AREVA NP

Advanced Considerations for Modelling a BWR in MELCOR

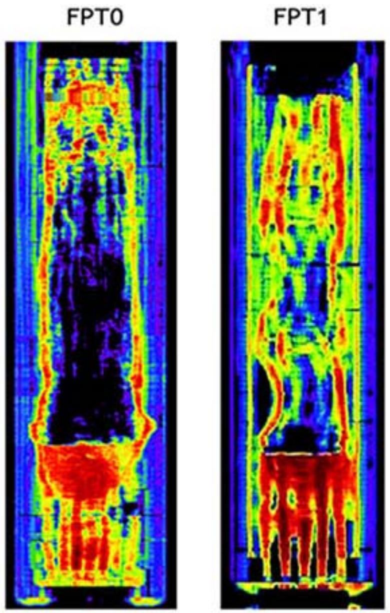
BRAUN Matthias / HUPP Markus
AREVA GmbH
EMUG 2017

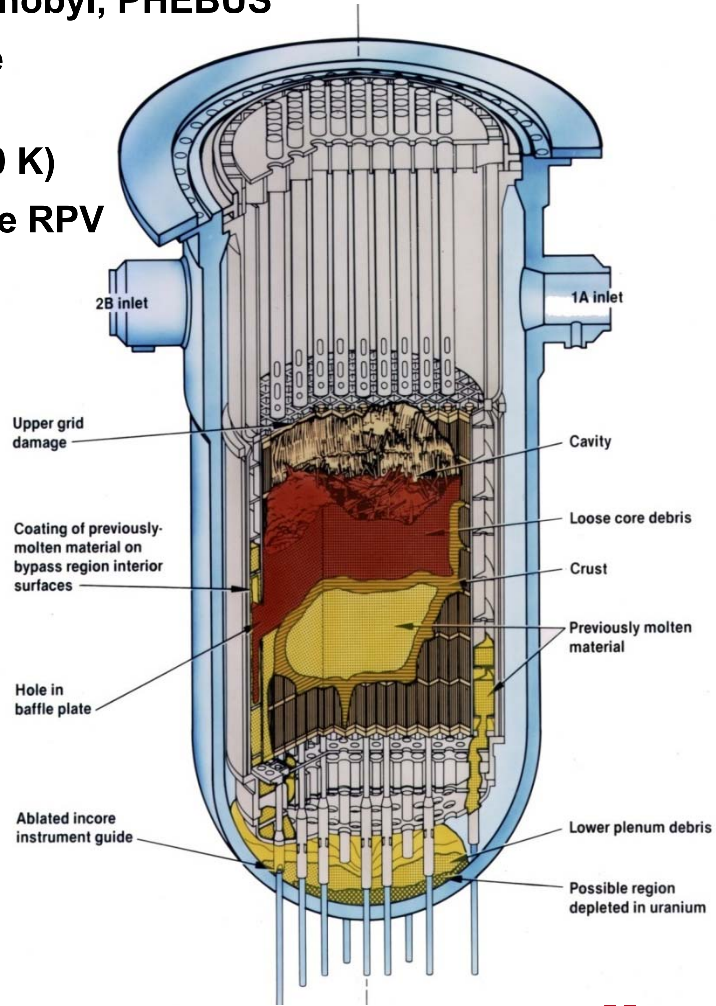
AREVA

Table of Content

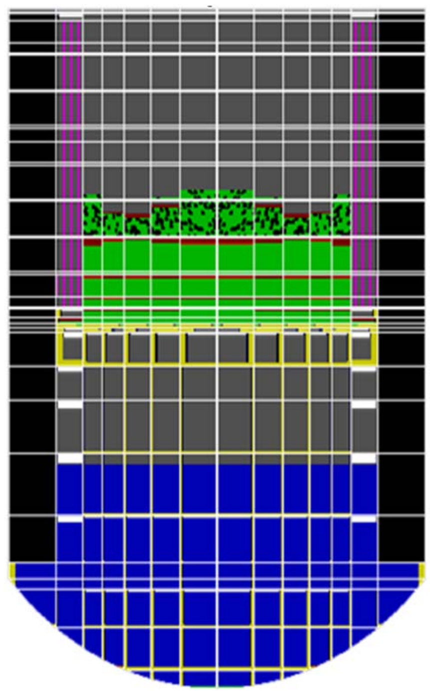
Question of Notation: Core Melt Accident I of V

- **Does the reactor core really melt?**
  - **Melting of oxidic nuclear fuel observed in TMI2, Chernobyl, PHEBUS**
  - **Questionable how representative these examples are**
  - **Chernobyl: Power excursion in a graphite-moderated reactor (carbon sublimes at 3900 K)**
  - **TMI2: Stabilization of a non-coolable debris bed in the RPV with a long phase of internal heat-up**
  - **PHEBUS: Temperature was not a free parameter**





Question of Notation: Core Melt Accident II of V



- **For Fukushima-like scenarios MELCOR predicts**
  - **Core collapse faster than a heat-up of the fuel up to the point of melting (MELCOR: 2800 K)**
  - **Within core region only metals (Fe: 1800 K, Zr: 2100 K) melt**

- **DEBRIS-QUENCH Experiments**
  - **Rapid collapse of completely oxidized fuel rods into debris bed**
  - https://www.iam.kit.edu/wpt/downloads/Stuckert_QWS19_2_2013.pdf

Question of Notation: Core Melt Accident III of V

- Large masses of oxidic melt anticipated in lower head?

PWR

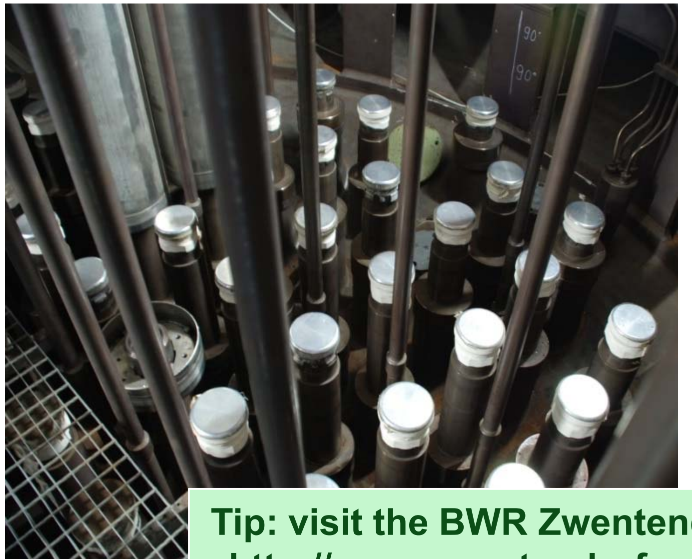
- Few metallic structures in the RPV core and lower head
- Low heat conduction from within the oxidic core debris onto the RPV wall
- Long grace period until failure of lower head (thick wall, small/no penetrations)

-► rather high debris peak temperatures

BWR

- Large metallic masses in lower RPV
- After melting of steel internals, RPV failure / penetration failure is probably not far

-► Debris peak temperatures close to the melting temperature of metals



Tip: visit the BWR Zwentendorf http://www.zwentendorf.com/

Question of Notation: Core Melt Accident IV of V

- **Fission product release in Fukushima**

	normalized Core inventory [Bq / MW]	measured soil contamination [Bq/kg]	elemental / oxide boiling temperature [K]	relative measure of release [Bq/kg / Bq]	normalized to CS137
Cs134	2.2E+14	5.20E+05	963 / ~1200	2.33E-09	8.E-01
Cs137	1.7E+14	5.30E+05	963 / ~1200	3.04E-09	**1.E+00**
Te129m	3.5E+13	1.04E+05	1263 / 1518	2.94E-09	1.E+00
Ag110m	2.0E+12	3021	2483	1.50E-09	5.E-01
Nb95	1.2E+13	1100	5017/ ~2000	9.41E-11	3.E-02
Am241	2.6E+11	3.3	2880 / 2800	1.29E-11	4.E-03
Cm242	6.8E+13	4	3383 / 3130	5.89E-14	2.E-05
Cm244	7.1E+12	2	3383 / 3130	2.83E-13	9.E-05
Pu238	4.9E+12	0.26	3509 / 3073	5.32E-14	2.E-05
Pu239 + Pu240	1.1E+12	0.12	3509 / 3073	1.05E-13	3.E-05

(Te129 and Ag110m averaged over many measurements, rest measured on playground at plant site)

http://www.tepco.co.jp/en/press/corp-com/release/11042711-e.html

http://radioactivity.nsr.go.jp/ia/contents/6000/5247/25/5600_20120313_1_01.pdf.

- **Low release of Americium -► peak temperatures below 2800 K**
- **Medium release of Silver -► most of the debris remains at or below 2400 K**

AREVA

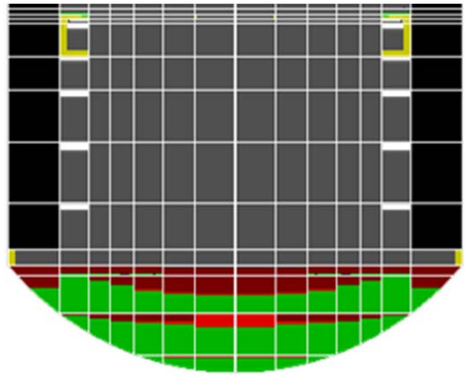
Question of Notation: Core Melt Accident V of V

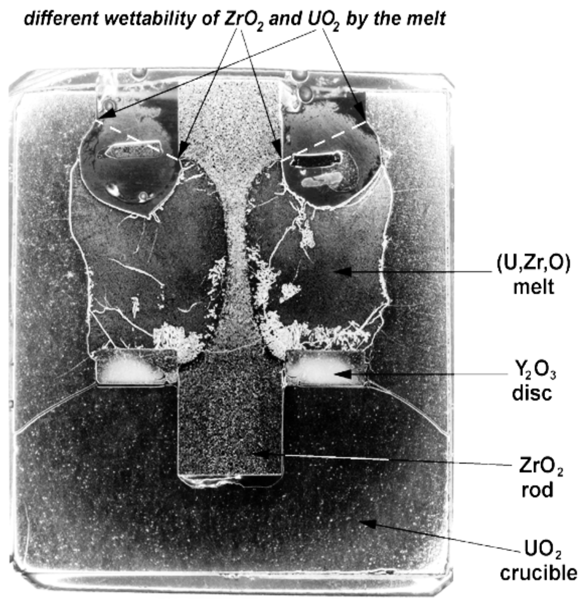
- **MELCOR state 1400MW BWR before RPV failure:**
  - **Metallic Melt: 6t Zr, 18t Fe**
  - **Debris: 170t UO2, 50t Zr, 30t ZrO2, 60t Fe, 3t FeO**
  - **Oxidic Melt: 2t FeO**
  - **Peak temperature: 2400 K to 2500 K**

- **Experimental melting results:**
  - **Fast solution of UO2 / ZrO2 in Zr at >2300°K**
  - **Mass fraction of ~50 Uranium in melt**
  - **UO2/ZrO2 solution and precipitation of ceramic Zr-U-O particles**

- **If in Fukushima molten UO2/ZrO2 is found**
  - **Oxide solution by molten Zr / Fe is significant**
  - **MELCOR best practice oxide melting of 2800 K is still too high to describe late accident phase**

- **If mostly metallic melt and oxidic particles is found**
  - **MELCOR seems to reasonably describe the accident**





Crucible HF33 (2100°C, 100s)

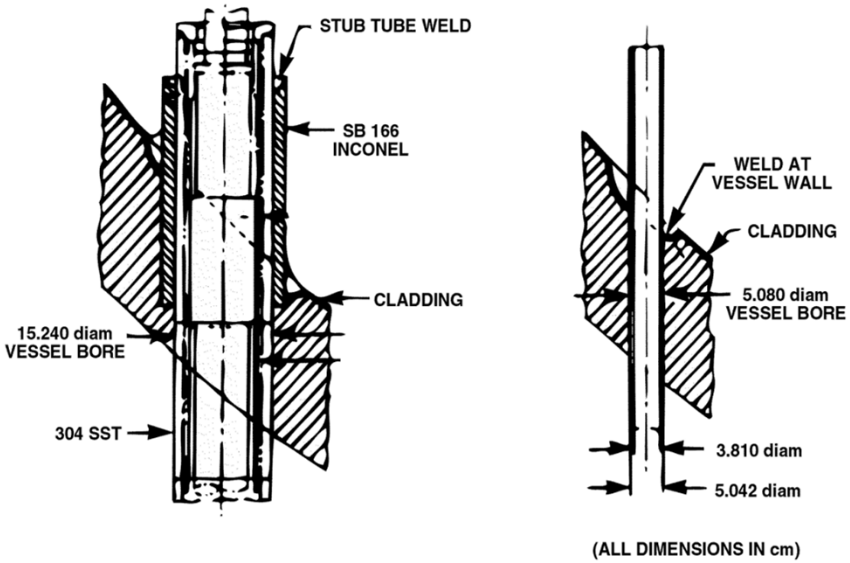
https://www.iam.kit.edu/wpt/downloads/Stuckert_Nuclear_Slovenia_2002.pdf

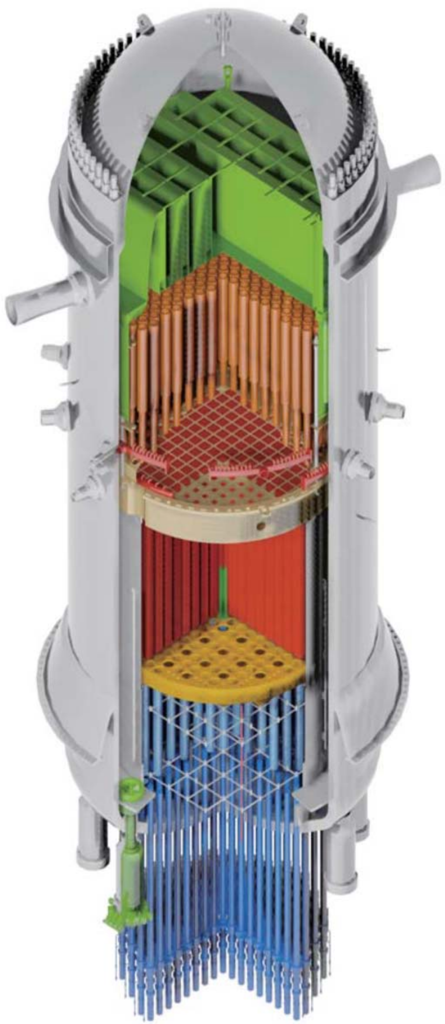
bibliothek.fzk.de/zb/berichte/FZKA6379.pdf

AREVA

Assumptions Concerning RPV Failure I of III

- **BWR penetrations in lower head**
  - **CRD housings (80 to 200)**
  - **Core instrumentation (20 to 50)**





- **Penetrations heat-clamped into the holes of the RPV**
  - **Thermal expansion of stainless steel > carbon steel**
  - **Friction force should prevent penetration ejection**
  - **-► Early RPV failure due to penetration failure unlikely**

AREVA

Assumptions Concerning RPV Failure II of III

- **LHF4 and OLHF4 experiments (PWR geometry)**
  - **With RPV creep, gap opens around penetration**
  - **RPV failure at total strain of 7% (LHF4) and 11% (OLHF4)**
  - **Without penetrations, RPV failure at ~18% creep**
  - **BWR have more and larger penetrations**

- **Conclusions**
  - **BWR RPV failure rather shortly after start of creep**
  - **Global failure of RPV lower head seems unlikely**
  - **Rather small opening area**
    -► thermohydraulic RPV failure ≠ melt relocation?

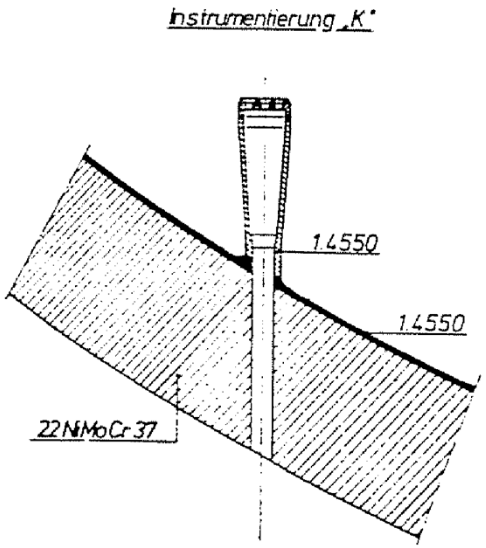
- **MELCOR: reducing SC1601(4) (default 0.18)**
  - **Would be nice if RPV total creep damage would be available as c/p variable**
  - **Recommended value for SC1601(4) depends on penetration under scrutiny**

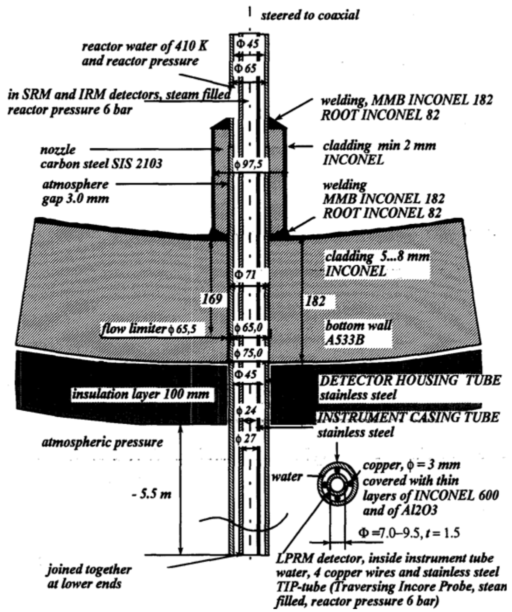
http://www.gl.iit.edu/govdocs/resources/tmi2vessel.html

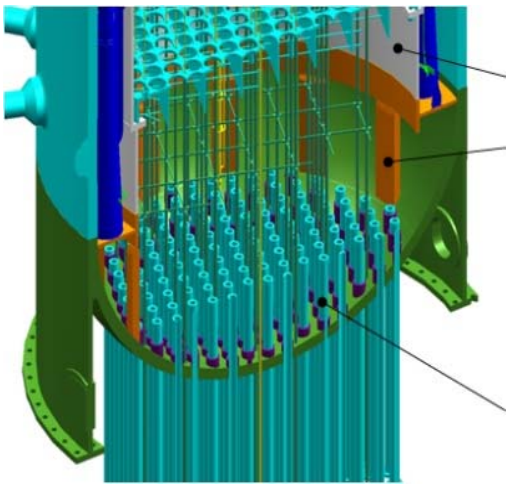
https://www.oecd-nea.org/nsd/docs/2002/csni-r2002-27.pdf

Assumptions Concerning RPV Failure III of III

- **Deviations to original GE design**
  - **German BWR: inward bulge of pump instrumentation**
    - **-►early RPV failure after melt relocation into lower head still possible**
  - **Nordic BWR: LPRM penetrations welded on studs**
    - **-►early de-welding of the penetrations, and drop-out after start of RPV creep**
  - **ABWR: CRD housings have no external rod drop protection**
    - **-►early de-welding of the CRD housings, and drop-out after start of RPV creep**

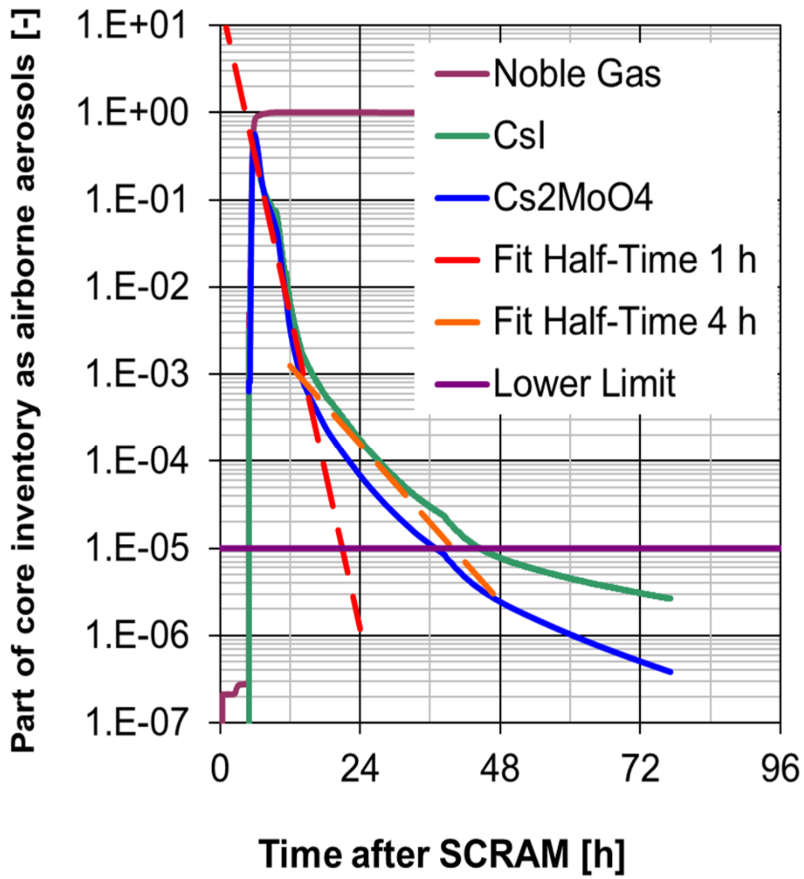






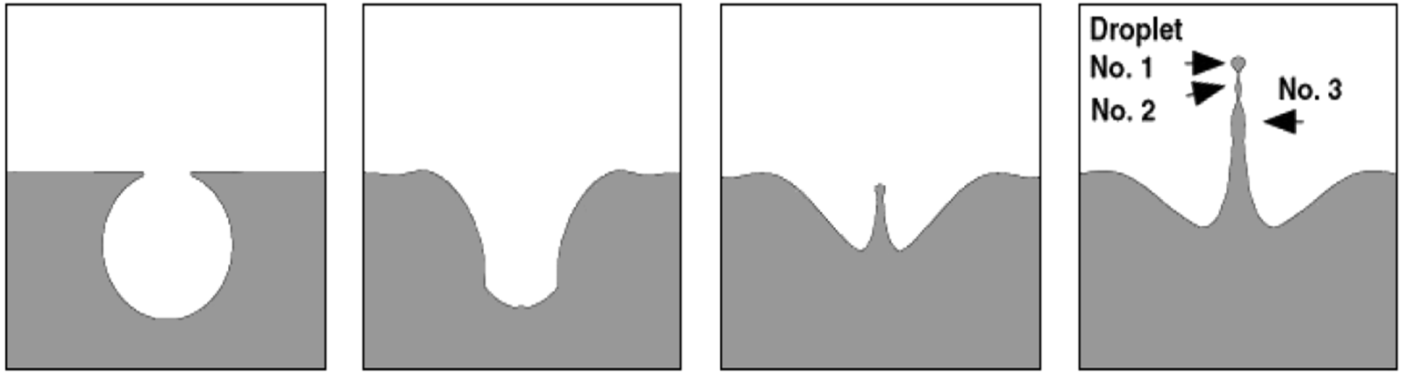
Long-term Fission Product Release I of II

- **MELCOR does include re-evaporation of FP, but not mechanical re-release of aerosols**
    - **After 2-3 days containment atmosphere becomes cleaner than normal air**
    - **Systematic under-prediction of source terms, especially for long-lasting scenarios**
- **Fix-able by post-processing,
e.g. by imposing lower FP concentration limit in the containment atmosphere**



Long-term Fission Product Release II of II

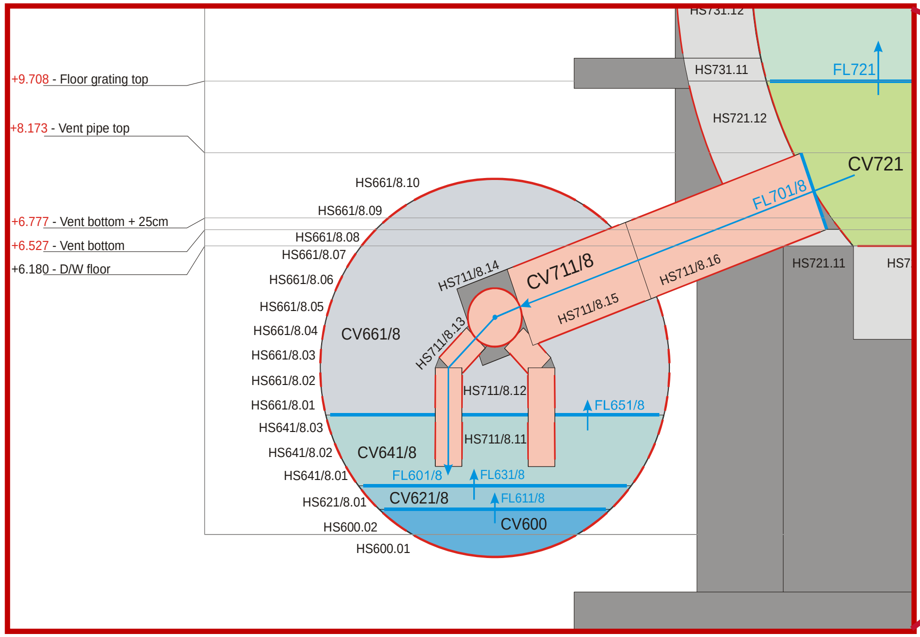
- **Inclusion of entrainment due to contaminated boiling water**
  - **Entrainment is dominant source of airborne aerosols in case of a boiling pool above core melt**

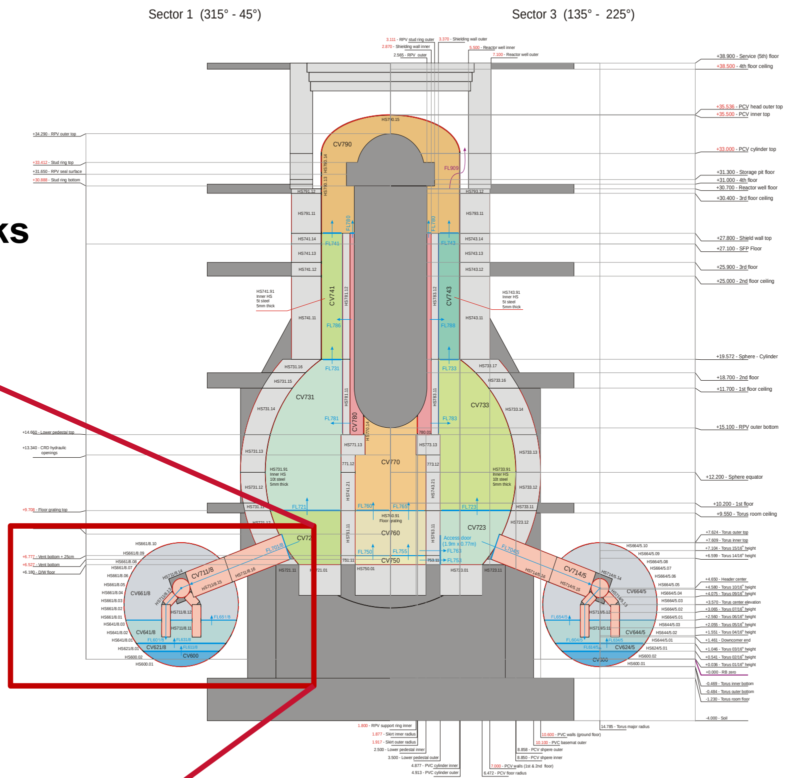


  - **(Gas/steam mass flow bubbling through the pool surface) x (Entrainment factor) = (Water mass flow ejected from pool into atmosphere as splashing droplets)**
  - **Droplets of contaminated water form new air-borne radioactive aerosols**
  - **Experimentally deduced entrainment factors 1.E-4 to 1.E-6 (orders of magnitude uncertainty)**
  - **Entrainment can be modeled in MELCOR by CF and RNAS aerosol source cards**

Purpose of a Clean Nodalization Diagrams

- **Clean detailed nodalization diagram**
  - **Time consuming (20 h – 40 h)**
  - **Makes good first impression**
  - **Facilitates generation / clean-up of model**
  - **Helps debugging / quality assurance**
  - **Invaluable for documentation of MELCOR works**
  - **Vector graphics needed due to small font size**





AREVA