

Fukushima Related Activities at Europe and Germany and Current MELCOR Applications for Supporting Severe Accident Safety Analyses

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Introduction

- After the Fukushima severe accidents both European stress tests and a national stress test at Germany have been initiated.
- The European Stress Test had the focus on three topics directly derived from the preliminary lessons learned from the Fukushima accidents.
- Shortly after the Fukushima accidents, a national stress test has been initiated at Germany in order to re-assess the robustness of German NPPs under Fukushima like conditions (external hazards, Station Black-out).
- At GRS a technical safety organisation supporting the German Federal Ministry BMU on the field of nuclear safety, several activities regarding severe accident analyses are running. These projects are focused on shutdown modes, external hazards, spent fuel pool behaviour, and assessment of severe accident management (SAM) measures.
- Following, more details regarding these issues mentioned before will be presented.

European Stress Tests – General (1)

- European (EU) Council requested on March 2011 that stress tests had to be performed on all EU nuclear power plants.
- Objective was to assess the safety of the plants under Fukushima like conditions.
- **E**uropean **N**uclear **S**afety **R**egulators **G**roup (ENSREG), the European Commission, and the **W**estern **E**uropean **R**egulators' **A**ssociation (WENRA) have defined the scope and modalities of the stress tests.
- Main topics of the tests:
 - Natural hazards (including earthquake, flooding, and extreme weather),
 - loss of safety systems, and
 - severe accident management.
- Three step approach:
 - Operators had to performed an assessment of their plants and had to make proposals for improvements,
 - the national regulators had to make an independent review of the operators' assessments, and
 - peer review of the national reports submitted by the regulators.

European Stress Tests – General (2)

- 15 EU Union countries with NPPs as well as Ukraine and Switzerland performed the stress tests and were subjected to the peer review (final assessments of the operators submitted at October 31, 2011, final national reports of the regulators submitted at December 31, 2011, peer review started at January 1, 2012).
- The peer review started with a desktop review of the national reports. Following, a 14-days meeting with all reviewers has been held for a topical review.
- In addition, in March 2012 a series of country reviews has been initiated. Each country was visited by a review team. A plant selected by the team has been visited also.
- Peer Review has been completed with a main report and 17 country reports.
- Peer Review Report has been approved by ENSREG and the European Commission at April 26, 2012.
- After that, an EU action plan as well as country-specific action plans have been developed.
- Consistent compilation of the peer review recommendations and suggestions has been prepared.
- All documents have been made available for the public (<http://www.ensreg.eu/EU-Stress-Tests>).

European Stress Tests – Outcome (3)

- Four European Level Recommendations:
 - WENRA shall develop guidance on natural hazards assessment as well as guidance on the assessment of margins beyond the design basis and cliff-edge effects.
 - Periodic Safety Review shall be performed for re-assessment of the plant safety as often as appropriate but at least every 10 years.
 - Implementation of protecting measures regarding containment integrity, like:
 - Depressurization of reactor circuit to avoid high-pressure core melt,
 - Prevention of hydrogen explosions (e.g. PARs), and
 - prevention of containment overpressure (e.g. filtered containment venting)
 - Measures for prevention of accidents and limitation of their consequences in case of extreme natural hazards (e.g. bunkered equipment, mobile equipment protected against extreme natural hazards, etc.)

European Stress Tests – Outcome (4)

- Additional more detailed recommendations and suggestions (only a selection):
 - Natural hazards:
 - Installation of seismic monitoring system with related procedures and training,
 - Assessment of margins for both flooding and external hazards etc.
 - Loss of Safety Systems:
 - Alternate cooling and heat sink (e.g. wells, air-cooled cooling towers, etc.),
 - Enhancement of on-site and off-site AC power supplies,
 - Enhancement of DC power supplies,
 - Improvement of the robustness of spent fuel pools,
 - Enhancement of functional separation and independence of safety systems,
 - Mobile devices (pumps, electrical generators, air compressors, etc.)
 - Bunkered or hardened systems, etc.
 - Severe Accident Management:
 - Hydrogen monitoring system,
 - Enhancement of Severe Accident Management Guidelines (SAMG),
 - SAMG validation,
 - Extension of SAMGs to all plant states, etc.

National Stress Test – Objective (1)

- The Government of Germany has been demanded by the German Parliament to perform a new risk analysis for all German NPPs under the light of the Fukushima accidents.
- That analysis was started before the EU stress tests.
- Objective was to assess the robustness of the plants against beyond design accidents under Fukushima like conditions.
- The German Reactor Safety Commission (RSK) an expert group on the field of reactor safety and consulting the federal ministry in charge of reactor safety received the order to develop a catalogue of requirements for the national stress test and to assess the results.
- That catalogue of requirements has been issued as a questionnaire to the operators. The answers has been assessed by the Commission with the support of GRS.
- Examination of the operators' answers and assessment of the robustness of each German NPP has been published at May 16, 2012 in an advisory opinion.
- **As a result of both the accident itself and the stress tests an improvement and extension of the German Severe Accident Management Program (SAMP) is currently underway.**

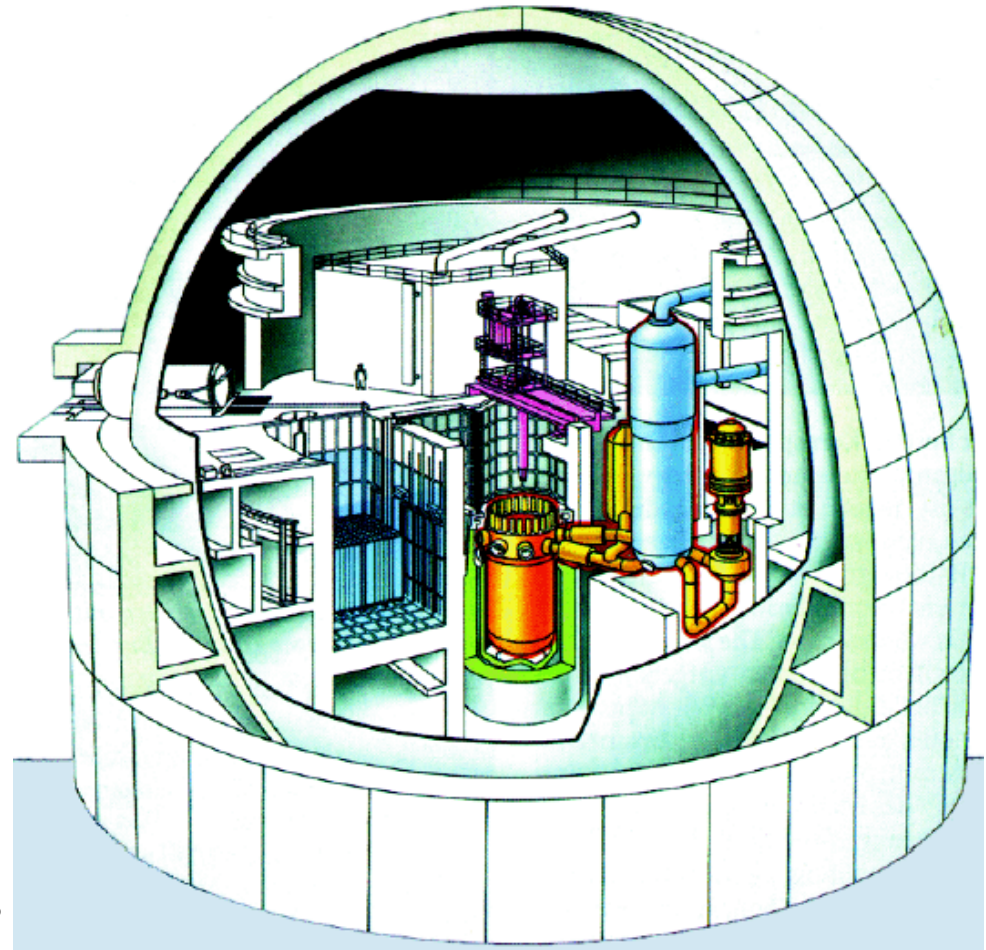
National Stress Test – Status-quo of SAMP of German NPPs before Fukushima Accidents (2)

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.

National Stress Test – Status-quo of SAM of German PWR before Fukushima Accidents (3)

- 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



National Stress Test – Status-quo of SAM of German PWR before Fukushima Accidents (4)

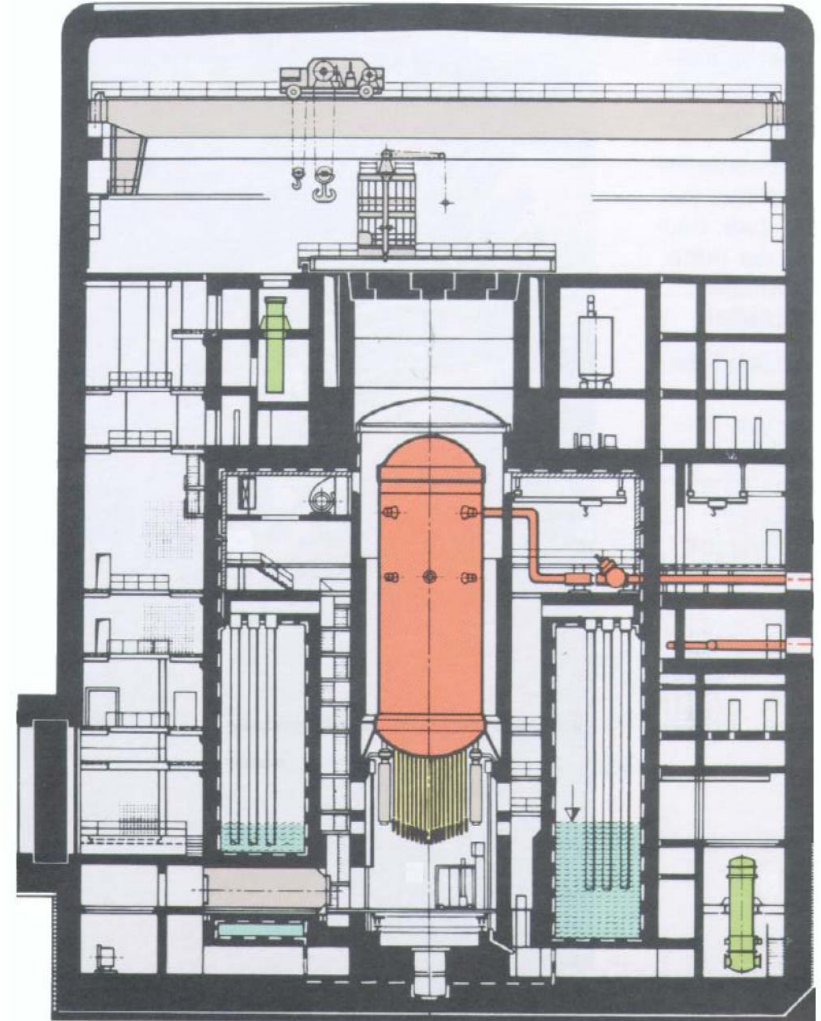
AM Measure	KWB A*)	GKN 1*)	KWB B*)	KKU*)	KKG	KWG	KKP 2	KBR	KKI 2	KKE	GKN 2
Emergency management manual	●	●	●	●	●	●	●	●	●	●	●
Secondary side bleed	●	●	●	●	●	●	●	●	●	✓	✓
Secondary side feed	●	●	●	●	●	●	●	●	●	●	●
Primary side bleed	●	●	●	●	●	●	●	●	●	●	●
Primary side feed	●	●	●	●	●	●	✓	●	●	✓	✓
Assured containment isolation	●	●	●	●	●	✓	●	●	●	✓	✓
Filtered containment venting	●	●	●	●	●	●	●	●	●	●	●
Catalytic recombiners to limit hydrogen formation	●	●	●	●	●	●	●	●	●	●	●
Emergency power supply from neighboring plant	●	●	●	□	□	□	●	□	□	□	●
Restoration of off-site power supply	●	●	●	●	●	●	●	●	●	●	✓
Additional off-site power supply (underground 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

National Stress Test – Status-quo of SAM of German BWR-72 before Fukushima Accidents (5)

- 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
 - N₂ inertisation of wetwell
 - PARs in both wetwell and drywell for severe accidents



National Stress Test – Recommendations of the German Reactor Safety Commission (6)

- From both the national stress test and the ongoing discussions inside RSK, the Commission identifies a need of improvement and extension concerning:
 - long-term energy supply (e.g. mobile generator, supply connections (partially realized)),
 - 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,
 - identification of available safety margins,
 - SAM measures for the protection of the building structures surrounding SFP of a BWR against hydrogen combustions (e.g. passive autocatalytic recombiners etc.),
 - optimization of existing measures, and
 - need of a SAMG Concept ⇒ On behalf of the utilities, AREVA is doing the development of the SAMG Concept for the German NPPs.
- An improvement (EOPs) and extension (SAMG) of the German SAM program is currently underway.

Assessing SAM Measures – Overview

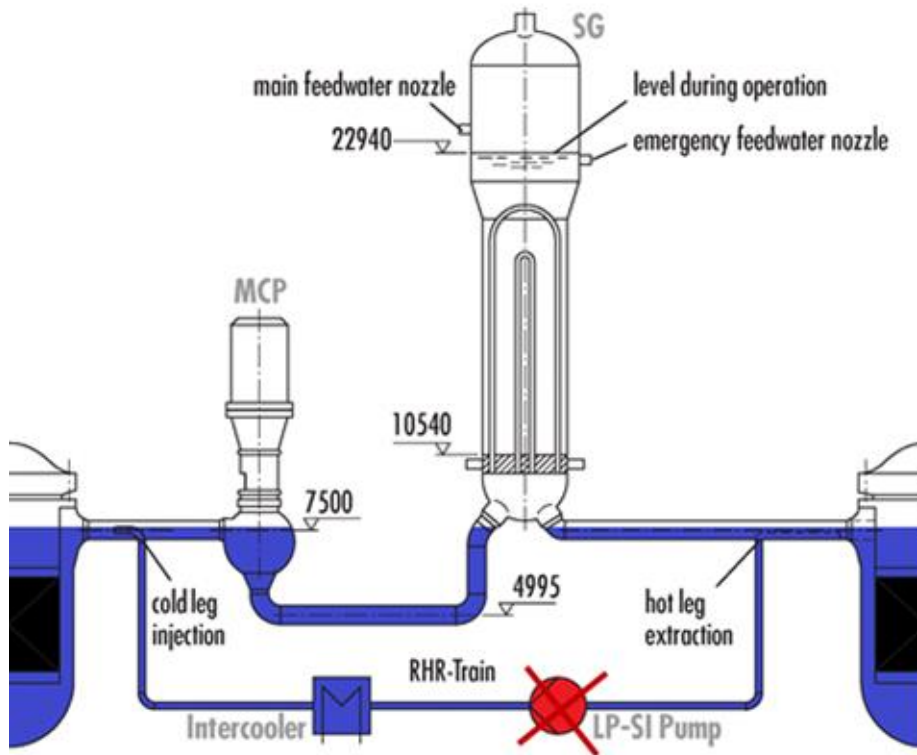
- Utilities of the German NPPs started to realize SAM measures in the eighties. That work partially went in parallel to the former discussions within RSK.
- Finally, the measures have been realized in the late eighties and nineties in accordance to the recommendations of the RSK (recommendations from 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 SAM measures implemented before Fukushima accidents 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 are implicitly assessed by Level 1 PSA. Mitigative measures like primary bleed, filtered containment venting, and hydrogen countermeasures are examined in 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.
 - Various hydrogen countermeasures to mitigate severe accidents have been investigated in the nineties. GRS carried out detailed investigations supporting the discussions in Germany about the basic requirements for implementation of a PAR system.
- The current improvement and extension of the SAMP will be discussed in parallel inside the RSK and the technical boards of the Commission.

Current Severe Accident Analyses at GRS – Shutdown Mode Analyses (1)

- A project financial supported by the German Federal Ministry BMU is running regarding analyses of severe accident sequences during shutdown modes and in consequence of external hazards for both PWR and BWR.
- Little experience with severe accident analyses for these events, because up to now no consideration in PSA Level 2 studies is demanded.
- Gain of related knowledge regarding the progression of severe accidents in shutdown modes and in consequence of external hazards events.
- These results can be used for both supporting future Level 2 PSA studies and identification of possible mitigative accident measures.
- For PWR: 11 relevant scenarios has been identified for the shutdown modes of a PWR and 5 representatives will be calculated using the MELCOR Code.

Current Severe Accident Analyses at GRS – Shutdown Mode Analyses (2)

- Preliminary results for the event: Failure of RHR, “Mid-loop” Operation, RPV Open

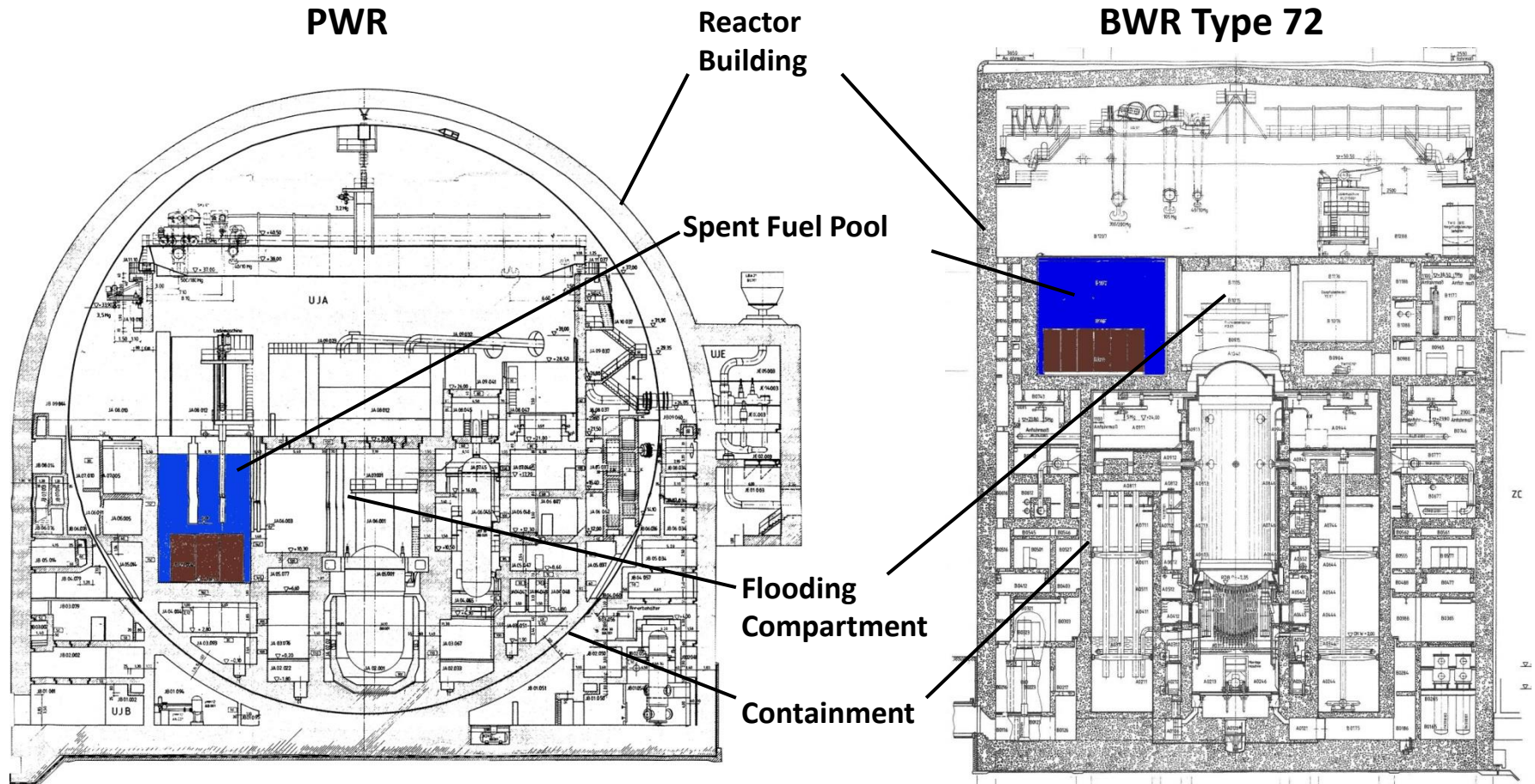


Event	Time
Shutdown	-40:00 h
Accu injection (assumption)	00:00 h
Begin of core uncover ($L_{RPV} \leq 6,63$ m)	13:23 h
Gap release	14:31 h
Exposure of core ($L_{RPV} \leq 2,73$ m)	17:14 h
Failure of lower core grid	21:25 h
Dry out of lower plenum	22:00 h
Melt ejection into cavity	25:01 h
Begin of venting ($p_{initiation} = 7.0$ bar)	262:01 h
end of venting ($p_{end} = 3.5$ bar)	275:21 h

Current Severe Accident Analyses at GRS – Spent Fuel Pool Analyses (3)

- Research project financially supported by the German Federal Ministry BMWi regarding the extension of probabilistic analyses for spent fuel pools (SFP).
- Supporting deterministic analyses of the accident progression inside the SFP are being performed inside the project.
- The accident progression is being analyzed for both PWR and BWR pools by using the integral code MELCOR.
- Development of a basic approach for consideration of SFP within Level 2 PSA, the quantification of event trees, and the identification of possible mitigative accident measures.
- Conceptual differences between reactor types PWR and BWR have to be considered for the analyses.

Current Severe Accident Analyses at GRS – Spent Fuel Pool Analyses (4)



- SFP located inside containment
- PAR above SFP region

- SFP located outside containment
- No PAR at SFP region

Current Severe Accident Analyses at GRS – SA Analyses PWR (5)

- A new project on behalf of BMU has been started recently at GRS regarding the assessment of the improvement of existing SAM and the new SAMG for PWR by deterministic analyses using MELCOR.
 - Analyses of two events “Station Black-out (SBO)” and “Small break LOCA with multiple failures” (significant contribution to core damage states or release categories of PSA Level 2).
 - Calculation of the SBO event with both the current status of the EOPs and the improved EOPs (e.g. increased capacity of batteries, mobile generators, etc.), comparable assessment of the analyses in order to show the benefit.
 - Severe accident analyses of both events under consideration of planned SAMG developed by AREVA.
- ⇒ Quantification and assessment of the benefit due to the improvement of SAM strategy of PWR.

Conclusions

- After the Fukushima accidents several stress tests has been performed at Europe.
- The European Stress Tests start in May 2011 to assess the safety of the plants under Fukushima like conditions. Main topics were natural hazards, loss of safety systems, and severe accident management. 17 countries participated in the tests.
- Four European Level Recommendations as well as several more detailed recommendations and suggestions have been issued.
- The results of the stress tests has been published within a main report and 17 country reports. Furthermore, an EU action plan as well as country-specific action plans were written. All documents have been made available for the public on <http://www.ensreg.eu/EU-Stress-Tests>.
- Before the EU Stress Tests, a national stress test has been performed at Germany. Objective was the assessment of the robustness of all German NPPs against beyond design basis accidents, like natural hazards, Station Black-out etc.
- Based on the results of the stress tests and the on-going discussion at Germany, recommendations for the improvement (EOP) and extension (SAMG) of the SAMP of German NPPs are available. First plant modifications has been realized already.
- GRS is working on several projects partially including Fukushima relevant issues with the objectives to analyses sever accident sequences and to assess additional measures for an optimization of the current SAM concept of German NPPs.

Thanks for your attention!

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