Current activities and experience with application of MELCOR 2.1 at UJD SR

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Outline

- Introduction
- Input deck adaptation/development for MELCOR 2.1
- Calculations performed
- Example of the results
- Difficulties encountered
- Foreseen activities

Introduction

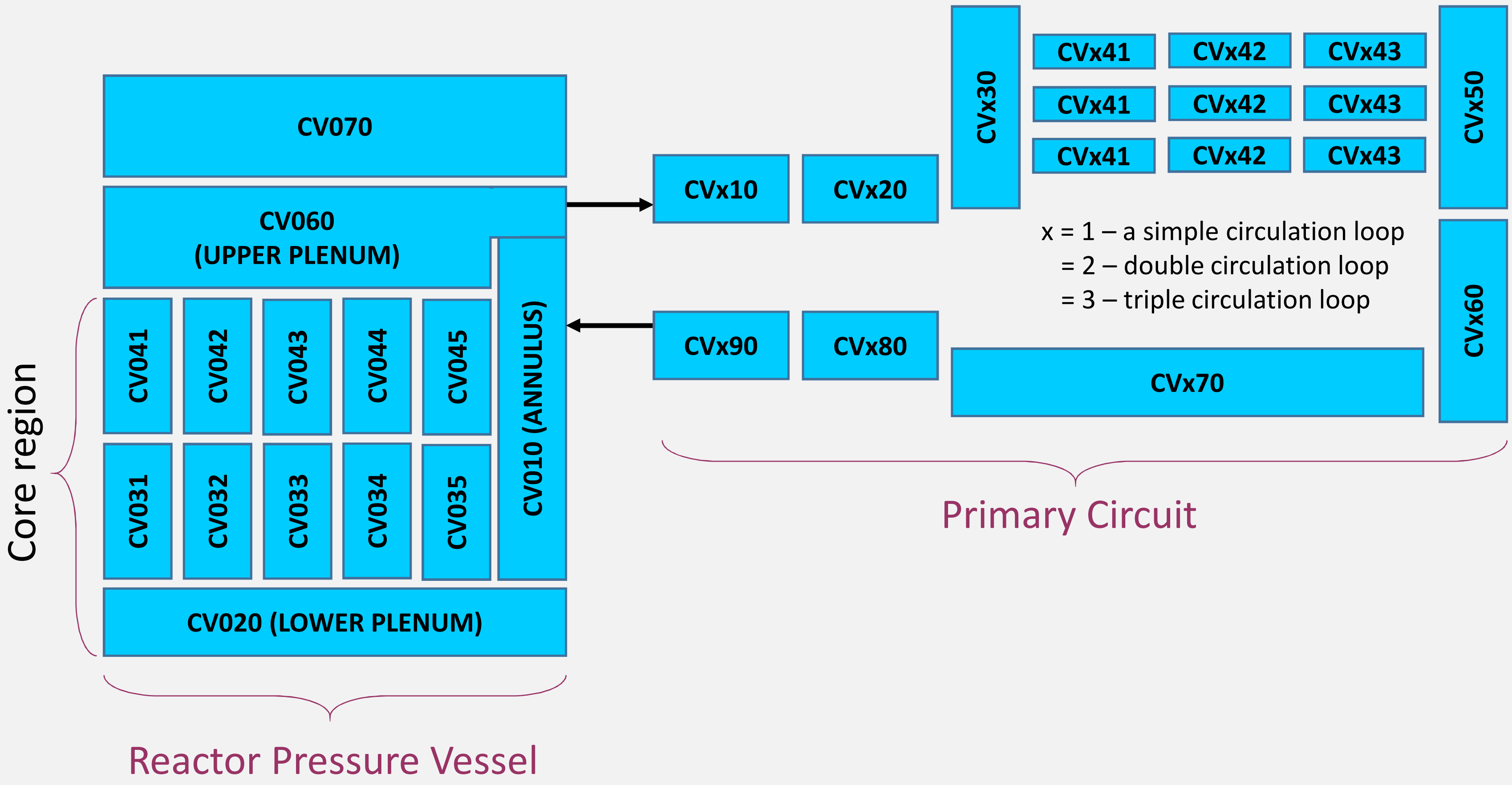
- New Agreement between UJD and US NRC on participation in the US NRC program on Severe Accident Research signed in January 2014 (MELCOR 2.1)
- UJD started with input deck adaptation/development for Slovak VVER- 440/V213 NPPs and MELCOR 2.1
- Participation in MELCOR workshop, MCAP and CSARP meetings (September 2014)
- Calculation of selected severe accident scenarios
  - the measures for severe accident management and staff interventions of NPP were considered
  - as a support for independent regulatory review

Input deck adaption/development

Primary and secondary circuits

- 3-loops model consisting of
  - a simple circulation loop with pressurizer
  - double and triple circulation loops
- 69 control volumes (14 for RPV, 11 CVs per 1 loop, 4 CVs for PRZ, 4 CVs for HAs, 13 CVs for secondary circuit)
- 94 flow paths, 199 heat structures
- a relatively simple SG model
  - primary side of SGs axially divided into 3 sections, each with 3 vertical levels of HS representing heat-exchange tube bundle
  - a single volume used for secondary side

Nodalization scheme of RPV and PC



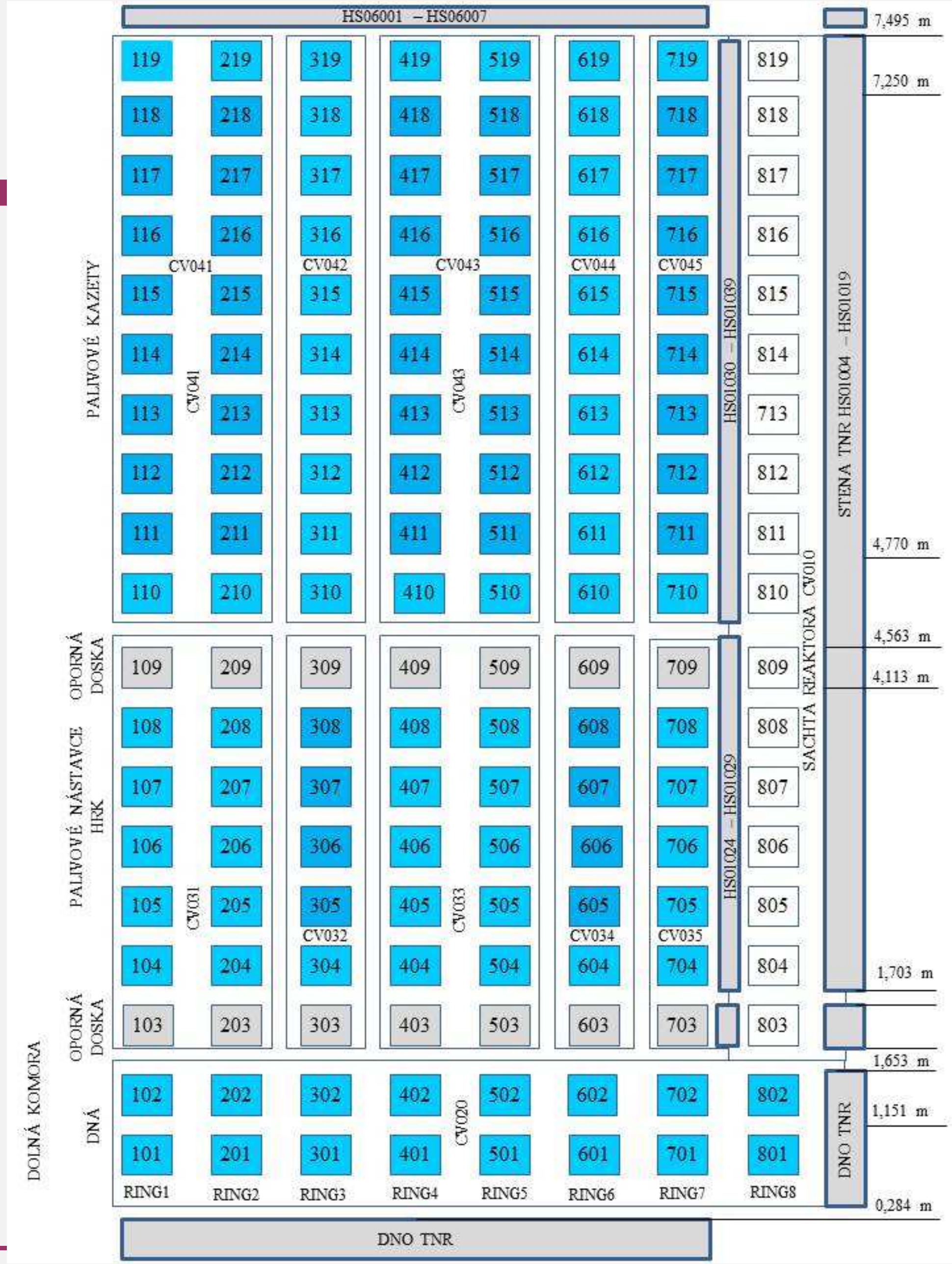
Input deck adaption/development

Core region

- Divided into 8 radial rings (including annulus of RPV) and 19 axial levels
- 312 fuel rods – located within Ring 1, 2, 4, 5 and 7
- 37 control rods – located within Ring 3 and 6
- Fuel in active core within axial levels 11 – 18; fuel section of control assemblies within axial levels 5 – 9
- BWR model used – corresponds better to VVER-440 core with fuel rod canisters, however limitations for core shroud modeling

RPV bottom

- 10 heat nodes in 9 segments



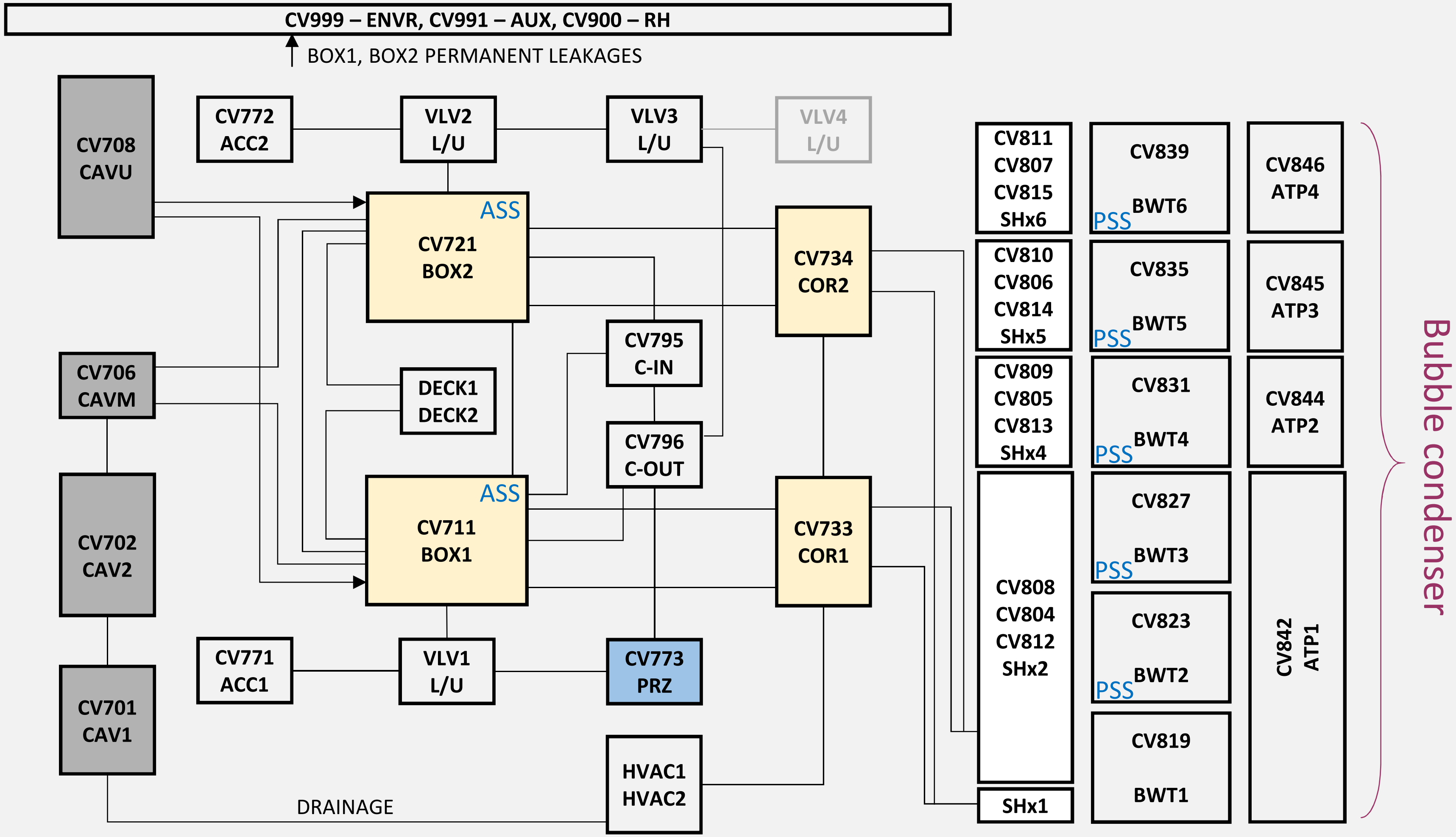
HS06001 – HS06007
7,495 m
7,250 m
4,770 m
4,563 m
4,113 m
1,703 m
1,653 m
1,151 m
0,284 m
PALIVOVÉ KAZETY
CV041
CV042
CV043
CV044
CV045
HS01030 – HS01039
STENA TNR HS01004 – HS01019
SACHTA REAKTORA CV010
OPORNÁ DOSKA
PALIVOVÉ NÁSTAVCE HRK
OPORNÁ DOSKA
CV031
CV032
CV033
CV034
CV035
HS01024 – HS01029
DOLNÁ KOMORA
DNÁ
CV020
DNO TNR
119 219 319 419 519 619 719 819
118 218 318 418 518 618 718 818
117 217 317 417 517 617 717 817
116 216 316 416 516 616 716 816
115 215 315 415 515 615 715 815
114 214 314 414 514 614 714 814
113 213 313 413 513 613 713 713
112 212 312 412 512 612 712 812
111 211 311 411 511 611 711 811
110 210 310 410 510 610 710 810
109 209 309 409 509 609 709 809
108 208 308 408 508 608 708 808
107 207 307 407 507 607 707 807
106 206 306 406 506 606 706 806
105 205 305 405 505 605 705 805
104 204 304 404 504 604 704 804
103 203 303 403 503 603 703 803
102 202 302 402 502 602 702 802
101 201 301 401 501 601 701 801
RING1 RING2 RING3 RING4 RING5 RING6 RING7 RING8
DNO TNR

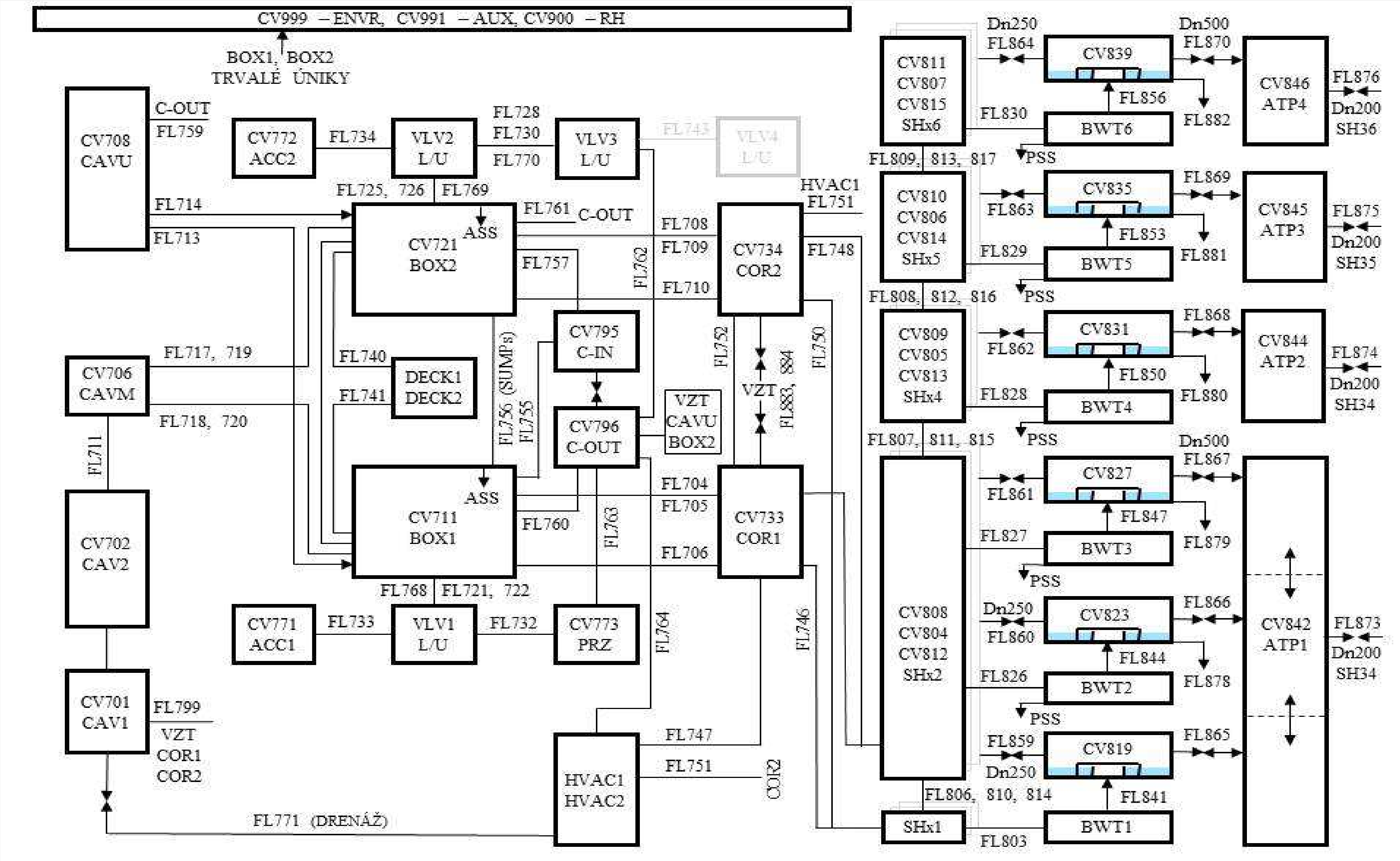
Input deck adaption/development

Containment

- 77 control volumes + 3 CVs (reactor hall, surrounding rooms, environment)
- 129 flow paths (including 2 FL paths for permanent leakages)
- 155 heat structures
- Bubble condenser – 3 levels at the bottom modelled individually, upper levels 4 – 12 grouped by 3 levels per modelling horizontal level, a single air trap volume communicates with each group of 3 vertical levels

Nodalization scheme of the containment





CV999 – ENVR, CV991 – AUX, CV900 – RH
BOX1, BOX2
TRVALÉ ÚNIKY
CV708
CAVU
C-OUT
FL759
FL714
FL713
CV772
ACC2
FL734
VLV2
L/U
FL728
FL730
FL770
VLV3
L/U
FL743
VLV4
L/U
FL725, 726
FL769
CV721
BOX2
ASS
FL761
C-OUT
FL708
FL709
FL710
FL762
FL757
CV734
COR2
HVAC1
FL751
FL748
CV706
CAVM
FL717, 719
FL718, 720
FL711
FL740
FL741
DECK1
DECK2
CV795
C-IN
FL756 (SUMPs)
FL755
CV796
C-OUT
VZT
CAVU
BOX2
FL752
VZT
FL883, 884
FL750
CV702
CAV2
CV711
BOX1
ASS
FL760
FL704
FL705
FL706
FL763
CV733
COR1
FL768
FL721, 722
CV771
ACC1
FL733
VLV1
L/U
FL732
CV773
PRZ
FL764
FL746
CV701
CAV1
FL799
VZT
COR1
COR2
FL747
FL751
COR2
HVAC1
HVAC2
FL771 (DRENÁŽ)
CV811
CV807
CV815
SHx6
Dn250
FL864
CV839
Dn500
FL870
CV846
ATP4
FL876
Dn200
SH36
FL856
FL882
FL830
BWT6
PSS
FL809, 813, 817
CV810
CV806
CV814
SHx5
FL863
CV835
FL869
CV845
ATP3
FL875
Dn200
SH35
FL853
FL881
FL829
BWT5
PSS
FL808, 812, 816
CV809
CV805
CV813
SHx4
FL862
CV831
FL868
CV844
ATP2
FL874
Dn200
SH34
FL850
FL880
FL828
BWT4
PSS
FL807, 811, 815
Dn500
FL867
FL861
CV827
FL847
FL879
FL827
BWT3
PSS
CV808
CV804
CV812
SHx2
Dn250
FL860
CV823
FL866
CV842
ATP1
FL873
Dn200
SH34
FL844
FL878
FL826
BWT2
PSS
FL859
Dn250
CV819
FL865
FL841
FL806, 810, 814
SHx1
FL803
BWT1

Input deck adaption/development

Engineering safety features and operator actions

- Emergency Core Cooling systems:
  - High-Pressure and Low-Pressure Injection Systems (3 trains per system)
  - Hydro-accumulators (4 HAs)
- Active and passive spray systems in the containment (ASS, PSS)
- Passive Autocatalytic Re-combiners (modeled using ESF package)
- Specific SAM measures modeled by dedicated flow paths allowing to:
  - aggressively depressurize the primary and/or secondary circuits
  - Drain water of the Bubble Condenser trays
  - flood the cavity by water (located on the floor of SG boxes)
- Emergency Source of Coolant – possible use for feeding SS, ECCS, cavity flooding, feeding of SGs, etc.

Input deck adaption/development

Redefinition of various data/ parameters

- Concrete composition in the reactor cavity
- Decay heat and initial radionuclide composition
- Properties of Passive Autocatalytic Re-combiners (AREVA empirical constants for FR90/1-150, FR90/1-750T, FR90/1-1500 PARs used)
- Some of material properties

Input deck adaption/development

Selected parameters of the model	
Parameter	**Value**
Mean initial enrichment of the fuel	4,25%
Pressure in HA	3,50 MPa
Mass of fuel in the core	49 736 kg
Mass of zirconium in the core	18 688 kg
Mass of stainless steel modelled in the RPV	42 185 kg
Free volume in the containment	52 055 m^3
Permanent leakages in the containment	5,54%/ 24 hod
Free volume in the reactor hall (both units)	163 700 m^3
Passive autocatalytic recombiners in the containment	28×PAR FR1-1500T, 4×PAR FR1-750T

Analyses performed

13 scenarios successfully calculated, variants on:

- IE (SBO; LOCAs, IFLOCA or SGTR - all combined with loss of power)
- operator actions (PC depressurization through SAM PRZ valve, drainage of BC trays, cavity flooding)
- assumptions related to the containment state (intact, failed – before or at the time of V.B., by-passed)
- operation regime (full power, shutdown – opened RPV)
- Assumption of

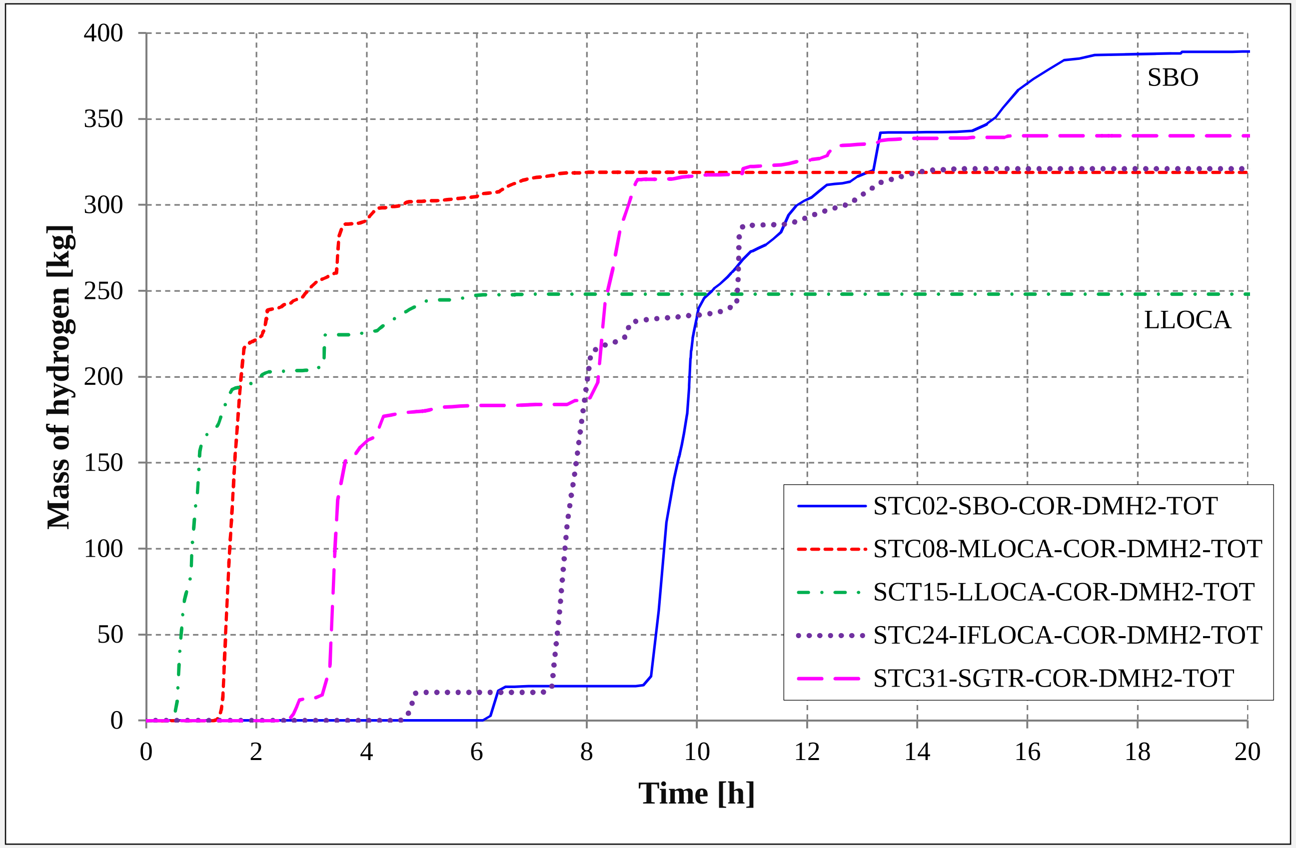
Analyses performed

List of scenarios calculated					
No.	**Initiating event**	**Operator action**			**Containment**
		PC depress.	**Drainage of BC trays**	**Cavity flooding**	
STC01	BLACKOUT	no	no	no	sealed
STC02	BLACKOUT	Yes	Yes	no	sealed
STC03	BLACKOUT	Yes	Yes	no	failed before V.B.
STC08	MLOCA_100mm_HL	Yes	Yes	no	sealed
STC09	MLOCA_100mm_HL	Yes	Yes	no	failed before V.B.
STC15	LLOCA_2x496mm_HL	Yes	Yes	no	sealed
STC16	LLOCA_2x496mm_CL	Yes	Yes	no	sealed
STC17	LLOCA_2x496mm_HL	Yes	Yes	no	failed before V.B.
STC18	LLOCA_2x496mm_HL	Yes	Yes	Yes	sealed
STC24	IFLOCA_20mm_HL	Yes	Yes	no	bypass
STC30	SGTR	Yes	no	no	failed at V.B.
STC31	SGTR	Yes	no	no	bypass
STC36	OR	no	no	no	-

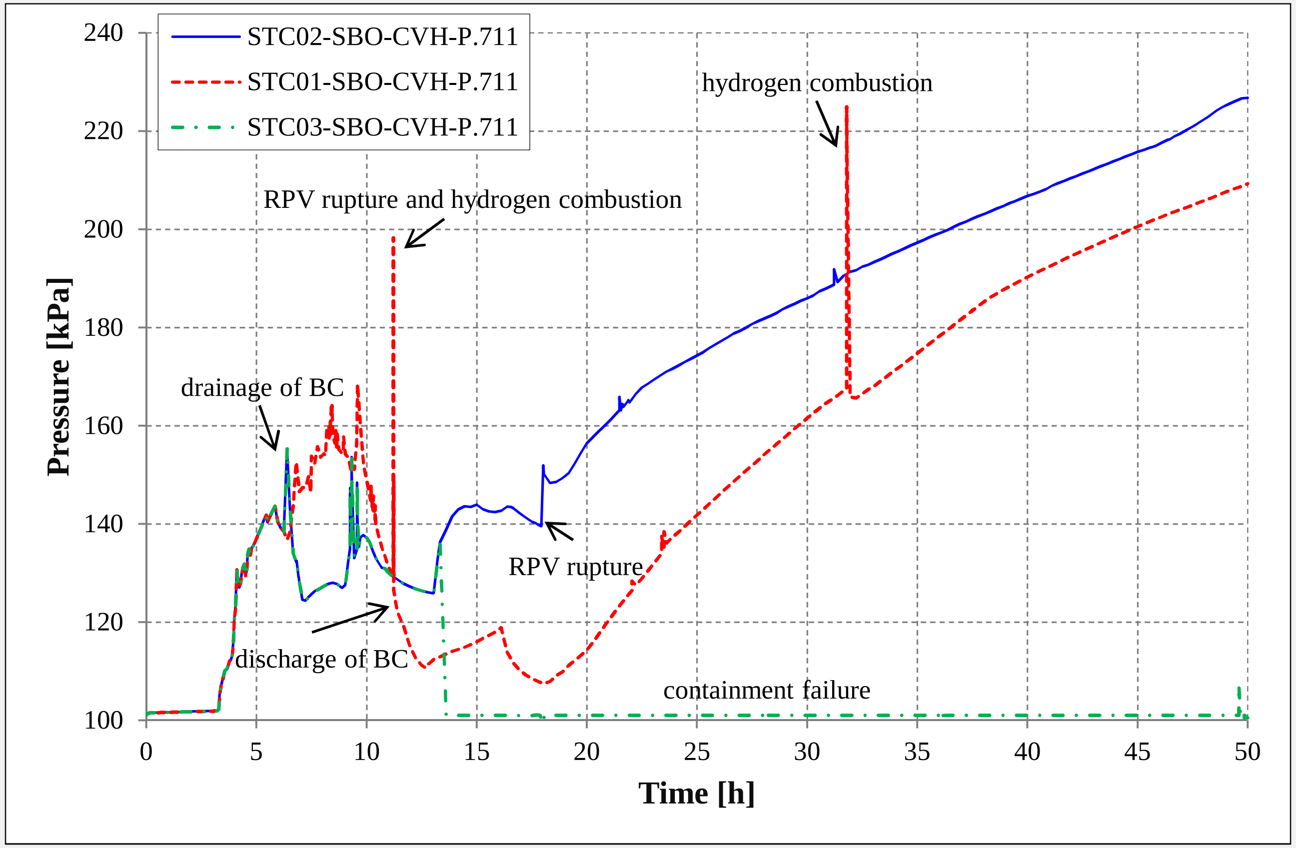
Timing of key events and other results for analyzed scenarios

No.	Time of gap release, s	Time of core support plate failure, s	Time of lower head failure, s	Time of the containment failure, s	Mass of hydrogen produced in RPV, kg	Pressure in the containment after 2 days, kPa
STC01	22 583	34 367	40 348	-	416	209
STC02	22 583	46 973	63 702	-	379	226
STC03	22 583	46 973	63 577	48 000	395	101
STC08	4 539	12 380	29 786	-	319	244
STC09	4 539	12 415	27 888	8 000	312	101
STC15	1 579	11 237	24 084	-	248	246
STC16	634	9 725	19 814	-	199	234
STC17	1 579	11 153	24 176	4 000	221	101
STC18	1 579	11 605	-	-	271	300
STC24	16 746	38 591	52 706	-	321	195
STC30	9 236	38 959	56 093	56 093	340	101
STC31	9 236	38 959	56 093	-	340	233
STC36	10 234	31 944	61 078	-	364	atm.

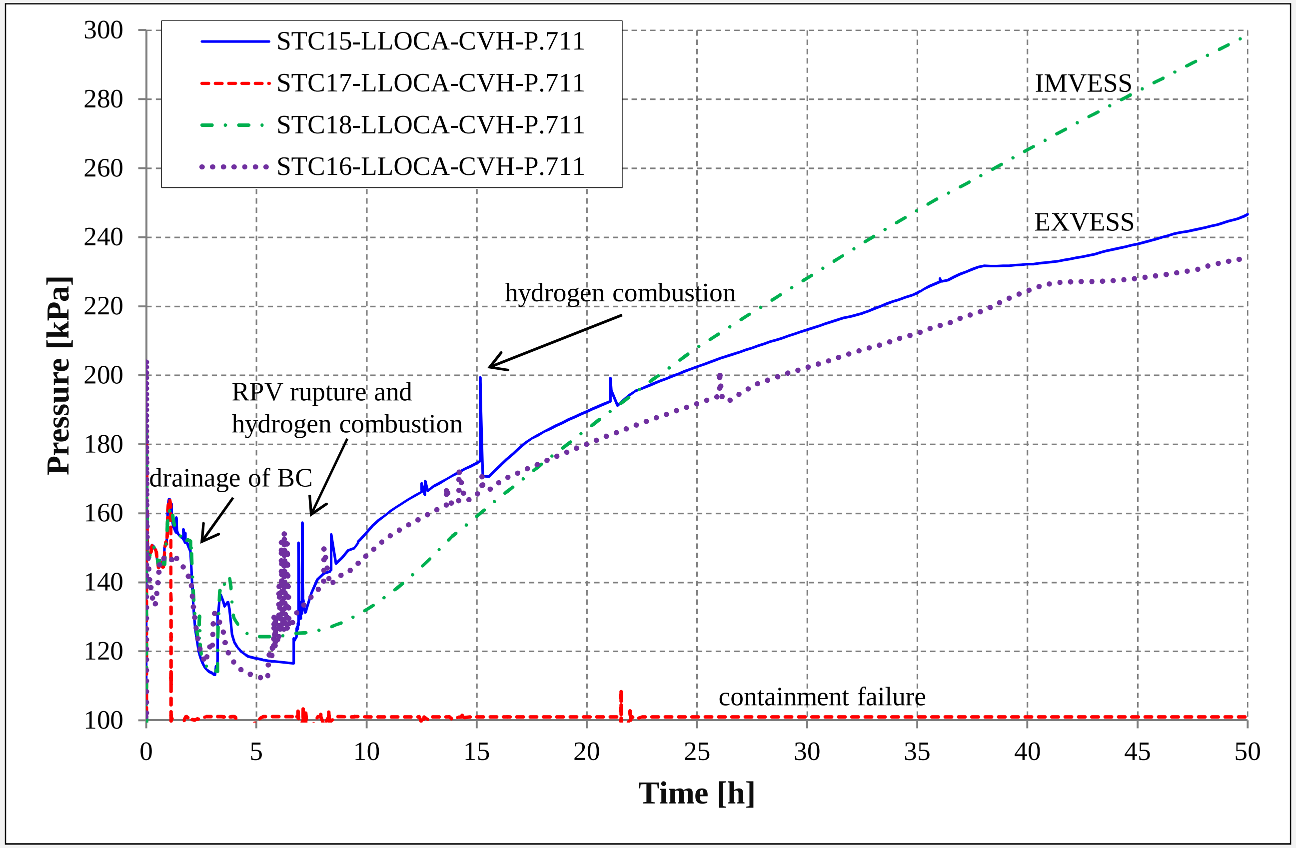
Mass of hydrogen produced in RPV



Pressure in the containment (SBO)



Pressure in the containment (LLOCA)



Difficulties encountered

- Elliptical geometry of RPV bottom modeled as a truncated hemisphere
  - lower mass of steel comparing to real RPV (by 1371 kg)

- How to switch off the model of lower head failure ?
  - following of description in the Users manual was without success

- Incorrect functioning of ESF-PAR model observed:
  - in conditions of high H_2 and low O_2 concentrations in the containment after vessel failure and start of MCCI
  - discrepancy between mass and volume flowrates through PARs
  - negative PAR outlet temperature

Difficulties encountered

- Sometimes core barrel melted laterally (all material melted in the respective core cell) but the support plate still remaining in place

- How to model lower head for in-vessel retention concept (external cooling of RPV)
  - After the debris relocation to lower plenum (i.e. contact between debris and lower head) RPV failure occurs
  - Attempt to increase the number of axial levels in the lower head (3 instead of 2) was not a help
  - Heat transfer mainly in axial direction (downward) and only minor fraction transferred in radial direction
  - Is it possible to modify it ?

Foreseen activities

- Modification / improvement of the input deck
  - Initial fuel enrichment of 4,87%
- Calculation of various scenarios with open reactor model
- Development of model for the Spent Fuel Storage Pool

Thank you for your attention.