Lessons learned from Analyses of Fukushima Accident (Units 2 & 3)

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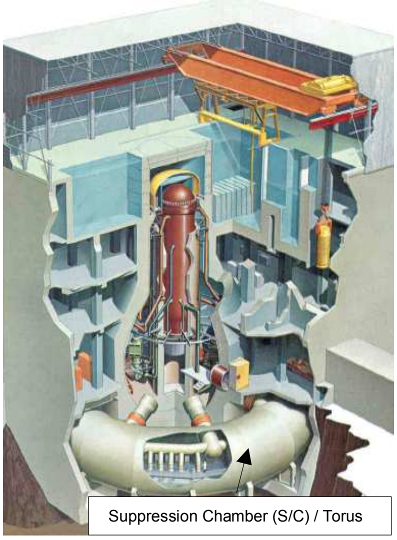
1. Background and Goal of the present Work

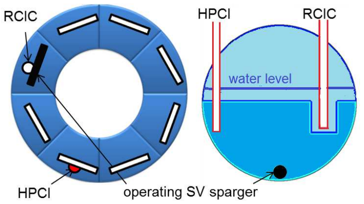
GRS contributes to the OECD/NEA Fukushima project BSAF with severe accident simulations of the Fukushima Daiichi NPP, Units 2 and 3. The coupled GRS codes ATHLET-CD/COCOSYS were used and a part of the analyses results is presented here. It is related to lessons learned with regard to an appropriate containment i.e. suppression chamber (S/C) nodalisation of a BWR plant in case of a severe accident.

2. Simulation setup – Wetwell/Torus Nodalisation

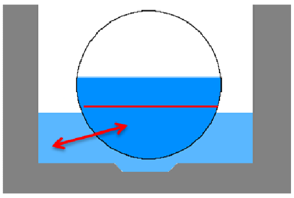
Up to now it was common practice to use a simple single volume nodalisation for the simulation of the conditions inside the S/C during accidents in lumped parameter codes, e.g. in COCOSYS. For the analysis of design basis accidents this approach seems sufficient since systems are available to cool the S/C water during releases from the reactor. This approach is not appropriate under the conditions of the severe accidents in Fukushima, Units 2 and 3, where a detailed S/C nodalisation is necessary to provide reasonable results of the observed containment pressure transients based on physical explanations. The S/C is split in accordance with its main design into 16 zones, 2 layers with 8 zones each. This allows the consideration of the steam/water mixture injection into different parts of the S/C via the steam driven injection systems RCIC and HPCI and through the spargers of the operating safety valve(s) (SRV). Known injection phenomena like chugging or incomplete condensation and thermal stratification within the water pool of the S/C have been satisfactorily modelled by this approach.



Fukushima BWR with Mark I Containment



Schematic S/C (Torus) Nodalisation
(injection locations marked)

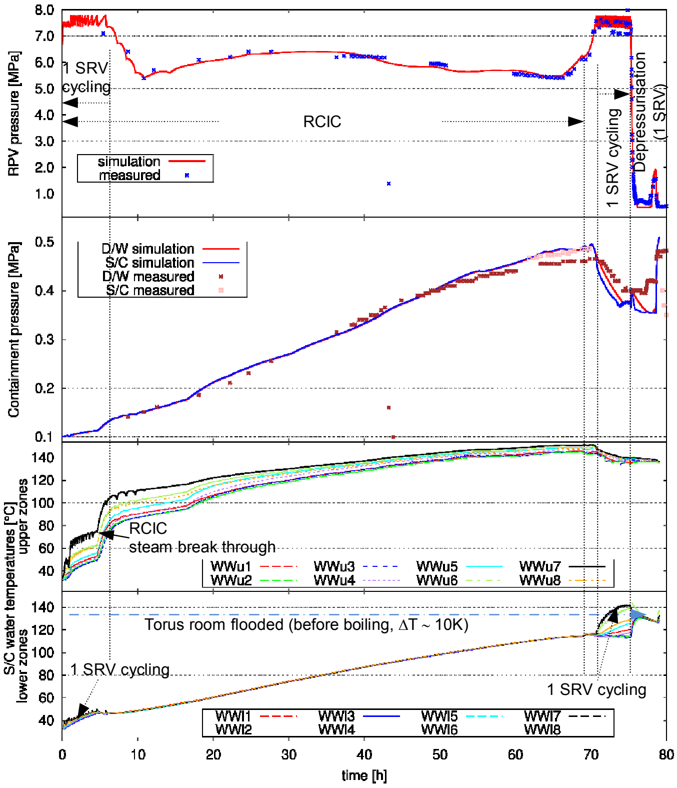


Flooded Torus Room, Unit 2
(additional heat losses)

3. Calculation Results

3.1. Unit 2

After the arrival of the tsunami and the resulting complete loss of power, heat from the core was removed by steam release through one SRV. The steam driven RCIC system injected water into the reactor but was operated in an uncontrolled manner. Eventually, the water level reached the main steam line, resulting in a two phase flow towards the RCIC turbine while decreasing the pressure in the RPV. After the failure of the RCIC system after ~69 h the pressure increased up to the actuation limit of one SRV. Core degradation started shortly after the RPV depressurisation, just before water injection into the RPV using diesel driven fire pumps started.

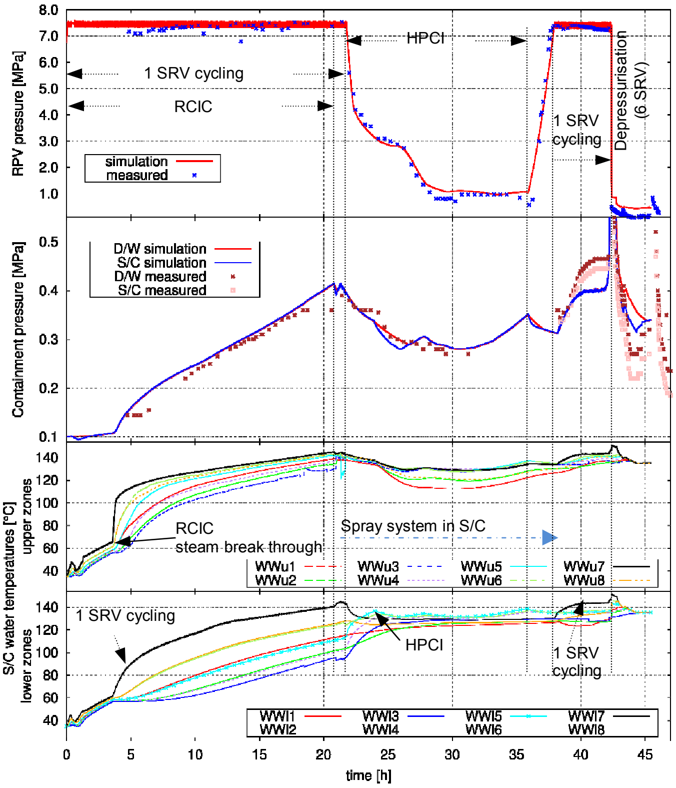


RPV and Containment pressure, S/C water temperature in upper and lower zones

The containment pressure transient until 70 h can only be well calculated if, in addition to the detailed S/C nodalisation allowing modelling of temperature stratification and of steam injection phenomena, substantial heat losses from the S/C are considered, which could be caused by a partly flooded torus room. Most experts agree with this plausible assumption. Further, the decreasing containment pressure after ~70 h is caused by the beginning SRV discharge into the sub-cooled water in the lower S/C zones. This causes a pressure decrease due to the mixing of subcooled water from the lower S/C zones with saturated water in the upper zones, justifying the need of a detailed S/C model.

3.2. Unit 3

The early accident phase is similar to Unit 2, except that the availability of battery power allowed the operators to adjust the RCIC mass flow, so that the level did not reach the main steam line. One SRV was sufficient to control the RPV pressure and to release steam into the S/C, thus removing heat from the core. After RCIC was shut down at ~20 h, and before the HPCI system was started, diesel driven pumps were used to initiate the S/C spray system. The HPCI system was stopped after ~36 h and the following RPV pressure increase prevented water injection for about 7 - 8 h until its depressurisation. During this time the core degradation started.



RPV and Containment pressure, S/C water temperature in upper and lower zones

The approach of the subdivided suppression chamber is able to explain the containment pressure increase during the RCIC operation followed by the pressure decrease during the actuation of the S/C spray system and the HPCI operation. The nodalisation of the S/C allows treating known injection phenomena during RCIC and HPCI operation like chugging or incomplete condensation and models thermal stratification in the S/C water (axial and azimuthal) as shown above. The pressure peak at about 42.5 h is caused by the release of non-condensable gases during the core degradation followed by S/C venting.

4. Conclusions and Acknowledgements

With the same detailed nodalisation of the S/C considering its design characteristics, a physically sound explanation of the observed containment pressure transients in Units 2 and 3 can be provided by the ATHLET-CD/COCOSYS analyses. Many other results are in good agreement with corresponding data of the severe accidents as well. The future work in the next phase of the OECD/NEA Fukushima project BSAF substantiate these findings, allowing the transfer to other safety assessments for NPP.

The authors gratefully acknowledge the funding of the BMWi (German Federal Ministry for Economic Affairs and Energy).

Poster ID Number: IAEA-CN-235-79
IEM on Strengthening Research and Development Effectiveness in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant,
IAEA Headquarters, Vienna, Austria, 16–20 February 2015