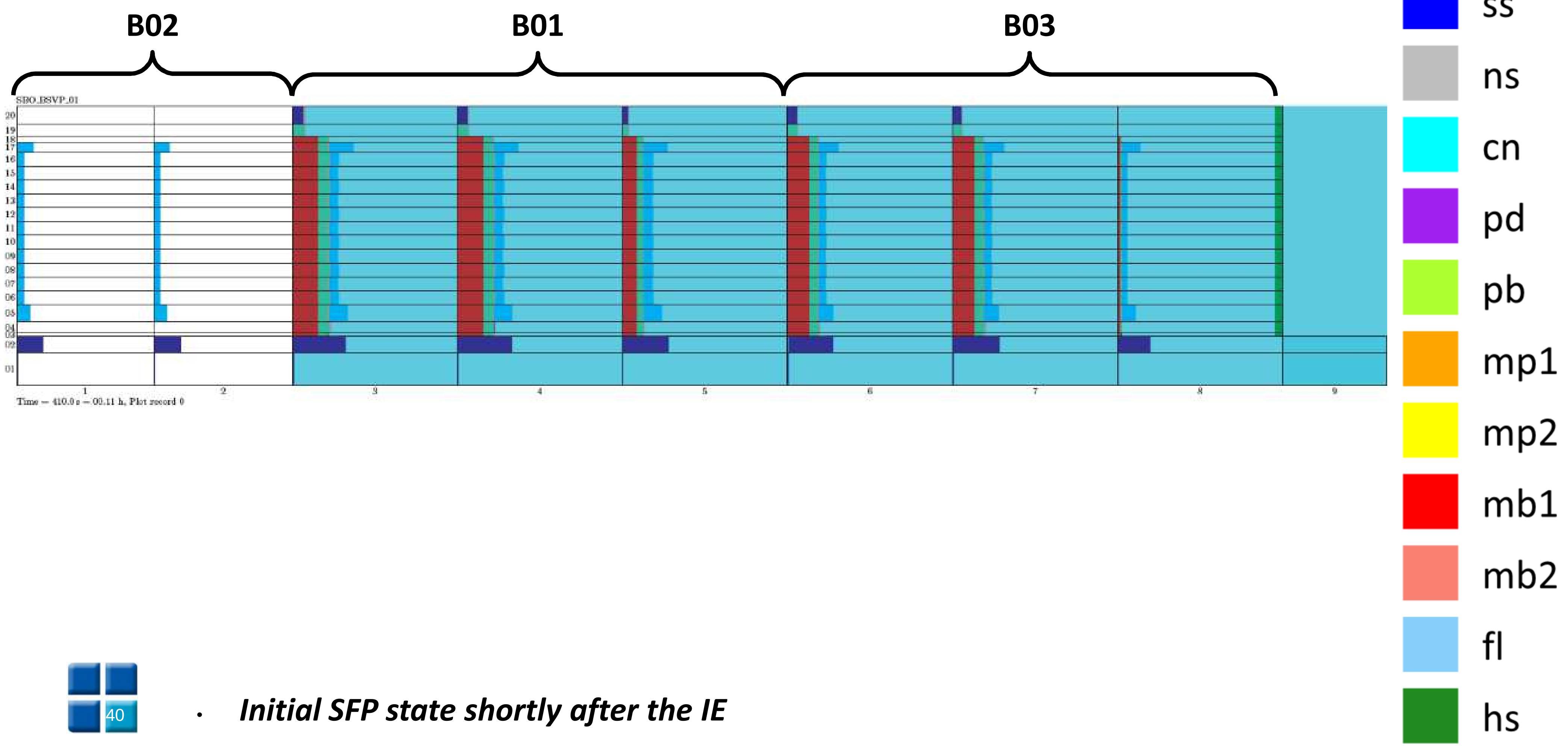
RPV accident progress: 8.38 h (10/11)

- *Material relocation from LP – right after RPV LH failure*

RPV accident progress: 228 h (11/11)

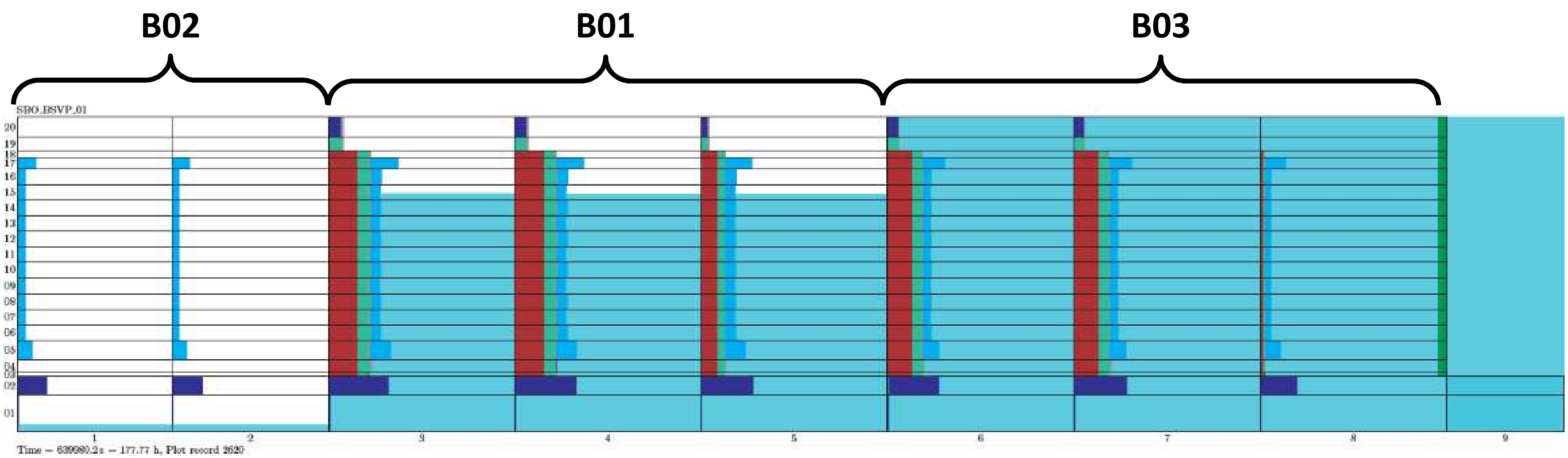
- *End of calculation – last remnants of debris gone from LP*

SFP accident progress: 0.0 d (1/4)



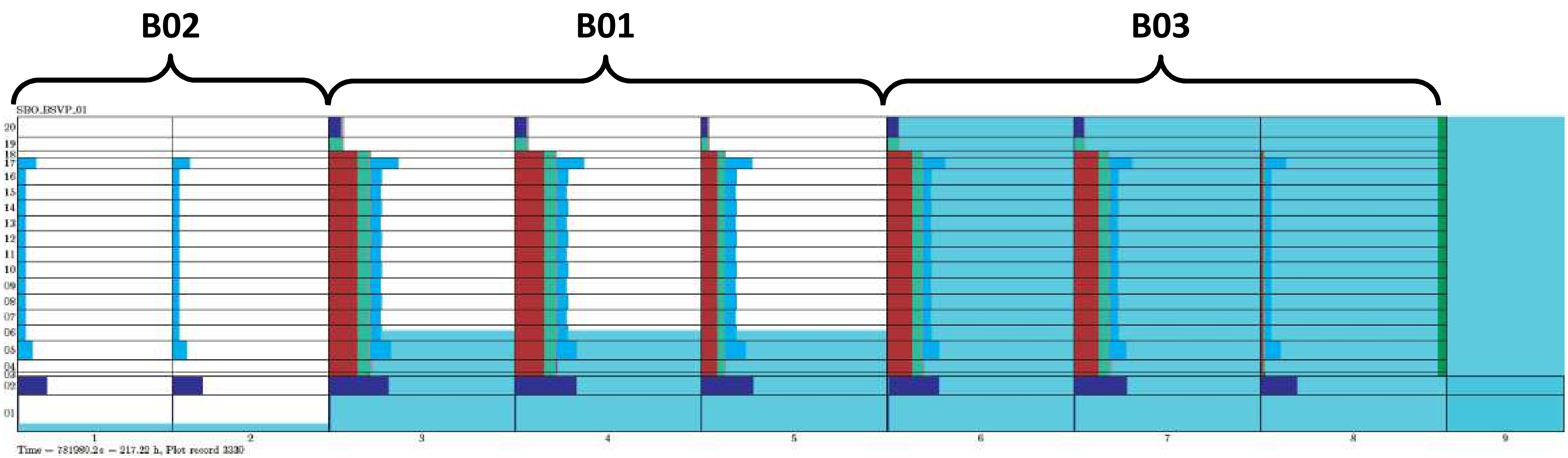
- *Initial SFP state shortly after the IE*

SFP accident progress: 7.4 d (2/4)



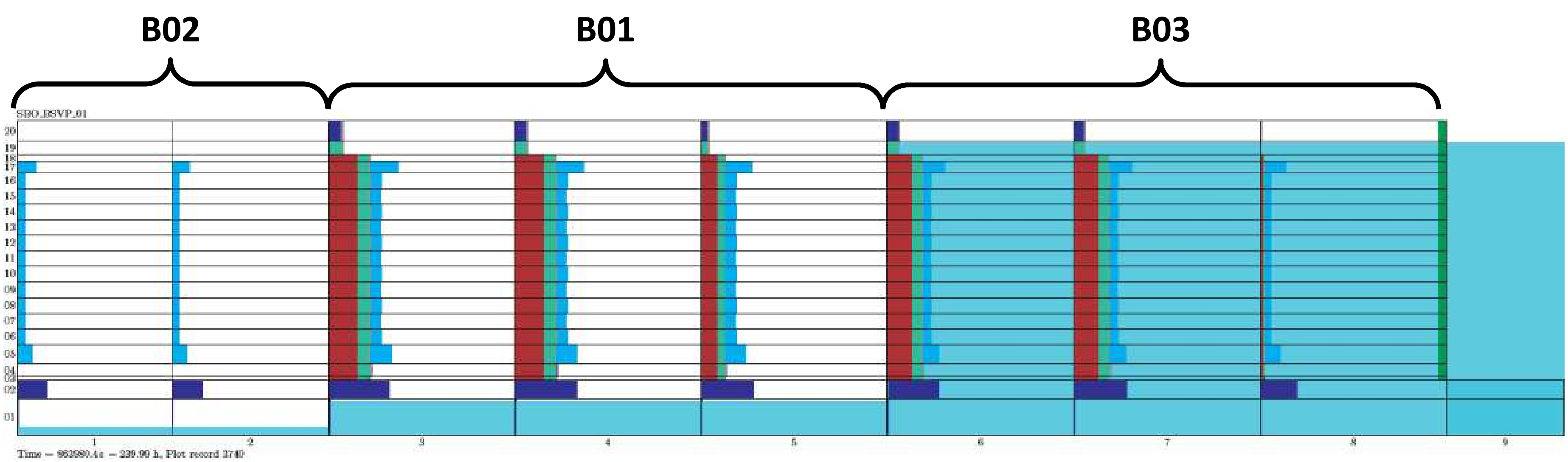
- *Ongoing FAs uncovery in the B01 pool*

SFP accident progress: 9.1 d (3/4)



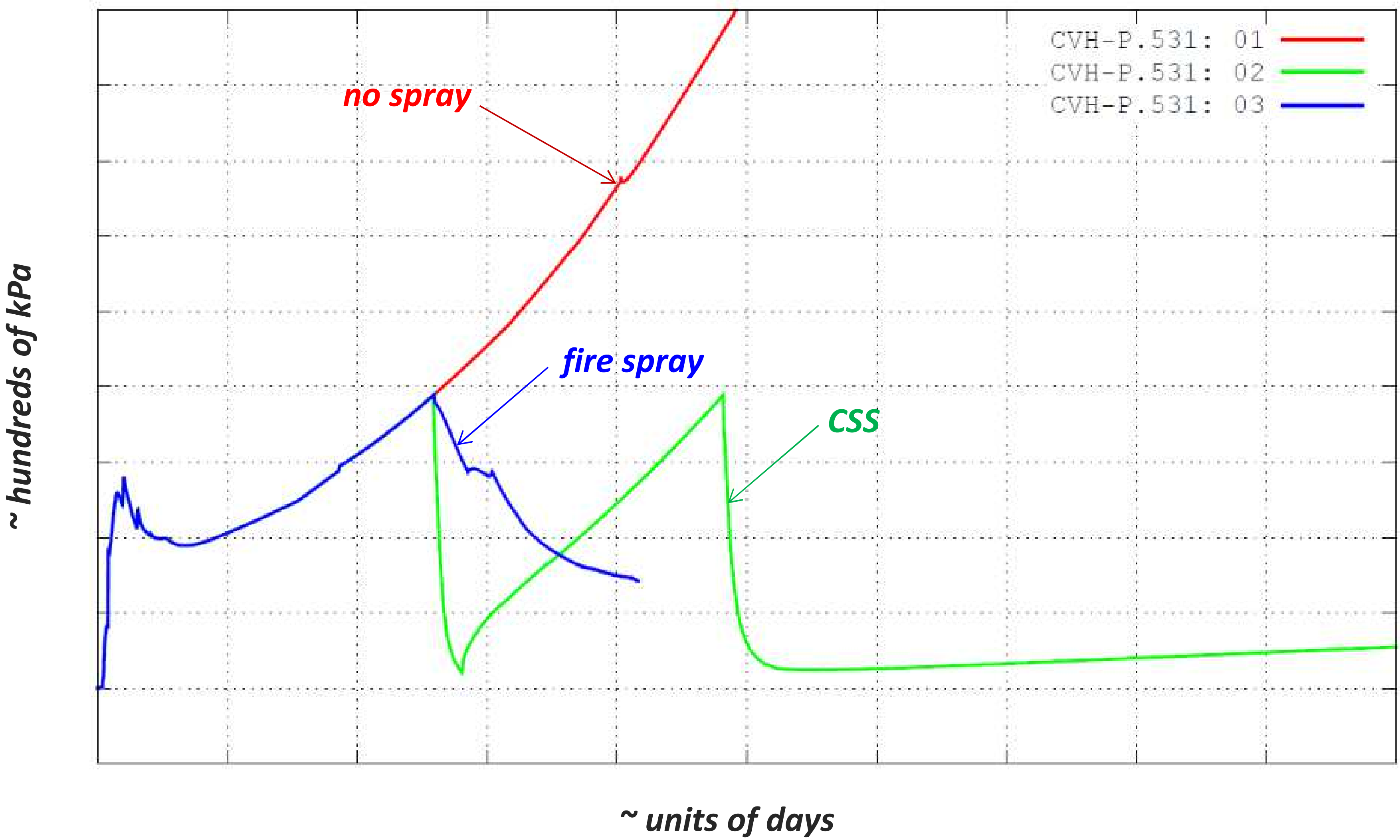
- *Further decrease of water level in the B01 pool*

SFP accident progress: 10 d (4/4)

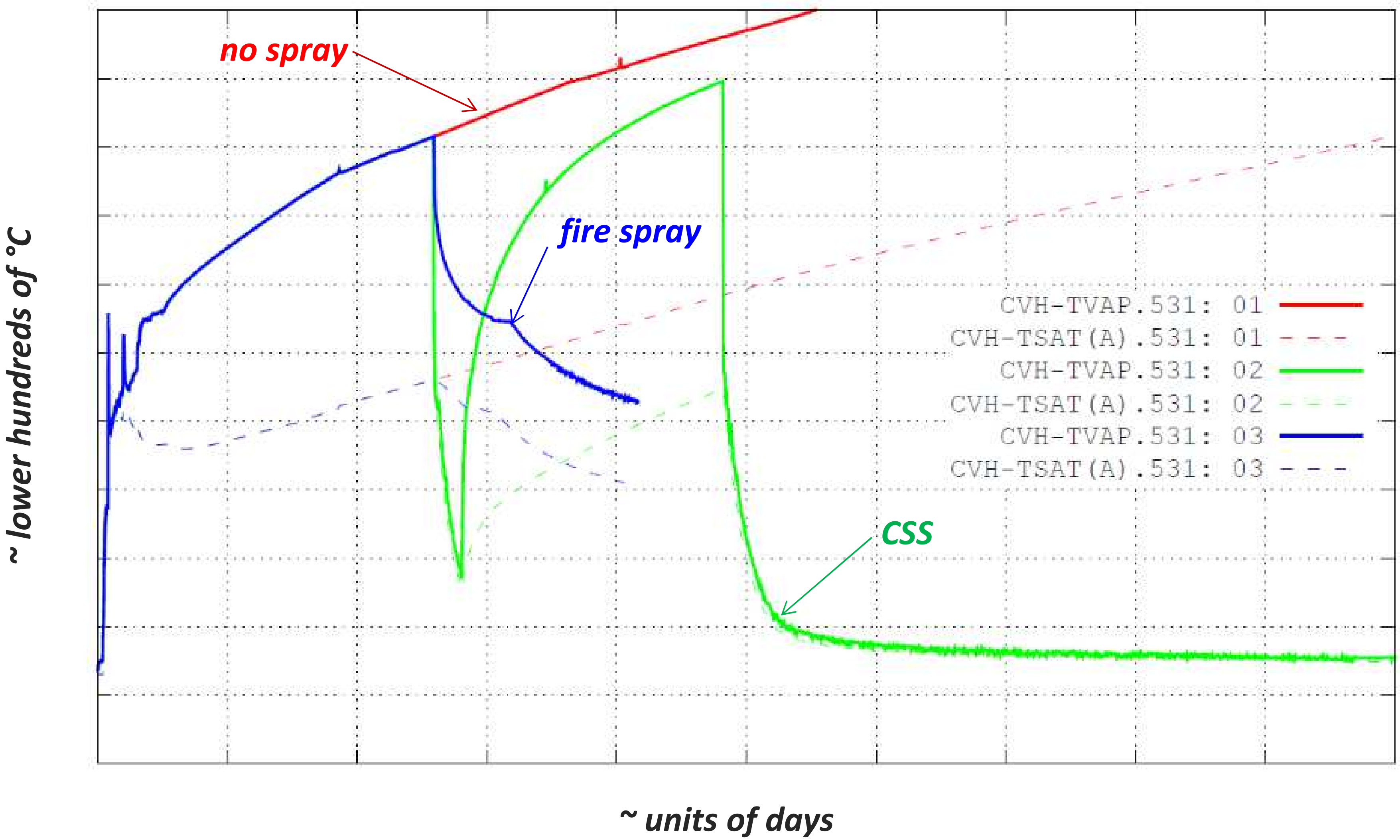


- *End of calculation – H_2 production start in B01, FAs in B03 start to uncover*

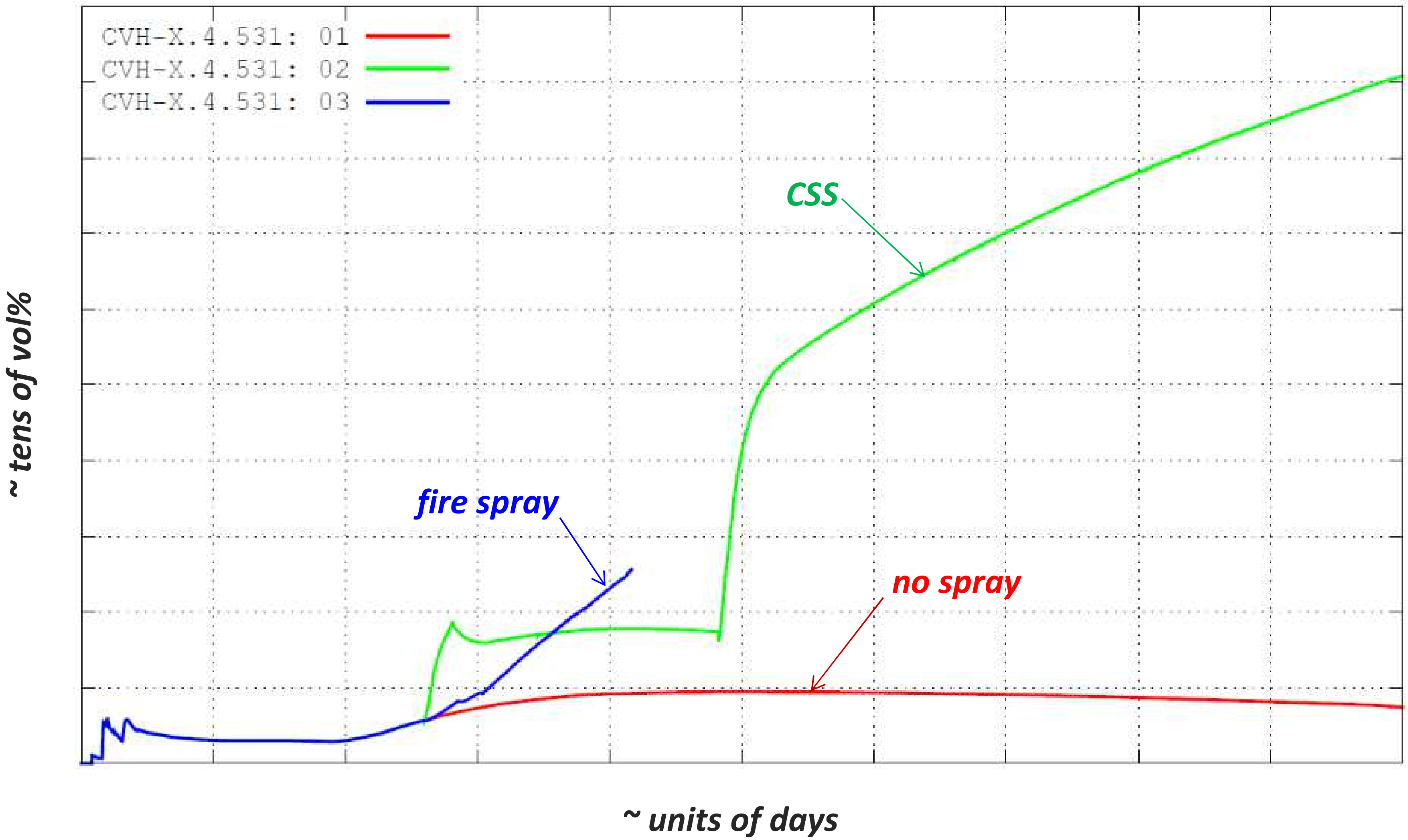
CTMT response: pressure



CTMT response: temperature (in RH)



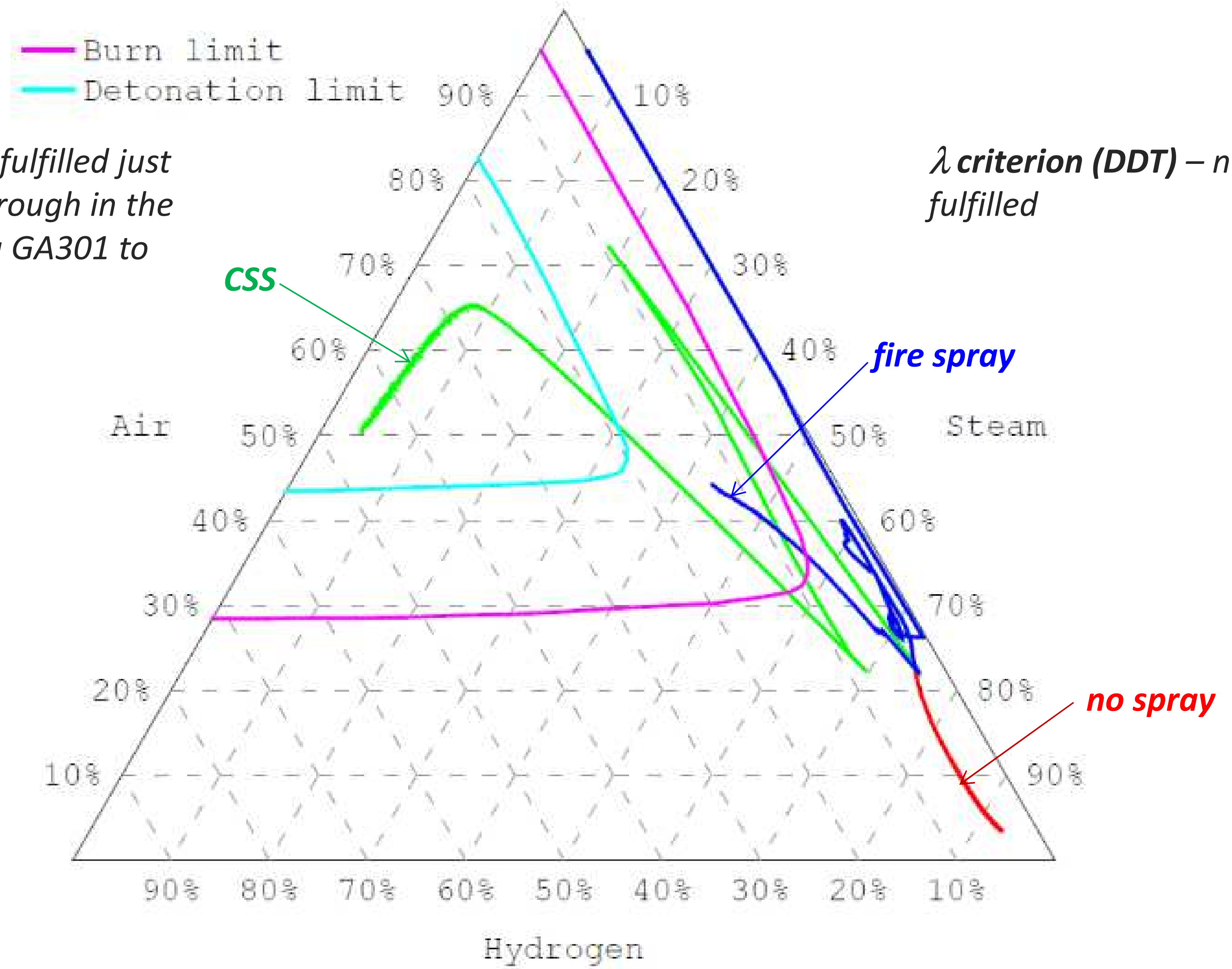
CTMT response: H_2 concentration (in RH)



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*



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

UJV GROUP