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Experiences with MELCOR 1.8.6 for Level 2 PSA Plant Analyses

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Introduction

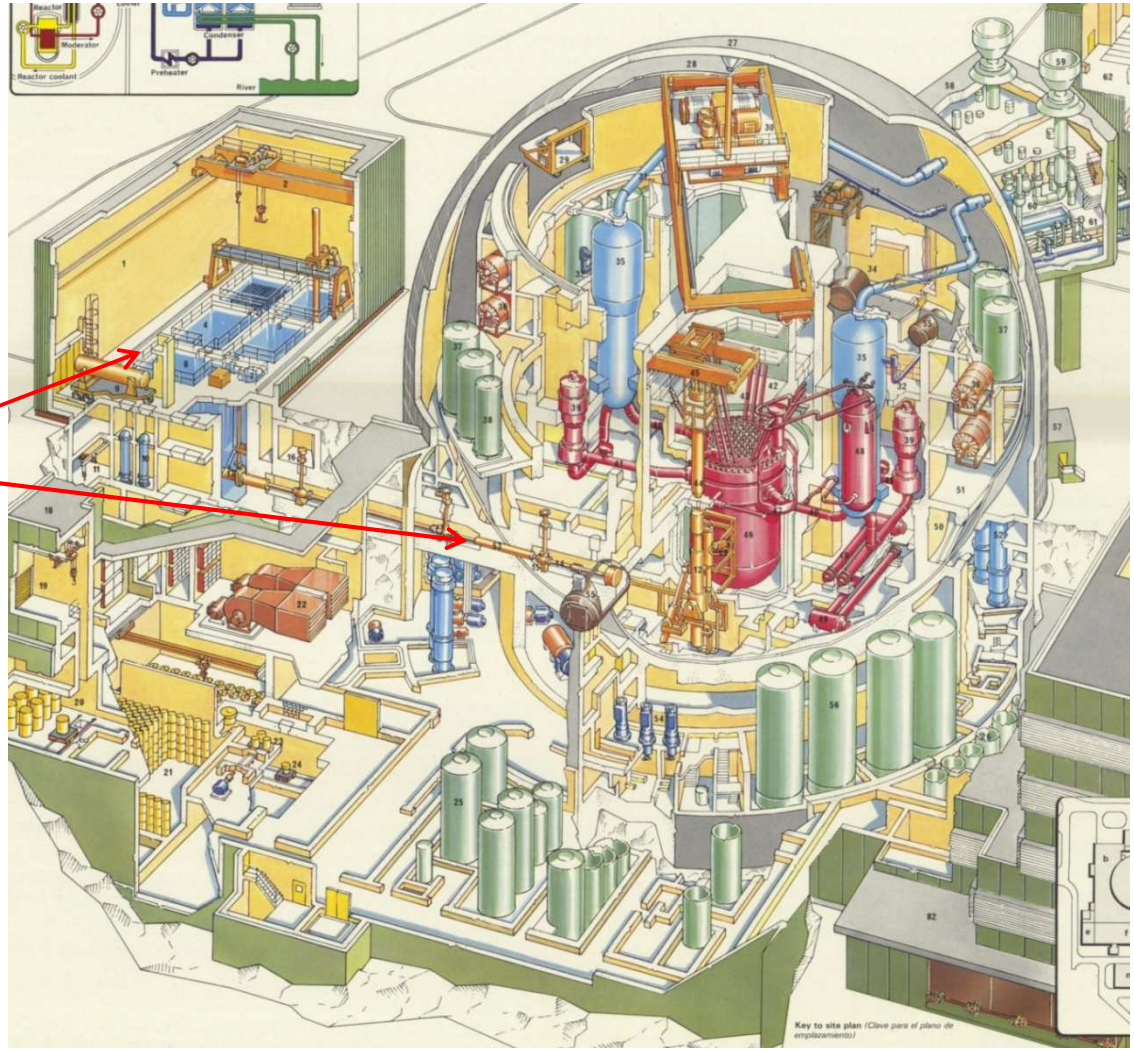
- PSA Level 2 is being performed at GRS for the Argentinean Pressurized Heavy Water Reactor (PHWR) Atucha II
- Atucha II is a 745 MWe second generation Pressurized Heavy Water Reactor (PHWR) with a Siemens/KWU design.
- MELCOR 1.8.6 YV revision 3165 has been used for severe accident and source term analyses
- A detailed input deck has been developed in 2008/09, starting from determination of relevant RN release paths from containment into environment; containing:
  - Primary System including Moderator Loops
  - Secondary System including Feed Water & Steam System
  - ECC System: 4 Safety Injection pumps, 4 Flooding Tanks, 4 ACCUs
  - Main reactor protection signals
  - Detailed reactor building - containment and annulus - & ventilation systems
  - Relevant sections of the auxiliary building

⇨ **Selected issues concerning the modeling and observations of the lower plenum of RPV and buildings are concluded and described based on MELCOR calculations for the Atucha II power plant.**

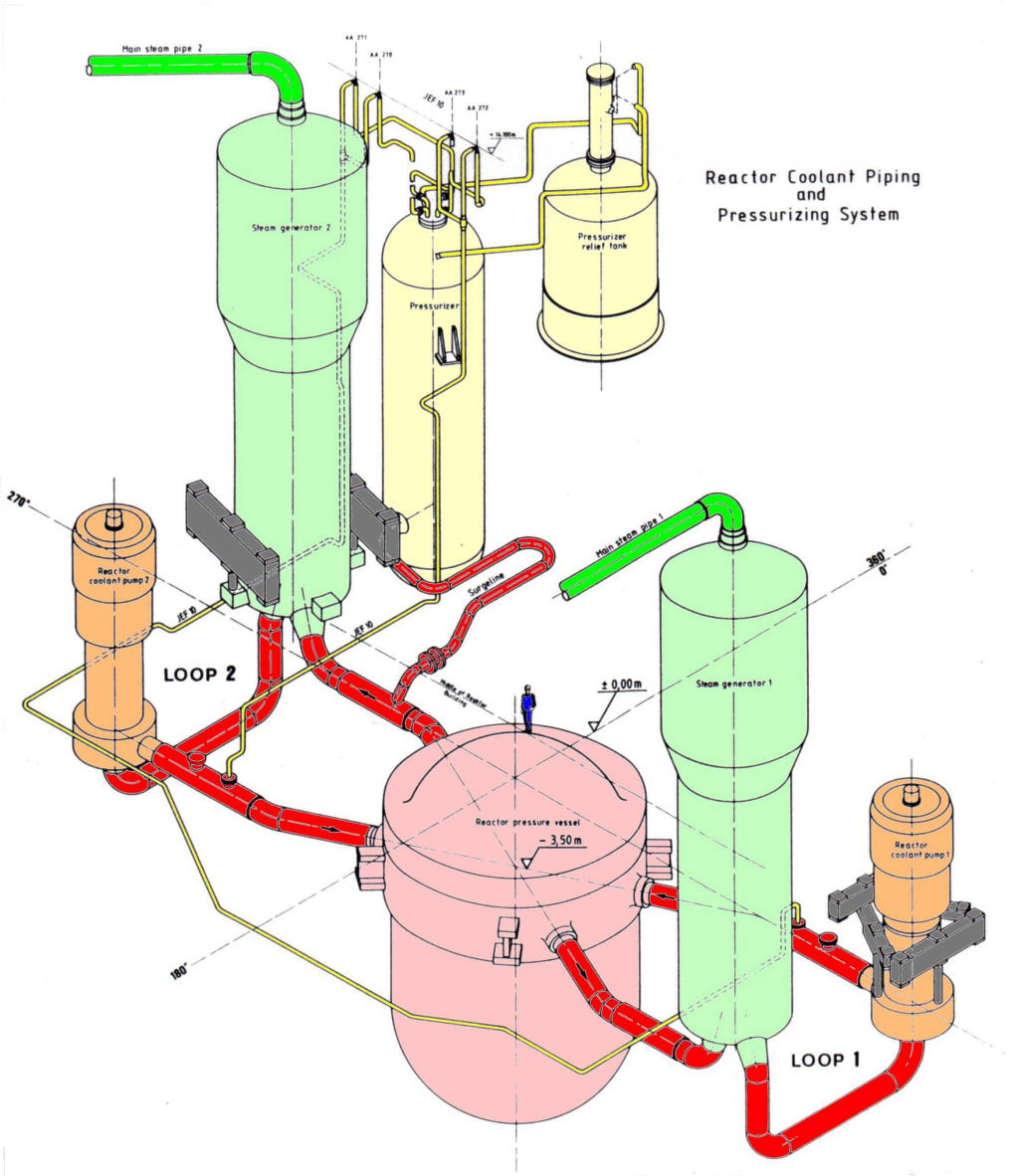
MELCOR – Short Overview of Atucha II

Atucha II – Plant Layout

- Typical modern German large dry containment
- Modifications for online refueling:
  - no spent fuel tank in containment
  - fuel assembly transport under-ground to spent fuel pool building
- Expected RN release paths strike different buildings
- Plant upgrading due to PSA level 2:
  - PAR (Passive Auto-catalytic Recom-biners) system to be installed
  - External RPV cooling as AM measure under discussion

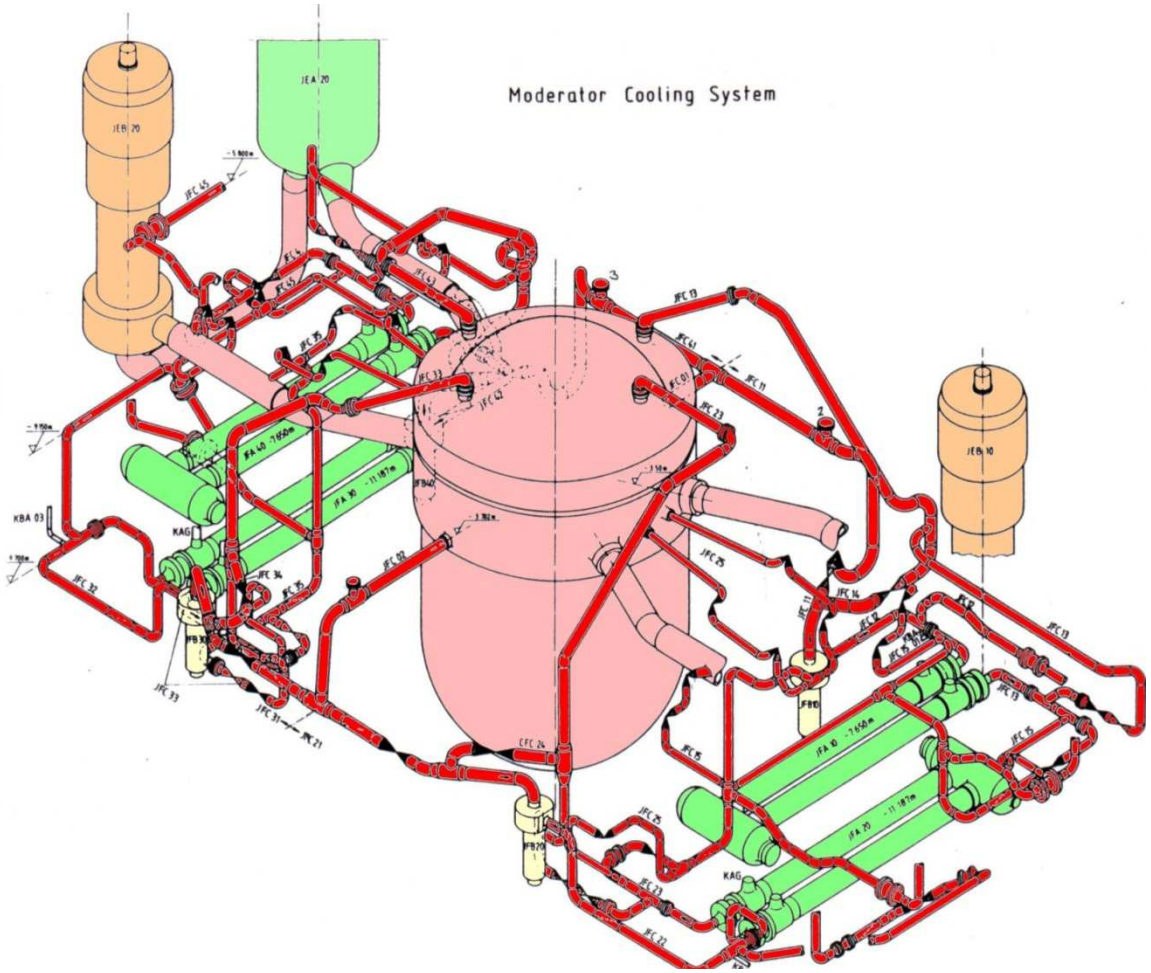


Atucha II - Reactor Coolant Circuit (RCS) lay-out



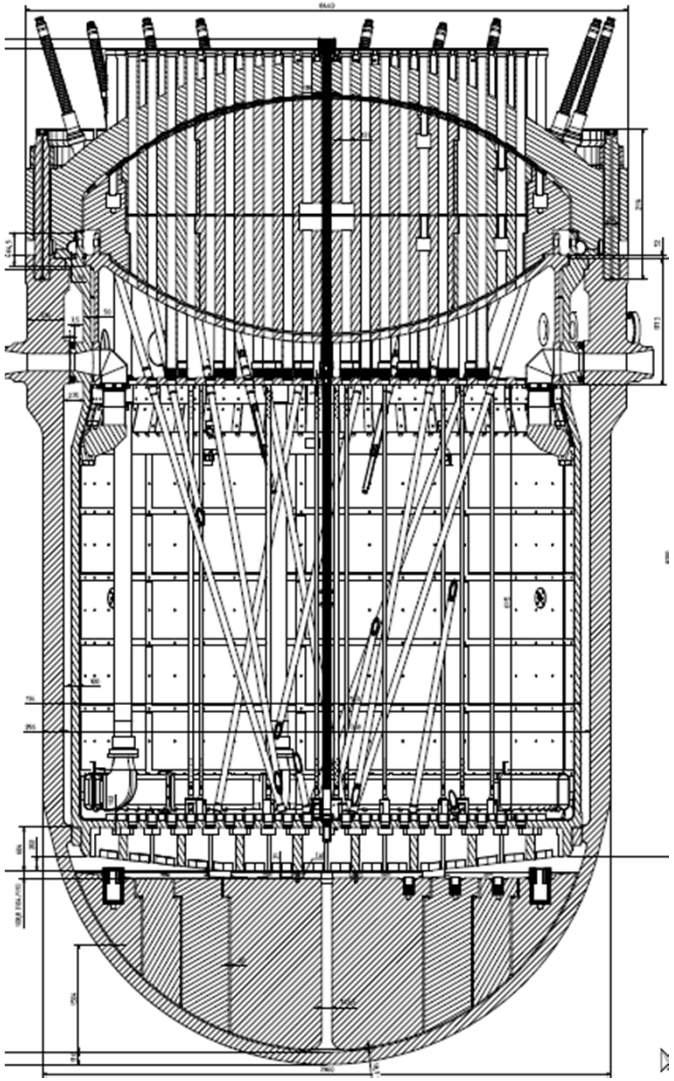
- Typical design of a German PWR
- Two loops, pressurizer and relief tank
- Operating pressure:
  ~11.5 MPa RCS & MCS
  ~5.6 MPa sec. circuit

Atucha II - 4 Loop Moderator Circuit (MCS)



- 4 moderator loops with a heat exchanger each
- Moderator temperature at a lower value as RCS temp.
- Removed heat used to pre-heat SG feed water in normal operation
- MCS used as ECCS and RHR system in addition to SG heat removal in accidents

Atucha II - Reactor Pressure Vessel (RPV)

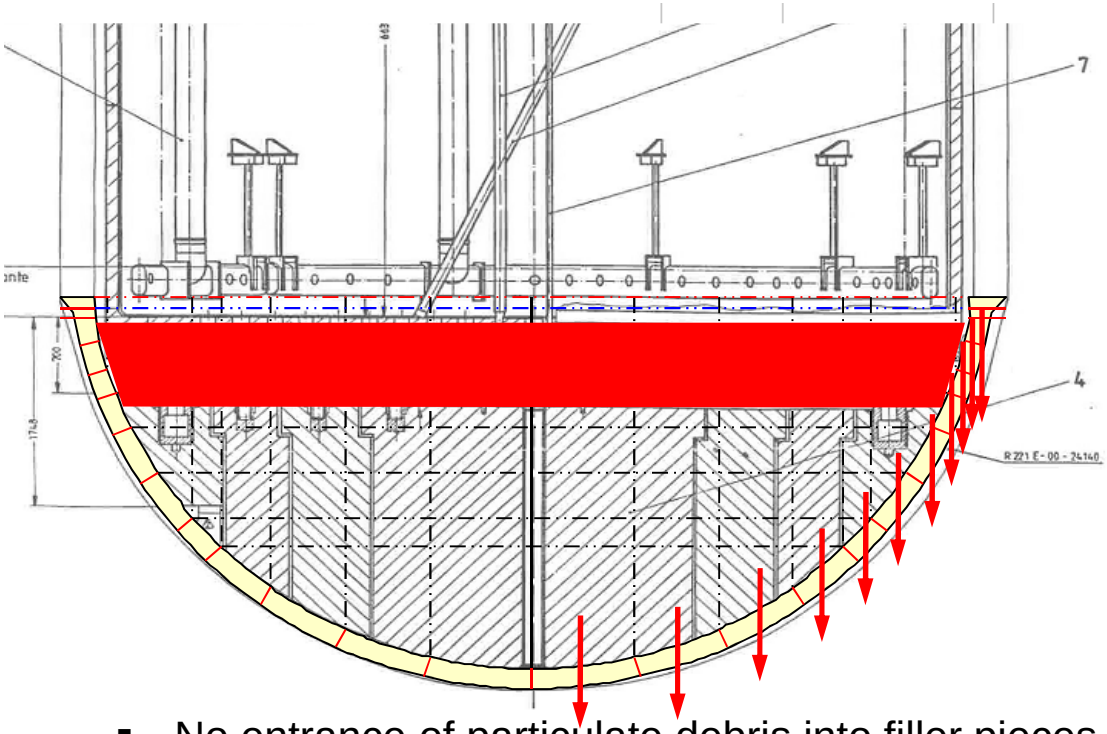


- **RPV internals are:**
  - 1 fuel assembly (37 fuel rods) inside a zircaloy coolant channel
  - 451 zircaloy channels are located inside a big moderator tank
  - 94 m^3 coolant volume and 199 m^3 moderator volume in core filled both with heavy water
  - Moderator at same pressure as coolant, but at a significant lower temperature
  - 18 steel / hafnium control rods
  - Large lower and upper filling bodies (steel)

MELCOR – Best Practices and Observations

RPV core an lower plenum

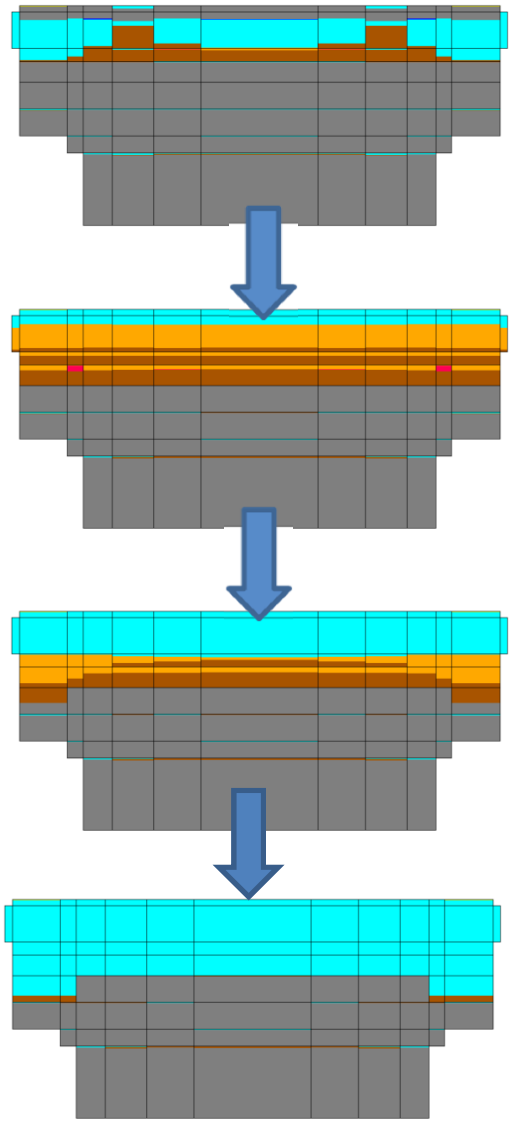
Atucha II - Lower Plenum Modeling (1/2)



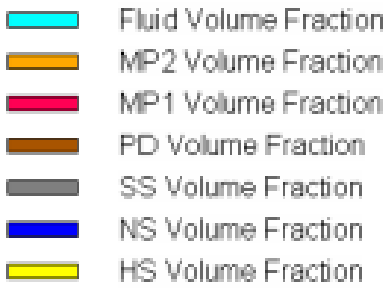
- Filler pieces (ca. 500 t) made of steel in lower plenum modeled as supporting structures (columns) with failure temperature of 1705 K
- Gap above filler pieces is large enough to collect all melt from core
- Collected melt is in contact with RPV wall only in the upper part of the lower plenum, some water my be in cavity
- 11 segments for RPV wall are used

- No entrance of particulate debris into filler pieces region (very small gaps) in order to stabilize the calculation
- No significant pressure gradient at the RPV wall has to be expected => Additional failure criterion (outer segment temperature > 1573 K) as conservative assumption => Successive opening of 11 artificial penetrations (1 per segment), to allow more PD/melt relocation into cavity
- Relocation timing of PD/melt into cavity after lower head failure calculated by MELCOR

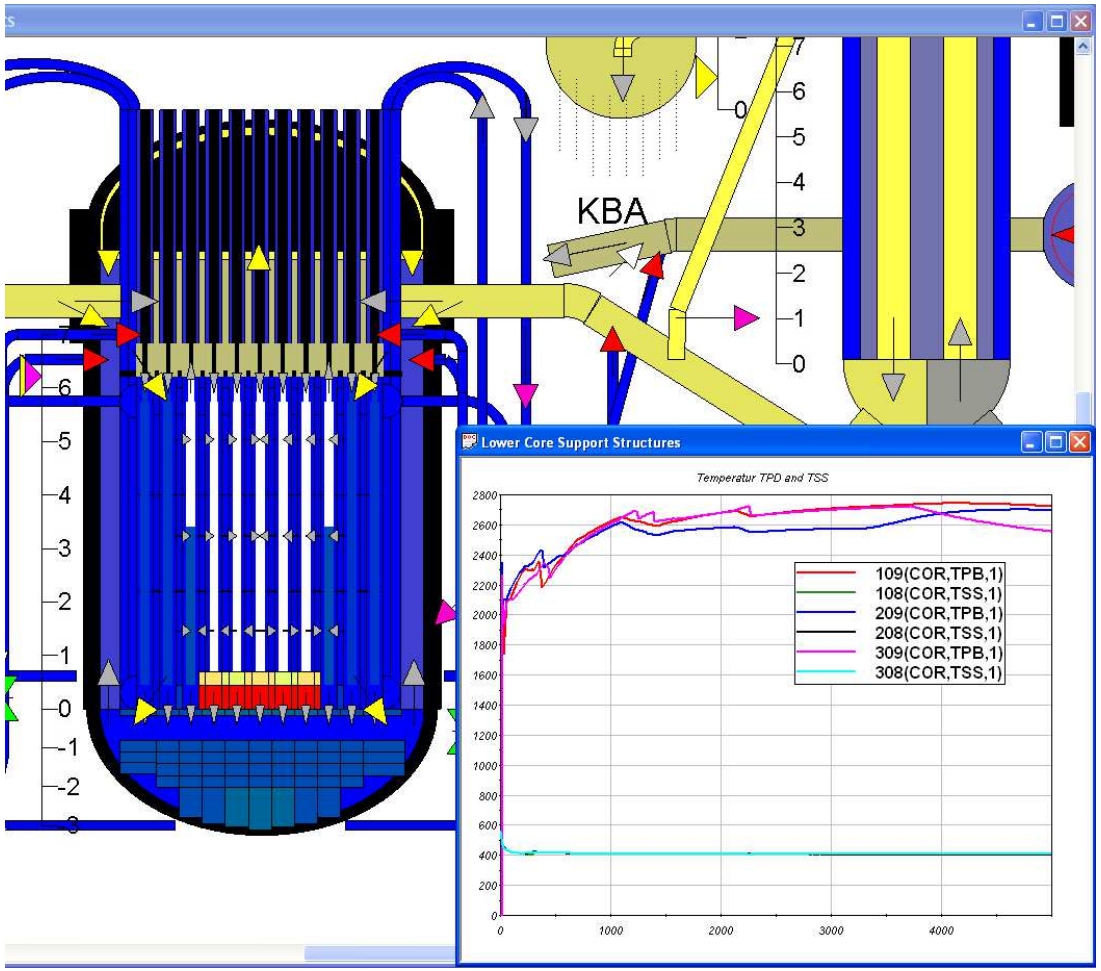
Atucha II - Lower Plenum Modeling (2/2)



- Example for a calculated melt progression inside lower plenum.
- Four phases at:
  - Shortly after failure of core support structure,
  - shortly before RPV failure,
  - one hour after RPV failure,
  - end of calculation.
- Despite of the special design of lower plenum in case of Atucha II, the calculated behavior looks quite reasonable. PD/MP2 temperatures only slightly above steel meting point.
- **Question:** Why is there always MP2 and PD in each LP axial level?



MELCOR – Observations Regarding Lower Plenum Behavior (1/2)

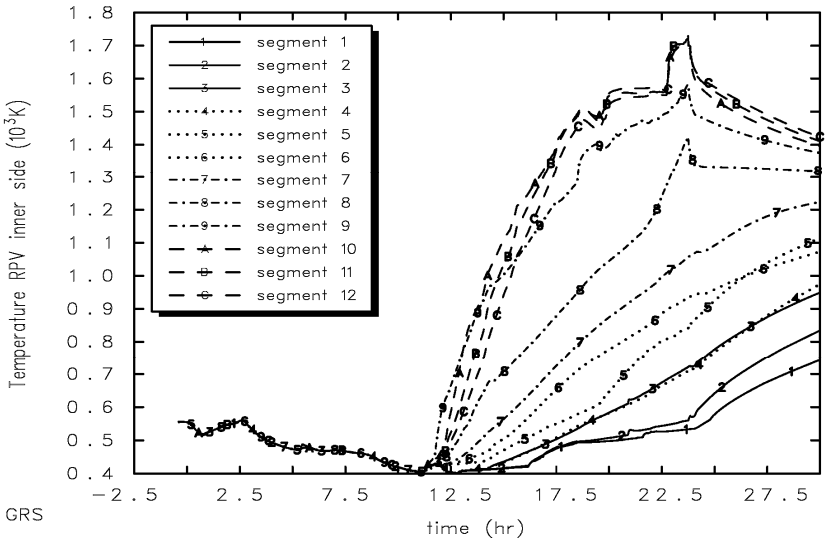


- Example for thermal behavior of lower core support structure
- Input deck uses a BWR core model
- Core debris of the inner rings lying on the support structure
- RPV flooded with water
- Debris temperatures at about 2700 K.
- Temperatures of the core support structures constantly at about 400 K

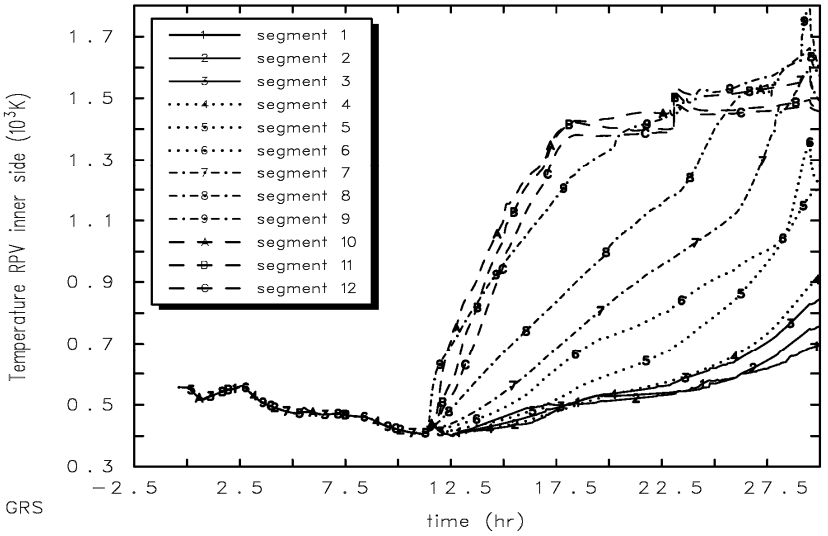
⇨ Under-prediction of heat transfer by conduction from debris to support structure?

⇨ SS model needs improvement for BWR and PWR like geometries

MELCOR – Observations Regarding Lower Plenum Behavior (2/2)



With Containment Isolation



Without Containment Isolation

- An accident sequence has been calculated with and without containment isolation.
- Calculated time sequences:

	Case with Cont. Isol.	Case without Cont. Isol.
Gap Release	**14171 sec. ≅ 3.9 hr**	**14177 sec. ≅ 3.9 hr**
Start Core Failure	**18947 sec. ≅ 5.3 hr**	**18943 sec. ≅ 5.3 hr**
Failure Core Sup.	**40615 sec. ≅ 11.3 hr**	**40849 sec. ≅ 11.3 hr**
RPV Failure	**85530 sec. ≅ 23.8 hr**	**106285 sec. ≅ 29.5 hr**

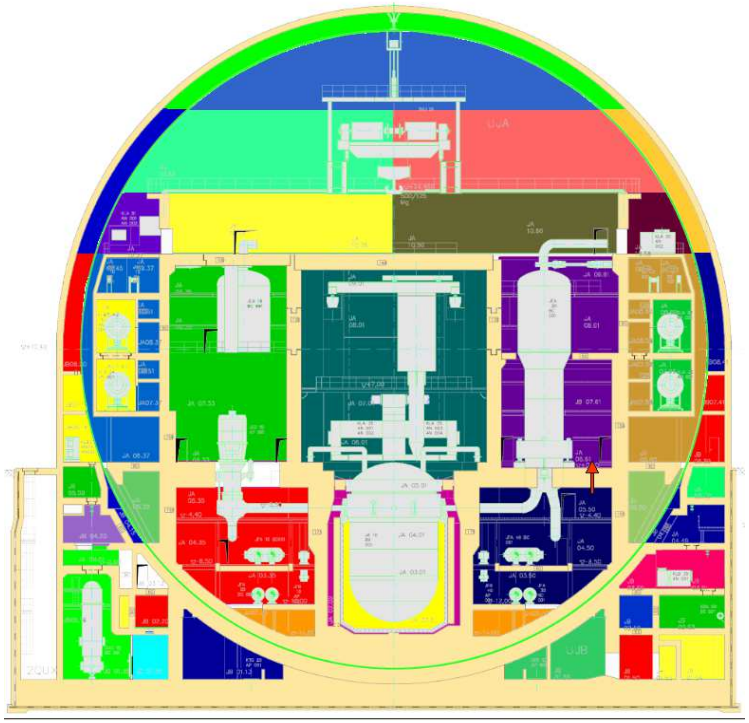
- RPV failure is delayed by about 5.7 hours in case of non-isolated containment

⇨ External heat transfer at the lower plenum seems to be very sensitive. May be a checking of heat transfer models necessary?

MELCOR – Best Practices and Observations

Building Nodalisation

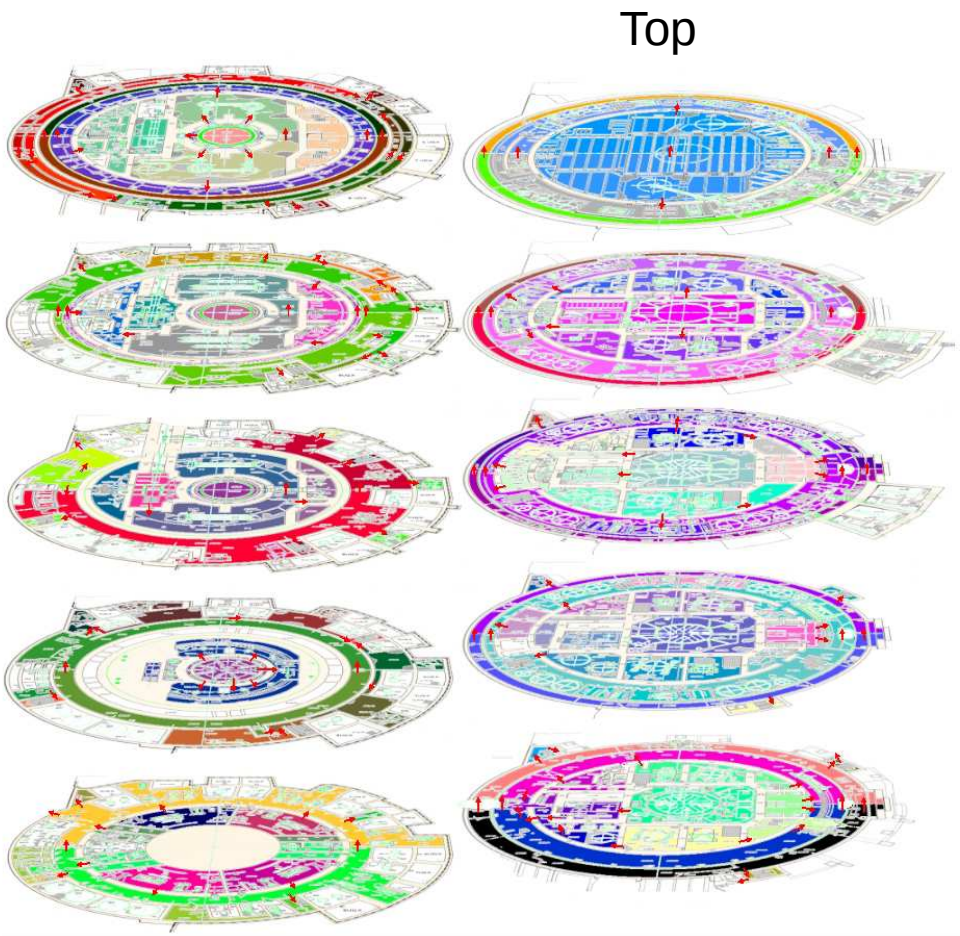
Atucha II – Modeling of Reactor Building - Containment



- All data (volumes, flow connections, surfaces of walls, floors, etc.) for rooms has been collected.
- All relevant burst membranes inside containment has been considered, e.g. on the ceiling of the steam generator boxes, between reactor hall and steam generator boxes etc.
- Nodalisation scheme defined :
  - 33 CV (6 building levels) – nearly all rooms are modeled, some small rooms are lumped together,
  - 80 FL for open connections, doors, burst membranes,
  - 6 FL for air ventilation system,
  - 23 FL for drainage system to containment sump and support system sump,
  - 475 HS modeled for walls, floors/ceilings, metallic grids and supporting beams,
  - Main ECCS tanks, crane components; RCS structures are part of RCS input,
  - 2 MELCOR cavities – reactor cavity and sump
  - containment design leakage to annulus modeled (0.25 vol.%/day)

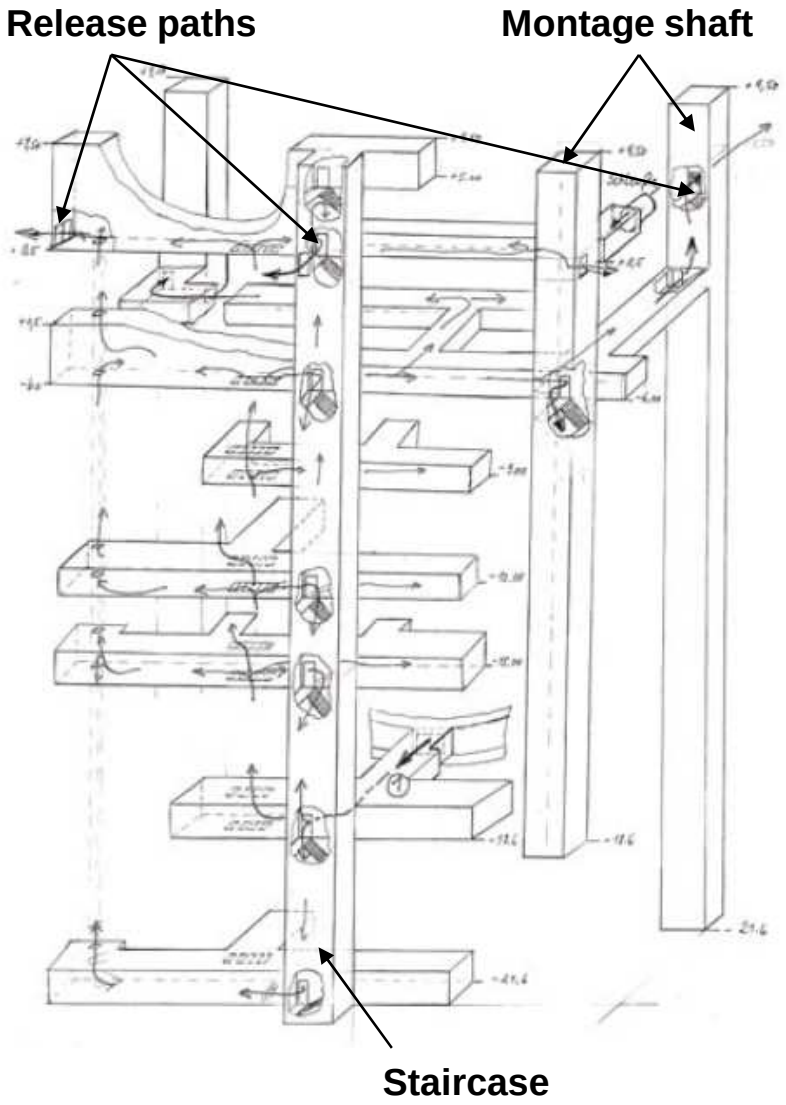
Atucha II – Modeling of Reactor Building - Annulus

- All data (volumes, flow connections, surfaces of walls, floors, etc.) has been collected for all rooms.
- Nodalisation scheme defined:
  - 50 CV (8 building levels, nearly all rooms),
  - 110 FL,
  - release paths through:
    - filtered air ventilation system,
    - stair cases to environment,
    - to auxiliary building,
  - ~300 heat structures incl. metal grids and main components (tanks),
  - door model the same as in containment,
  - four MELCOR cavities: each ECCS pump room



Atucha II - Modeling of Auxiliary Building

- All data for all relevant rooms has been collected (volumes, flow connections, surfaces of walls, floors, etc.).
- Smaller number of rooms relevant due to relevant release pathes and door opening direction.
- **Main rooms are along corridors in each building level and montage shaft.**
- Montage shaft covered partly by concrete panels.
- Nodalisation scheme defined:
  - 15 CV (9 building levels),
  - 25 FL (no air ventilation system) and
  - 100 heat structures.
- Release paths through doors to environment.



Atucha II – Fission Product Release Paths

Detailed modeling of release paths from containment:

- potential failure locations in sump region to annulus due to melt attack
- hatch between annulus and auxiliary building
- emergency doors of annulus to environment
- emergency doors of auxiliary building to environment
- Several paths through air ventilation lines, filtered annulus air system and stack

Atucha II – Modeling of Membranes and Doors

- Modeling of membranes and doors by valves and control functions
  - failure of burst membranes on SG compartment ceilings with distribution of pressure difference,
  - failure of burst membranes in doors and walls;
  - failure of sealed T90 doors estimated in opening direction and against it
  - door re-closure mechanisms taken into account for selected doors, but a 10% remaining opening assumed after failure

MELCOR - Observations Regarding Behavior inside Buildings

- Cavity behavior:
  - Homogeneous mixing model for cavities has been used.
  - Change between "**H**eavy **M**ixture **L**ayer" (HMX) and "**L**ight **M**ixture **L**ayer" (LMX) corium occurred after the transfer into another cavity (that transfer diverge between calculated cases where a similar behavior has been expected). For the MELCOR user it would be helpful to get more information (may be in the output) about the reason for changing the type of corium.
  - Balancing of melt levels between adjacent cavities and an application of a "melt transfer time model" should be done.
  - Sometimes code abort with SPARC90 problem in FL of the Cavity Package.

- Iodine pool chemistry model:
  - The iodine pool model hasn't been used for the calculations as suggested in the past.
  - But, for the evaluation of the fission product behavior and especially for the assessment radionuclide release inside Level 2 PSA studies, a reasonable iodine pool model would be helpful which allows at least a rough assessment of the iodine behavior inside buildings (iodine species released).

Summary

- The PSA level 2 was completed End of March 2011
- The modeling of lower plenum of RPV and of several buildings (like containment, reactor building annulus and auxiliary building) has been exemplified shown for our MELCOR calculation of the Atucha II power plant.
- Largest, most comprehensive and universal usable input deck ever developed at GRS with support by CNEA and NA-SA.
- Input deck qualification done mainly in 2009 in comparison to RELAP.
- Several MELCOR code errors were reported in 2009/2010 to SNL during input deck qualification → SNL kindly supported us with code updates typically after a short time of error correction work → repetition of MELCOR analyses was always done.
- MELCOR case selection based on PSA level 1 of Atucha II.
- The approach of modeling has been depicted for selected issues.
- Furthermore, some observation indicated by our work with MELCOR at the Level 2 PSA of the Atucha II power plant has been discussed.