Existing Severe Accident Management Measures for German NPP and Current Activities for Improvement as Consequences of the Fukushima Accident

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July 4, 2012

LAS/ANS Symposium „Fukushima Outcomes“

Rio Othon Palace Hotel, Rio de Janeiro, Brazil
July 2, 2012 - July 5, 2012

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SAMP development in Germany - History

- The development of Severe Accident Management Program has been initiated in Germany by the TMI Accident and was intensified by the Chernobyl Accident.
- An expert group called German Reactor Safety Commission (RSK) is working for consulting the federal ministry in charge of reactor safety. It issues advisory opinions which generally have to consider in the nuclear regulation.
- An intensive discussion of SAM has been started inside RSK in the beginning of the eighties and has been continued into the nineties.
- Two recommendations of German Reactor Safety Commission (RSK) regarding the severe accident management have been published in the nineties: They are the basis for the SAM measures implemented in the German NPPs:
  - *Behandlung auslegungsüberschreitender Ereignisabläufe für die in der Bundesrepublik Deutschland betriebenen Kernkraftwerke mit Druckwasserreaktoren, Positionspapier der RSK zum anlageninternen Notfallschutz im Verhältnis zum anlagenexternen Katastrophenschutz, Ergebnisprotokoll der 273. RSK-Sitzung am 09.12.1992*
  - *Maßnahmen zur Risikominderung bei Freisetzung von Wasserstoff in den Sicherheitsbehälter von bestehenden Kernkraftwerken mit Druckwasserreaktor nach auslegungsüberschreitenden Ereignissen, Ergebnisprotokoll der 314. RSK-Sitzung am 17.12.1997*

SAMP development in Germany - History

- Re-assessment of the SAMP realized at German NPPs by RSK started in 2009. New recommendations of German Reactor Safety Commission (RSK) regarding the severe accident management has been published in 2010:
  - *Rahmenempfehlung für die Planung von Notfallschutzmaßnahmen durch Betreiber von Kernkraftwerken, Empfehlung der SSK und RSK, Verabschiedet in der 429. RSK-Sitzung am 14.10.2010, gebilligt in der 244. SSK-Sitzung am 3.11.2010*
- Beside the new recommendations of 2010, the former recommendations of the RSK regarding severe accident management continue to stay in force.
- In consequence of the Fukushima accident the improvement and extension of the SAM measures of German NPPs is being discussed by RSK.

SAMP development in Germany - History

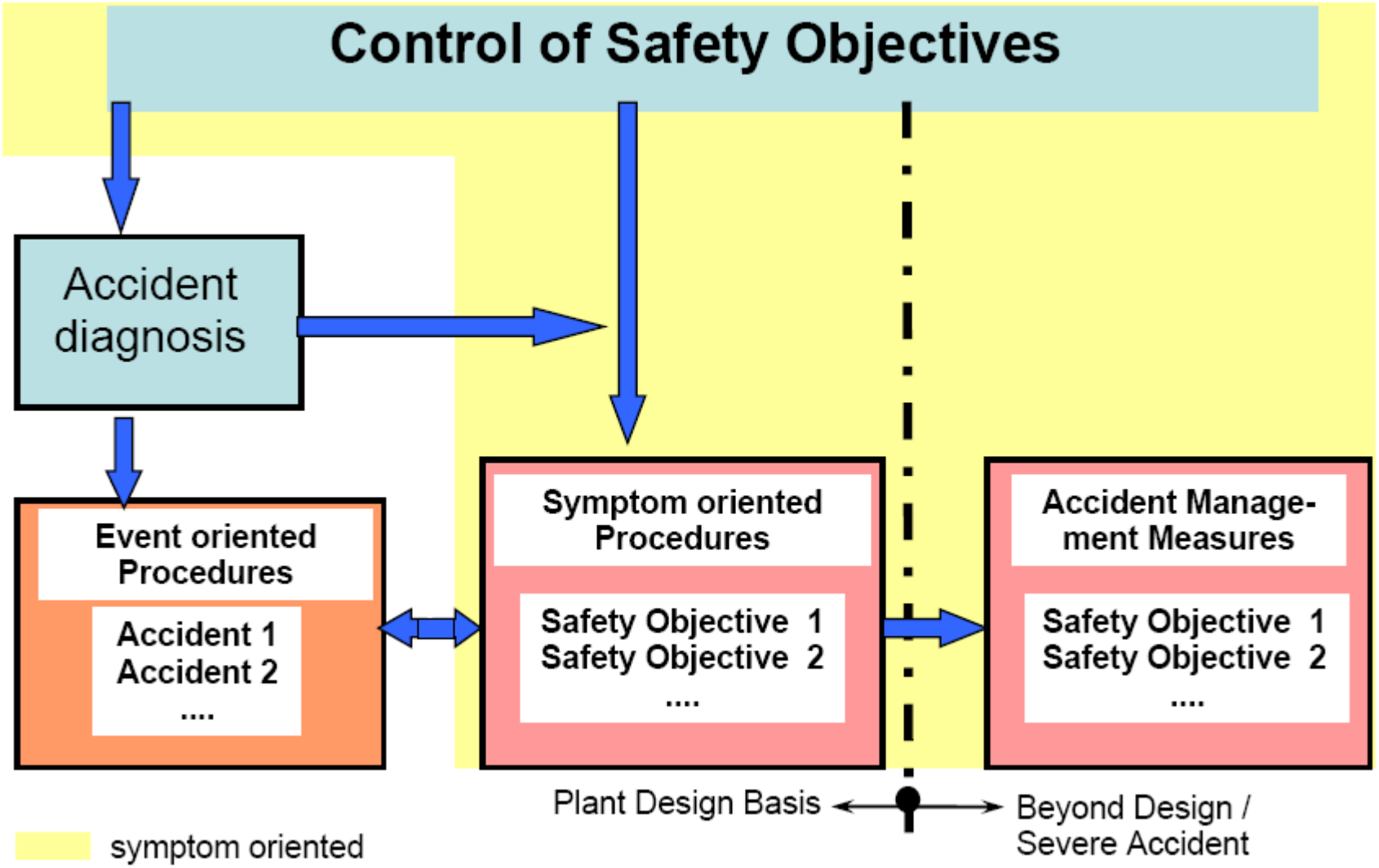
- **Agreement between utilities and government (since mid 80th)**
  - No formal requirements in licensing and supervision domain existed in Germany at the time AMP development started after TMI and Chernobyl accidents.
  - Results of first risk analyses “GRS Risk Study Phase B” (PSA level 1-3) have been a basis.
  - Responsibility for AMP implementation lies with the local government (5 federal countries inside Germany where NPP are located).
  - In 1986 the utilities offered to realize the recommendations on SAMP of the German Reactor Safety Commission (RSK) on a voluntarily basis; these recommendations have been published by the Supreme Federal Regulatory Authority.
  - Decisions on important SAM measures have been made in each case individually after intensive discussions in RSK.
  - Formalized cost benefit criteria had been considered as neither useful nor practicable and were not applied.
  - Implementation of SAM measures was done mainly with hardware modifications and development of EOP / SAM procedures (in the 90th). No systematic development of SAMG at that time.

SAMP development in Germany - Principles

Principles of SAM Measures

- The SAM measures should not impair plant operation under normal or upset conditions nor may they unacceptably interfere with existing procedures.
- SAM measures take credit of all existing systems and equipment.
- The usual design criteria for safety systems such as the single failure criterion are not applied.
- SAM actions are in general considered as manual actions (by crisis team).
- SAM measures may be initiated only after a sufficient period of time essential for diagnosis and decision making and preparation.
- It must be possible to interrupt or repeat the SAM measures at any time.
- Any necessary equipment for initiating SAM measures must be arranged in such a way that operator errors or inadvertent initiation during normal operation are avoided.
- Normally prohibited actions on safety related systems (e.g. defeating interlocks, overriding protective trips) are permissible under proper control.
- Separate documentation of SAM measures is done: “Emergency Management Manual (NHB)”.
- Decisions on SAM measures by crisis team / head of plant.

SAMP development in Germany – Organization of the SAM Measures

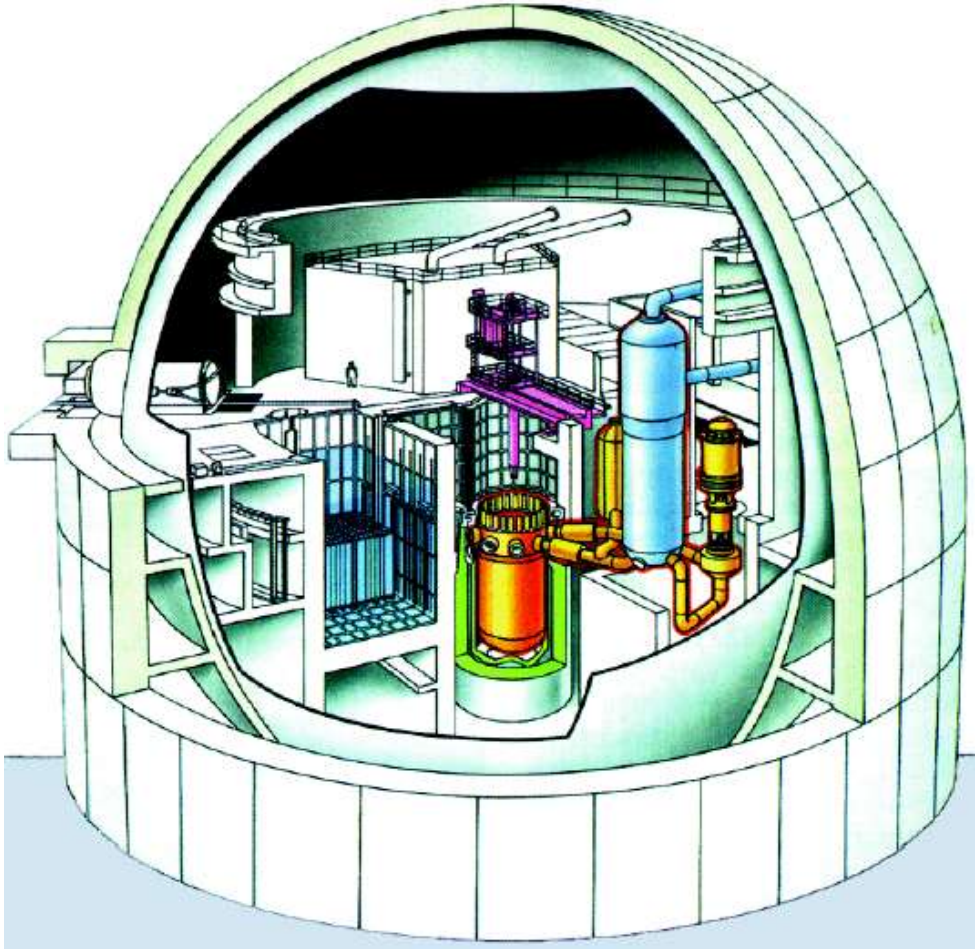


Third Level of Defence; Operating Manual

Fourth Level of Defence; Emergency Manual

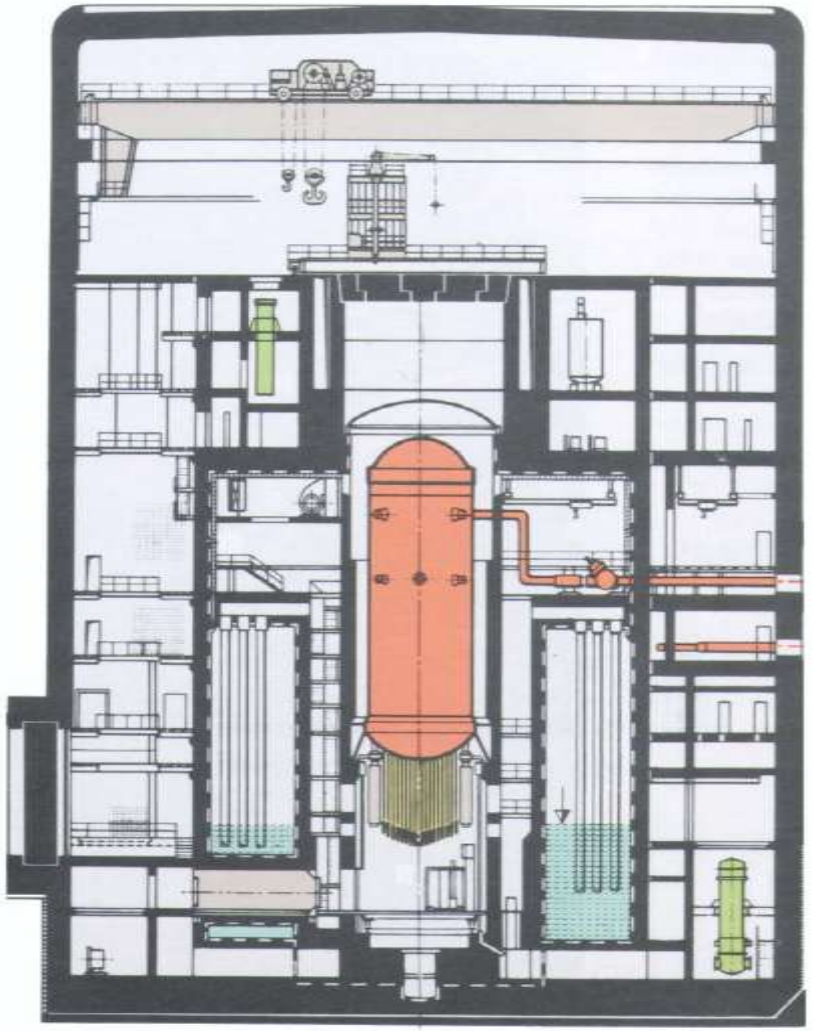
SAMP development in Germany – Status PWR

- 2 different generations in operation
- Power up to 1450 MWe (incl. power upgrades)
- **Containment:**
  - Steel: ~56 m Ø , ~30 mm wall thickness
  - 70.000 m³ free volume
  - No spray
  - Design pressure 6.3 bar abs.
- **Major SAM measures**:
  - Secondary and Primary Bleed and Feed
  - Secured containment isolation
  - Filtered containment venting
  - PAR system for severe accidents



SAMP development in Germany – Status BWR 72

- Two units in operation - 1300 MWe
- **Containment**:
  - Concrete building with steel liner
    ~ 29 m Ø, 40.5 m height
    ~17.800 m³ free volume incl. wetwell
    steel liner thickness <8 mm
  - Design pressure ~4.3 bar abs.
  - Spray in drywell (not safety relevant)
- **Major SAM measures**:
  - Depressurization of RPV
  - Secured containment isolation
  - Filtered venting
  - N_2 inertisation of wetwell
  - PARs in both wetwell and drywell for severe accidents



SAMP development in Germany – SAM Measures of German PWR

AM Measure	KWB A*)	GKN 1*)	KWB B*)	KKU*)	KKG	KWG	KKP 2	KBR	KKI 2	KKE	GKN 2
Emergency management manual	●	●	●	●	●	●	●	●	●	●	●
Secondary side bleed	●	●	●	●	●	●	●	●	●	✓	✓
Secondary side feed	●	●	●	●	●	●	●	●	●	●	●
Primary side bleed	●	●	●	●	●	●	●	●	●	●	●
Primary side feed	●	●	●	●	●	●	✓	●	●	✓	✓
Assured containment isolation	●	●	●	●	●	✓	●	●	●	✓	✓
Filtered containment venting	●	●	●	●	●	●	●	●	●	●	●
Catalytic recombiners to limit hydro-gen formation	●	●	●	●	●	●	●	●	●	●	●
Emergency power supply from neighboring plant	●	●	●	□	□	□	●	□	□	□	●
Restoration of off-site power supply	●	●	●	●	●	●	●	●	●	●	✓
Additional off-site power supply (un-derground cable)	●	●	●	●	●	●	●	●	●	●	●
Supply-air filtering for the control room	●	●	●	●	●	●	●	●	●	✓	●
Sampling system in the containment	❍	●	❍	●	●	●	●	●	●	●	●

*** NPPs have been shut off in 2011**

✓ design ● realized through backfitting measures ❍ applied for □ not applicable

Procedures for Assessing SAM Measures – Overview

- Utilities of the German NPPs started to realize SAM measures in the eighties. That work partially went in parallel to the discussions within RSK.
- Finally, the measures have been realized in the late eighties and nineties in accordance to the recommendations of the RSK (recommendations from 1992 and 1997).
- The measures proposed by the utilities have been discussed and assessed by the RSK for each plant. The necessary backfitting of the plants was approved by the state authorities.
- In addition, the implemented SAM measures has been assessed several times after their implementation:
  - Secondary and primary bleed & feed have been analyzed and assessed in the frame of requests of the utilities for power upgrades. Deterministic analyses have been conducted using thermal-hydraulic code systems like ATHLET, RELAP5.
  - Preventive SAM measures like secondary and primary bleed & feed are implicitly assessed by Level 1 PSA. Mitigative measures like primary bleed, filtered containment venting, and hydrogen countermeasures are examined in the frame or Level 2 PSA. Both Level 1 (power operation and shutdown mode) and Level 2 PSA (power operation mode) are part of the Periodic Safety Reviews and are demanded by the German nuclear rules; for all German NPPs such PSR has been offered to the state authorities.
  - Various hydrogen countermeasures to mitigate severe accidents have been investigated in the nineties. E.g. GRS carried out detailed investigations supporting the discussions in Germany about the basic requirements for implementation of a PAR system.

Procedures for Assessing SAM Measures – Example for PAR Concept

Example of SAM Measure – Passive Autocatalytic Recombiners

- GRS carried out in the 90th detailed investigations supporting the discussions in Germany about the basic requirements for the implementation of a Passive Autocatalytic Recombiner (PAR) system in large dry containments.
- The following specific topics have been investigated:
  - positioning of catalytic recombiners in a multi-compartment containment configuration (development of generic criteria),
  - determination of the local and overall capacity of a recombiner system, needed to prevent high hydrogen accumulation and global combustion,
  - influence of the recombiner system on the gas distribution in the containment under accidental conditions (extent of gas mixing), and
  - consequences of a failure of local catalytic devices due to blow-down forces or catalytic poisons.
- Implementation of PARs in large dry containments was recommended by the German Reactor Safety Commission and realized inside the NPPs.
- Basic design analyses for KONVOI PWR have been performed by GRS.
- Following representative severe accident case selection have been used:

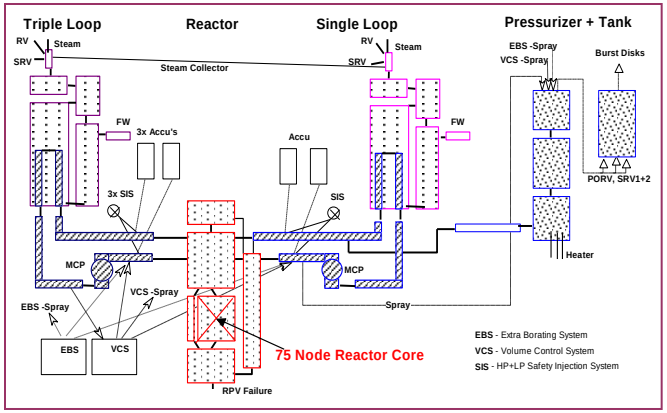
Procedures for Assessing SAM Measures – Example PAR Concept

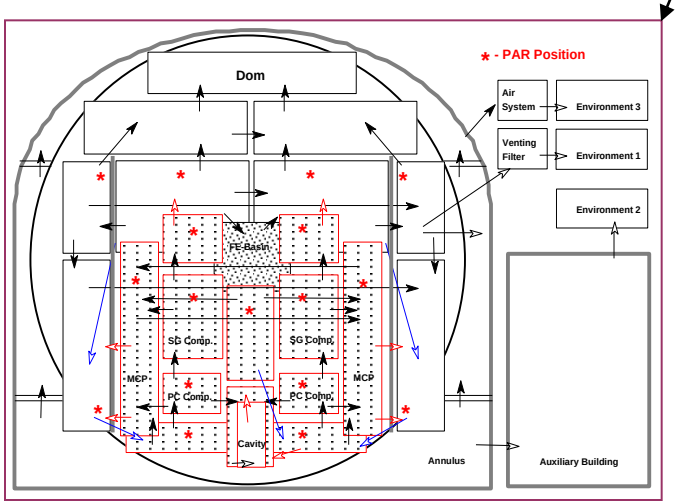
Selected representative Severe Accident Scenarios
for PAR Concept Design Analyses:

fast (0.5 - 1.5 h)	LBLOCA: - rupture of the surge line
intermediate (1 - 3 h)	SBLOCA: (primary depressurization not required) - Leak of 50 cm^2, hot leg, without secondary side depressurization
partial core damage	Total loss of power (station blackout) - with primary depressurization and flooding of a partial damaged core after restoration of the power supply (only in-vessel)
slow (> 3 h)	Loss of secondary feedwater supply with primary depressurization
	SBLOCA: (primary depressurization not required) - Leak of 50 cm^2, hot leg, with secondary side depressurization

Procedures for Assessing SAM Measures – Example PAR Concept

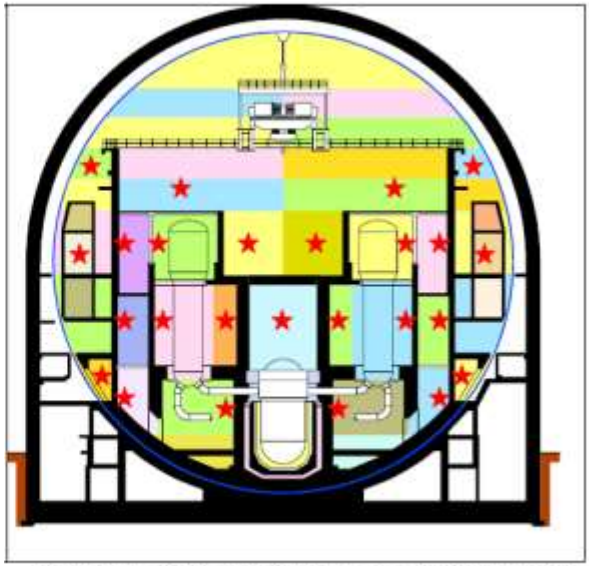
Approach used to analyse the representative cases:



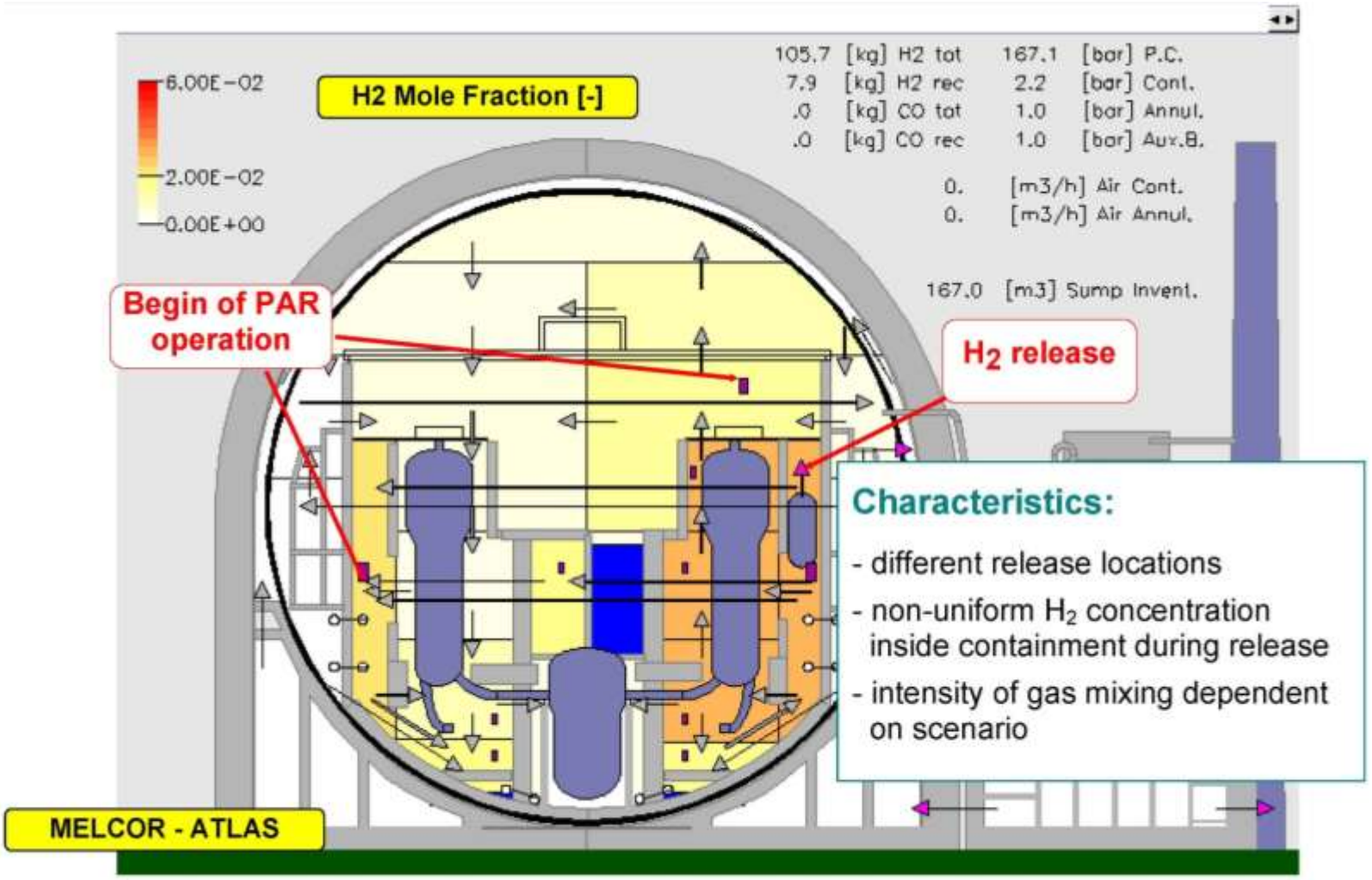


- MELCOR integral analyses to get “source data” from RCS / cavity into containment
- RALOC / COCOSYS detailed containment analysis for set-up of PAR concept - each room in containment modelled separately: ~130 volumes and 460 flow paths.

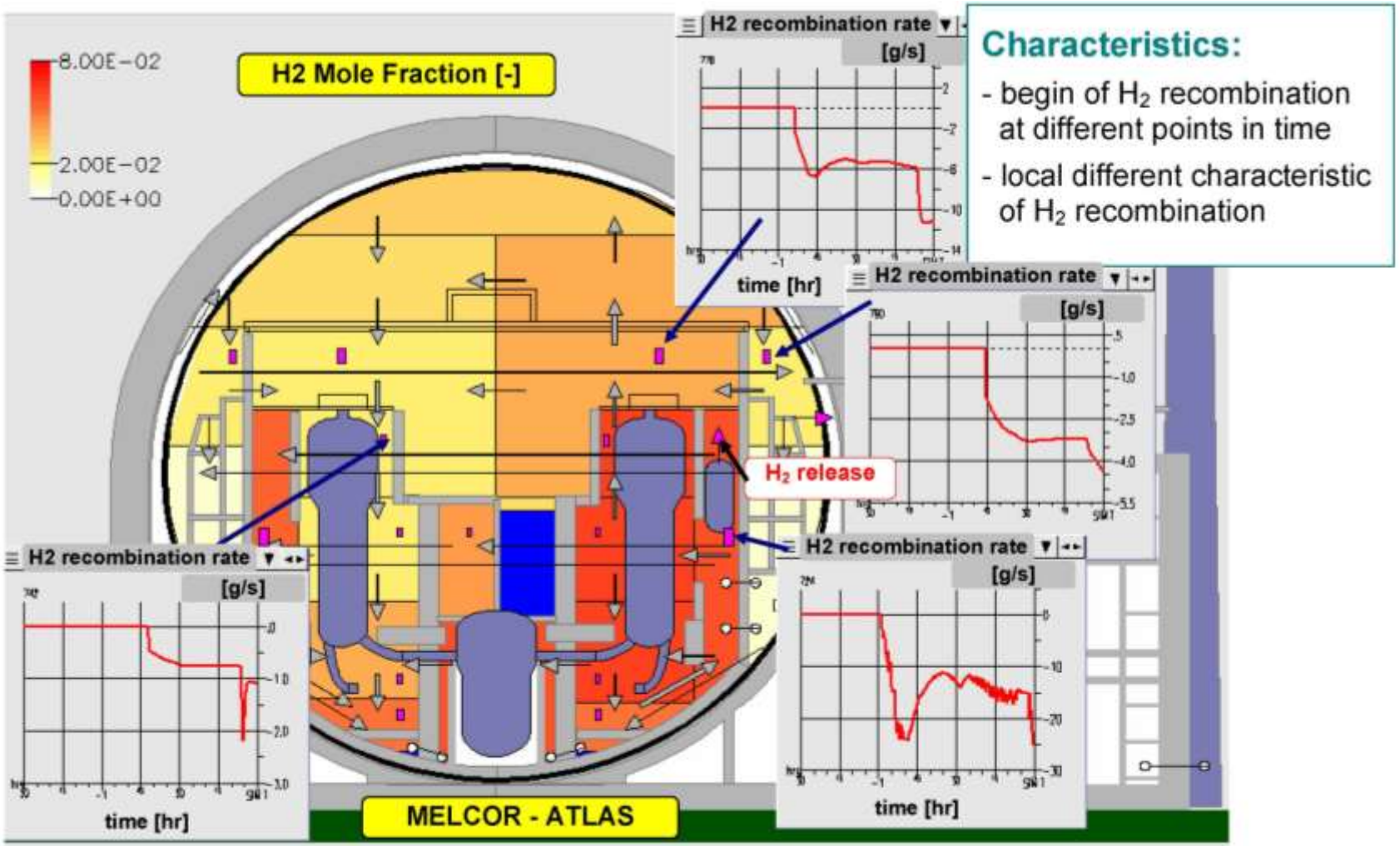
source data



Procedures for Assessing SAM Measures – Example PAR Concept



Procedures for Assessing SAM Measures – Example PAR Concept



Procedures for Assessing SAM Measures – Example PAR Concept

- Main Results of the PAR Investigations:
  - An PAR system results in a lower containment pressure in the long-term due to the mol reduction and steam condensation.
  - The temperature level is slightly increased due to the exothermic O_2-H_2-reaction.
  - The integral recombination rate depends on the local and global convection pattern inside the containment including minor important door leakages.
  - In the inner containment (inside missile shield) combustible gas mixtures exceeding 10 Vol.-% H_2 could be developed locally for short times even with PAR system (mainly in the neighborhood of the H_2-injection location).
  - PARs could act as an igniter (result of latest experiments and recent discussion inside German RSK) and would ignite the mixture at low H_2 conc.
    - Such ignitions are in general no threat to containment integrity
    - Negative concentration gradient to the outer containment shell prevents flame propagation
    - Early ignition prevents large pressure spikes
  - After about 1 day the containment atmosphere of a German PWR becomes inert due to the continuous O_2-consumption by the catalytic reaction

Recent and Future Developments of SAM in Germany

- **Upgrading of German Nuclear Regulations**
  - determination of new “Safety Criteria for Nuclear Power Plants” - project at GRS on behalf of BMU since 2003, Revision D has been published on http://regelwerk.grs.de,
  - upgrading of “old” German regulations for all safety levels of the defence-in-depth concept, especially for safety level 4,
  - extension of “requirements” on SAM (Interpretation I-7 (former Modul 7 of Revision D)),
  - New German “Safety Criteria for Nuclear Power Plants” were in “testing period” from 2009 up to 2010; recently GRS has delivered Revision E to the Federal Ministry BMU.
  - First findings from the Fukushima regarding SAM measures have already been included into the new nuclear rules.
- **After the Fukushima accident a National and an European ‘Stress Test’ have been carried out. The objective of both was to assess the safety of the plants under Fukushima like conditions.**
- **As a result of both the accident itself and the stress tests an improvement and extension of the German SAM program is currently under discussion.**

Recent and Future Developments of SAM in Germany

- **The RSK came to the conclusions, that there is a need of improvement and extension concerning:**
  - Further development of the SAM concept under external hazards conditions, with
    - long-term energy supply (e.g. mobile generator, supply connections etc.),
    - long-term heat removal from reactor core and spent fuel pool (ultimate heat sink ⇨ diverse heat sink like e.g water/air heat exchanger, groundwater well etc.),
    - long-term heat removal from wetwell of a BWR,
    - safe release of off-gases containing combustible gases by the filtered containment venting system,
    - availability of the measures under conditions of long-term station black-out, and
    - identification of available safety margins,
  - SAM measures for the protection of the building structures surrounding SFP of a BWR against hydrogen combustions (e.g. recombiners etc.), and
  - optimization of existing measures.

Recent and Future Developments of SAM in Germany

- **At GRS several projects are running which include several Fukushima relevant issues:**
  - For the Federal Ministry BMU detailed analyses of the Fukushima accident using the severe accident analyses code ATHLET-CD/COCOSYS are being performed ⇨ better understanding of what happened and for drawing conclusions for the German NPPs.
  - In the field of research several projects are carried out:
    - deterministic analyses of severe accident progression inside spent fuel pools of both PWR and BWR,
    - Detailed analyses of a severe accident scenario similar to the Fukushima accident for a German BWR using the ATHLET-CD/COCOSYS code,
    - investigation of the endangerment due to re-criticality inside SFP and reactor, and
    - Structure mechanical analyses regarding the integrity of the containment under dynamic loads from inside and outside (under the assumption of multiple earth quakes within a given time-frame).

⇨ Optimization of the German plants especially regarding SAM measures.

Summary

- Basis of the current German SAM concept are three recommendations of the German Reactor Safety Commission (RSK).
- The focus of the concept is the prevention of severe accidents in combination with some specific mitigative SAM measures. Nevertheless, the implementation of the SAM concept in the German plants included hardware modifications.
- Under an agreement between the utilities and the Federal Government the SAM Programs has been realized in the German NPPs during the 80th and 90th.
- Both the preventive and mitigative SAM measures implemented in the plants have been successfully assessed several times in the past.
- Currently, the German RSK is assessing the German SAM concept as an consequence of the Fukushima accident. Up to now, several recommendations concerning the improvement and extension of the SAM of the plants has been issued.
- In the frame of the upgrade of the German nuclear rules, the requirements for SAM have been revised. They cover the current status of R&D and first findings from the Fukushima accident. The upgrade will soon replace the current nuclear rules.
- GRS is working on several projects partially including Fukushima relevant issues with the objective to derive additional measures for a potential optimization of the current SAM concept of German NPPs.

Thanks for your attention!

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