ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

ADVANCES IN THE ENEA ACTIVITY ON PLANT APPLICATIONS

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Contents

ENEA BWR Activities Framework

ENEA AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

- The ENEA activities related to the MELCOR code are oriented to the simulation and evaluation of severe accident evolutions and source term for "safety assessment", mainly focusing on the characteristics of NPPs located at the Italian border.

- Concerning BWRs, in order to start this activity, a general, investigative work and code simulations of the Fukushima accident will be performed.

- In order to develop the FUKUSHIMA unit 1 MELCOR Nodalization, following the SANDIA approach reported in the **Fukushima Dai-ichi Accident Study** (SAND2012-6173), the nodalization will be based on the Peach Bottom reactor (different power but similar reactor).

- The activity is part of a work planned in the ambit of a national project funded by the Economic Development Ministry (ENEA-MSE agreement).

BWR MELCOR Nodalization References

- The references used to develop the BWR Peach Bottom nodalization are :

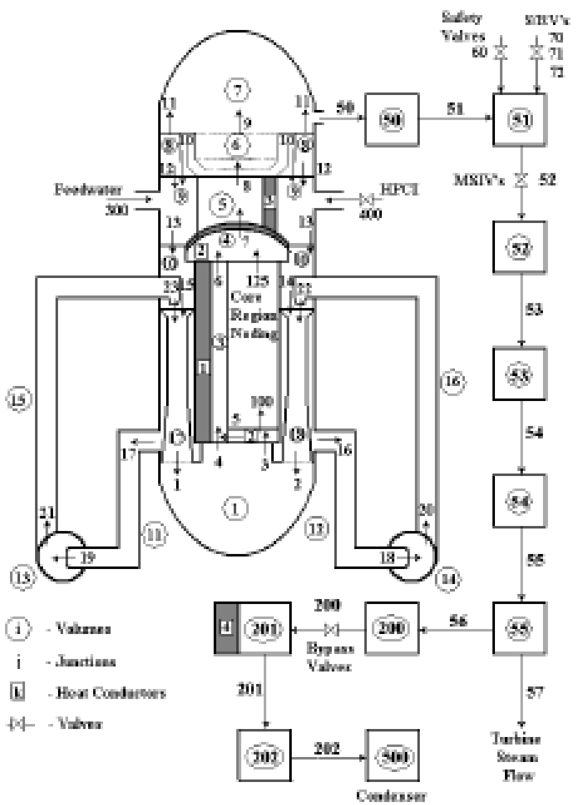
  - BOILING WATER REACTOR TURBINE TRIP (TT) BENCHMARK, Volume I: Final Specifications,
    NEA/NSC/DOC(2001)1

  - Severe Accident Source Term Characteristics for Selected Peach Bottom Sequences Predicted by the MELCOR Code,
    NUREG/CR-5942

BWR MELCOR Nodalization References

NEA/NSC/DOC(2001)1

Figure A.1. RETRAN nodalization diagram



NUREG/CR-5942

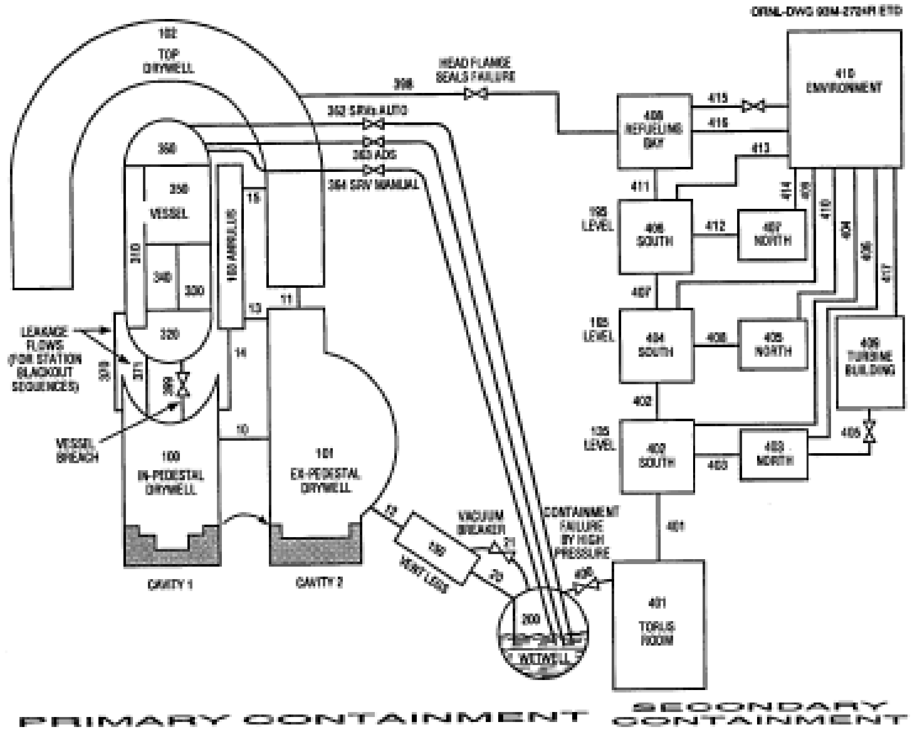
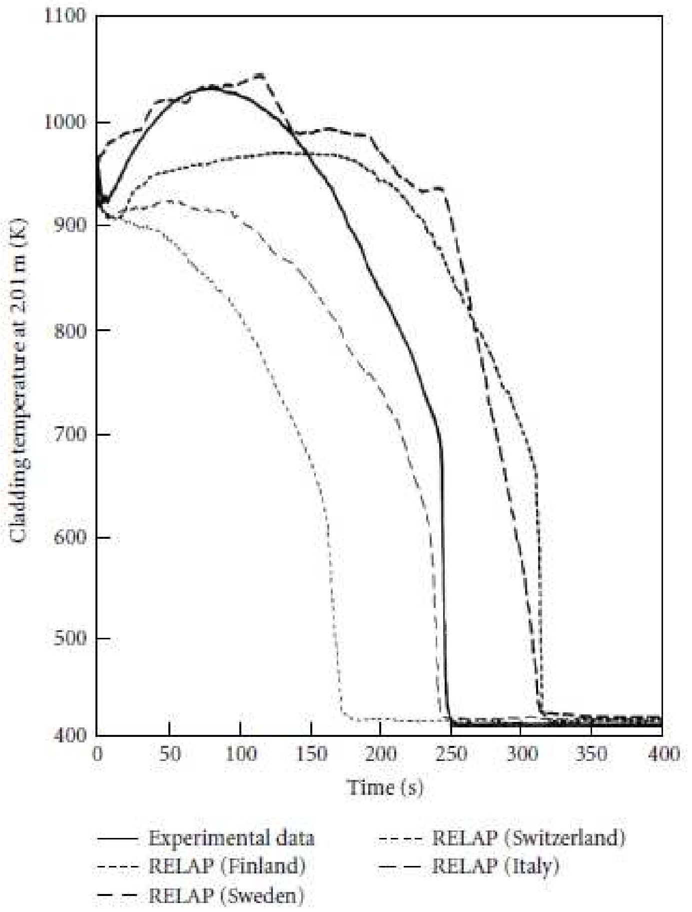


Figure 4.3 Volumes and flowpaths in the primary and secondary containment at Peach Bottom

COMPUTATIONAL TOOLS INFORMATION's

Severe Accident Code	MELCOR 2.1.5310
Symbolic Package	SNAP 2.2.6
Plotting Tools	APTPLOT 6.5.1
Operative System	Window 7, 64 bit

Use of the GRAPHYCAL USER INTERFACE



User Effect: different results for the cladding temperature in the ISP25 test from different users adopting the same code and BIC

Hindawi Publishing Corporation Science and Technology of Nuclear Installations Volume 2008, Article ID 874023, 16 pages doi:10.1155/2008/874023

In relation to the code assessment (thermal Hydraulic or severe accident code), in order to reduce the *unavoid user effect* influencing the validation results, documented in the

- *User effect on the transient system code calculations, NEA/CSNI/R(94)35, January 1995*
- *Good practices for user effect reduction, NEA/CSNI/R(98)22, November 1998*
- *Approaches and Tools for Severe Accident Analysis for Nuclear Power Plants, IAEA Safety Reports Series No 56, 2008*

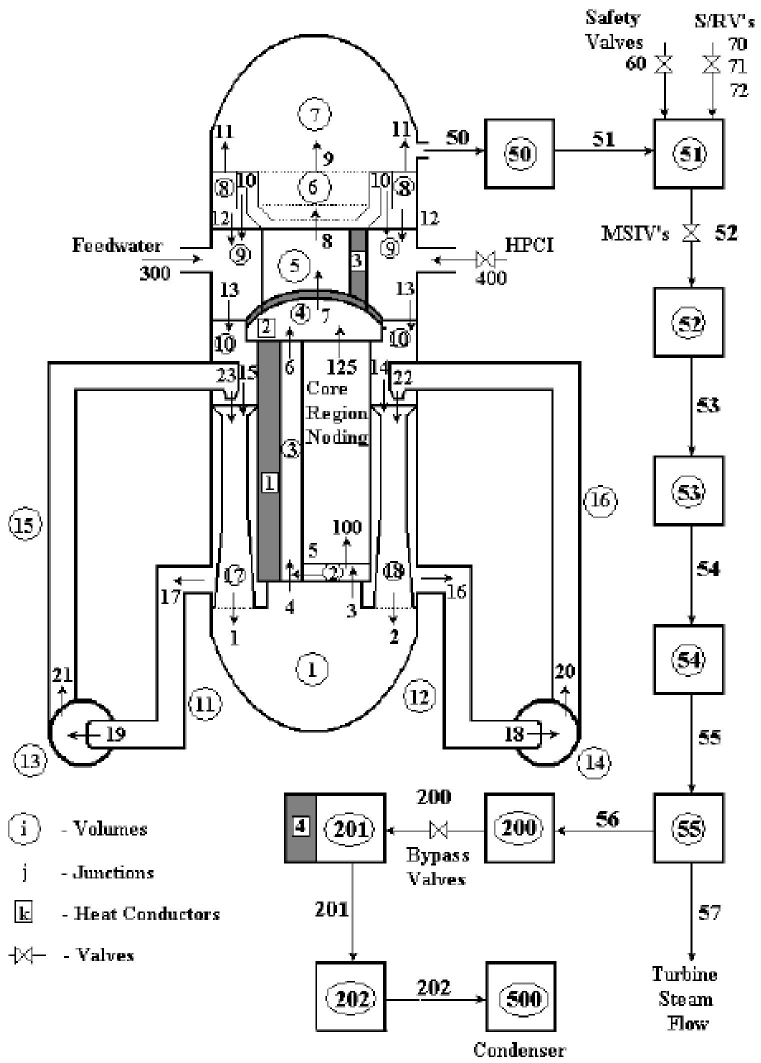
The CSNI suggestion are followed:

CSNI	
User training	
Improved user guidelines	
User discipline	
Quality assurance	
Code improvement	
Graphical user interfaces	Allow the code users more time to check the input deck, interpret the data, and run time control
	Develop input decks by eliminating inconsistent choices
	GUI would also isolate the code users from the computational engine, automatically preventing the user from selecting an option.

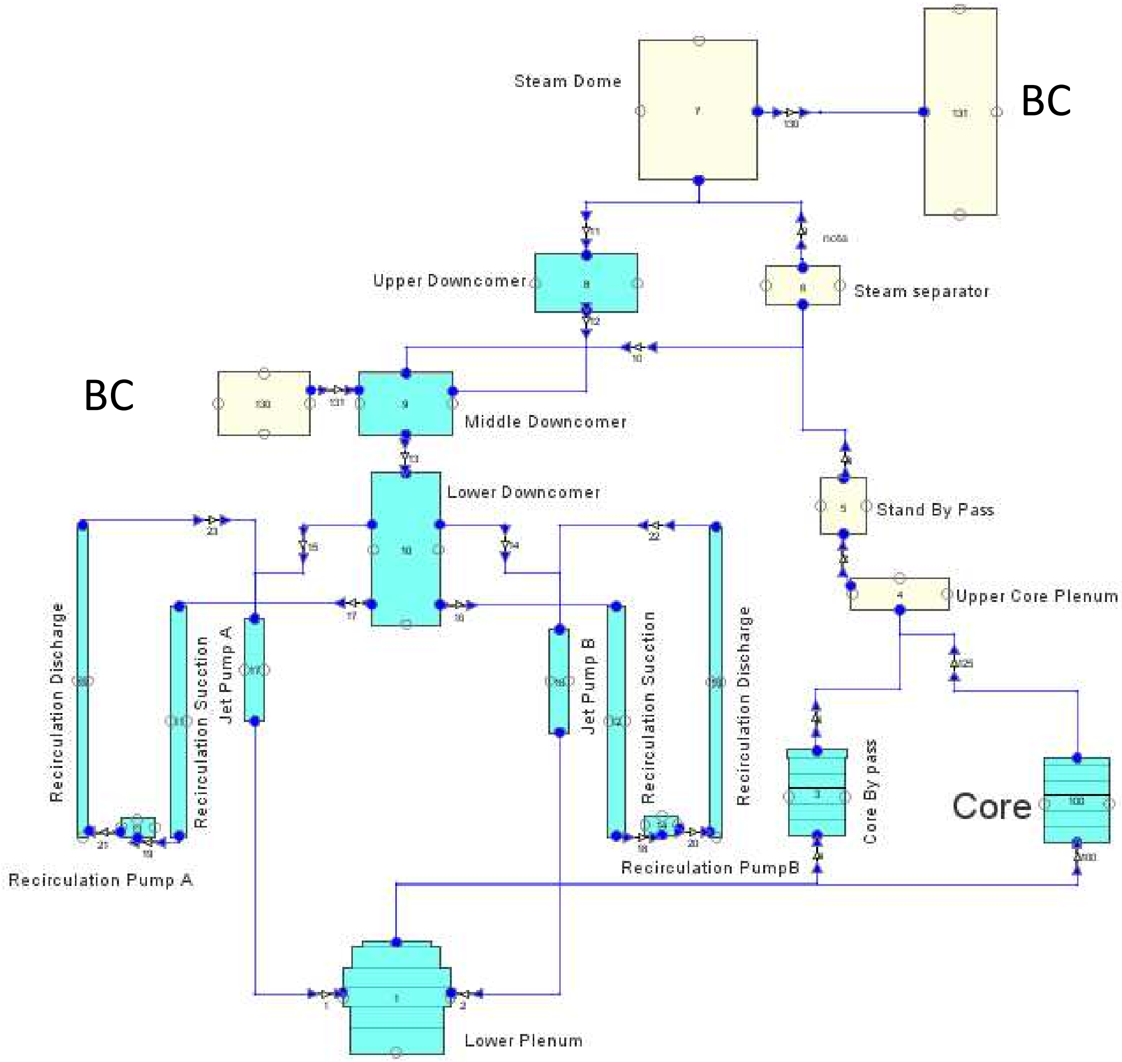
START TO USE MELCOR DIRECTLY WITH SNAP

BWR MELCOR Nodalization Description
RPV

RETRAN Nodalization



MELCOR Nodalization – made by using SNAP



BWR Modelling features

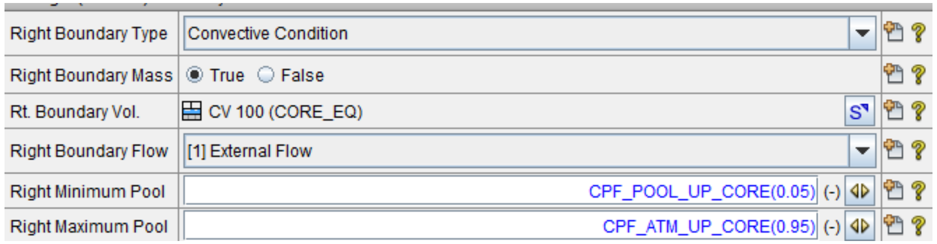
Equivalent core heat structure:

Critical Pool Fraction :

CPFPR: 0.05

CPFAR: 0.95

Allow the heat transfer to both phases reducing the numerical problem



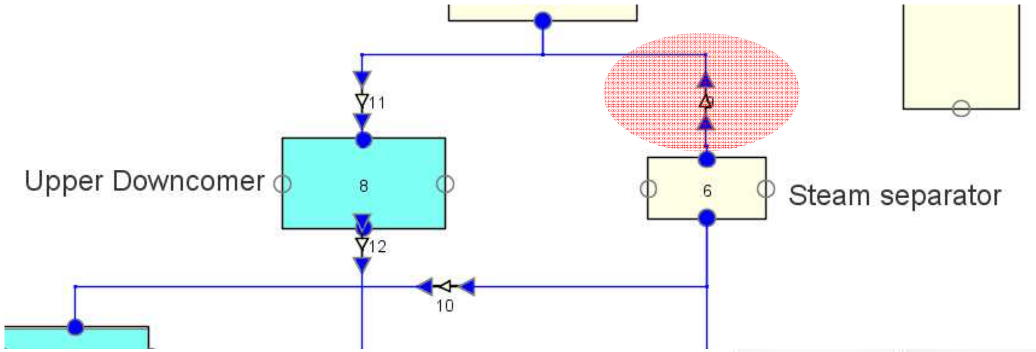
Numeric option of SNAP has been used

Equivalent Separator model:

Momentum exchange length :

XL2PF : 0

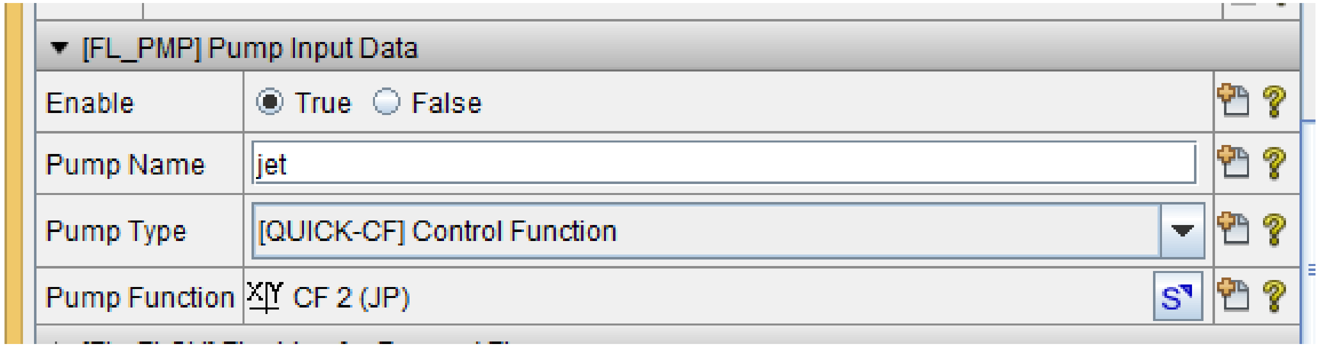
A momentum exchange length of zero can be used to model a perfect separator

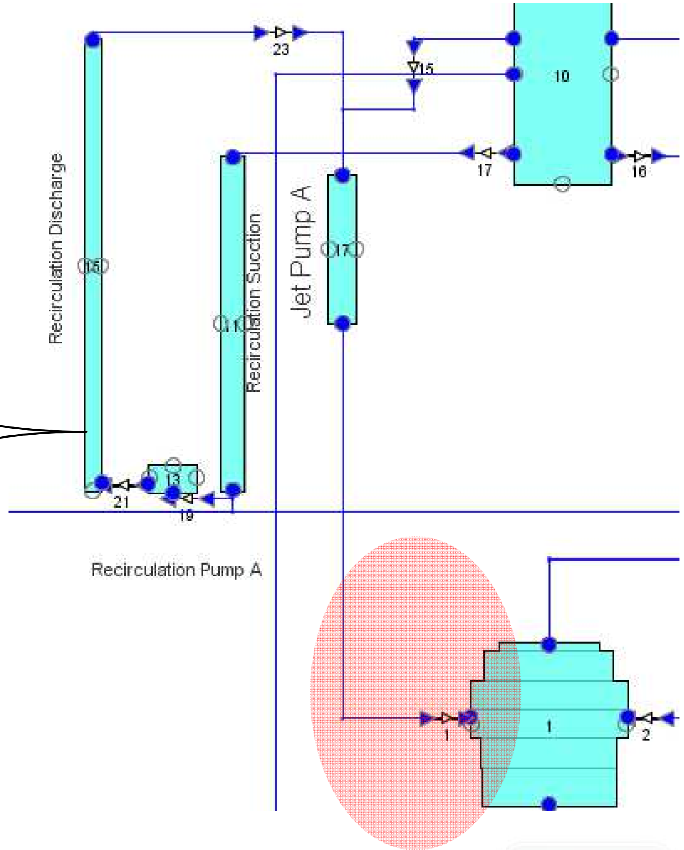


BWR Modelling features

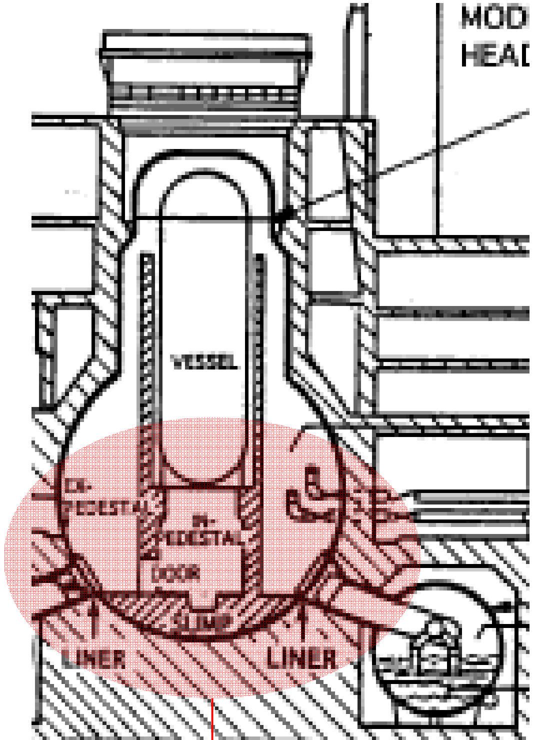
Equivalent jet pump:

Though I have considered the divergent I need to had a pump input data with control function in order to have the correct mass flow rate in the core





BWR MELCOR Nodalization Description
Primary Containment



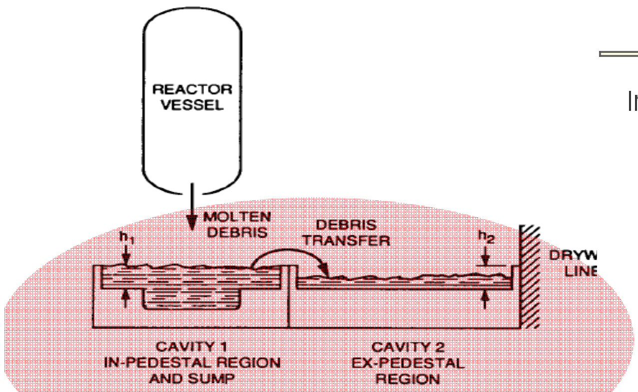


Figure 4.5 Dual-cavity drywell model

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Table 4.2. Volumes used in the primary and secondary containment

Volume No.	Volume name	Volume [ft^3 (m^3)]	Volume gas [ft^3 (m^3)]	Volume liquid [ft^3 (m^3)]	Temperature [°F (K)]	Pressure [psia (MPa)]
100	Drywell-In-pedestal	8,546 (242)	8,493 (240.5)	53[a] (1.5)	145 (336)	15.7 (0.108)
101	Drywell-Ex-pedestal	101,618 (2,878)	Full	0[b]	145 (336)	15.7 (0.108)
102	Drywell-Top	36,605 (1,037)	Full	0	145 (336)	15.7 (0.108)
103	Drywell-Annulus	2,788 (79)	Full	0	261 (400)	15.7 (0.108)
150	Vent pipes	19,953 (565)	19,183 (543)	770 (22)	145 (336)	15.7 (0.108)
200	Wetwell	251,880 (7,133)	112,018 (3,172)	139,881 (3,961)	90 (306)	14.4 (0.099)
401	Torus room	191,612 (5,426)	Full	0	90 (306)	14.2 (0.097)
402	South 135 level	182,011 (5,154)	Full	0	82 (301)	14.7 (0.101)
403	North 135 level	182,011 (5,154)	Full	0	82 (301)	14.7 (0.101)
404	South 165 level	83,201 (2,356)	Full	0	80 (300)	14.7 (0.101)
405	Remain 165 level	249,532 (7,066)	Full	0	80 (300)	14.7 (0.101)
406	South 195 level	86,591 (2,452)	Full	0	80 (300)	14.7 (0.101)
407	Remain 195 level	171,840 (4,866)	Full	0	80 (300)	14.7 (0.101)
408	Refueling Bay	1,096,444 (31,048)	Full	0	80 (300)	14.7 (0.101)
409	Turbine Bldg.	5,255,677 (148,825)	Full	0	80 (300)	14.7 (0.101)
410	Environment	3.5×10^{11} (10^{10})	Full	0	80 (300)	14.7 (0.101)

[a] This value is for a dry cavity. For a flooded cavity this liquid volume is 1032.6 ft^3 (29.24 m^3).
[b] This value is for a dry cavity. For a flooded cavity this liquid volume is 2826 ft^3 (80.0 m^3).

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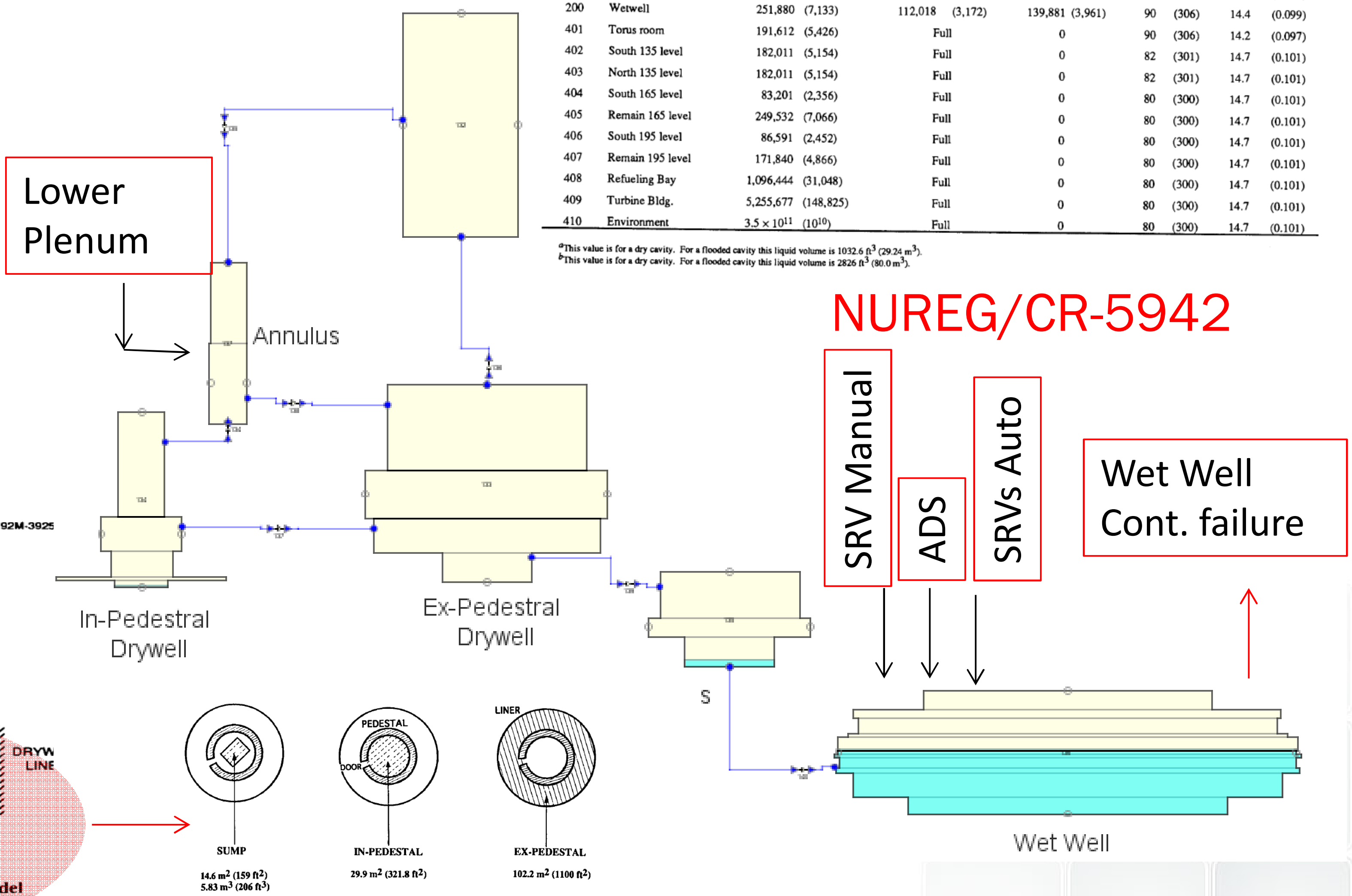

Figure 3.3 Horizontal view of the different regions of the Peach Bottom cavity

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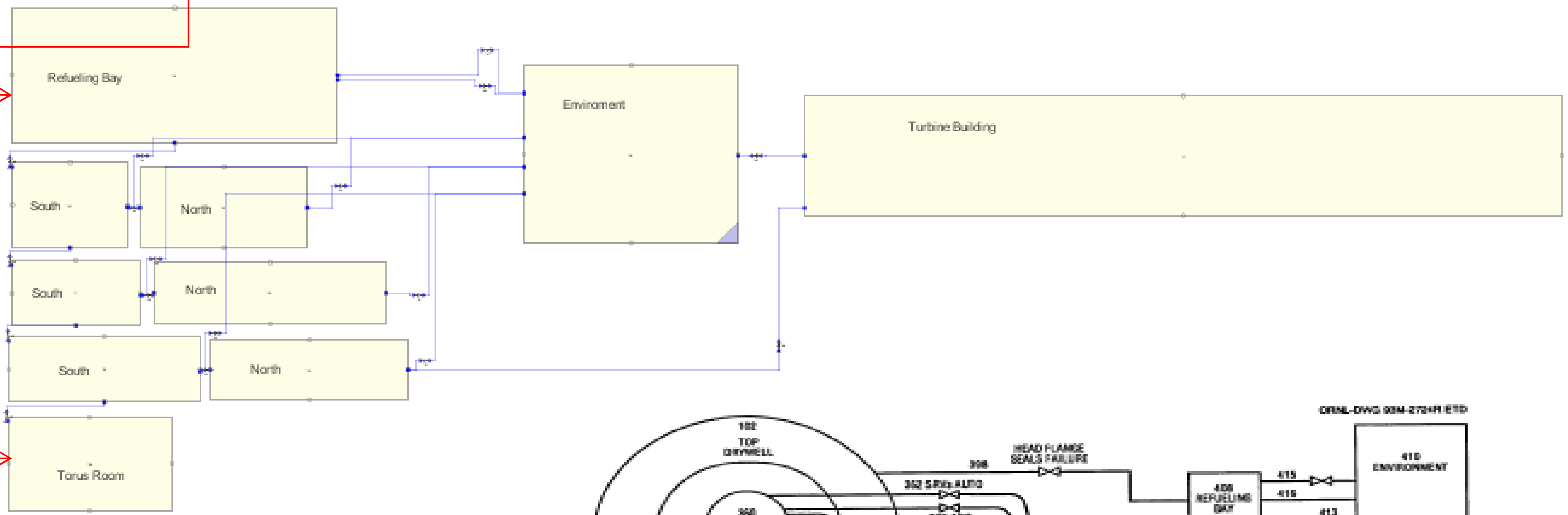
BWR MELCOR Nodalization Description
Secondary Containment

Head Flange Seal Failure



Wet Well Cont. failure

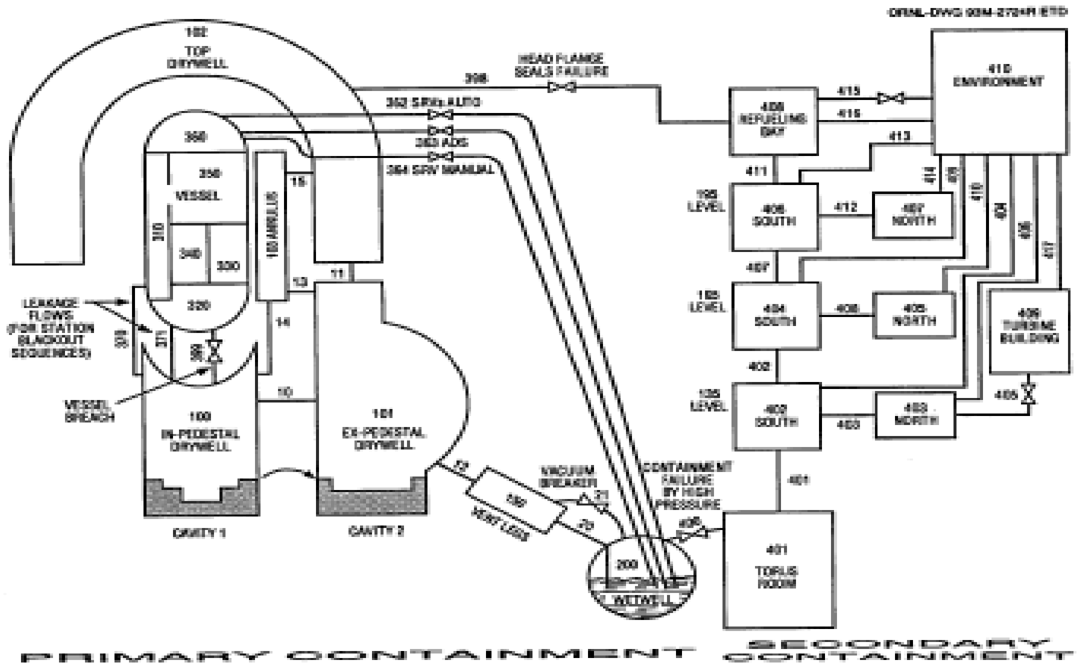


Figure 4.3 Volumes and flowpaths in the primary and secondary containment at Peach Bottom

BWR MELCOR Nodalization Description
Flow Path Reference

AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Table 4.3. Flowpaths used in the MELCOR model of Peach Bottom

Flowpath No.	From volume	To volume	Flowpath name	Area (ft^2)	Fraction open initially	Control function
10	100	101	In-Pedestal to Ex-Pedestal	92.6	1.0	
11	101	102	Ex-Pedestal to Top-Drywell	673.7	1.0	
12	101	150	Vent Opening to Legs	288.5	1.0	
13	101	103	Ex-Pedestal to Annulus	2.3	1.0	
14	100	103	In-Pedestal to Annulus	34.4	1.0	
15	102	103	Top-Drywell to Annulus	56.9	1.0	
20	150	200	Legs Exit	286.3	1.0	
21	200	150	Vacuum Breaker	20.0	0.0	Yes
311[a]	310	320	Intact Recirculation Pump	3.7	1.0	
312	310	320	Internal Jet Pumps	7.3	1.0	
323	320	330	Lower Plenum to Bypass	66.2	0.0129	
324	320	340	Lower Plenum to Channel	85.5	0.6174	Yes
335	330	350	Bypass to Steam Separators	66.2	1.0	
345	340	350	Channel to Steam Separators	85.5	0.6756	
356	350	360	Steam Separators to Dome	51.3	1.0	
361	360	310	Dome to Downcomer	281.0	1.0	
362	360	200	Automatic SRVs	1.3	0.0	Yes
363[b]	360	200	Manual ADS (5 SRVs)	0.5	0.0	Yes
364[b]	360	200	Manual 1 SRV	0.1	0.0	Yes
370[b]	310	100	Leakage of Recirculation Pumps	2.9×10^{-5}	0.5	
370A[a]	310	101	LOCA 1	3.92	1.0	
371	320	100	Leakage of Control Rod Pumps	3.6×10^{-5}	0.5	
372[a]	310	101	LOCA 2	3.92	1.0	
398	100	408	Drywell Head Seals Failure	0.4	0.0	Yes
399	320	100	Vessel Breach	0.1	0.0	Yes
400	200	401	Wetwell Cont. Failure	7.0	0.0	Yes
401	401	402	Torus to Level-135	92.6	1.0	
402	402	404	Level-135 to Level-165	357.4	1.0	
403	402	403	Level-135 South to North	269.0	1.0	
404	402	410	Leak to Environment of Level-135-South	0.3	1.0	

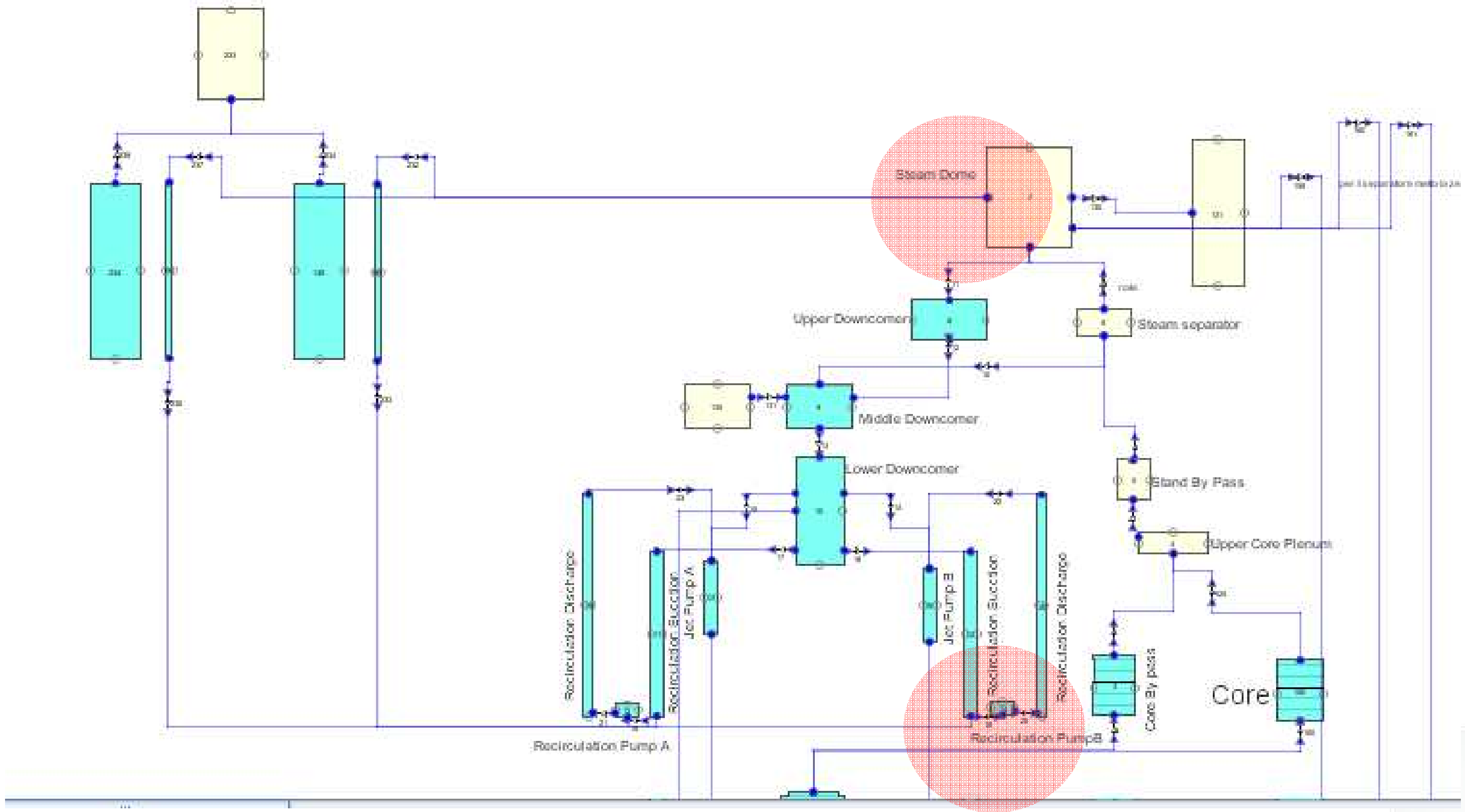
Table 4.3. Flowpaths used in the MELCOR model of Peach Bottom (cont.)

Flowpath No.	From volume	To volume	Flowpath name	Area (ft^2)	Fraction open initially	Control function
405	403	409	Level-135 South to Turbine Bldg.	30.1	0.0	Yes
406	403	410	Leak to Environment of Level-135-North	0.3	1.0	
407	404	406	Level-165 to Level-195-Shaft	357.4	1.0	
408	404	405	Level-165-South to North	471.5	1.0	
409	404	410	Leak to Environment of Level-165-South	0.3	1.0	
410	405	410	Leak to Environment of Level-165-North	0.3	1.0	
411	406	408	Level-195 to Refueling Bay	357.4	1.0	
412	406	407	Level-195-South to North	803.0	1.0	
413	406	410	Leak to Environment of Level-195-South	0.3	1.0	
414	407	410	Leak to Environment of Level-195-North	0.3	1.0	
415	408	410	Blowout Panels of Refueling Bay	240.0	0.0	Yes
416	408	410	Leak to Environment of Refueling Bay	1.2	1.0	
417	409	410	Leak to Environment of Turbine Bldg.	3.1	1.0	

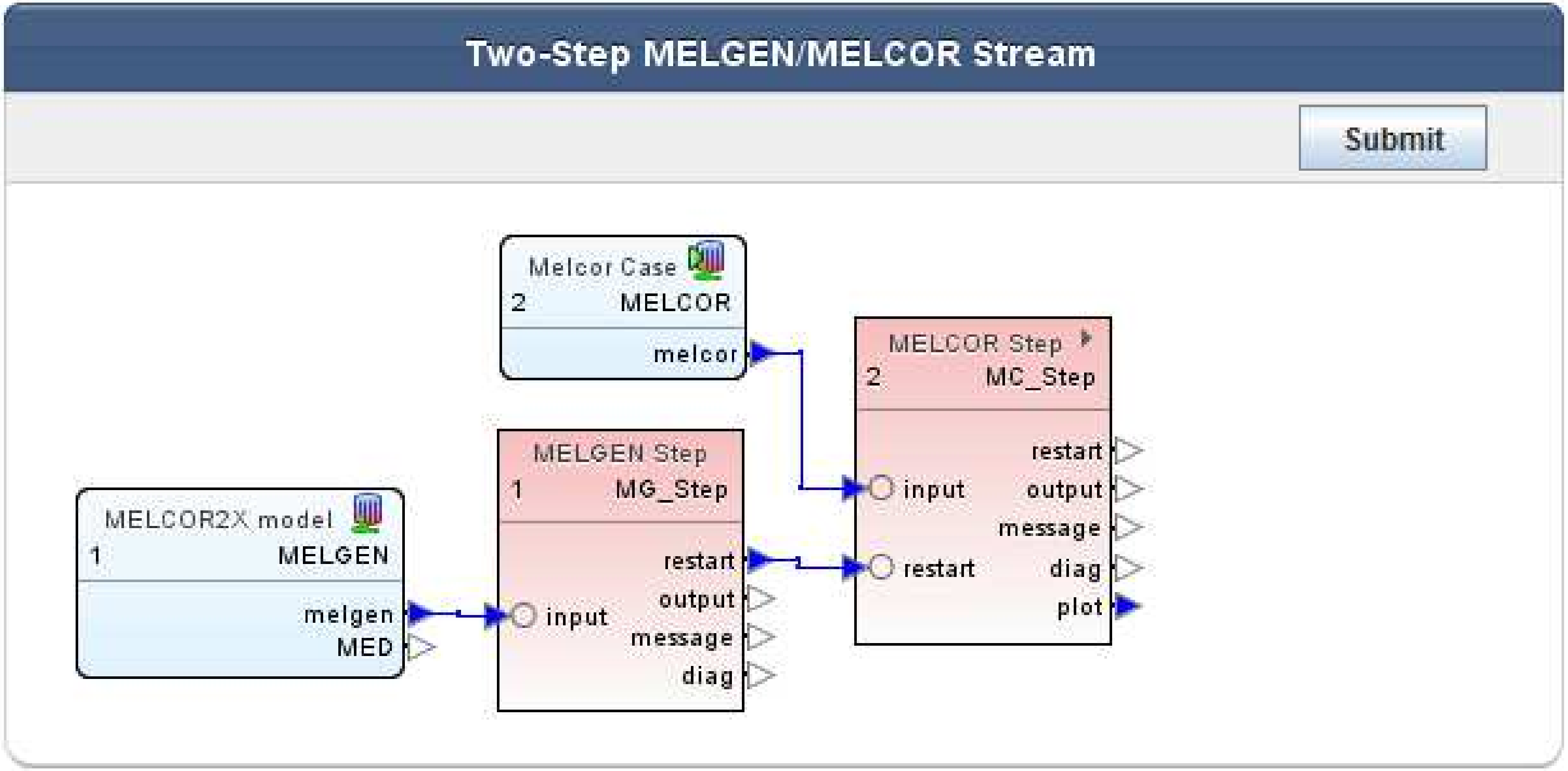
[a]This flowpath is only used in the LOCA sequence.
[b]This flowpath is only used in the station blackout sequences.

BWR MELCOR Nodalization Description
Isolation Condenser

Isolation Condensers-DRAFT Model



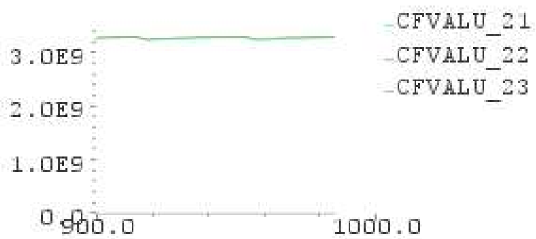
Steady State Analyses
SNAP Job Stream

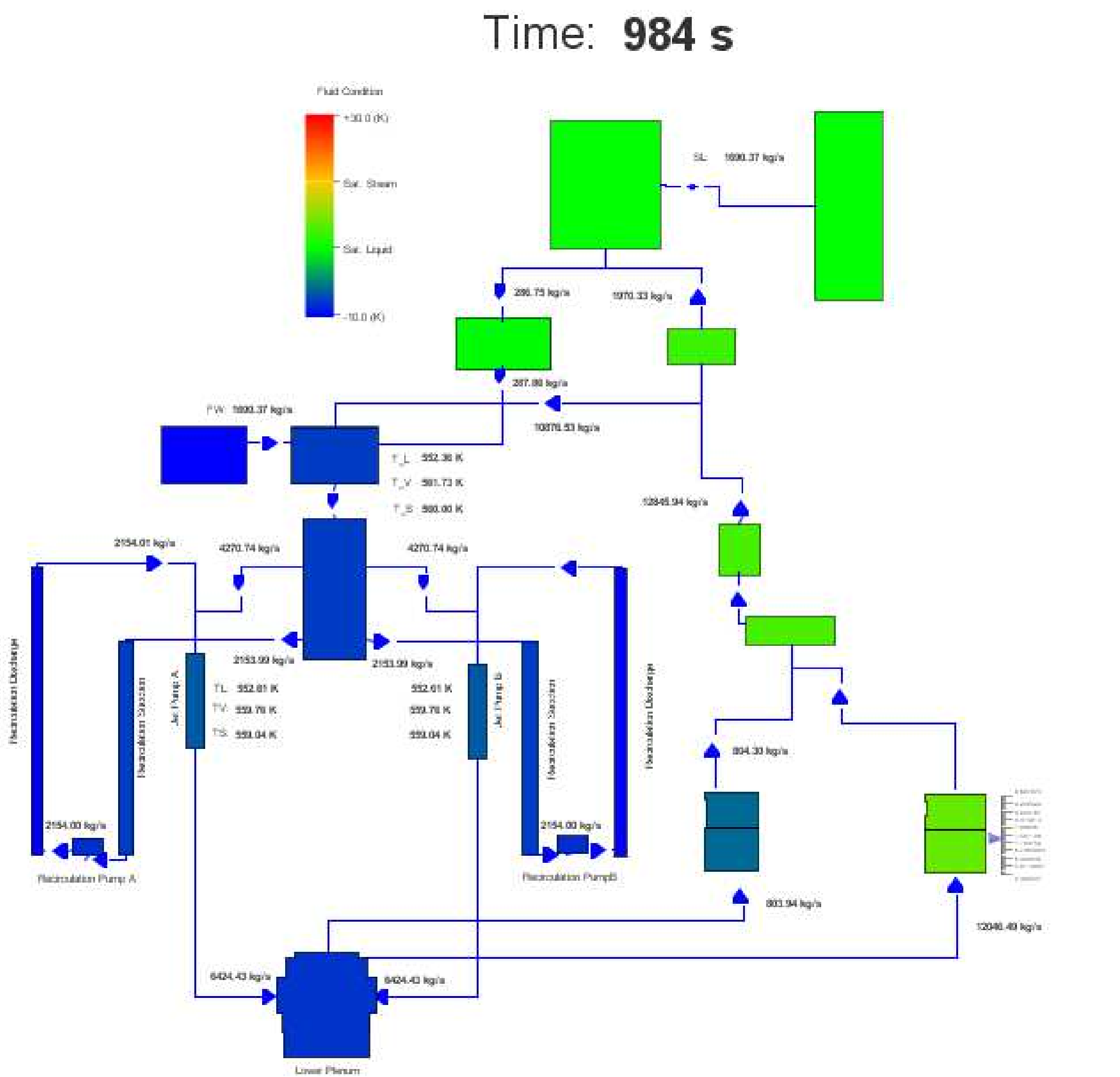


Steady State Analyses
SNAP Animation Model: Fluid Conditions

PARAMETERS	MELCOR	REF
Total jet Pump Flow	12848.86	12915 Kg/s
Jet Pump A Head	22.98	23.185 m
Jet Pump B Head	22.98	23.185 m
Jet Pump A differ. exit velocity	4.26 m/s	4.6834 m/s
Jet Pump B differ. exit velocity	4.26 m/s	4.6834 m/s
RC PUMP A Head	203.985	218.408 m
RC PUMP B Head	203.985	218.408 m
RC PUMP A Mass Flow Rate	2154.00 kg/s	2154.58 Kg/s
RC PUMP B Mass Flow Rate	2154.00 kg/s	2154.58 Kg/s
Flow velocity at pump A suction	8.43 m/s	8.382 m/s
Flow velocity at pump B suction	8.43 m/s	8.382 m/s
Suction Pressure A	7120379.0 Pa	7115389 Pa
Suction Pressure B	7120379.0 Pa	7115389 Pa
Core Flow By pass %	14	14
Tinlet core	552.74 K	551.45 K
RC *	5.07	6.03
Core Exit Quality**	15.0	13.1
Dome Pressure	7057258.5 Pa	7.033E6 Pa
FW mass flow rate	1690.37 kg/s	1679 kg/s
Power to the core fluid	3224291392	3.29E9 W

Core Power

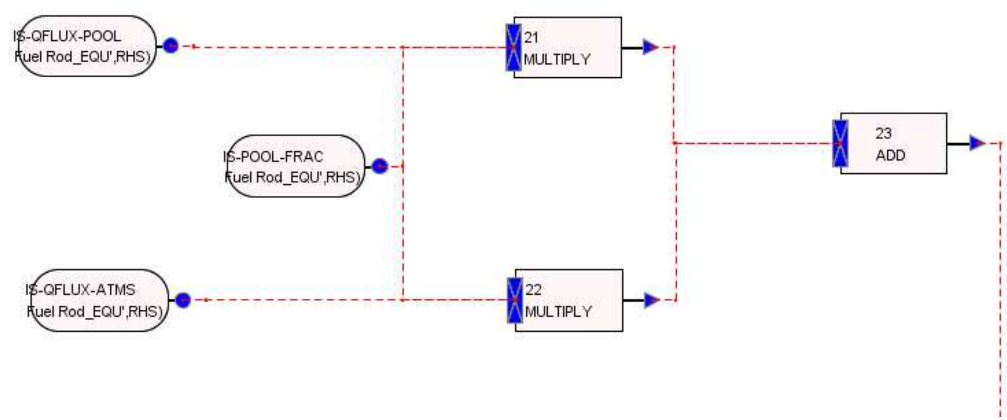




Steady State Analyses
SNAP Animation Model: Table with selected parameters

PARAMETERS	MELCOR	REF
Total jet Pump Flow	12848.86	12915 Kg/s
Jet Pump A Head	22.98	23.195 m
Jet Pump B Head	22.98	23.195 m
Jet Pump A differ exit velocity	4.26 m/s	4.6634 m/s
Jet Pump B differ exit velocity	4.26 m/s	4.6634 m/s
RC PUMP A Head	208.965	216.408 m
RC PUMP B Head	208.965	216.408 m
RC PUMP A Mass Flow Rate	2154.00 kg/s	2154.56 Kg/s
RC PUMP B Mass Flow Rate	2154.00 kg/s	2154.56 Kg/s
Flow velocity at pump A sunction	8.43 m/s	8.382 m/s
Flow velocity at pump B sunction	8.43 m/s	8.382 m/s
Sunction Pressure A	7120379.0 Pa	7115389 Pa
Sunction Pressure B	7120379.0 Pa	7115389 Pa
Core Flow By pass %	14	14
Tinlet core	552.74 K	551.45 K
RC *	5.67	6.63
Core Exit Quality**	15.0	13.1
Dome Pressure	7057256.5 Pa	7.033E6 Pa
FW mass flow rate	1690.37 kg/s	1679 kg/s
Power to the core fluid	3224251392	3.29E9 W

POWER transferred to the fluid



HS-QFLUX-POOL (NameHS,sn):
Heat flux to pool at boundary surface sn of heat structure Name HS

HS-QFLUX-ATMS(NameHS,sn):
Heat flux to atmosphere at boundary surface sn of heat structure NameHS.

HS-POOL-FRAC(NameHS,sn)
Fraction of boundary surface sn of heat structure NameHS in the pool of its boundary volume.

ENEA PWR Activities Framework

- In the framework of the European Project CESAM (Code for European Severe Accident Management) **WP40-SAM.**, ENEA is involved in the development of a "PWR 900 like" with MELCOR code for benchmark the ASTEC code.

- In the framework of the ENEA-MSE agreement, our activities related to the MELCOR code are mainly related to the evaluation of severe accident source term for "safety assessment activity", mainly focusing on the characteristics of NPPs located at the Italian border.

PWR MELCOR Nodalization References

- The references used to develop the PWR900 like MELCOR nodalization are :

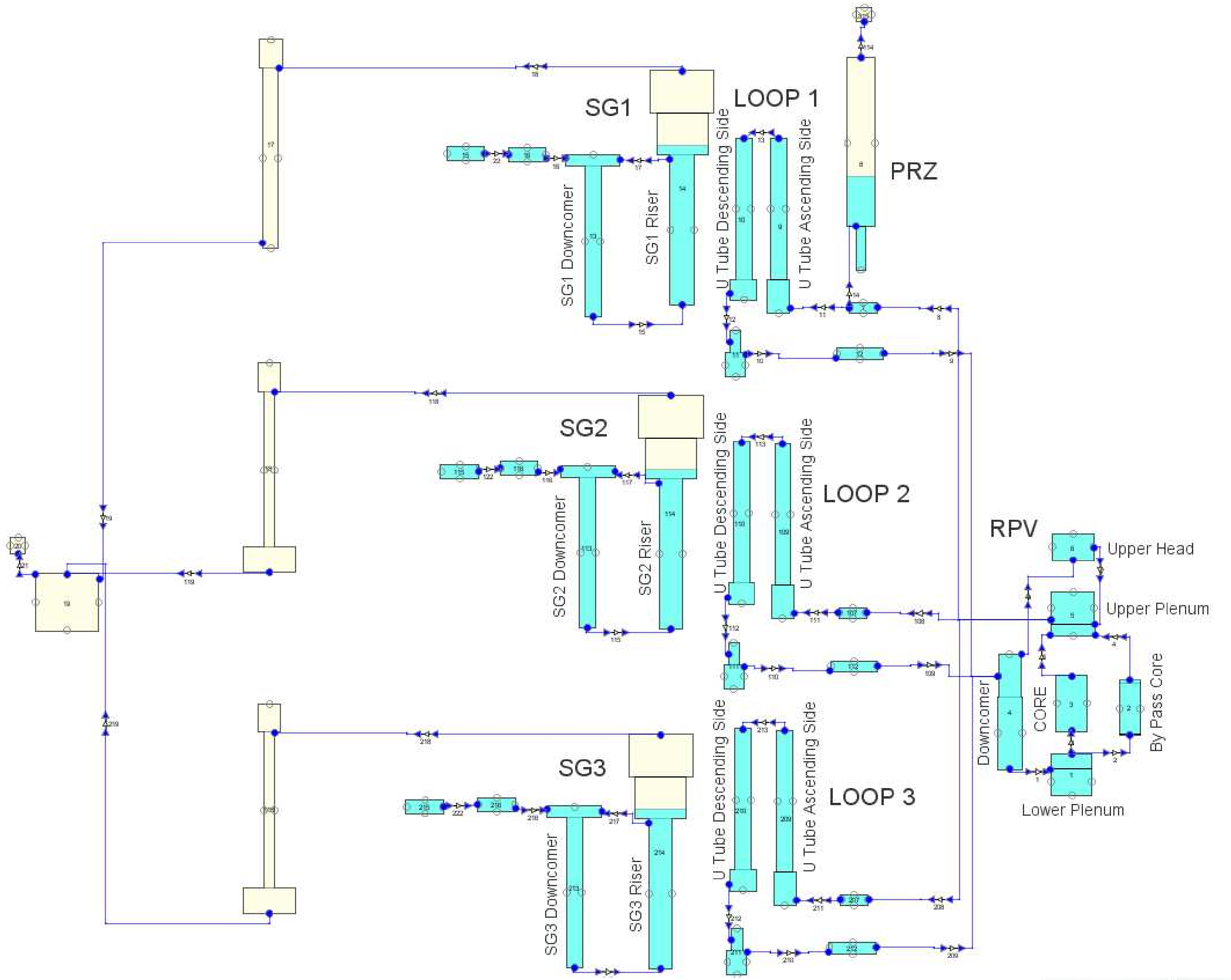
  - L. FOUCHER, ASTEC V20R3, PWR900 like ASTEC Input Deck, Rapport n PSN-RES/SAG/2013-451.

  - L. FOUCHER, ASTEC V20R3, PWR900 like ASTEC Steady state calculation, Rapport n PSN-RES/SAG/2013-466.

COMPUTATIONAL TOOLS USED

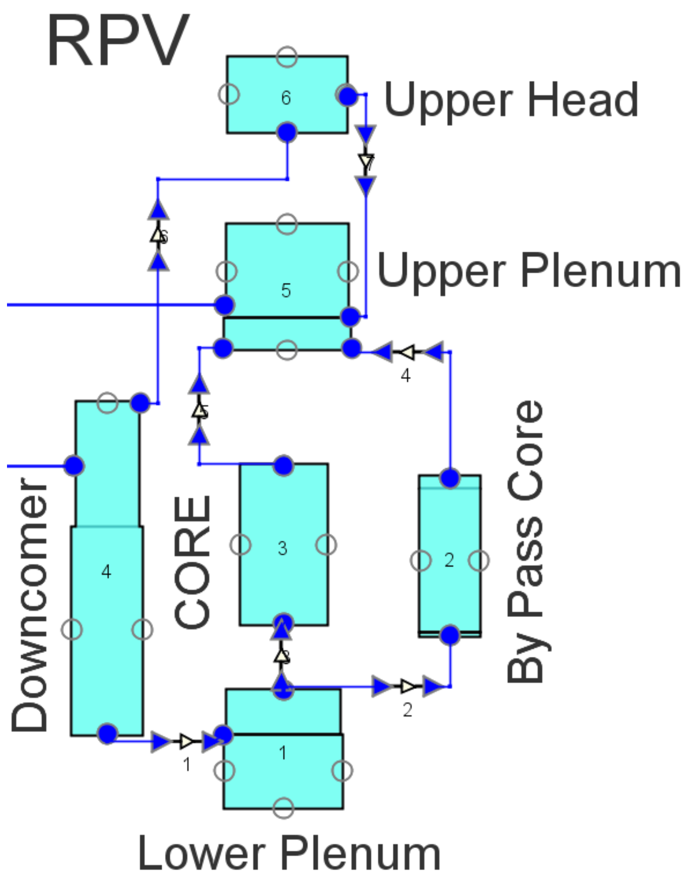
Severe Accident Code	MELCOR 2.1.5310
Symbolic Package	SNAP 2.2.6
Plotting Tools	APTPLOT 6.5.1
Operative System	Window 7, 64 bit

PWR MELCOR Nodalization Description

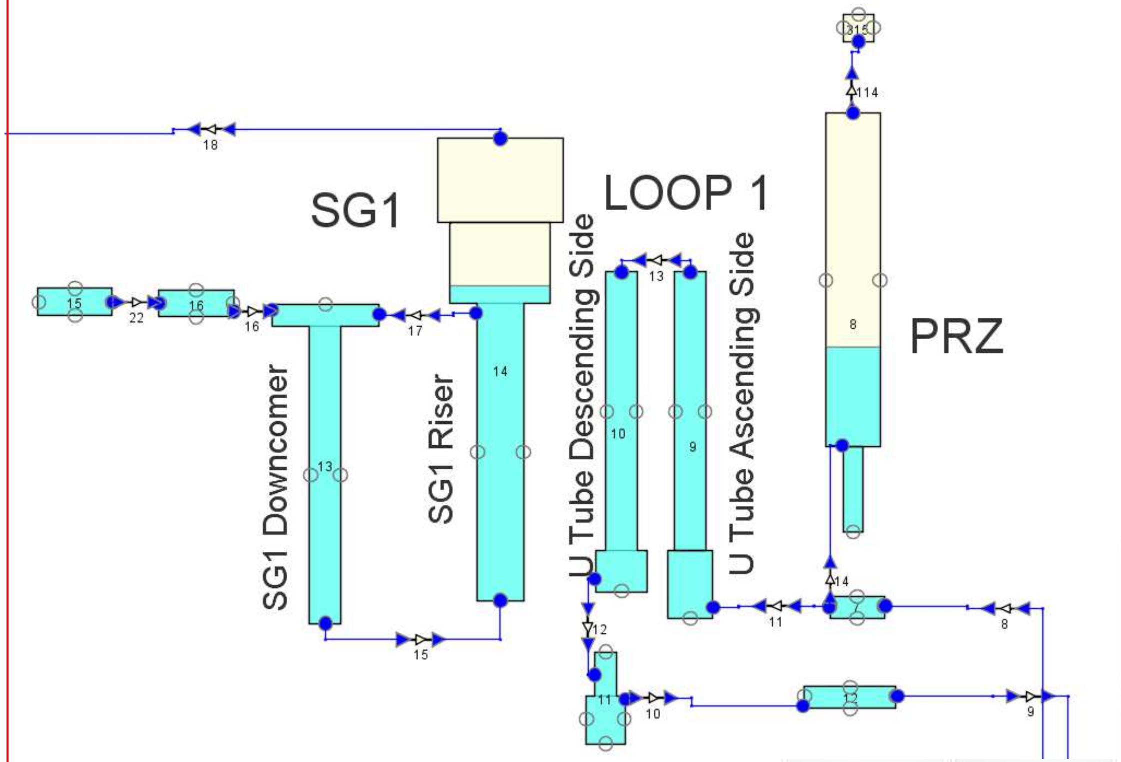


PWR MELCOR Nodalization Description
Details of RPV and LOOP 1

RPV Nodalization Details



Loop 1 Nodalization Details



PWR Modelling features

Equivalent SG ascending side heat structure:

Critical Pool Fraction :

CPFPR: 0.05

CPFAR: 0.95

Equivalent SG descending side heat structure:

Critical Pool Fraction :

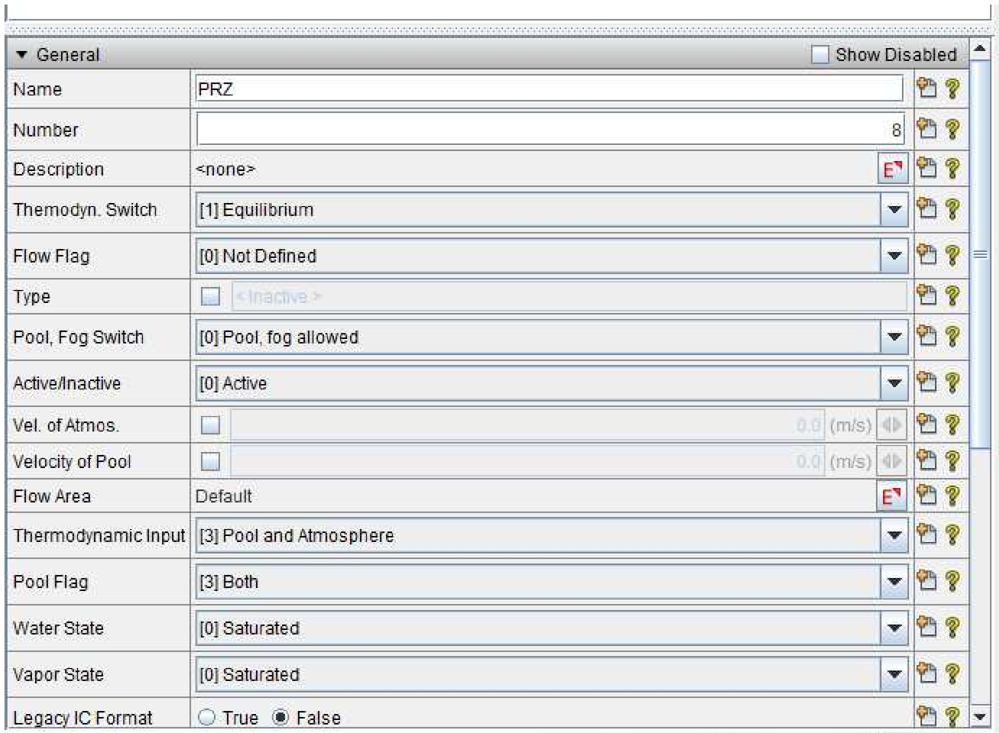
CPFPR: 0.05

CPFAR: 0.95

Equivalent PRZ model:

Thermodyn. Switch:

Equilibrium



Steady State Analyses - Steady state operating point parameters of the MELCOR VS ASTEC code

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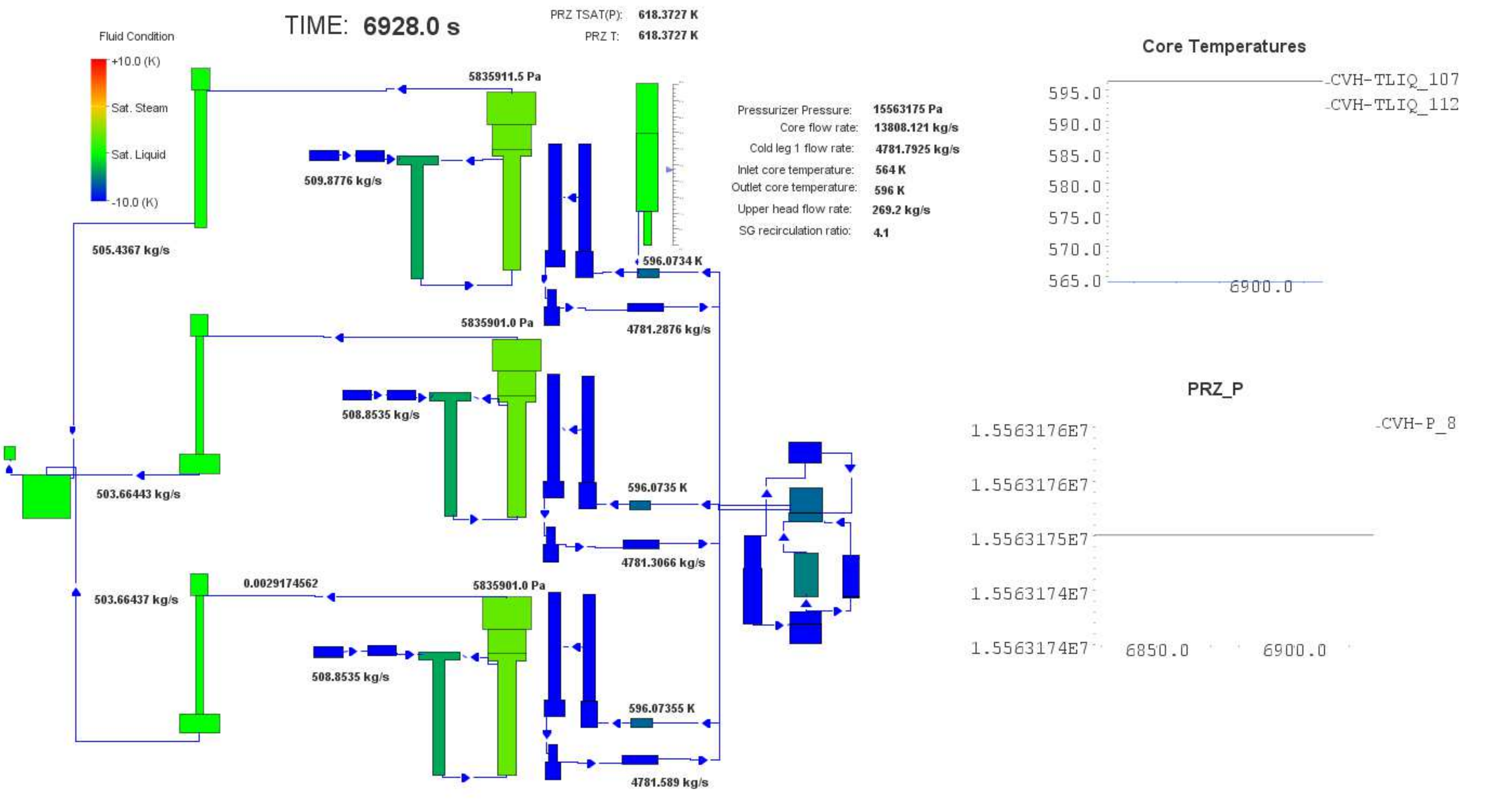
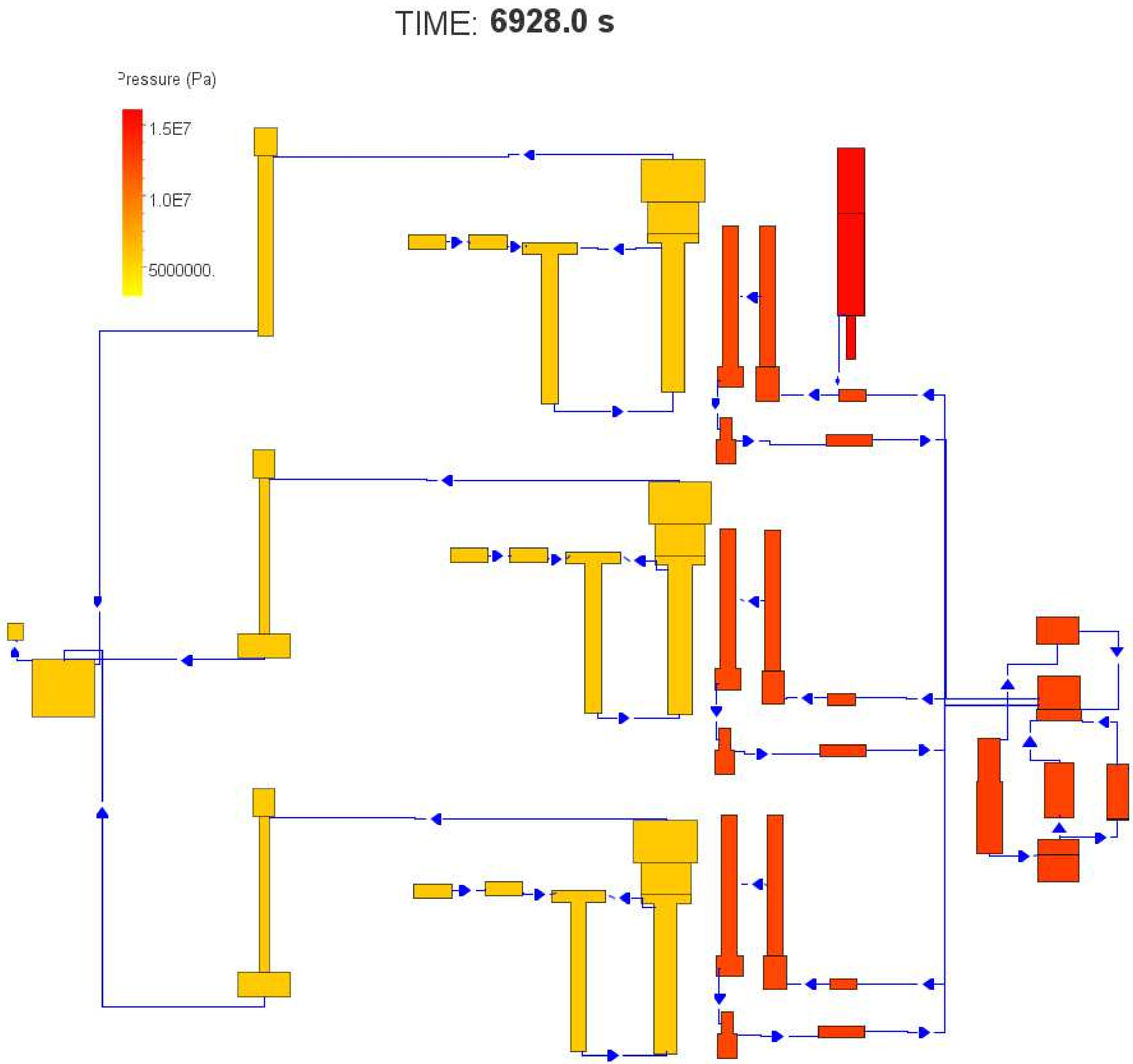
PARAMETERS	ASTEC	MELCOR (at about 7000s of calculation)
Pressurizer Pressure (bar)	155.16	155.63
Pressurizer Level (%)	50	~ 50
Cold Leg 1 Flow Rate (kg/s)	4735.6	4781.7925
Core Flow Rate (kg/s)	13928.0	13808.121
Upper Head Flow Rate (kg/s)	275	269.2
Inlet Core Temperature (K)	560	564
Outlet Core Temperature (K)	594.5	596
Separator Pressure (bar)	58.023	58.359
SG MFWS Flow Rate (kg/s)	512	510
Recirculation Ratio	4.15	4.1

Steady State Analyses
SNAP Animation Model: Fluid Conditions



Steady State Analyses
SNAP Animation Model: Pressure conditions



CONCLUSIONS

- Research activities in which ENEA uses MELCOR code are in progress and mainly focused on PWR and BWR "safety assessment studies".

- These research activities are developed in the ambit of an Italian project and in several International research frameworks.

- A conceptual study of Small Modular Reactors with MELCOR is planned.

- ENEA plans to give an active contribution in CSARP and EMUG.