UPM Research with MELCOR 2.x . PWR-W Applications

EMUG, Brugg Switzerland

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MELCOR history in the UPM

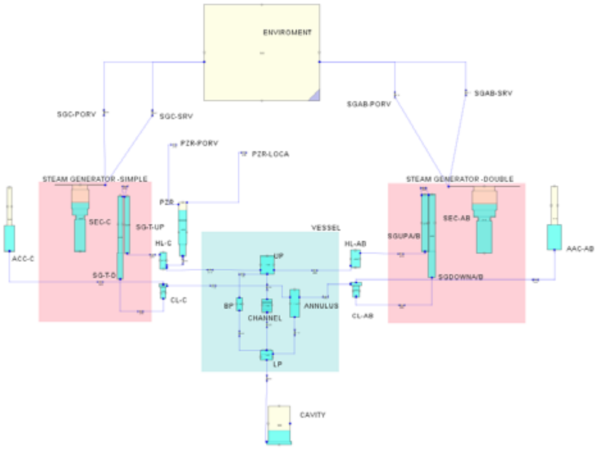
- UPM-CSN (Spanish Nuclear Safety Council) agreement to collaborate in CSARP (July 2017)
- The translation of Trillo NPP from MELCOR 1.8.5 to MELCOR 2.1 has been performed as part of the agreement between CSN and UPM.
- Previous works with MELCOR 1.8.3:
  - A PWR-W model was developed in the UPM and used for European report project.

- Currently UPM is working with different NPPs models (PWR-W, BWR, PWR-Siemens, AP1000) in several projects.

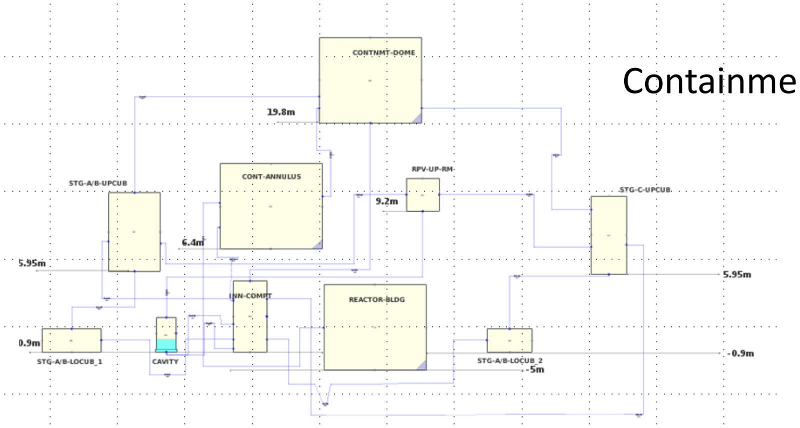
MELCOR Models

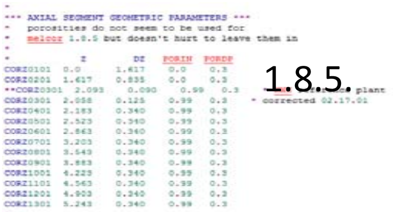
- PWR-Siemens (Trillo NPP)
    - Translation of the model from MELCOR 1.8.5 to 2.1
    - A set of sequences were used to verify the model

RCS



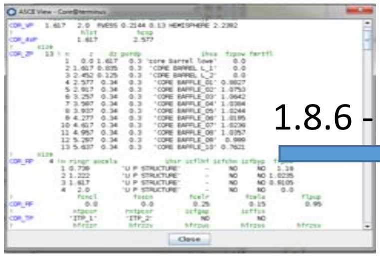
Containment





```
*
*** AXIAL SEGMENT GEOMETRIC PARAMETERS ***
*   porosities do not seem to be used for
*   melcor 1.8.5 but doesn't hurt to leave them in
*
*            Z          DZ    PORIN  PORDP
CORZ0101  0.0        1.617    0.0     0.3
CORZ0201  1.617      0.835    0.0     0.3
**CORZ0301  2.093      0.090    0.99    0.3      [illegible] plant
CORZ0301  2.058      0.125    0.99    0.3    * corrected 02.17.01
CORZ0401  2.183      0.340    0.99    0.3
CORZ0501  2.523      0.340    0.99    0.3
CORZ0601  2.863      0.340    0.99    0.3
CORZ0701  3.203      0.340    0.99    0.3
CORZ0801  3.543      0.340    0.99    0.3
CORZ0901  3.883      0.340    0.99    0.3
CORZ1001  4.223      0.340    0.99    0.3
CORZ1101  4.563      0.340    0.99    0.3
CORZ1201  4.903      0.340    0.99    0.3
CORZ1301  5.243      0.340    0.99    0.3
*
```

1.8.5.

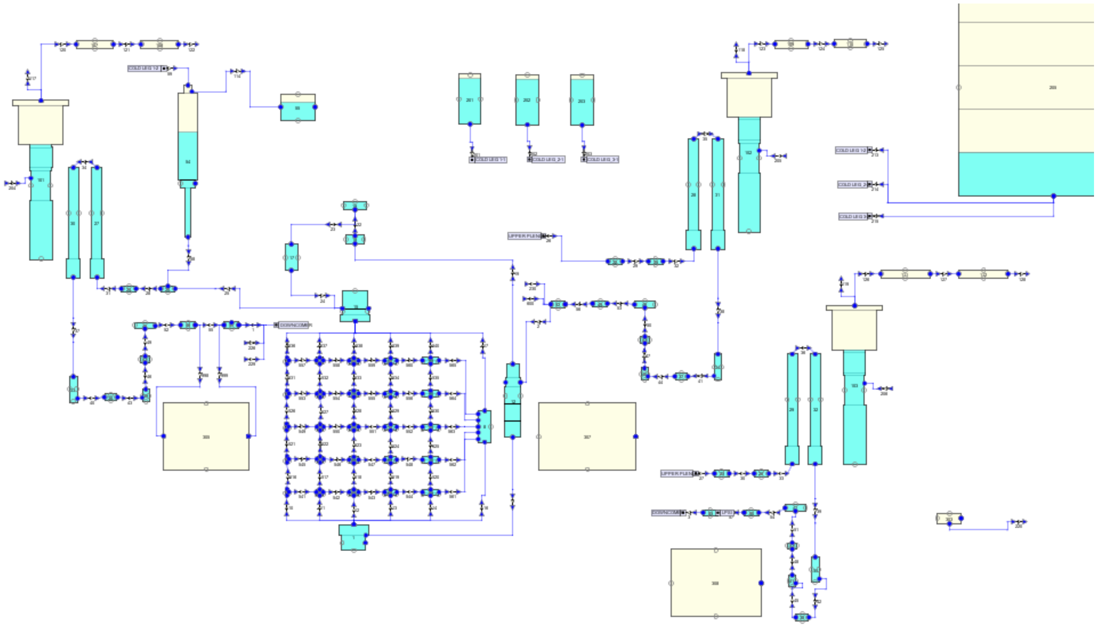


```
COR_VP    1.617   2.0  RVESS 0.2144 0.13 HEMISPHERE 2.2382
!              hlst          hcsp
COR_RVP          1.617          2.577
!       size
COR_ZP    13 ! n     z    dz porDp               ihsa  fzpow farttl
               1   0.0 1.617   0.3 'core barrel lowe'   0.0
               2 1.617 0.835   0.3  'CORE BARREL L_1'   0.0
               3 2.452 0.125   0.3  'CORE BARREL L_2'   0.0
               4 2.577  0.34   0.3   'CORE BAFFLE_01' 0.8827
               5 2.917  0.34   0.3   'CORE BAFFLE_02' 1.0753
               6 3.257  0.34   0.3   'CORE BAFFLE_03' 1.0642
               7 3.597  0.34   0.3   'CORE BAFFLE_04' 1.0384
               8 3.937  0.34   0.3   'CORE BAFFLE_05' 1.0244
               9 4.277  0.34   0.3   'CORE BAFFLE_06' 1.0195
              10 4.617  0.34   0.3   'CORE BAFFLE_07' 1.0236
              11 4.957  0.34   0.3   'CORE BAFFLE_08' 1.0357
              12 5.297  0.34   0.3   'CORE BAFFLE_09'  0.999
              13 5.637  0.34   0.3   'CORE BAFFLE_10' 0.7621
!       size
COR_RP     4 ! n ringr asecla           ihsr icfldt icfchn icfbyp  f
               1 0.739         'U P STRUCTURE'    -     NO     NO   1.18
               2 1.222         'U P STRUCTURE'    -     NO     NO 1.0235
               3 1.617         'U P STRUCTURE'    -     NO     NO 0.9105
               4   2.0         'U P STRUCTURE'    -     NO     NO    0.0
!              fcncl        fssch        fcelr        fcela        flpup
COR_RF           0.0          0.0         0.25         0.15         0.95
!             ntpcor      rntpcor       icfgap       icffis
COR_TP       'ITP_1'      'ITP_2'           NO           NO
!             hfrzzr       hfrzzv       hfrzpo       hfrzss       hfrzsx
```

1.8.6 - 2.1.

MELCOR Models

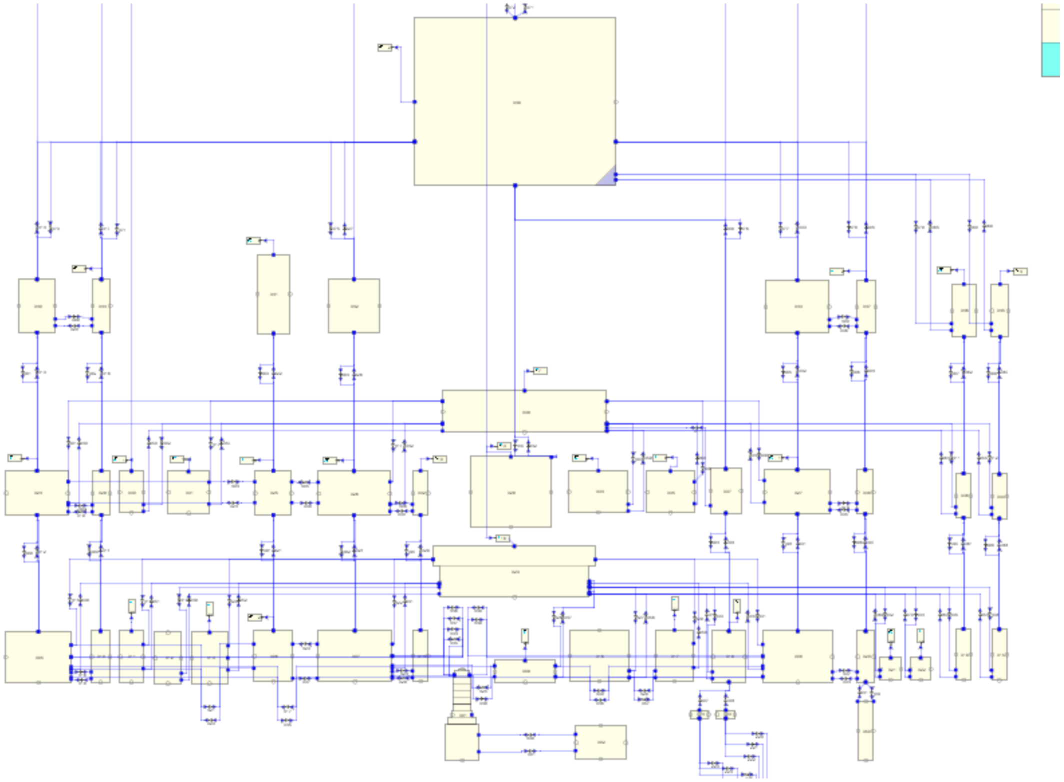
- PWR-W main features
  - Primary System
  - Secondary System up to Turbine admison Valves
  - RWST
  - Accumulators
  - HPSI, LPSI and Recirculation.



Based on: F. Martin-Fuertes *et al.*, “Analysis of three severe accident sequences (AB, SGTR and V) in a 3 loop W-PWR 900 MWe NPP with the MELCOR code,” *European Commission*, vol. EUR 16054, 1994

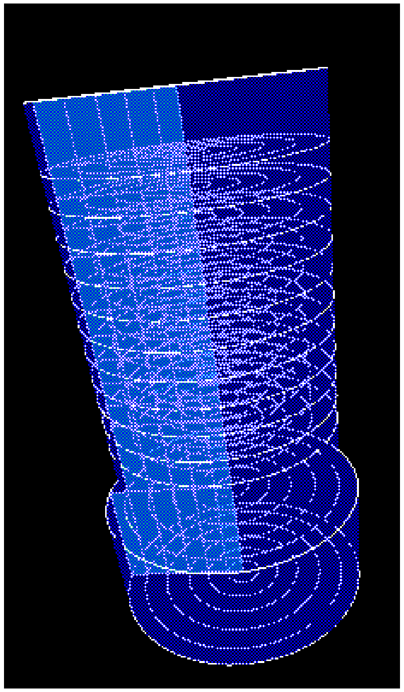
MELCOR Models

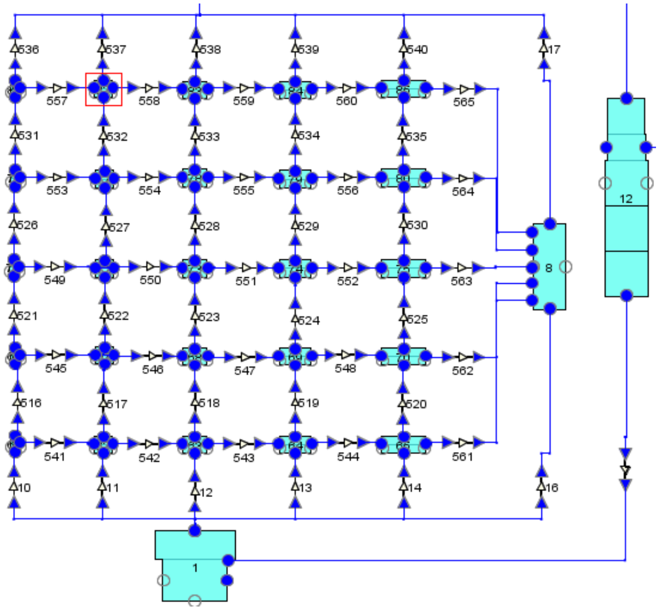
- PWR-W Containment
  - More than 40 CV
  - Connected two-way
  - Containment Spray included



MELCOR Models

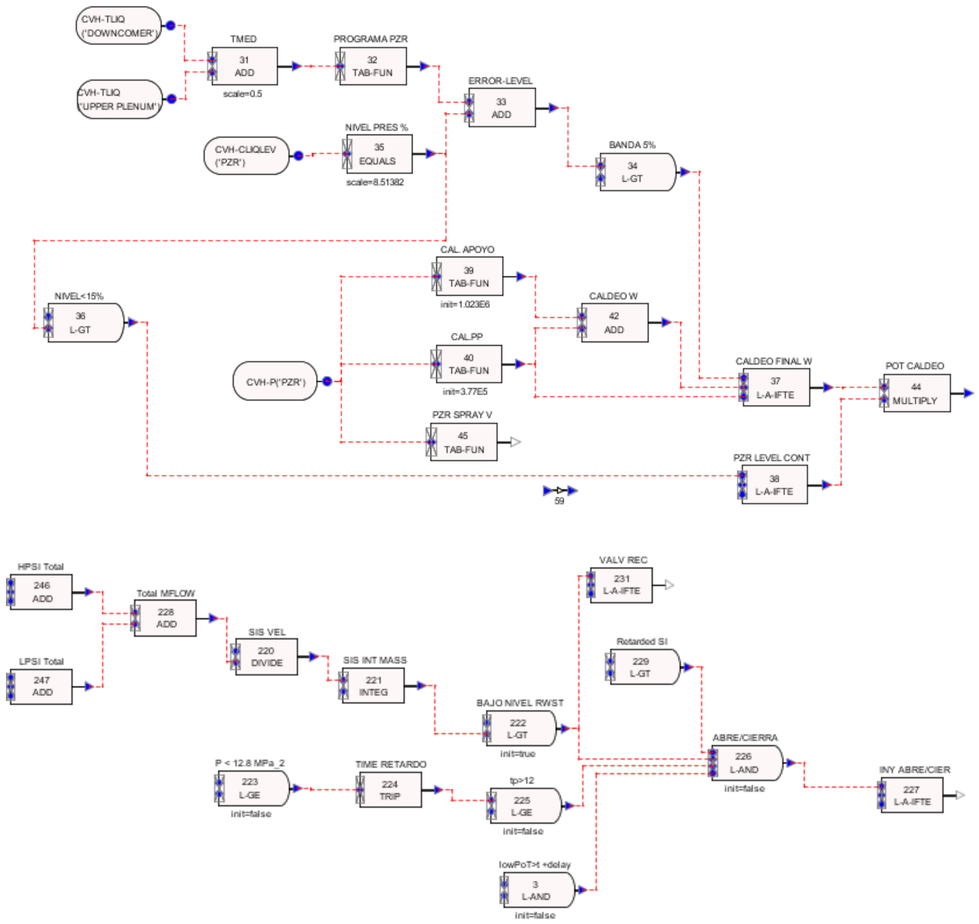
- PWR-W Vessel and core
  - 28 Heat Structures
  - 35 CV
  - 6 Rings 13 Levels





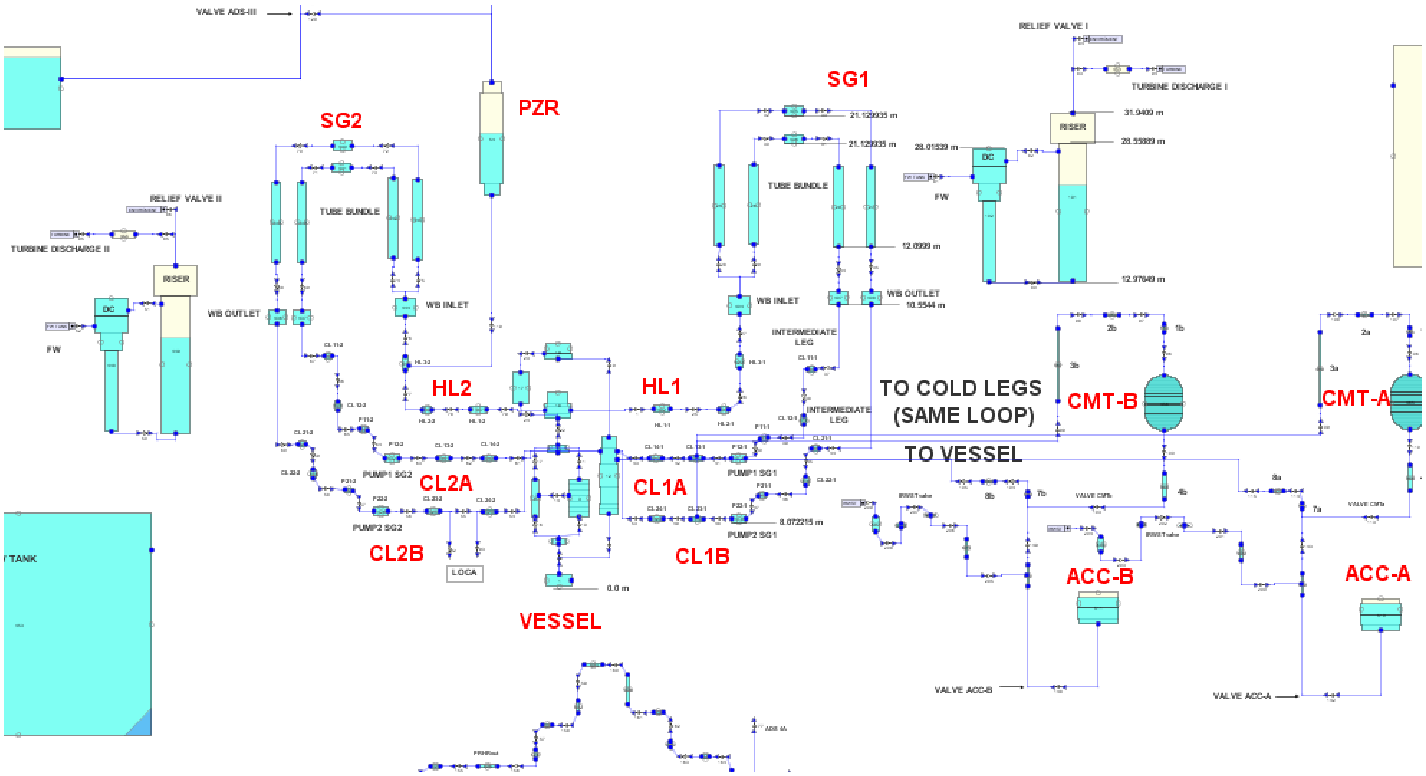
MELCOR Models

- PWR-W Control
  - Safety Injection System Control Modeled
  - PZR Control
  - Pumps performance
  - SCRAM



MELCOR Models

- AP1000



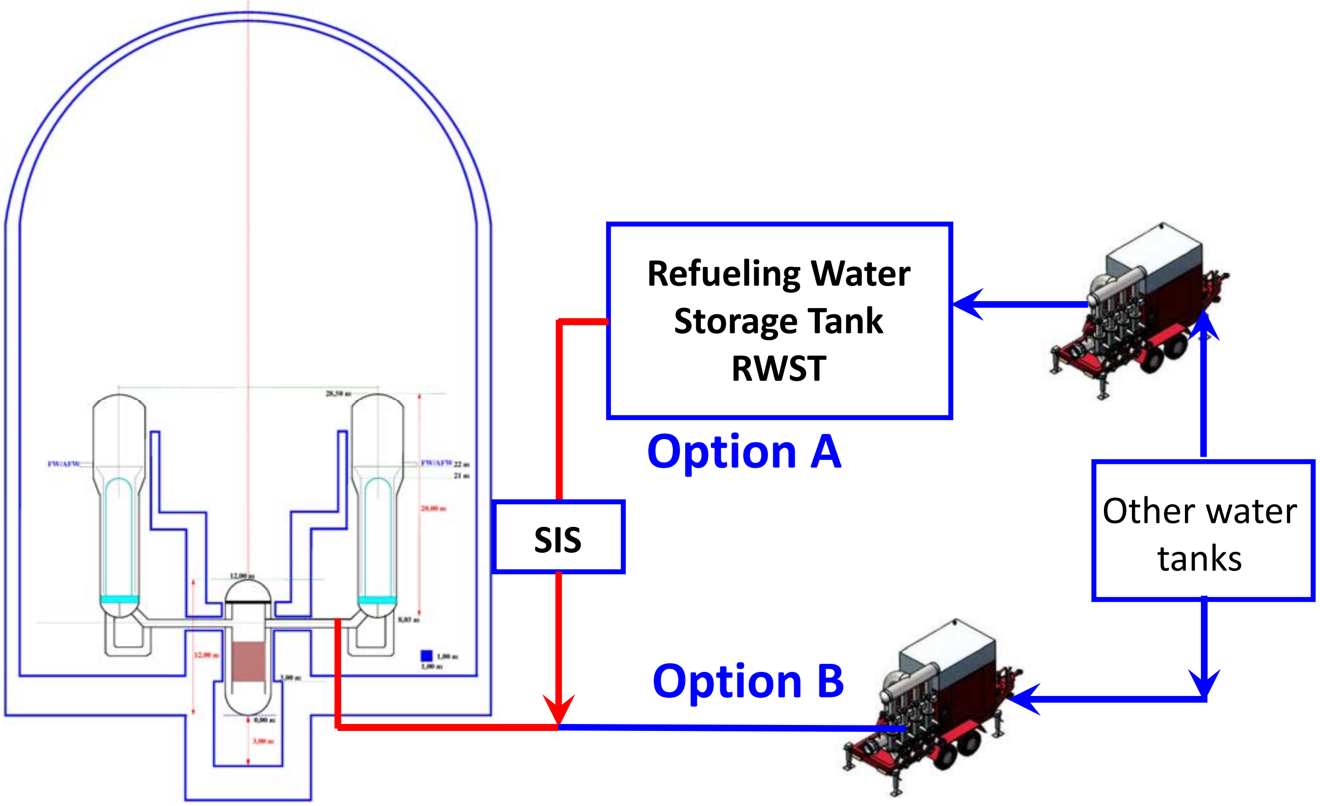
PWR-W MELCOR Model Results

Study of FLEX Strategies with the MELCOR code:

- Simulation of a Recirculation Failure after LBLOCA
- Comparison of Different Time Failures
- Comparison with ASTEC
- Study with RN package included
- Simulation of using portable equipment after recirculation Failure to inject into RCS.

LBLOCA with recirculation failure

- Injection with Portable Equipment into RCS
- Option B is selected and simulated with MELCOR 2.2



Refueling Water Storage Tank RWST

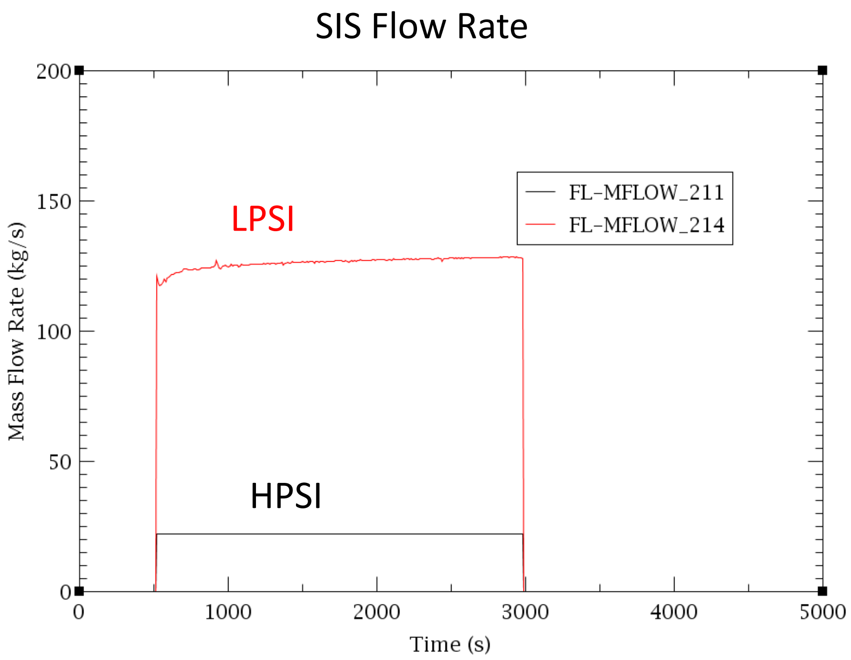
SIS

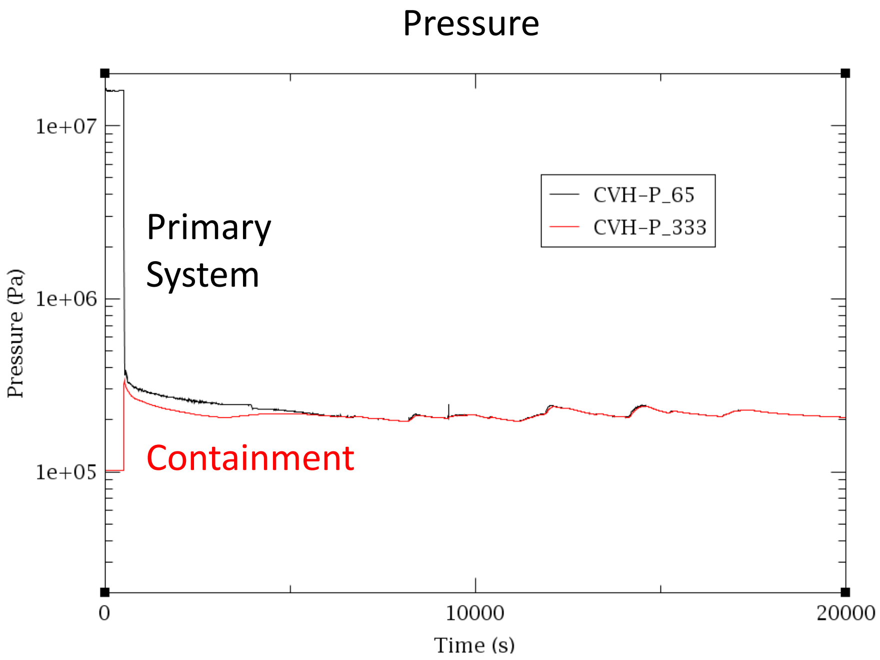
Option A

Other water tanks

Option B

PWR-W MELCOR Model Results

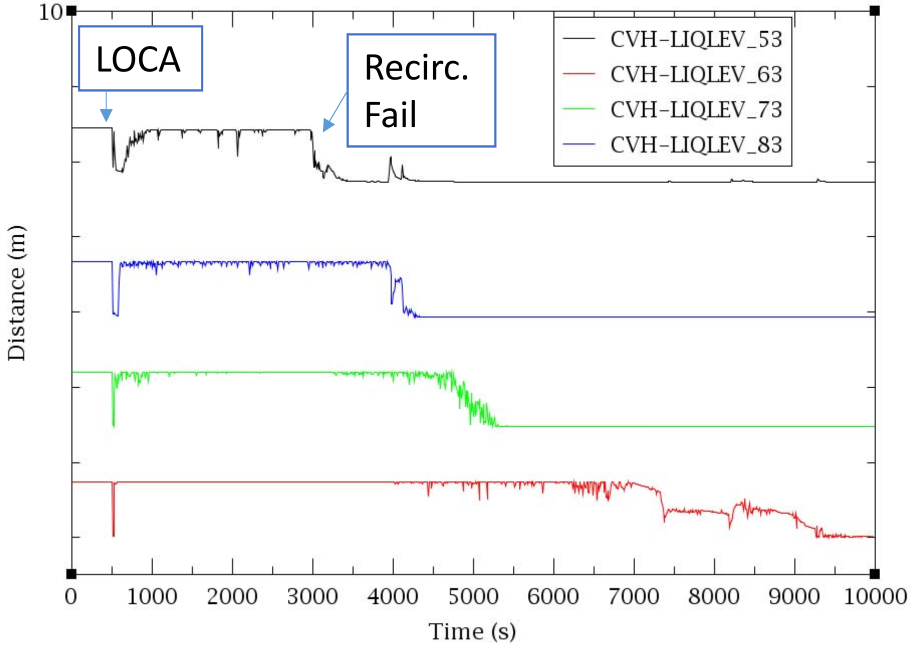




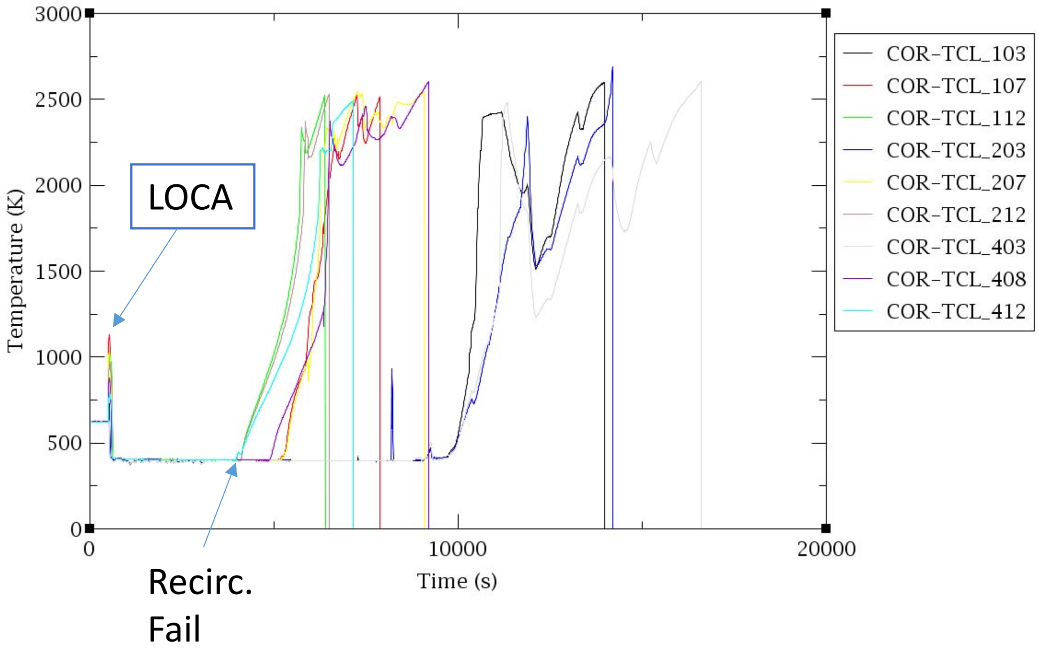
Correct Behavior of the Primary System and Containment pressure after LBLOCA

PWR-W MELCOR Model Results

Liquid level in Core control volumes

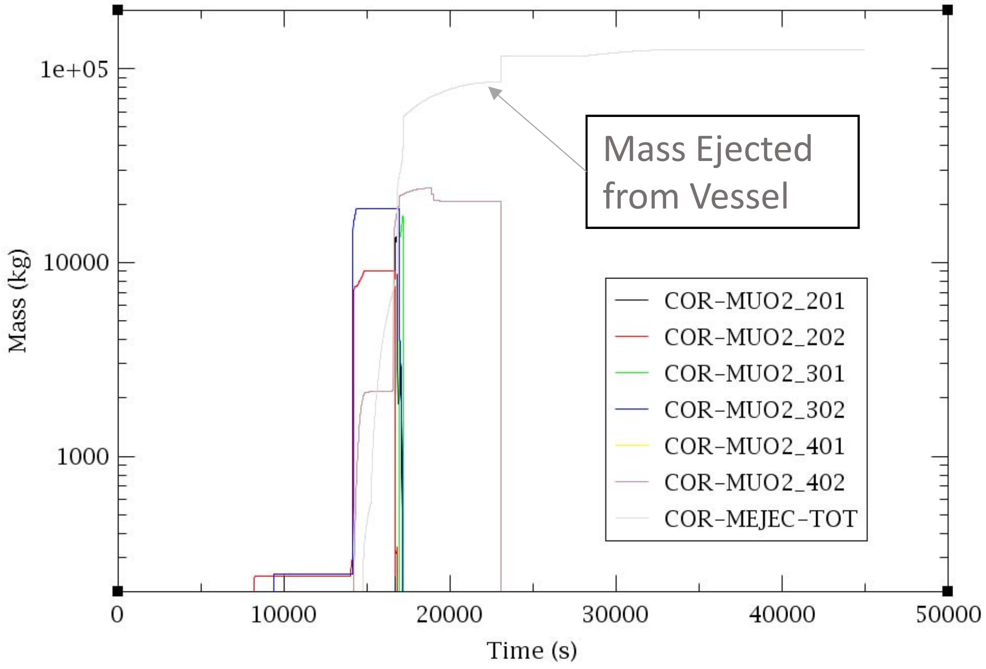


Temperature in Core nodes



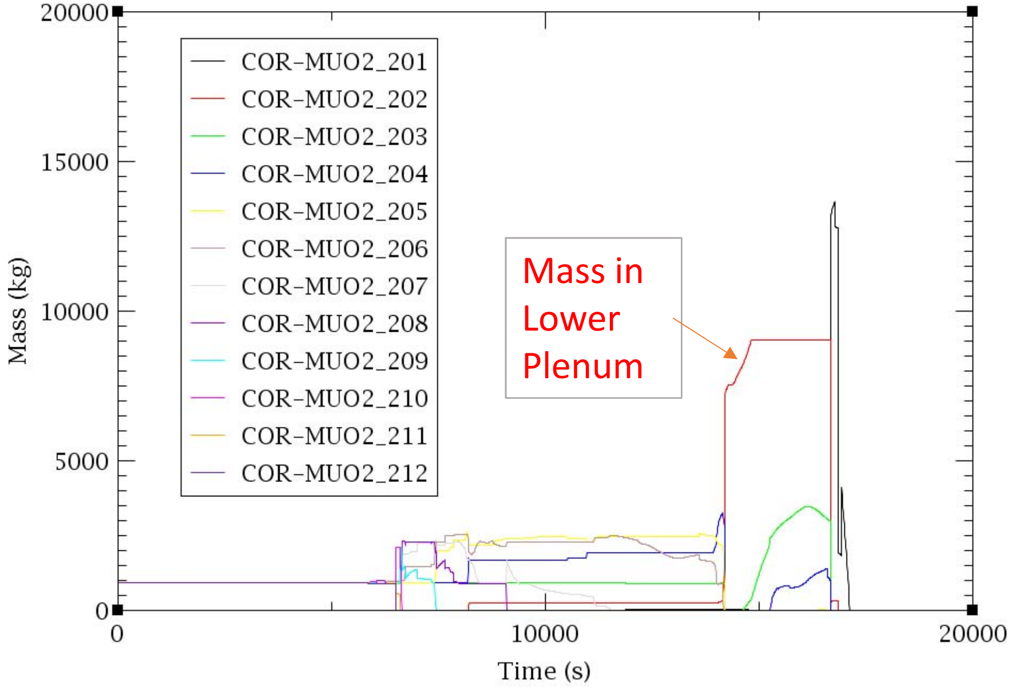
PWR-W MELCOR Model Results

UO2 Core masses in LP and ejected mass



Mass Ejected from Vessel

UO2 Core masses

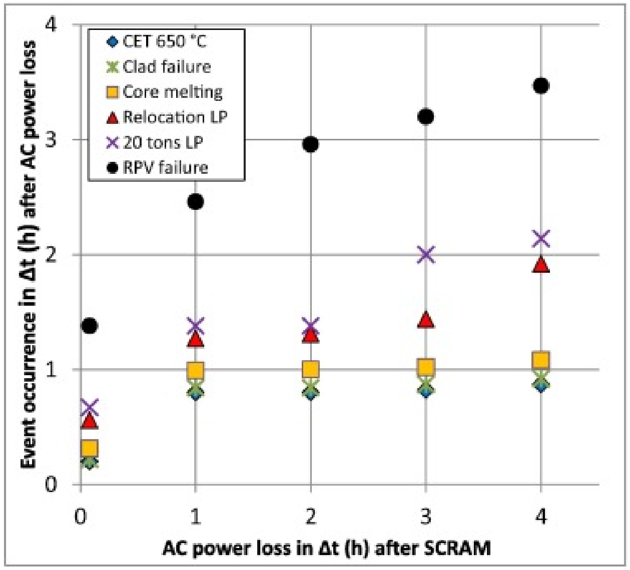


Mass in Lower Plenum

PWR-W MELCOR Model Results

PWR-W MELCOR Model Results

- Comparison with ASTEC (KWU) MBLOCA
  - Cladding Melting (~3600 s vs ~3300 s after recirc Loss)
  - Relocation in Lower Plenum (~ 4600 s vs ~ 5200 s after recirc Loss)
  - Vessel Failure (~ 9000 s vs ~ 11600 s after recirc Loss)



Ref: Investigation of SAM measures during selected MBLOCA sequences along with Station Blackout in a generic Konvoi PWR using ASTECV2.0. Ignacio García Gomez-Toraño et al. Annals of Nuclear Energy Volume 105, July 2017, Pages 226-239

PWR-W MELCOR Model Results

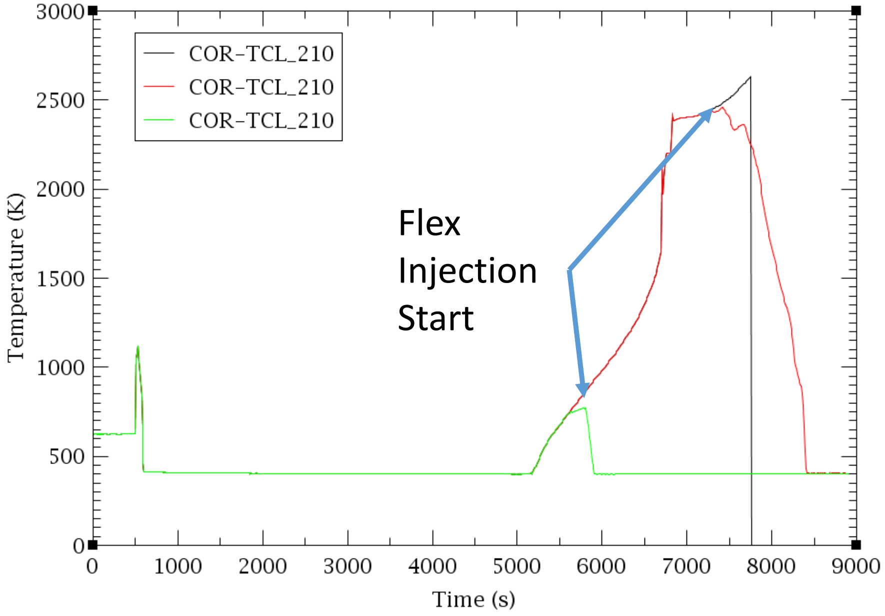
- Behavior of Core Temperature along different FLEX INJECTIONS

		Recirculation failure since recriculation begins									
			0 min	10 min	70 min	130 min	190 min	250 min	310 min	370 min	430 min
FLEX Inyection time since failure											
	30 min										
	60 min										
	90 min										
	120 min										
	150 min										
	180 min										
	210 min										
	240 min										
	>270 min										

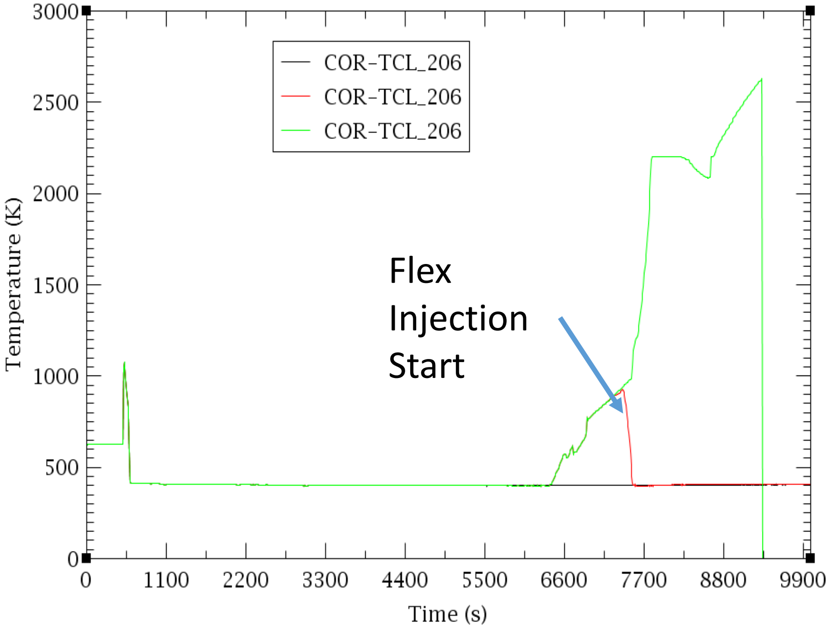
Calculation of the different Reponses against an injection of water in a degraded core with portable equipment. (Also using different equipment)

PWR-W MELCOR Model Results

- Behavior of Core Temperature along different FLEX INJECTIONS



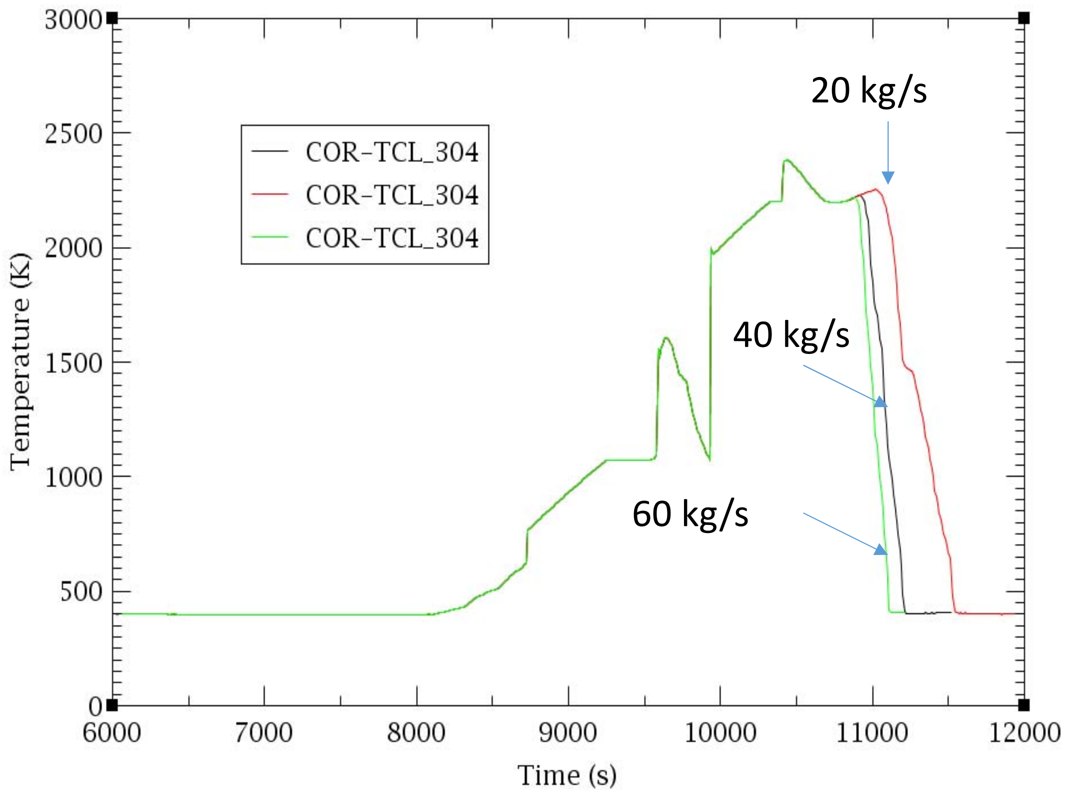
Flex
Injection
Start



Flex
Injection
Start

PWR-W MELCOR Model Results

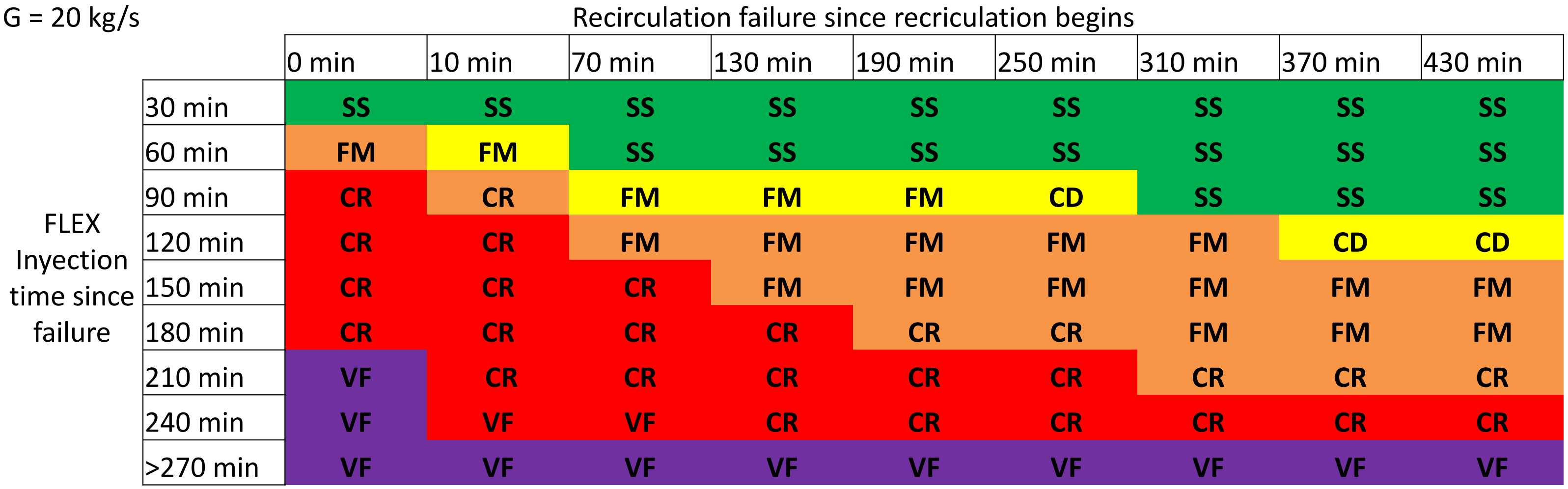
- Behavior of Core Temperature along different FLEX Injections
  - All mass flows are capable of cooling down hot core cladding
  - The difference between 60kg/s and 40 kg/s is relatively small.



PWR-W MELCOR Model Results

- Behavior of Core Temperature along different FLEX Injections

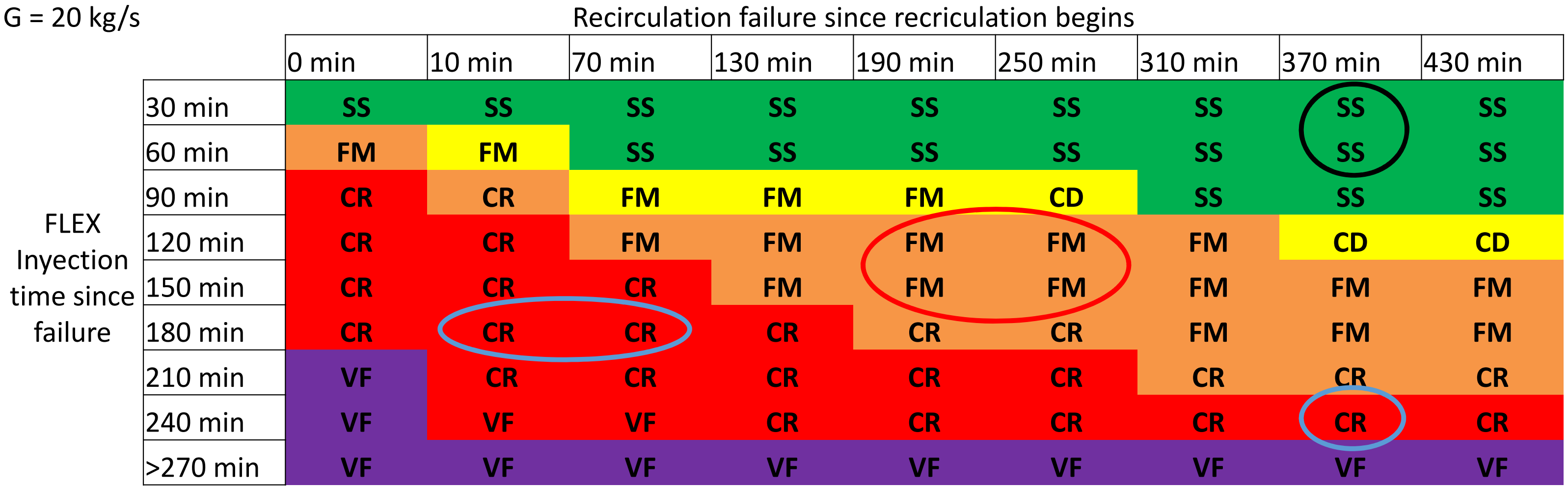
Safe State	🟩
PCT > 1477 K	🟨
Fuel Melting	🟧
Corium Relocation	🟥
Vessel Failure	🟪



G = 20 kg/s		Recirculation failure since recriculation begins								
		0 min	10 min	70 min	130 min	190 min	250 min	310 min	370 min	430 min
FLEX Inyection time since failure	30 min	SS	SS	SS	SS	SS	SS	SS	SS	SS
	60 min	FM	FM	SS	SS	SS	SS	SS	SS	SS
	90 min	CR	CR	FM	FM	FM	CD	SS	SS	SS
	120 min	CR	CR	FM	FM	FM	FM	FM	CD	CD
	150 min	CR	CR	CR	FM	FM	FM	FM	FM	FM
	180 min	CR	CR	CR	CR	CR	CR	FM	FM	FM
	210 min	VF	CR	CR	CR	CR	CR	CR	CR	CR
	240 min	VF	VF	VF	CR	CR	CR	CR	CR	CR
	>270 min	VF	VF	VF	VF	VF	VF	VF	VF	VF

PWR-W MELCOR Model Results

- Behavior of Core Temperature along different FLEX Injections.



G = 20 kg/s		Recirculation failure since recriculation begins								
		0 min	10 min	70 min	130 min	190 min	250 min	310 min	370 min	430 min
FLEX Inyection time since failure	30 min	SS	SS	SS	SS	SS	SS	SS	SS	SS
	60 min	FM	FM	SS	SS	SS	SS	SS	SS	SS
	90 min	CR	CR	FM	FM	FM	CD	SS	SS	SS
	120 min	CR	CR	FM	FM	FM	FM	FM	CD	CD
	150 min	CR	CR	CR	FM	FM	FM	FM	FM	FM
	180 min	CR	CR	CR	CR	CR	CR	FM	FM	FM
	210 min	VF	CR	CR	CR	CR	CR	CR	CR	CR
	240 min	VF	VF	VF	CR	CR	CR	CR	CR	CR
	>270 min	VF	VF	VF	VF	VF	VF	VF	VF	VF

PWR-W MELCOR Model Results

Behavior of Core Temperature along different FLEX Injections:

- After 270 min without injection, it is not posible to avoid vessel Failure
- If more than 25 tons of corium are relocated in the Lower Plenum, vessel failure is very likely (same conclusion as ASTEC).
- It is better to inject in the RCS as soon as possible, more than delaying the failure of the recirculation.

PWR-W MELCOR Model Results

Behavior of Core Temperature along different FLEX Injections.

- Enveloping Strategy to overcome lack of convergence
- Inference of accident progression if too small DT.
- MELCOR 2.2 used (more stable)
- DT max study provided 0.01 sec as the most stable
- Lack of convergence (small DT) cannot be esily predicted, sometimes causing Failure in apparently non-problematic scenarios.
- Reflooding of the hot core decreases the DT up to 1E-06 during the process.
- No problem detected in cases without Hot core reflooding.

PWR-W MELCOR Model Results

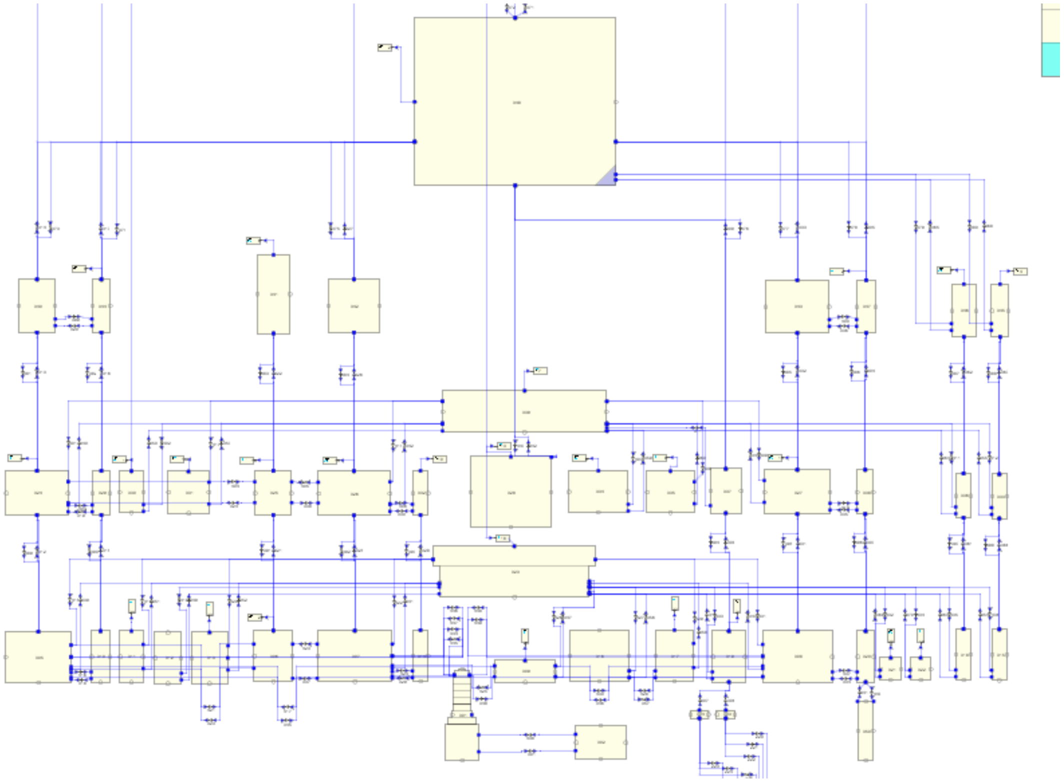
Study of Instrumentation Survival with the MELCOR code:

- LBLOCA with Recirculation Failure (SBO) is simulated.
- Instrumentation Survival during a Severe Accident
- Use of a subdivided containment to localize each instrument and obtain “local conditions”
- Developing a strategy for instrumentation Reading based on survivability.

PWR-W MELCOR Model Results

Study of Instrumentation Survival with the MELCOR code:

- Containment subdivided in several Rooms to provide a higher resolution on Temperature.
- Other studies have similar objectives and outcomes



Ref: J. L. Rempe, D. L. Knudson, and R. J. Lutz, "Scoping Study Investigating PWR Instrumentation during a Severe Accident Scenario," 2015

PWR-W MELCOR Model Results

Study of Instrumentation Survival with the MELCOR code:

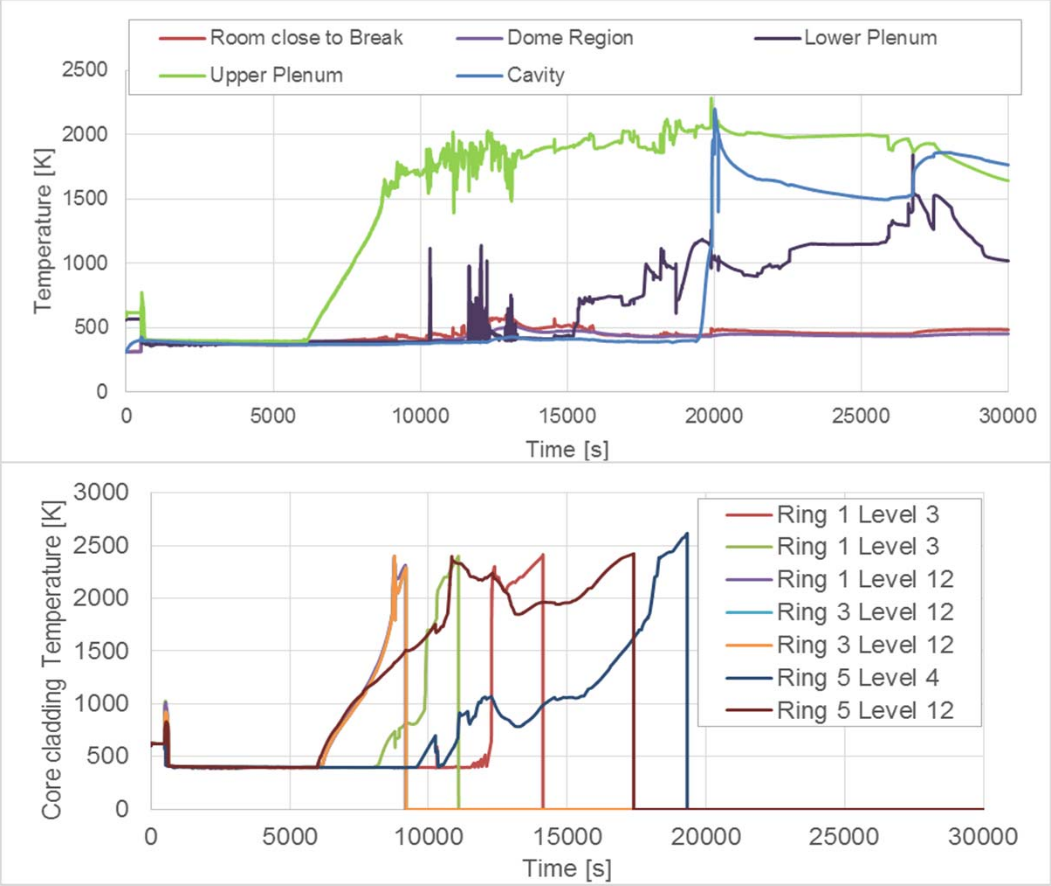
- Definition of different Damage Conditions of the Instrumentation
- Dose not taken into account in the present study (future research lines)

Damage Condition 0	Normal Operating Conditions
Damage Condition 1	**Anomalous operating conditions I**. The operating conditions are challenging or above the design, but useful measurements in tendency and values are still obtained.
Damage Condition 2	**Anomalous operating conditions II**. The limit is greatly surpassed, and measurements on value are no longer valid. The information on tendency and order of magnitude is still useful.
Damage Condition 3	**Damage Operating Conditions**. The instrument measurements are only reliable in terms of tendencies, not values or orders of magnitude.
Damage Condition 4	**Destruction Conditions**. The measurements lack of any value and they should not be used at all.

PWR-W MELCOR Model Results

Study of Instrumentation Survival with the MELCOR code:

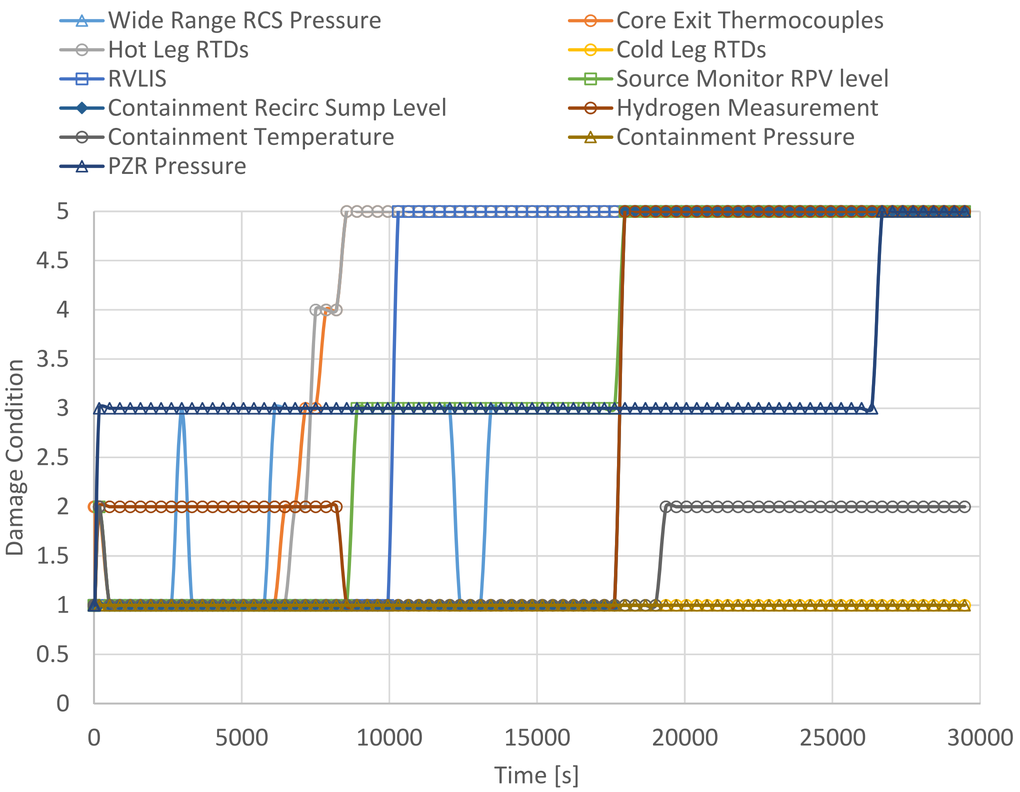
- LBLOCA with SBO at 5200 sec
- Different temperatures for different locations and containment compartments



PWR-W MELCOR Model Results

Study of Instrumentation Survival with the MELCOR code:

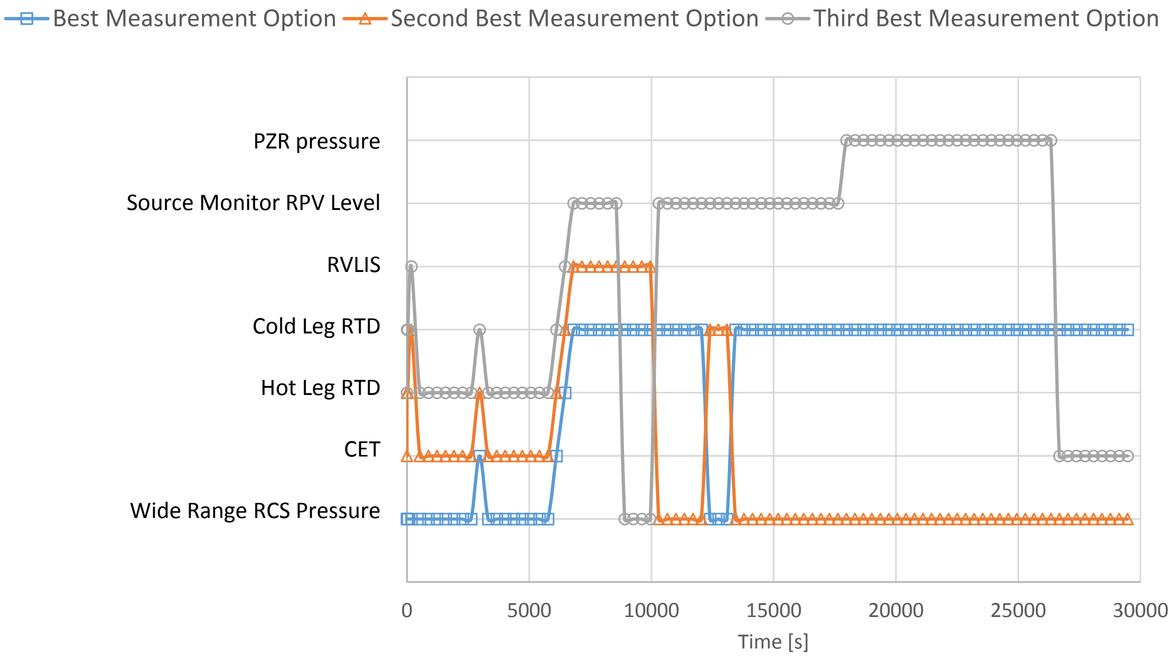
- Damage condition Evolution of the different instrumentation systems.
- Actions within the SAMGs make use of this instrumentation but no regard on which is the most reliable instrument.



PWR-W MELCOR Model Results

Study of Instrumentation Survival with the MELCOR code:

- Example of Best Measurement options to use for the CHLA “Inject into the RCS” (SAG-3)



PWR-W MELCOR Conclusions

1. PWR-W MELCOR Model used in the UPM is allowing the study of different accidents.
2. A SA scenario involving Portable equipment is simulated adequately with MELCOR 2.2
3. An enveloping strategy and careful choosing of parameters is used to determine the damage condition of the core and vessel and retain numerical stability.
4. A detailed containment and RCS nodalization allows to obtain “local” conditions of the instrumentation, which permits the study of the instrumentation survivability.

PWR-W MELCOR Main References

1. J. L. Rempe, D. L. Knudson, and R. J. Lutz, “Scoping Study Investigating PWR Instrumentation during a Severe Accident Scenario,” 2015
2. Investigation of SAM measures during selected MBLOCA sequences along with Station Blackout in a generic Konvoi PWR using ASTECV2.0. Ignacio García Gomez-Toraño et al. Annals of Nuclear Energy Volume 105, July 2017, Pages 226-239
3. D. J. Hanson, W. C. Arcieri, and L. W. Ward, “Assessing information needs and instrument availability for a pressurized water reactor during severe accidents,” *Nuclear Engineering and Design*, vol. 148, no. 2–3, pp. 233–252, Jul. 1994
4. F. Martin-Fuertes *et al.*, “Analysis of three severe accident sequences (AB, SGTR and V) in a 3 loop W-PWR 900 MWe NPP with the MELCOR code,” *European Commission*, vol. EUR 16054, 1994
5. J. L. Rempe and D. L. Knudson, “TMI-2 – A Case Study for PWR Instrumentation Performance During a Severe Accident. INL/EXT-13-28043,” 2013
6. N. Chikhi, J. Fleurot, Revisiting the QUENCH-11 integral reflood test with a new thermal–hydraulic model: Existence of a minimum injection rate Ann. Nucl. Energy, 49 (2012), pp. 12-22

MELCOR Models

Thank you very much for your attention