LESSONS LEARNED FROM 15 YEARS OF MELCOR APPLICATION FOR PSA LEVEL 2 STUDIES

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- # PSA Level 2 in Germany
- # Accident Management in Germany
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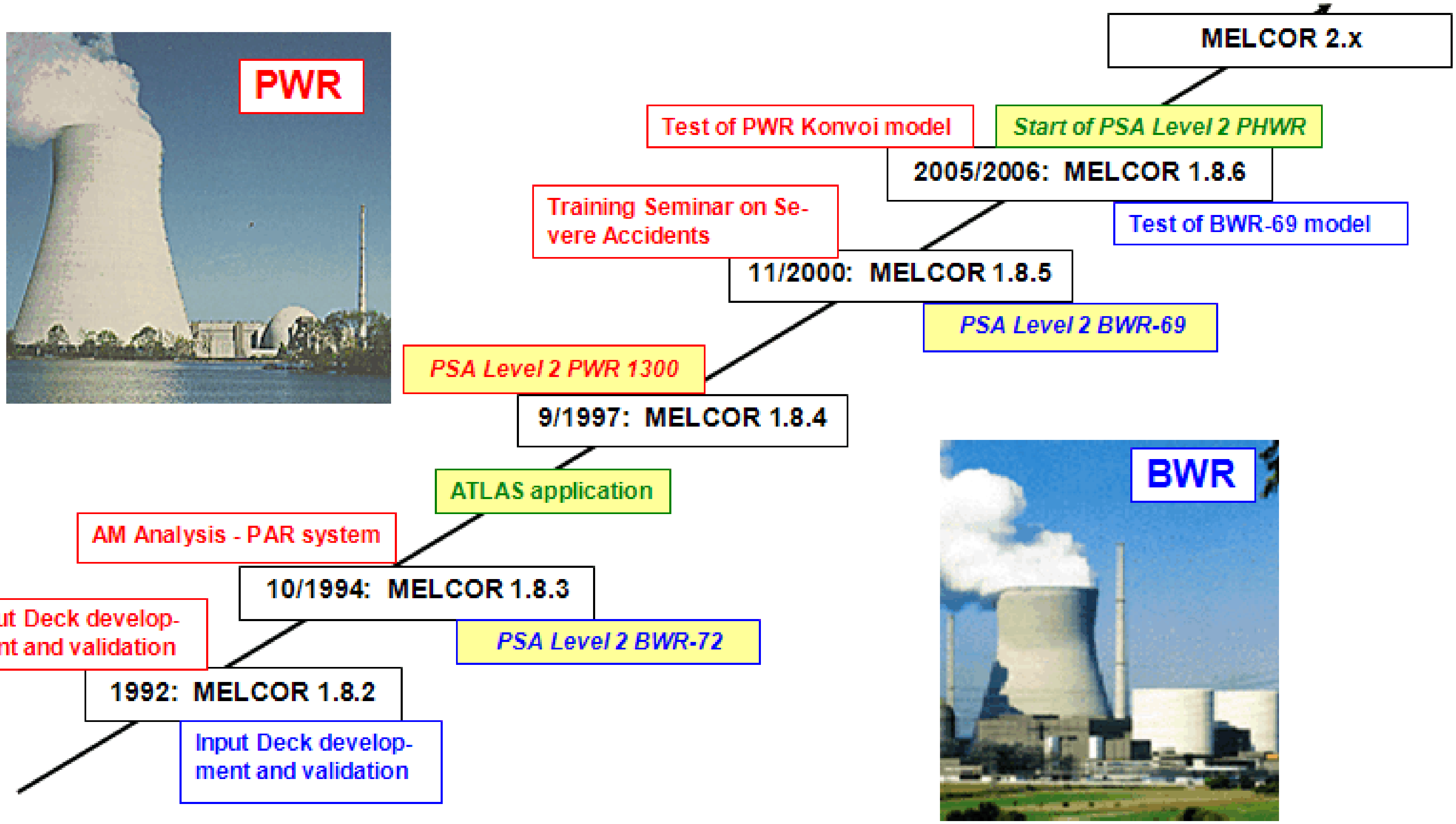
MELCOR Applications for BWR & PWR



Status of German AM Program

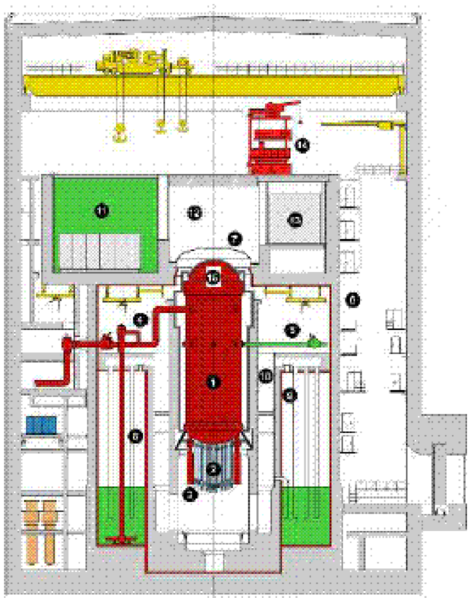
- The AMP concept consists of strategies and measures to prevent or to mitigate severe accidents (used by operators or onsite crisis team).
- So far no formal requirements exist in Germany.
- Utilities offered after TMI and Chernobyl accident voluntarily to realize recommendations of the German RSK on AM considerations.
- Decisions are made in each case individually after discussion in RSK. Formalized cost benefit criteria are considered not useful / nor practicable.
- AM measures covers main SA phenomena. Focus is on AM prevention.
- Supporting analyses are performed with ATHLET, COCOSYS and MELCOR
- Implementation of AM measures was done since 1986 mainly with significant hardware modifications. Severe Accident Management Guidelines (SAMG) are to be developed/implemented in future.
- Review of all legal requirements is under way at GRS on behalf of BMU.
- RIR (risk informed regulation) is not yet used in Germany.

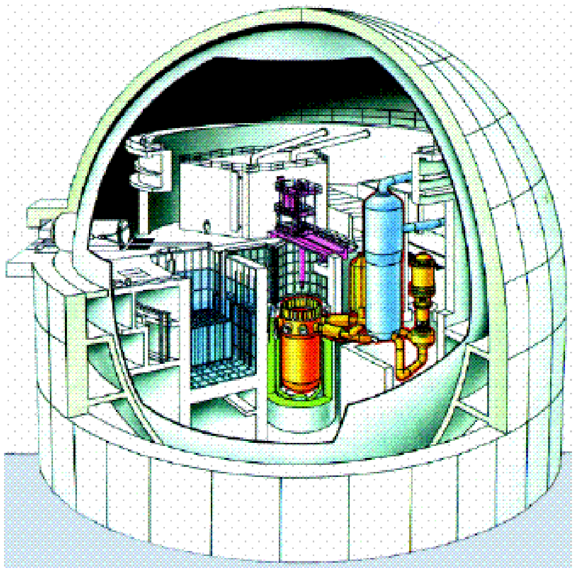
Status of PSA Level 2 in Germany

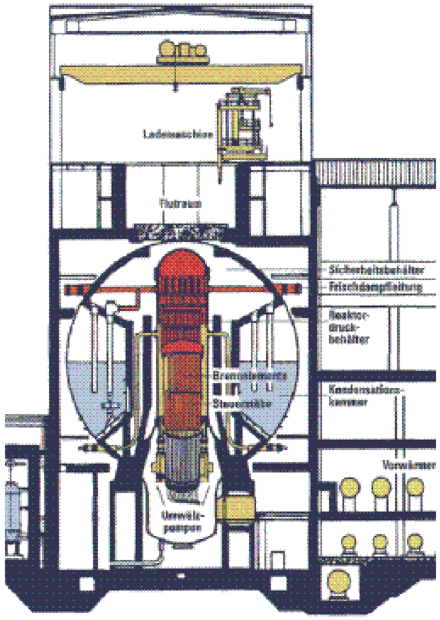
- Construction and operation licenses of NPP's have been granted in the past, based on purely deterministic analyses.
- Safety Review at a 10 years interval including a plant-specific PSA Level 1+ is mandatory required by the recent amendment of the Atomic Energy Act (2002).
- PSA Level 1+ has been part of the periodic safety review; PSA Level 2 not.
- PSA Level 2 have been performed by the GRS within R&D projects for three main German NPP types, exploring PSA Level 2 methodology.
  -> **MELCOR** was mainly used for severe accident and source term analyses.
- PSA Level 2 recently has become part of the periodic safety review.
  -> German utilities started to perform PSA Level 2 studies
  -> **German PSA Guidance** document was updated and published in 2005
  -> integral codes like **MELCOR, ASTEC** are recommended to be used
- PSA Level 3 is still not required in Germany.

Level-2-PSA after German Risk Study Phase B (DRS B)

BWR 1300 MW	PWR 1300 MW	BWR 900 MW
Type 72, no ref. Plant	Konvoi - GKN-2	Type 69 - KKP-1
BMBF Project	BfS/BMU Project	BfS/BMU Project
GRS-A-2519, Mai 1998	GRS-175, Okt. 2001	GRS, until 2005







- main purpose of all studies: research and methodology development/application

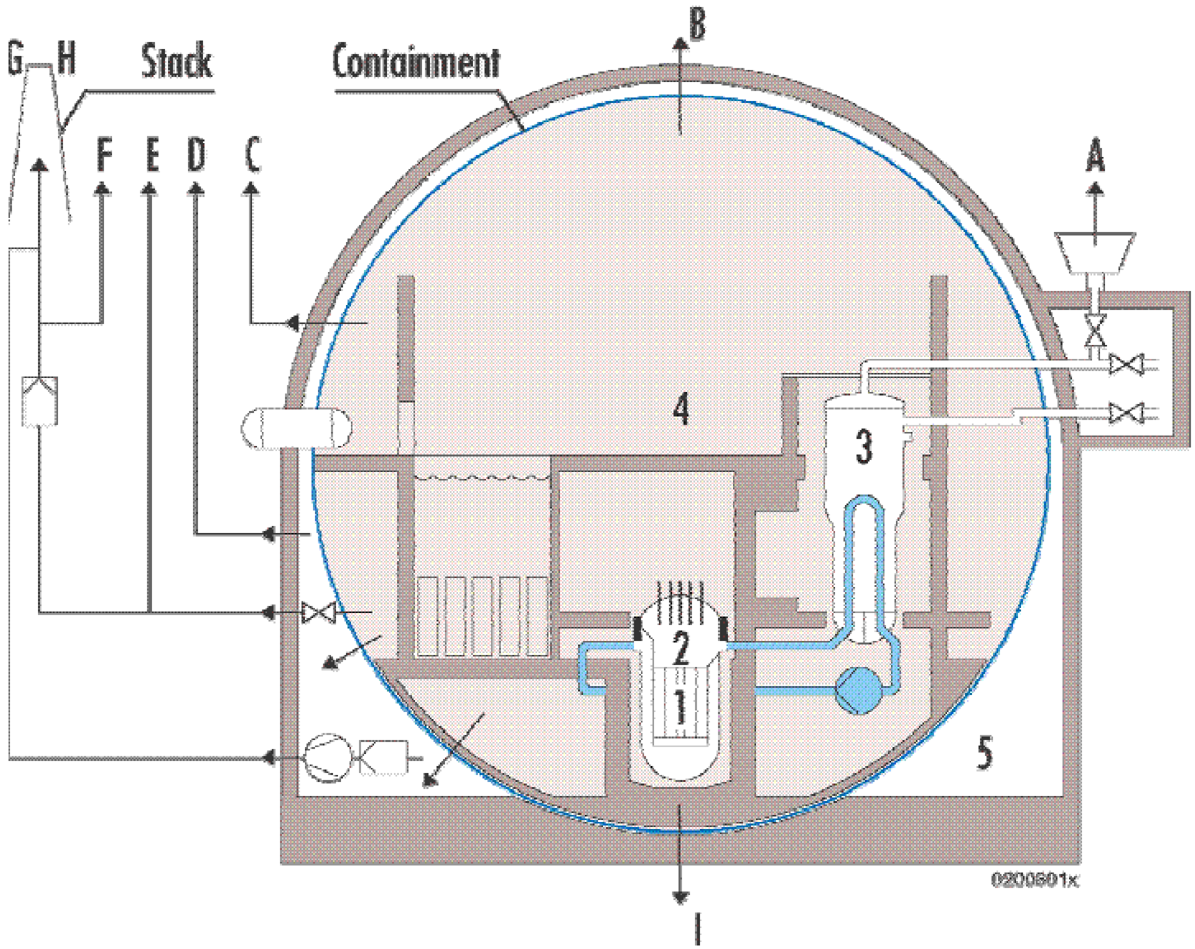
German PSA Level 2 Guidance Document <-> MELCOR

- To support a systematically development of PSA studies and the assessment of branching probabilities for severe accident progression event tree (APET) analysis.
- To reduce the potential of controversial expert views in the frame of the Periodic Safety Review Process on complex and not well known severe accident phenomena.
- There are two volumes, representing the status of knowledge; *published in 10/2005*:
  - The volume on *"Methods for PSA"* deals with:
    - Level1/2 interface (core damage state properties)
    - **Quality requirements for integral deterministic accident and source term analysis (MELCOR)**
    - Accident progression event tree (APET), issues to be considered
    - **Definition of release categories - source term**
    - Handling of uncertainties
  - The volume on *"Data for PSA"* gives advice:
    - how to quantify branching probabilities in the APET for complicated issues
    - how to specify for which branching probabilities generic, or plant-type specific or plant specific numbers need to be used.

Some recommendations are explained in next slides

Part 1 – PWR Application

Determine all probable RN release paths before MELCOR input deck set-up.



PWR 1300

A: SG safety valves

B: damages of buildings

C: failed containment air system

D: failed reactor or other building air system

E: failure of containment venting system before filter

F: failure of containment venting system after filter

G: through annulus filtered air systems

H: through containment filtered venting system

I: after penetration of basemat

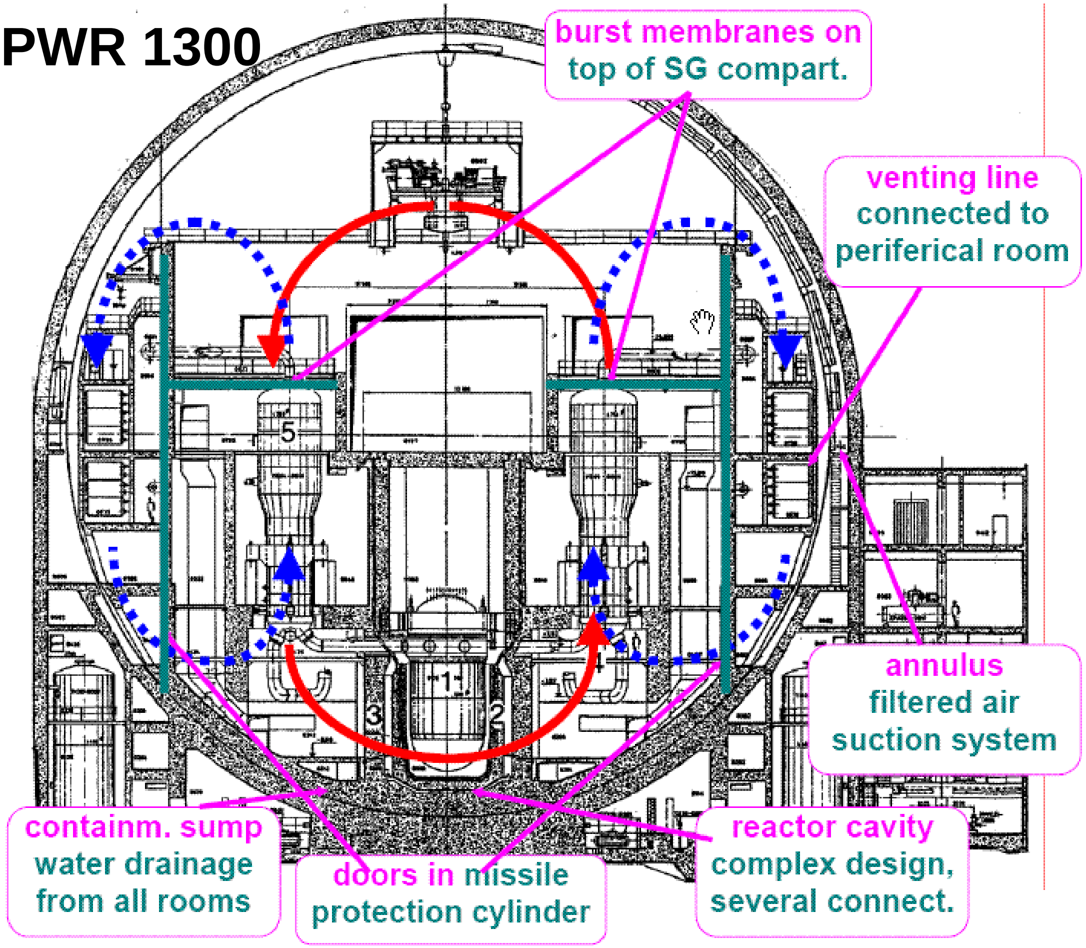
PSA L2 Best Practice - Severe Accident and Source Term Analyses

- **Develop adequate input for used codes** – MELCOR used in GRS
  - requires high knowledge of code user on severe accident phenomena
  - need for adequate and sufficient information on plant specifics and design
  - **use real plant data without conservative assumptions** as for DBA analyses
  - need for **appropriate modelling of relevant plant specifics** and **all probable fission product release paths into the environment**
  - need for sufficient detail of nodalisation schemes for all components and buildings to allow a realistic simulation of NPP behaviour under severe accident conditions
- **Validate developed input deck** – MELCOR used in GRS
  - against real plant data for normal plant operating conditions
  - by code to code comparisons with detailed GRS codes **ATHLET-CD**, **COCOSYS**
  - main integral code results for different accident phases and timing of sequence should be in good agreement to detailed codes

PSA L2 Best Practice - Severe Accident and Source Term Analyses

Take into account all source term relevant & plant specific aspects.

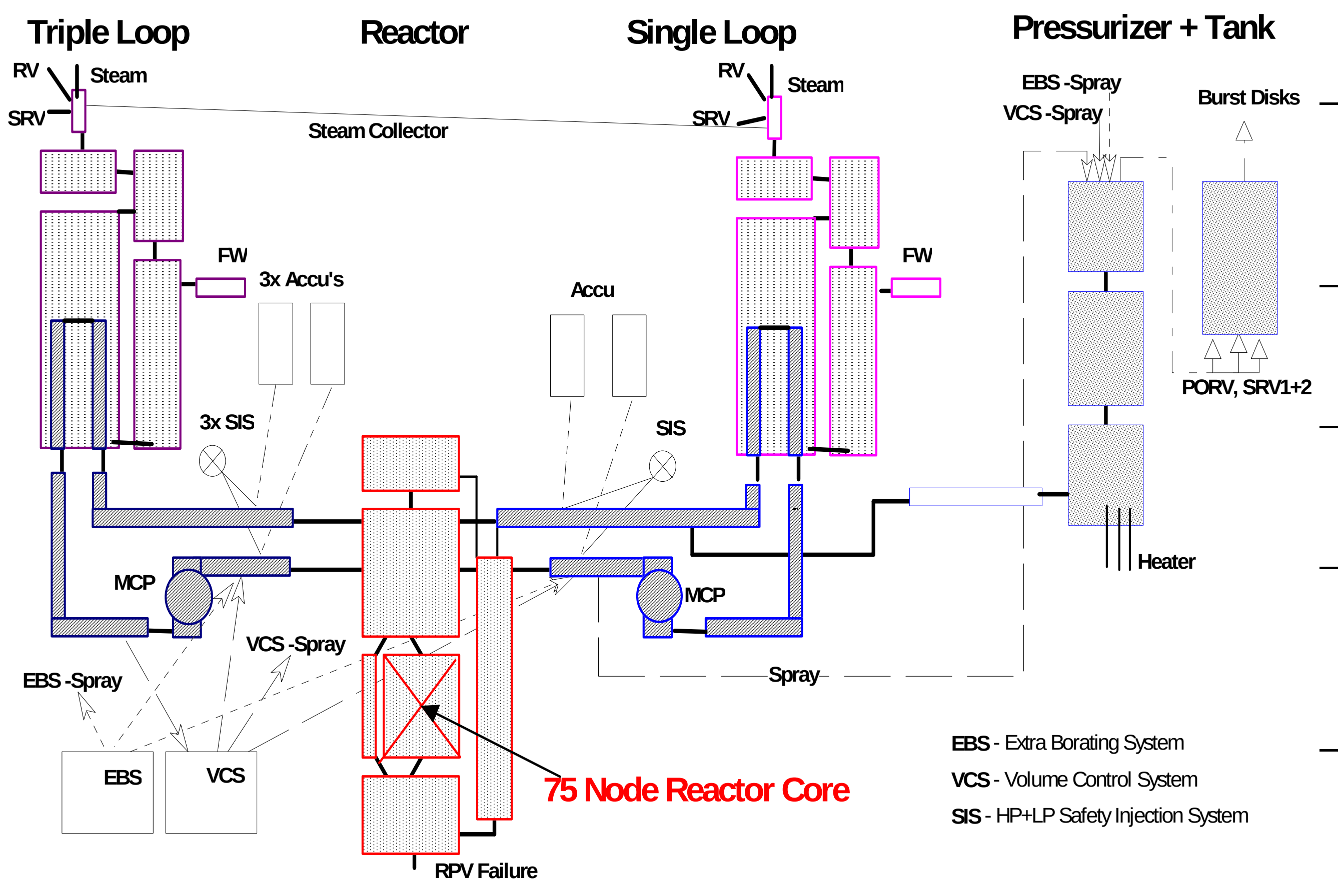
PWR 1300



- **multi-compartment design** -> different flow pattern, many possible leak path's into annulus and environment
- **convection flow** depends on scenario and is important for: FP transport and distribution, PAR effectiveness, ...
- single convection cell:
  - in most cases due to small Δp
  - few burst membranes destroyed
  - limited convection and gas mixing
- double convection cell:
  - only large break LOCA ->large Δp
  - many burst membranes destroyed
  - "doors" in missile protection cylinder opened
  - good convection and gas mixing

PSA L2 Best Practice - Severe Accident and Source Term Analyses

Develop adequate plant nodalisation schemes (MELCOR example for PSA L2)



PWR 1300

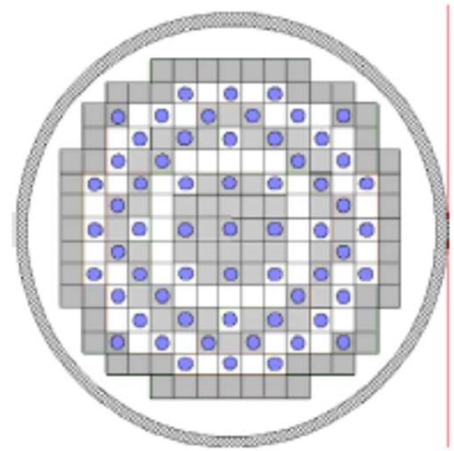
- adequate simulation of RCS geometry and consideration of all operational systems
- detailed pressurizer and prz. relief tank important for transients
- detailed SG secondary side model important for heat transfer
- detailed core model to get realistic oxidation, H2 generation and fission product release
- often much more core cells used for calculation of experiments as for real plants - why?

Lessons Learned - RCS Input for PWR Type Konvoi

- **detailed Pressurizer Model is important not only for transient scenarios**
  - minimum 3 nodes (bottom sub-cooled, middle saturated, top steam)
  - model of pressurizer spray system only by FL-package; thermal equilibrium option needed
  - pressurizer heater can be modelled by heat source to water in lowest CV
- **model of Prz. Relief Tank is needed - timing of releases into containment**
- **detailed SG Secondary Side - water circulation determines heat transfer**
- **plant specific systems are important in case of transient scenarios**
  - pressurizer spray system (0 - 40 kg/s) – different injection rates
  - pressurizer heater – different heater steps
  - volume control system (VCS, 3x 8 kg/s) – injection -> 4 loops, extraction <- 1 loop, spray -> prz.
  - extra borating system (EBS, 4x 2 kg/s) – injection -> 4 loops, spray -> pressurizer
- **Accumulators can be modelled by CF model instead of CV/FL model**
- **Safety Injection Systems by mass sources**

Lessons Learned - Core Input for PWR Type Konvoi

- **Radial Core Nodalisation**
  - Minim. 5 rings recommended to reflect radial power profile
  - "approx. equidistant rings" are better than "equal volume rings" -> more realistic core melting, oxidation, H2 generation

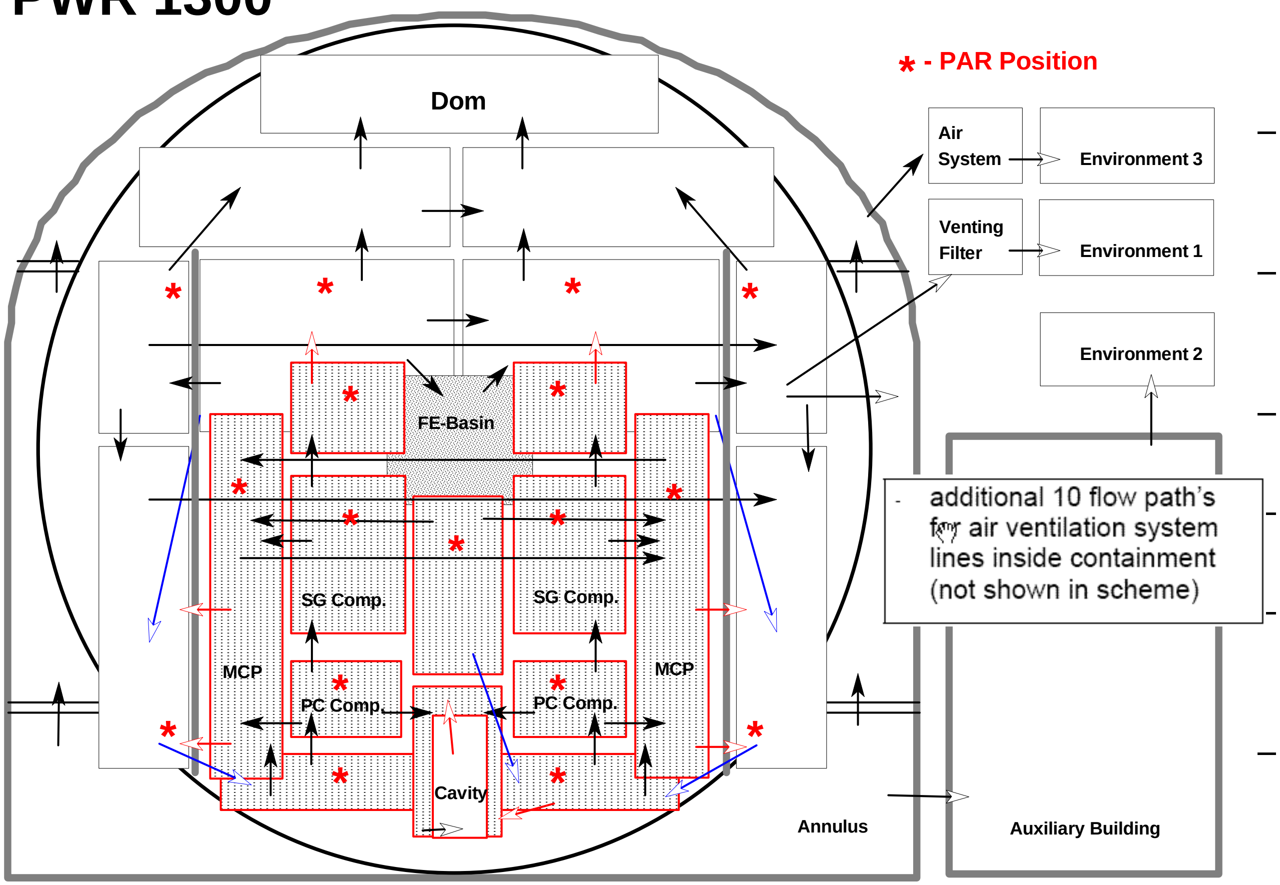


- **Axial Core Nodalisation**
  - one axial level per ~30 cm fuel length recommended
  - one level each for fuel element head and feet
  - one separate level for lower support plate, upper support plate as HS
- **redefine RN inventory - use real plant data (BOC ?, EOC)**
- **check defaults of Particulate Debris exclusion values in core**
- **check densities of used Core Material versus default values**
  - MELCOR requires geometrical data and masses of UO2, AIC, … ; uses default densities
  - mismatch of calculated and real volumes is possible due to differences in densities
  - e.g. density of UO2 in German plants 10300 kg/m³, default 10960 kg/m³ -> redefined in MP input

PSA L2 Best Practice - Severe Accident and Source Term Analyses

Develop adequate plant nodalisation schemes (MELCOR example for PSA L2)

PWR 1300



- large detail of nodalisation used to simulate specific convection loops
- selection of rooms in accordance with release flow paths into environment
- "death end" rooms to be avoided, if not existing in real plant
- avoid very large flow path areas (esp. in dome area)
- user defined PAR model implemented
- modelling of air ventilation system in containment and annulus
- realistic simulation of doors and burst membrane behaviour

Lessons Learned - Containment Input for PWR Type Konvoi

Multi Compartment Containment / Building

- selection of rooms in accordance with release flow paths into environment
- nodalisation scheme should simulate existing convection loops *(see next slide)*
- “death end” rooms to be avoided, if not existing in real plant
- realistic definition of FL opening heights important
- water drainage to building sump respectively lowest floor to be simulated along HS and between CV by FL; use HS film tracking net and realistic critical pool fractions
- reduction of FL area of connections between large open rooms (max. 10 - 20 m^2)
- justification of momentum exchange term in FL with combined water / gas flow
  - lower values decouple gas and water flow
  - higher values couple gas and water flow

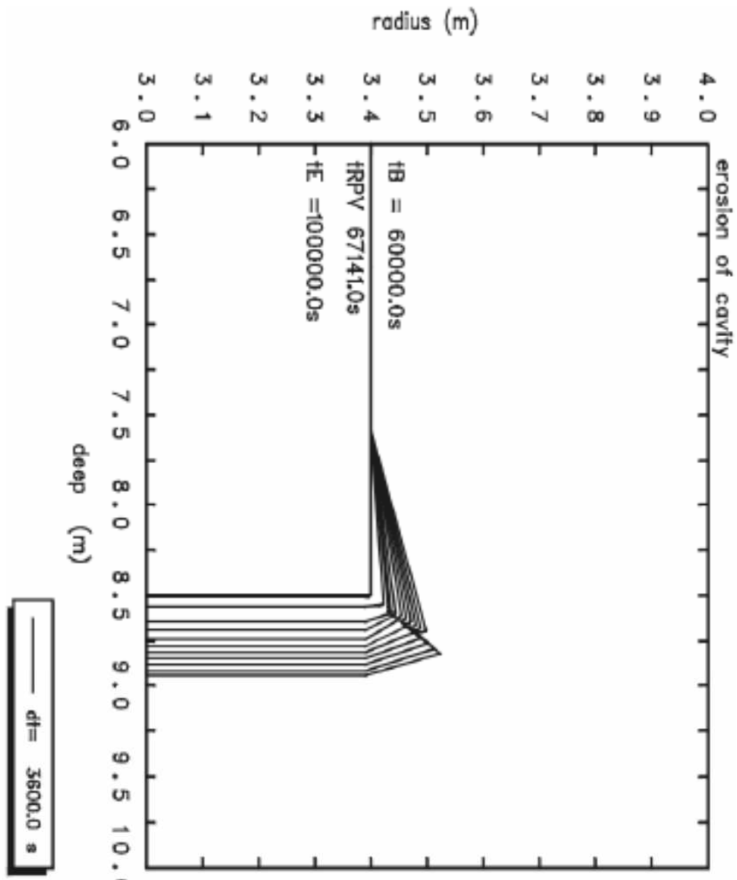
Doors between Rooms

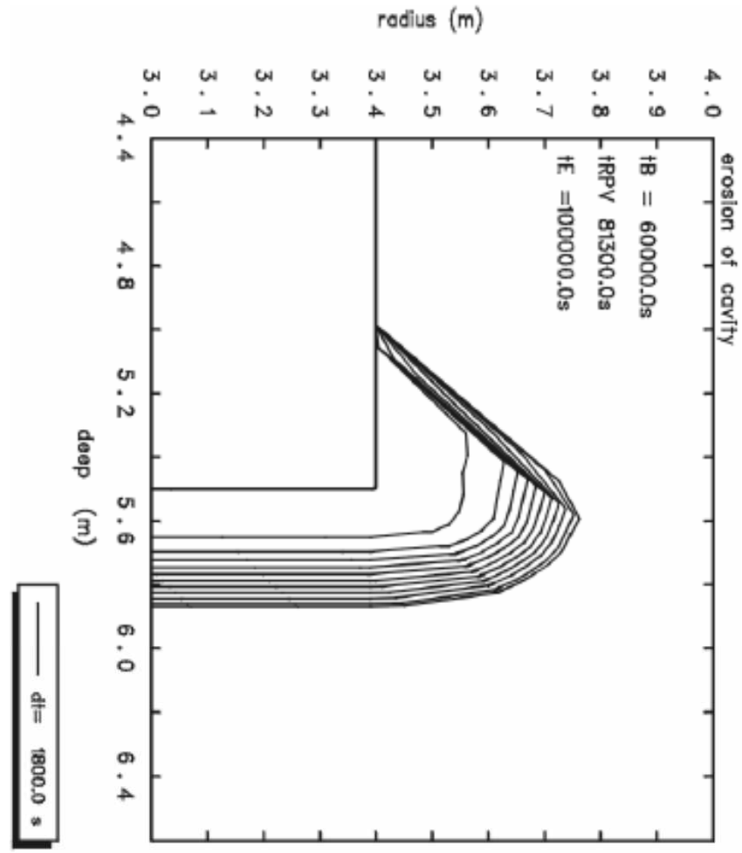
- doors are often not leak tight - small gaps simulated - simplifies pressure balance
- possible failure of doors dependent on Δp according to door opening direction, design and/or in case of a high water level

Lessons Learned - Containment Input for PWR Type Konvoi

- **Air Ventilation System of Containment**
  - during normal plant operation system removes heat released from RCS into containm.
  - availability of system during accidents dependent on plant design
  - air ventilation system ducts connects several rooms
  - ducts exists also if system is out of operation
  - ducts contribute to convection processes between rooms
- **Turbine Building**
  - not modeled – not of importance in case of severe accidents (PSA result)
- **Molten Core Concrete Interaction - Cavity Input in MELCOR**
  - add content of reinforcement bars (Fe) in basemat
  - use maximum number of NRAYS esp. on vertical part of cavity
  - homogeneous melt mixture model preferred for short term (default in MELCOR 1.8.5)
  - it gives good results compared to other codes like WECHSL

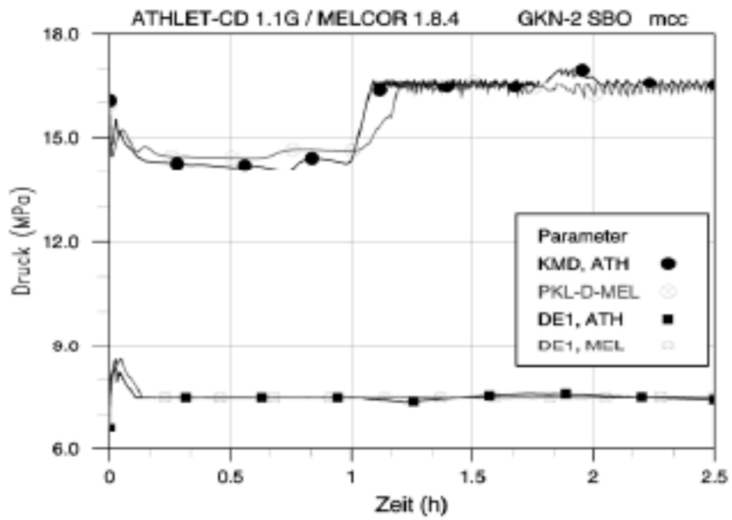
Lessons Learned - Cavity Input for PWR Type Konvoi

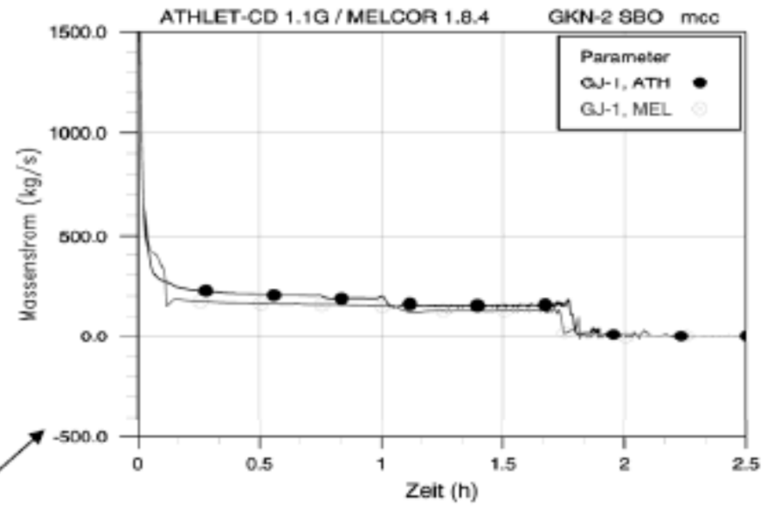


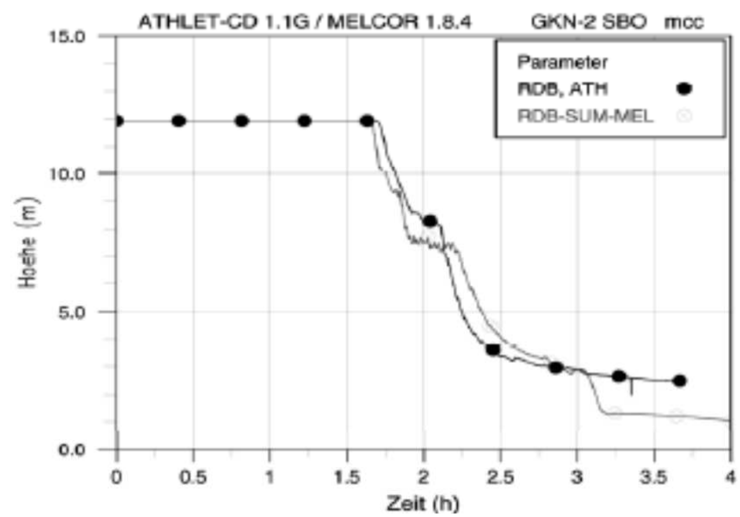


cavity points:	7 bottom, 3 corner, 10 axial	20 bottom, 10 corner, 70 axial
cavity height:	8.5 m	5.5 m

PSA L2 Best Practice – Input deck validation – PWR 1300

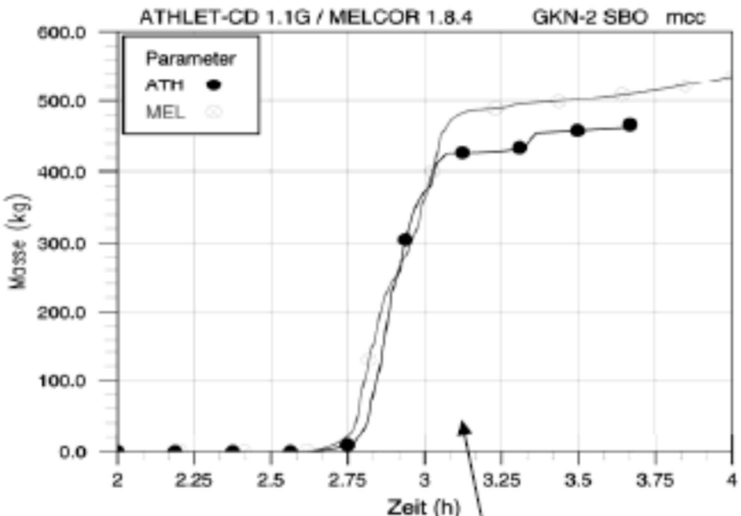


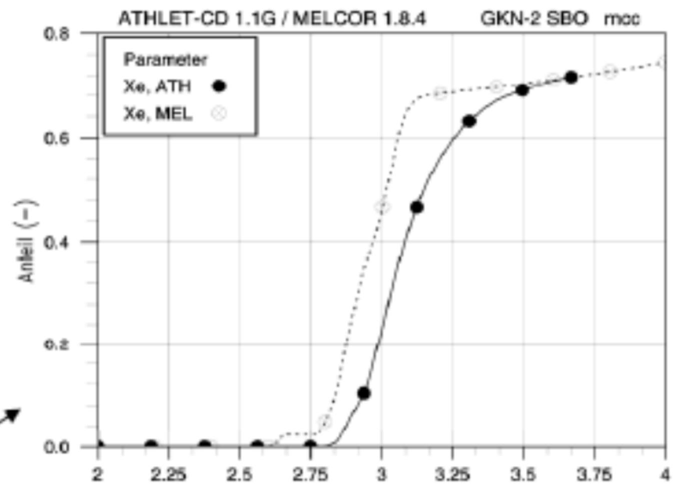


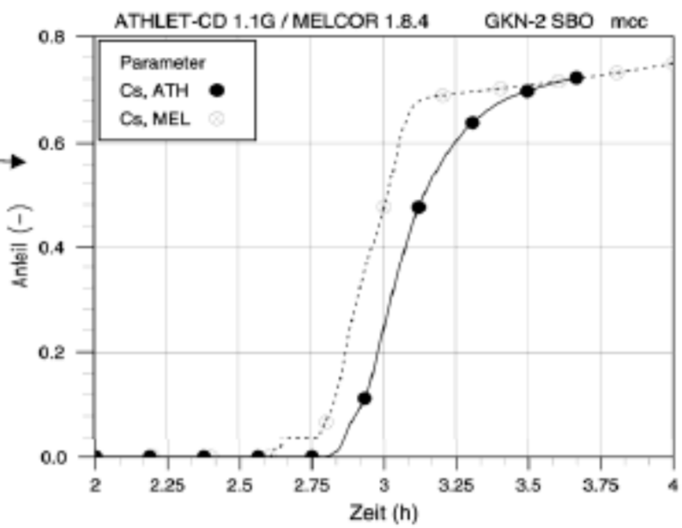


- comparison of pressure, mass flow in hot leg and water level in RPV
- MELCOR results with open symbols
- ATHLET-CD input deck with larger detail of thermohydraulic model and identical core model

PSA L2 Best Practice – Input deck validation – PWR 1300

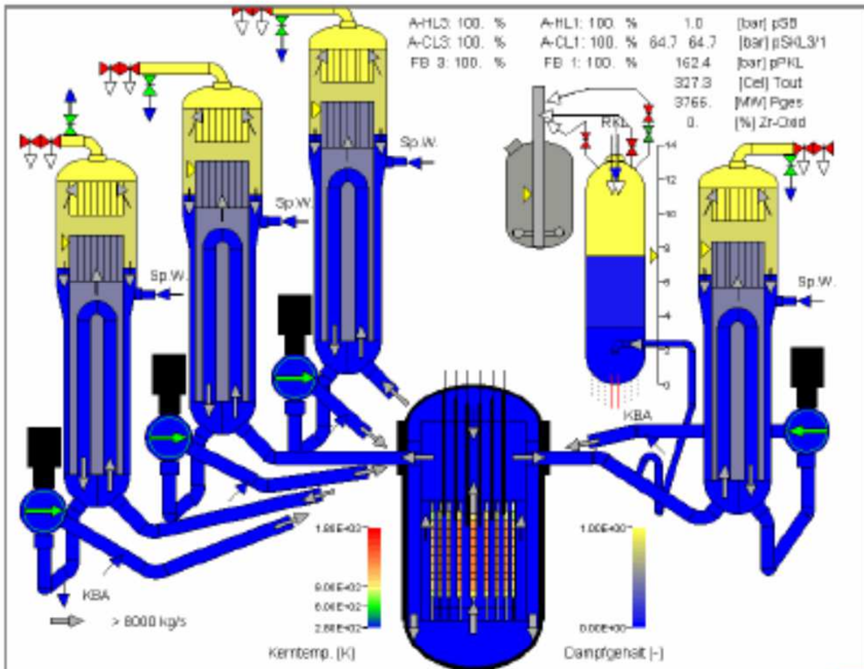




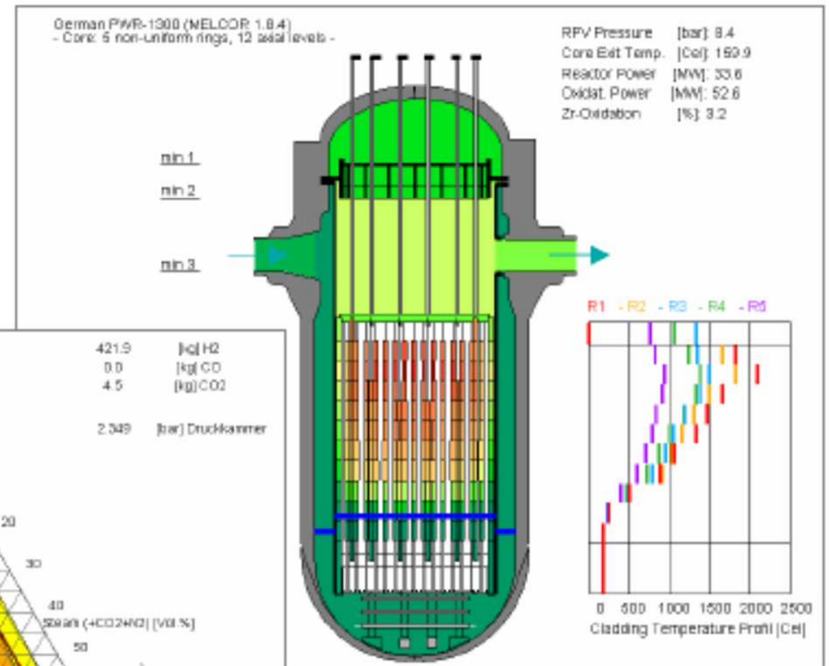


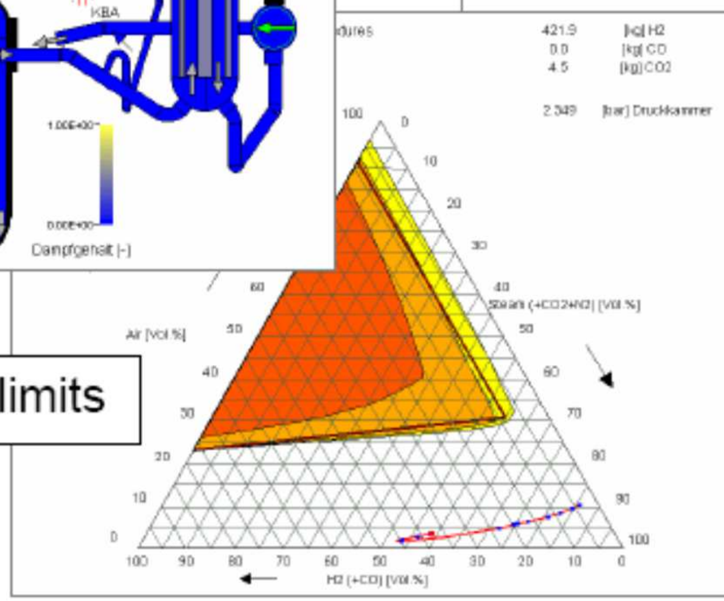
- comparison of H_2 generation, Xe release and Cs release
- MELCOR results with open symbols
- general good agreement achieved also for other sequences

MELCOR connected to ATLAS



RCS and core behaviour





combustion limits

Assessment of Results

Requirements on Severe Accident and Source Term Analyses

Assess the results carefully and determine source term relevant phenomena.

MELCOR PWR 1300:

H2 release from break during core melting; 200 cm² cold leg break with ECCS

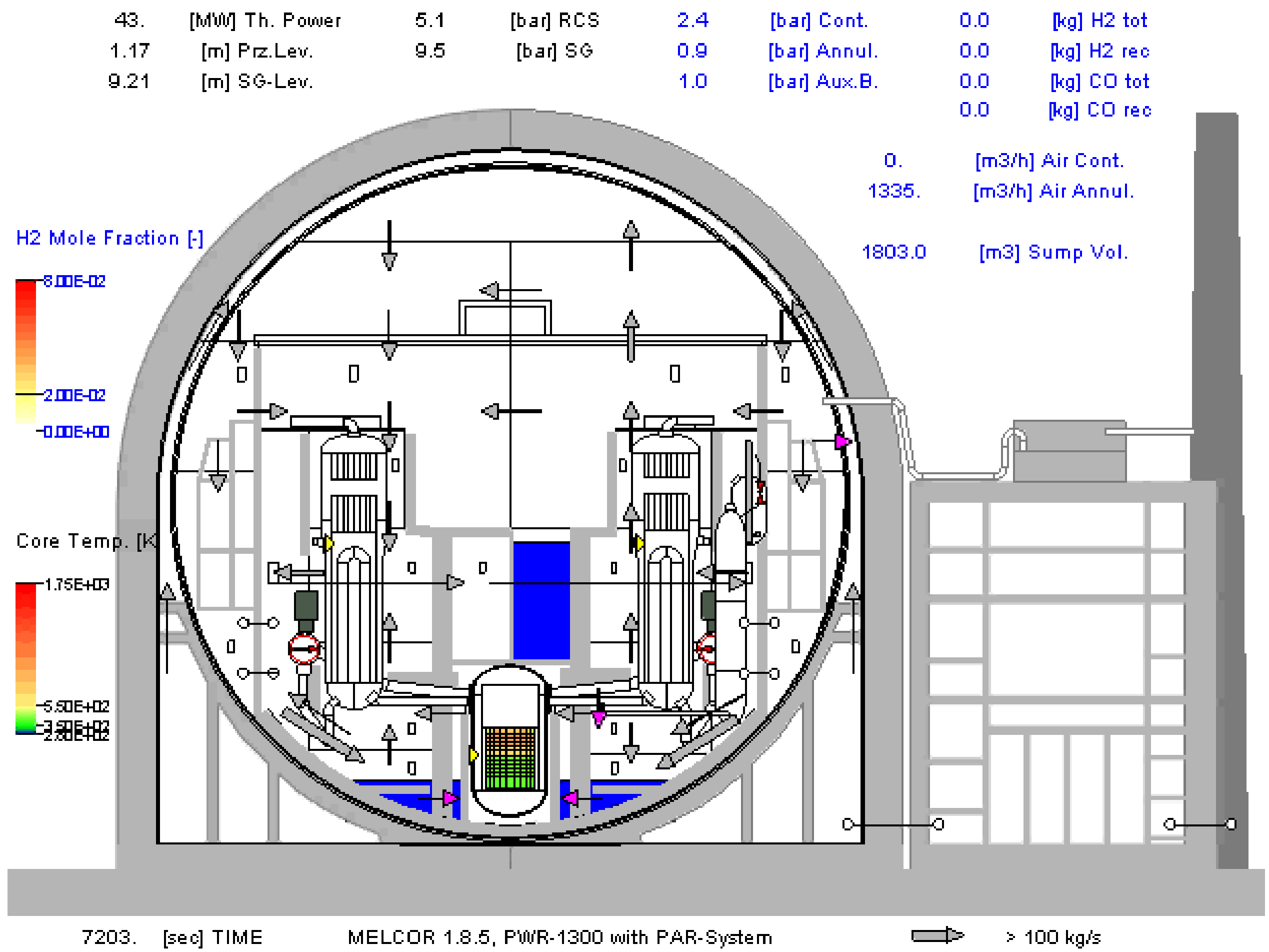
H2 always released together with steam; some H2 stored in RCS (esp. HP cases)

Non-uniform H2 concentration inside containment during release phase

Intensity of H2 mixing and start-up of PARs dependent on scenario, convection conditions, break flow, …

H2 combustions possible near break – PAR failure assumed and steam inertisation lost

Different H2 release locations: break / cavity after RPV failure

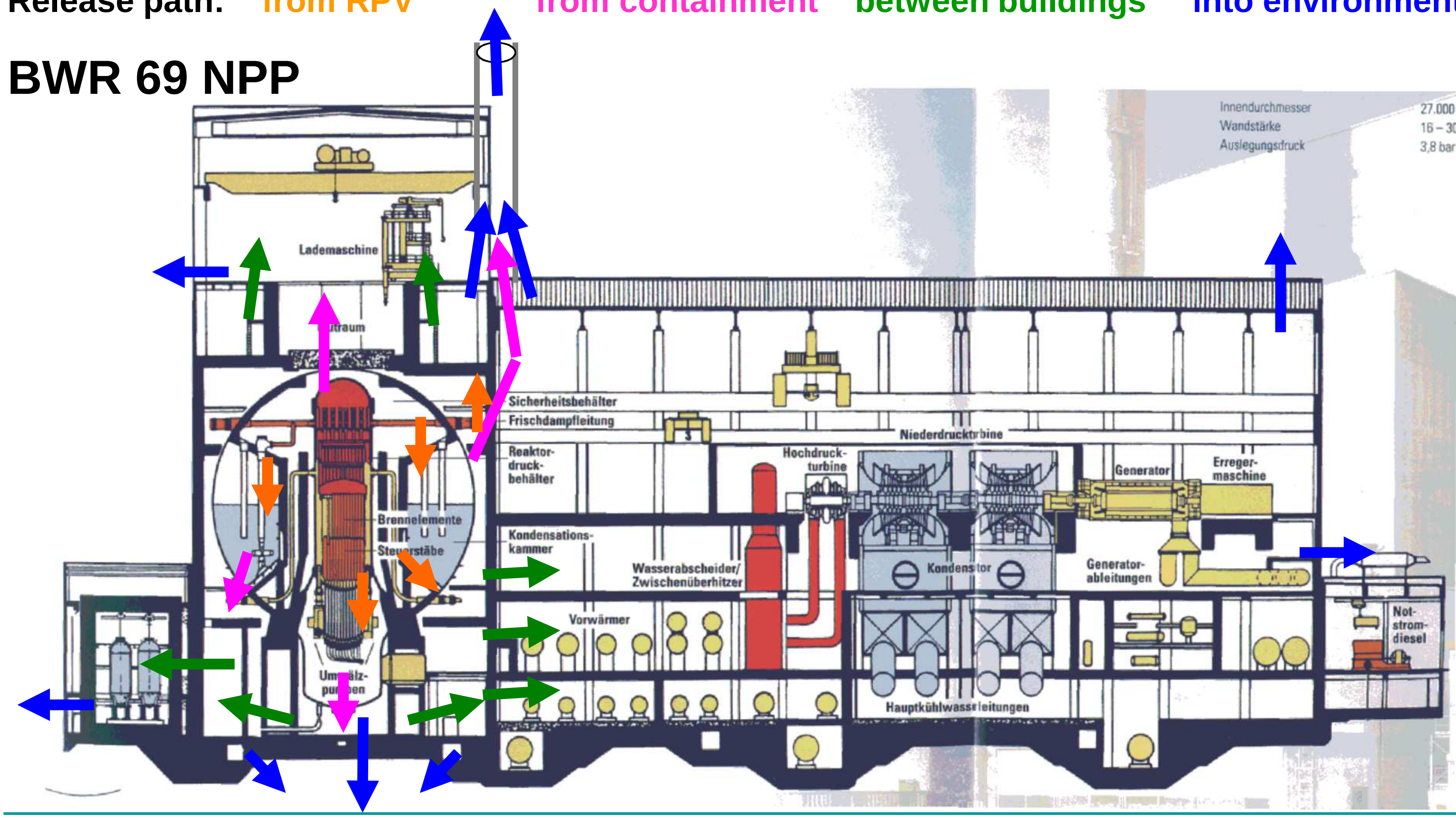


Part 2 – BWR Application

Determine all probable RN release paths before MELCOR input deck set-up.

Release path: from RPV — from containment — between buildings — into environment

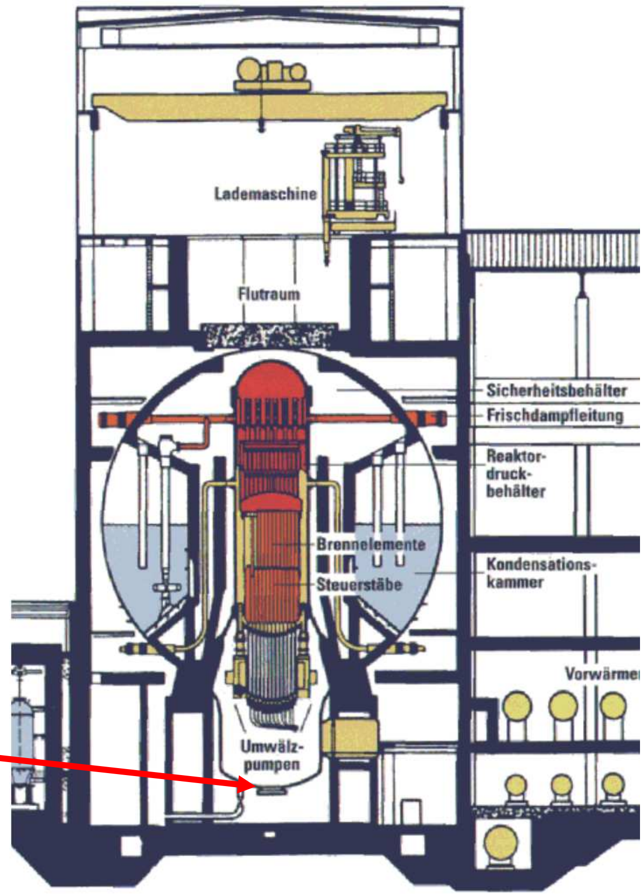
BWR 69 NPP



PSA L2 Best Practice - Severe Accident and Source Term Analyses

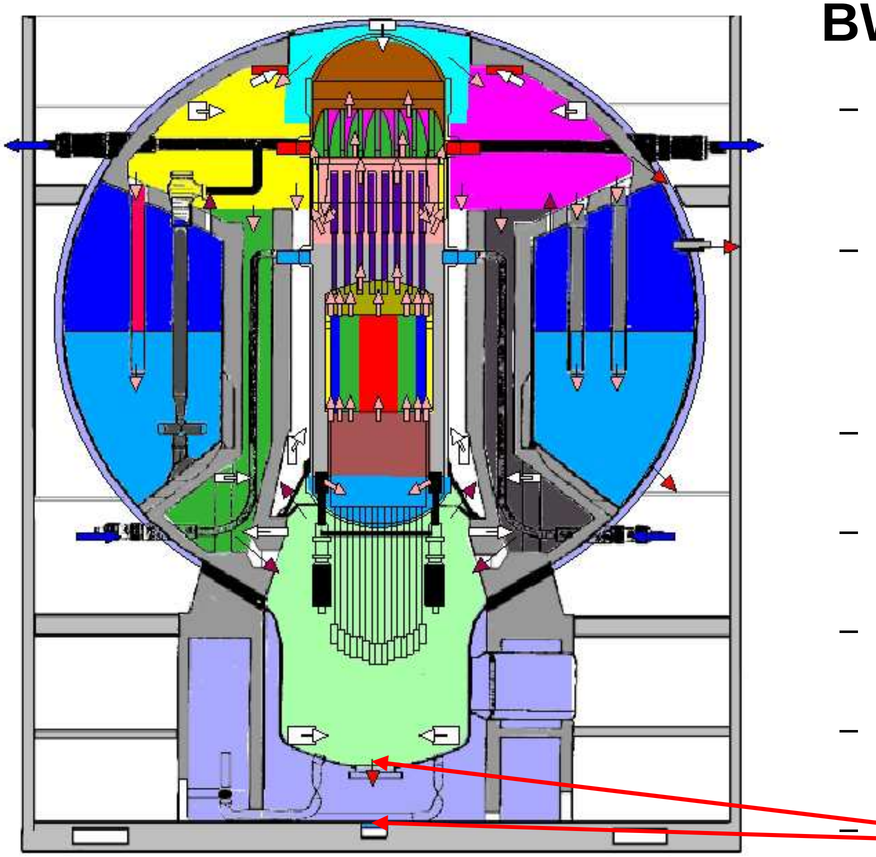
Take into account all SA phenomena, plant design and source term aspects.

- **BWR 69 plant features**
  - steel containment with:
    ~5500 m³ free volume
    ~2500 m³ water in wetwell
  - containment N2-inerted
  - filtered containment venting connected to wetwell
  - RPV not coolable by flooding from outside spray system in drywell
  - containment head sealing made from organic material – low failure temperature
  - **shortly after RPV failure containment will melt through in lower position at elevated pressure**
  - need for adjacent buildings model



PSA L2 Best Practice - Severe Accident and Source Term Analyses

Develop adequate plant nodalisation schemes (MELCOR example for PSA L2)



each coloured cell = one CV node of input deck

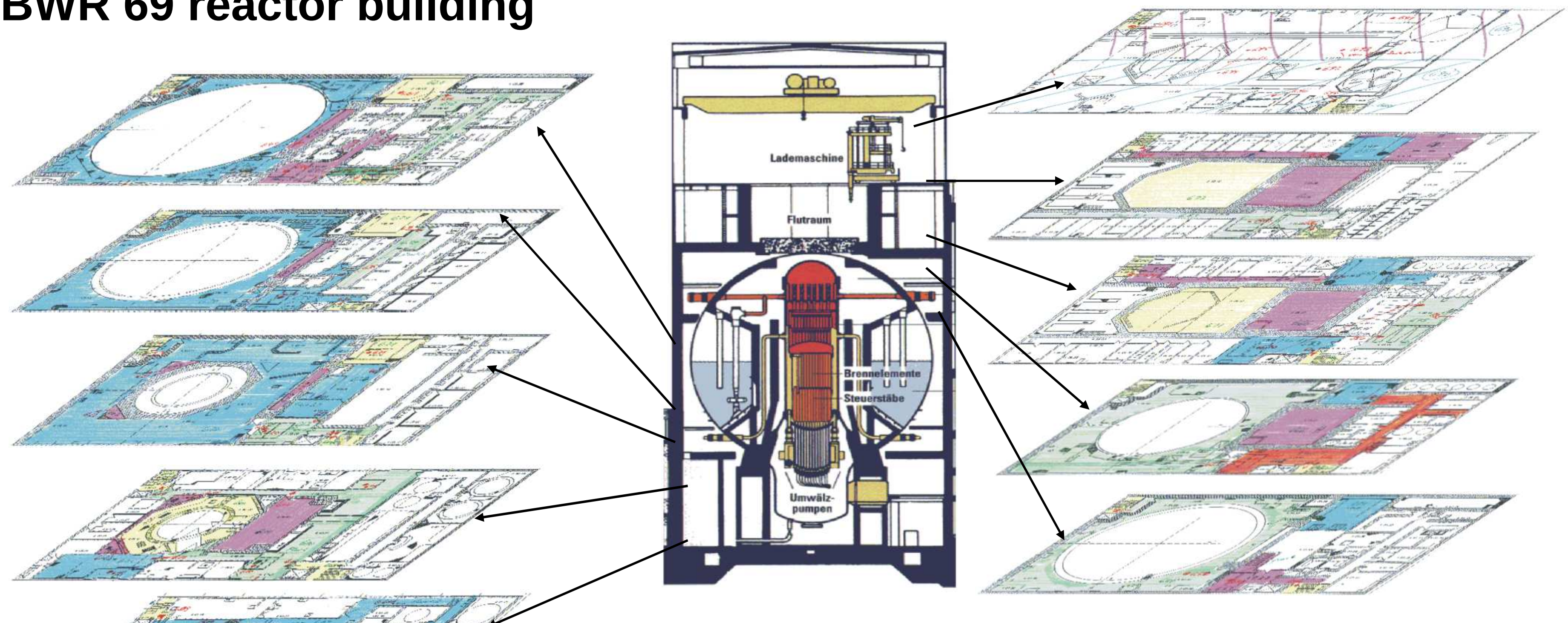
BWR 69 - RPV and containment

- detailed RPV model to calculate void fraction in core, steam separation, RPV water level, etc. (15 CV, 25 FL, 85 HS)
- detailed core model with 6 non-uniform radial rings and 15 levels + 6 levels in lower plenum -> lessons learned from experiments applied
- definition of plant specific radio nuclide inventory and decay power
- detailed containment model to consider plant specifics (12 CV, 33 FL, 70 HS)
- air ventilation systems in containment considered -> contributes to gas mixing
- filtered venting system, wetwell cooling systems considered as well
- 3 cavities, 2 of them outside containment in reactor building

PSA L2 Best Practice - Severe Accident and Source Term Analyses

Develop adequate plant nodalisation schemes (MELCOR example fro PSA L2)

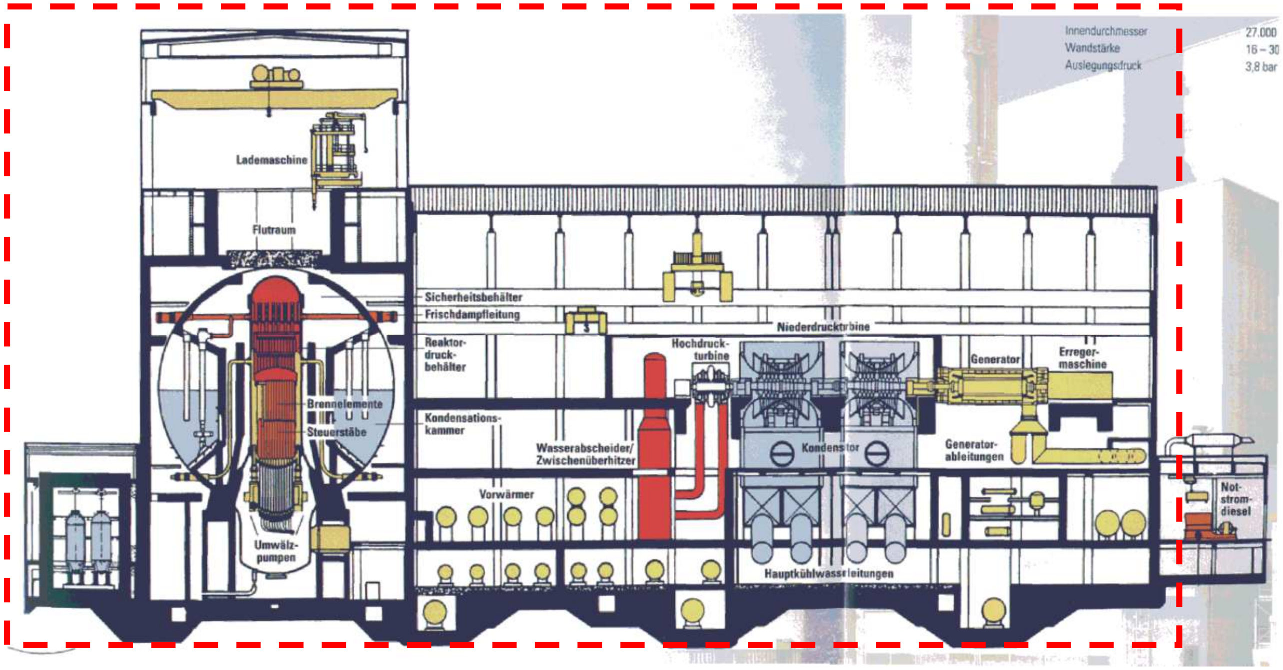
BWR 69 reactor building



- rooms have been selected according to possible radio nuclide release paths to the environment
- coloured rooms are modelled in MELCOR

PSA L2 Best Practice - Severe Accident and Source Term Analyses

Develop adequate plant nodalisation schemes (MELCOR example for PSA L2)



BWR 69 NPP

Reactor Building:
- 37 volumes in 10 levels,
- 85 flow path (many doors, burst discs, etc.),
- 2 release path
-160 heat structures

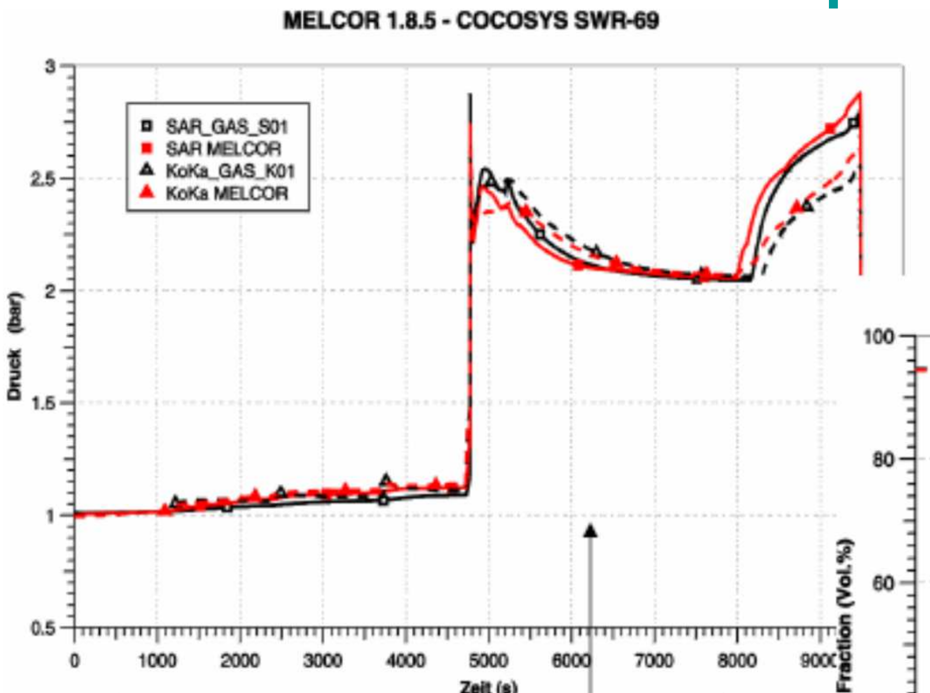
Turbine Hall:
- 15 volumes in 5 levels,
- 30 flow p., 2 release path
- 65 heat structures

BWS Building:
- 1 volume, 1 release path

Off-gas System + Stack: 1 volume, 1 release path

Environment: 4 volumes dependent on possible radio nuclide release paths

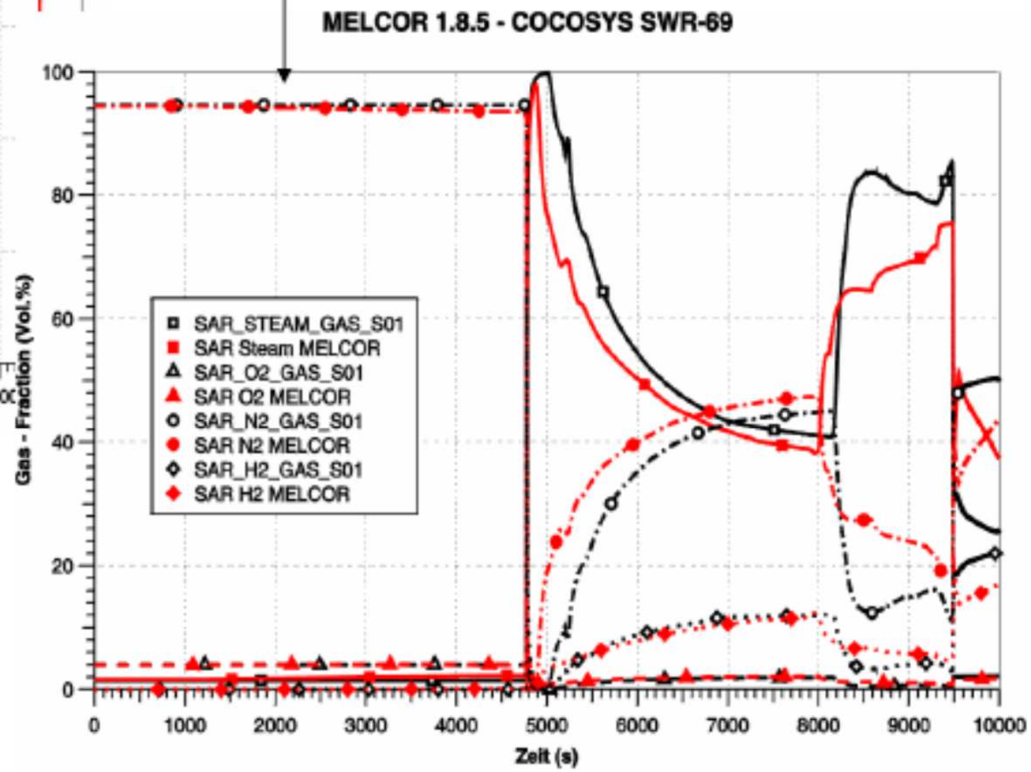
PSA L2 Best Practice – Input deck validation – BWR 69



BWR drywell and wetwell pressure trend

Loss of feed transient

BWR lower drywell gas concentrations



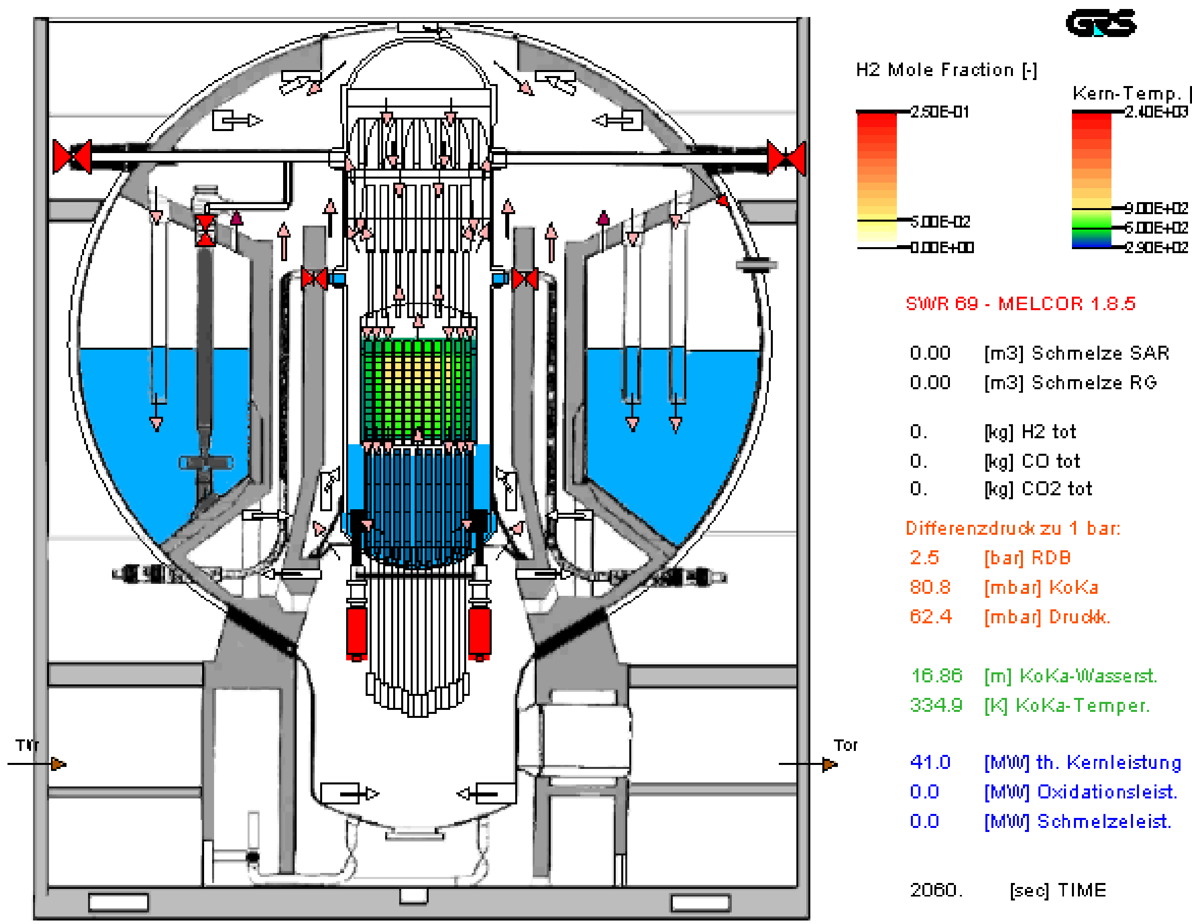
PSA L2 Best Practice - Severe Accident and Source Term Analyses

Assess the results carefully and determine source term relevant phenomena.

MELCOR BWR 69:

H2 release from RPV before / after containment failure

- H2 and aerosol accumulation in wetwell in early phase
- aerosol retention in wetwell
- H2 transfer from wetwell to drywell through small pressure equalisation pipes
- higher H2 concentration in whole containment after RPV failure
- high peak release of H2 and aerosols into buildings at containment failure
- still high H2 and aerosol content in containment in long term phase



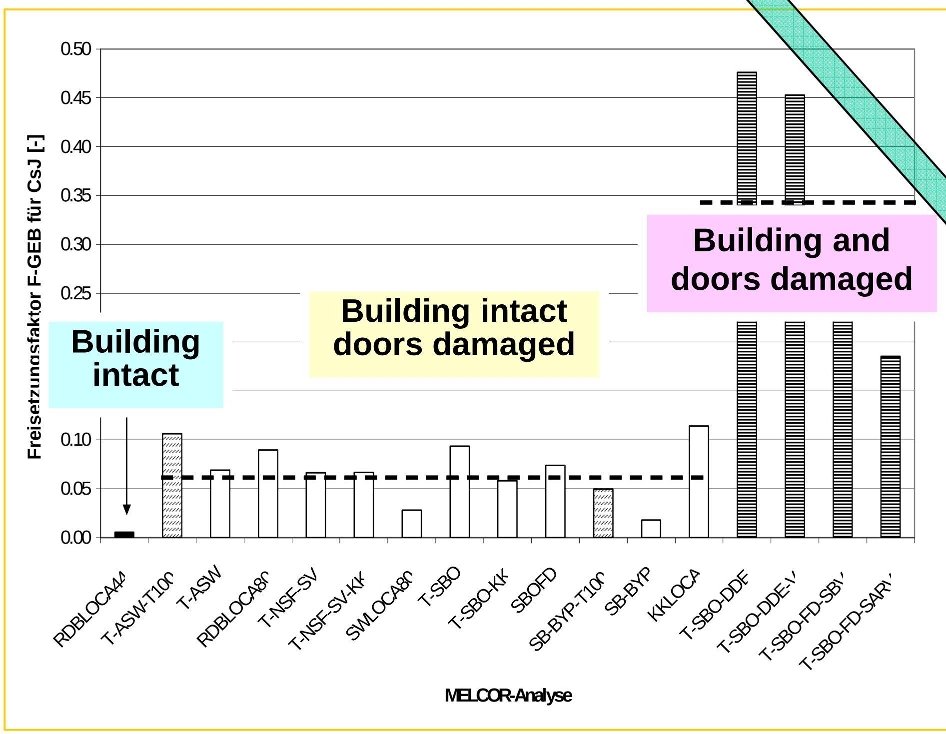
ATLAS Simulator of GRS

PSA L2 Best Practice - Severe Accident and Source Term Analyses

Determine source term data for PSA L2 – Example: BWR 69

MELCOR result example:

Release factor of CsJ from buildings to environment for various simulations



	CsJ	CsOH	Te	Kr
Building intact	**0.005**	**0.01**	**0.005**	**0.24**
Door damaged	**0.07** (0.02 - 0.11)	**0.07** (0.02 - 0.13)	**0.10** (0.02 - 0.21)	**0.88** (0.69 - 0.99)
Door and building damaged	**0.34** (0.19 - 0.48)	**0.33** (0.20 - 0.46)	**0.37** (0.19 - 0.53)	**1.0**

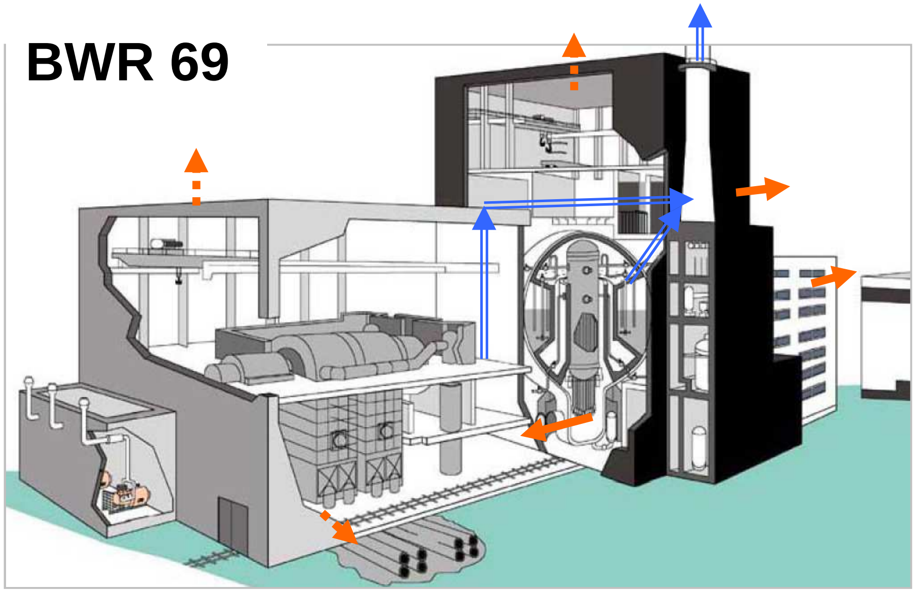
Event tree input:

Release fractions of CsJ, CsOH, Te and Kr from buildings to environment

Lessons Learned – Modelling of Building Aspects

Make an appropriate model of relevant plant specific details (MELCOR example)

- **Simulation of Doors and Burst Membranes between Rooms**
  - many doors and burst membranes exist inside reactor and turbine building and between them
  - failure of many doors, burst membranes, etc. due to containment failure at elevated pressure and H2 combustions

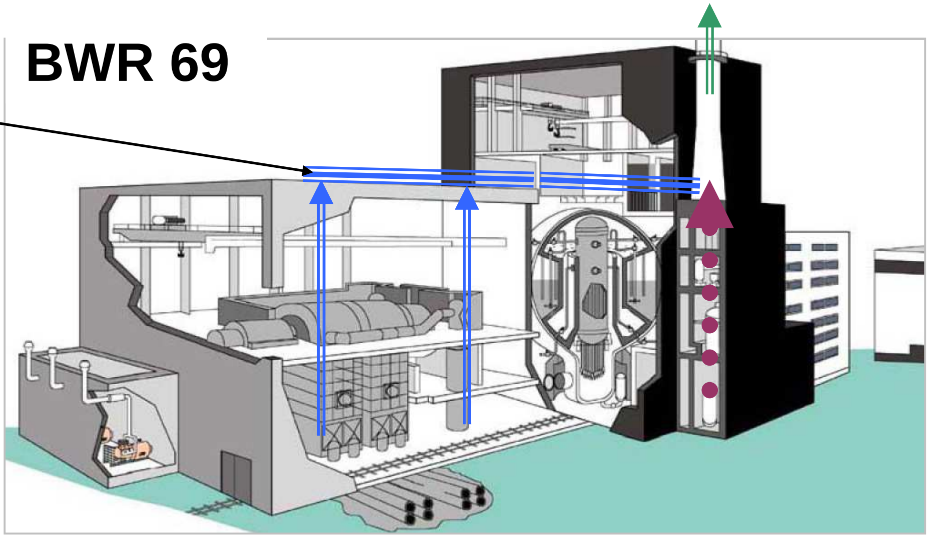


- **MELCOR approach:**
  - doors are not leak tight - small gaps simulated - simplifies pressure balance inside building
  - failure of doors dependent on Δp according to door opening direction and design
  - no failure of doors in case of high water level on floor (doors not leak tight)
  - re-closure of doors in case of stronger reverse flow modelled (10 % remain open)
    -> influence on source term was analysed by sensitivity study

Lessons Learned – Modelling of Building Aspects

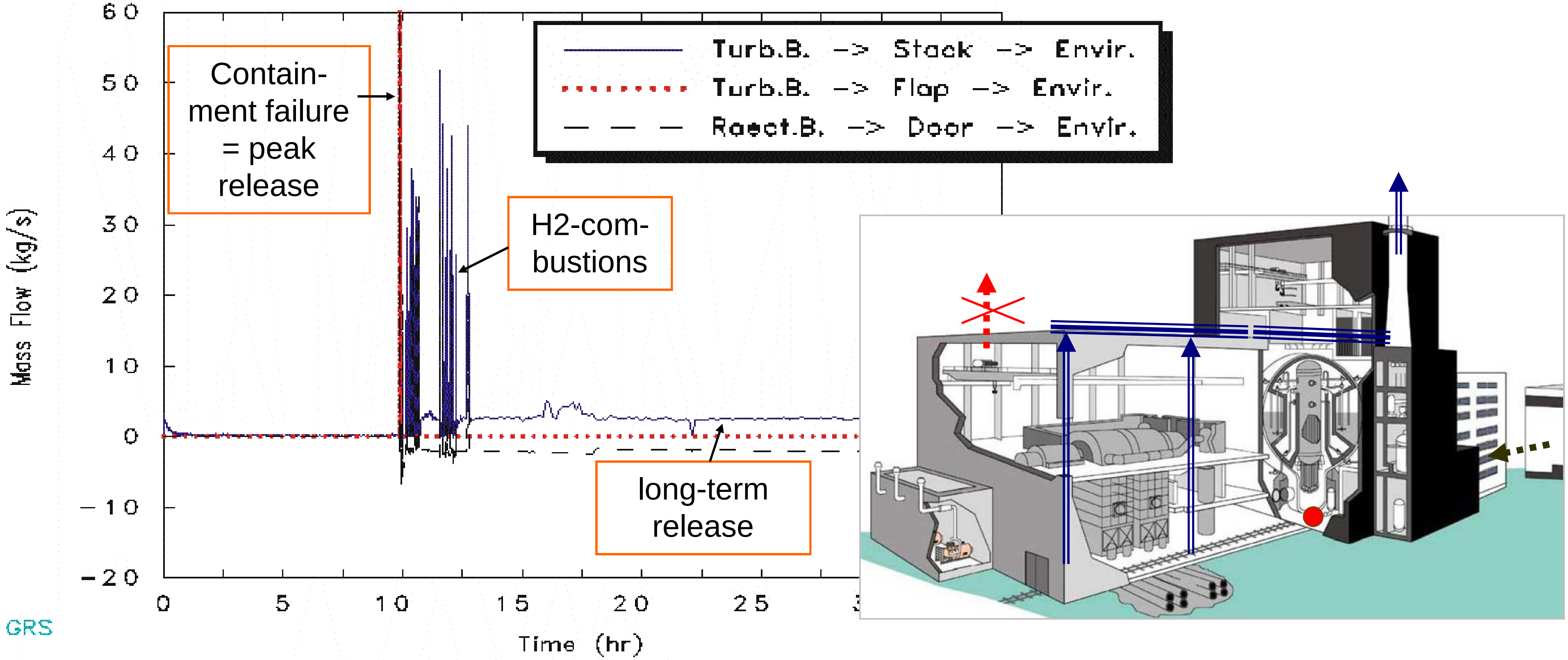
Make an appropriate model of relevant plant specific details (MELCOR example)

- **Air Ventilation System of Turbine Building**
  - sub-pressure in building during normal operation – systems switched off latest after containment failure
  - off-gas line stays open
  - enhanced mass flow from turbine building through stack into environment at containment failure



  - buoyancy force driven mass flow through stack during long term
  - sub-pressure build up in turbine and reactor building
    -> reverse mass flow direction into buildings though leaks, open doors, etc.
  - important for source term calculation
    ->off-gas system and stack modelled in MELCOR separately

Lessons Learned – Modelling of Building Aspects



Assess the results carefully and determine source term relevant phenomena:

- **passive long term release through stack** provides sup-pressure in buildings
- **backflow into reactor building through failed door** after initial peak release;
- **turbine building flaps in roof closed** after initial peak release

Summary – Best Practice

- MELCOR was the main tool used at GRS within PSA level 2 studies and to support the development of AM measures
- detailed MELCOR nodalisation schemes have been used to simulate plant specific details and relevant release paths for fission products
- extensive validation of MELCOR input deck performed by code to code comparisons with detailed codes
- "best estimate" data/results have been gained by analyses
- recommendations given in German PSA Guidance document are applicable and very helpful
- long(er) CPU time needed for MELCOR input was accepted to get higher quality of results (factor of 5 – 10 of process time)
- visualisation of analyses results with ATLAS was very helpful to understand NPP behaviour under severe accidents
- current project – Atucha 2 (PHWR) PSA L2 together with Argentina

Thank you for attention. Questions?