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Progression Of Postulated Loss-Of-Cooling Accidents In The Wet Storage Pool Of NPP Gösgen/Däniken

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ABSTRACT

The wet storage building of the nuclear power plant Gösgen/Däniken is the first building for the long term wet storage of spent nuclear fuel in Switzerland. Due to the Swiss moratorium against the export of spent nuclear fuel in 2006 it was necessary to store the spent fuel locally at the nuclear power plant site. The prolongation of this moratorium in 2016 does not allow reprocessing of spent fuel in the next years. As a direct conclusion from this moratorium it was decided to build a wet storage pool at Gösgen/Däniken which entered operation in 2008 with a capacity of 504 fuel assemblies. In a second stage of completion another 504 fuel assemblies can be stored in the pool. Two cooling towers will be available for the cooling of the wet storage pool with a maximum cooling capacity of 1.5 MW after the second stage of completion.

The present work describes postulated severe accidents with total loss of cooling in the wet storage pool (WSP) of the Gösgen/Däniken nuclear power plant. The accident progression in a spent fuel pool and even more in a wet storage pool is very slow due to the low nuclear decay heat. Therefore the investigation of such kind of accident was not assumed to be of high importance for a long time. The overall accepted assumption of an energy recovery after at least 24 hours would not lead to boiling of a spent fuel pool due to the low decay heat.

The severe accident in Fukushima Daiichi (11.03.2011) following the great Eastern earthquake and the related tsunami has shown that the power recovery can be delayed much longer, for more than a week. This long time of loss of cooling could endanger a spent fuel pool especially if the whole core is unloaded into the pool like in Fukushima Dai-Ichi unit 4 at the time of the accident.

Main goal of the work is to achieve information about the timing of postulated severe accidents in the wet storage pool and to define time frames for accident management measures to prevent fuel damage and fission product release.

1 INTRODUCTION

The wet storage pool of the NPP Gösgen/Däniken is placed in a separate building to provide long-term cooling for spent fuel assemblies, which were stored before in the spent fuel pool inside the containment of the nuclear power plant for about four cycles. After each cycle the oldest batch of the fuel assemblies inside the spent fuel pool will be transferred into the wet storage pool to empty the required place for the high burnup fuel removed from the reactor.

Due to the fact that severe accident codes in principal were written for the simulation of accidents in the reactor pressure vessel some models are used outside of their validated regions. The ongoing accident progression, if no accident management measures were taken, becomes more and more uncertain. The oxidation of the cladding at low temperatures after fuel uncovery and its heat up is a slow process, but only few experimental data exist below 1000 K. The chemical heat due to oxidation can strongly exceed the nuclear heat of the fuel and can be the main contributor to the heat up and fuel degradation.

As starting event for a severe accident an earthquake is assumed which destroys the cooling pipes (connection to the cooling towers) and additionally the external and internal power equipment. No SAMG is available for mitigation of bundle degradation and fission product release. Due to the loss of cooling the wet storage pool starts to heat up and boil down. Regarding the total decay heat of the spent fuel inside the pool the water heats up and boils down.

A set of calculations with the severe accident code MELCOR 2.1 has been performed to calculate the progression of a severe accident in the wet storage pool. Different heat loads and different amounts of fuel assemblies in the pool were selected to cover the full range of boil down scenarios.

Experimental data were used [1] to receive reasonable data for the buoyancy driven gas flow through the bundles after complete boil down of the pool water. For the radial heat loss two extreme storage policies, hot neighbor and cold neighbor storage, were used.

2 MODELING

All structures of the wet storage building and the wet storage pool were modeled as heat structures to allow steam condensation and heat conduction through the walls to achieve realistic conditions (Fig. 1). The environment is modeled as time independent volume connected to the building walls and the flow path of the air conditioning system which will fail by overpressure. The fuel is modeled in six groups with different heat load to reflect the storing times of the different batches. The distribution of the fuel assemblies in the spent fuel racks is modeled in two different storage policies, the hot neighbor storage and the cold neighbor storage (Fig. 2). The heat radiation between the different groups is modeled according the number of contact areas of the FA's. Here the radiation area between each two neighboring groups has to be multiplied with a view factor. A view factor of 0.5 was extracted from the results of the Sandia fuel experiment [1] to reflect the radiation barrier of the racks between the neighboring fuel elements. The MELCOR code calculates the heat radiation regarding the given radiation area.

The FA's are stored in 7x8 spent fuel racks with 18 racks placed in the pool. For the accident sequences six different heat loads were used (0.25 MW, 0.5 MW, 0.75 MW, 1 MW, 1.25 MW and 1.5 MW). The lowest three heat loads were calculated with the pool filled with 50% of fuel assemblies (504) and the highest heat loads were calculated with full pool (1008 FA's).

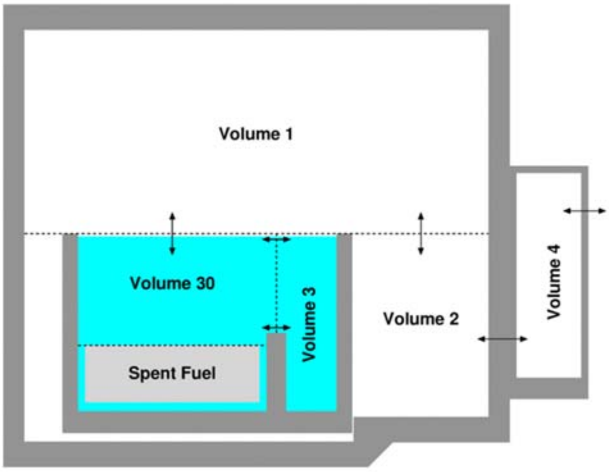

Figure 1: Model of wet storage building

For the completion of the modeling in the MELCOR code also two cavities were modeled, one representing the bottom of the wet storage pool and the other representing the floor of the building. The calculation of the accident sequence starts at four cycles after shut down, to remove all the short living nuclides from the fission product inventory.

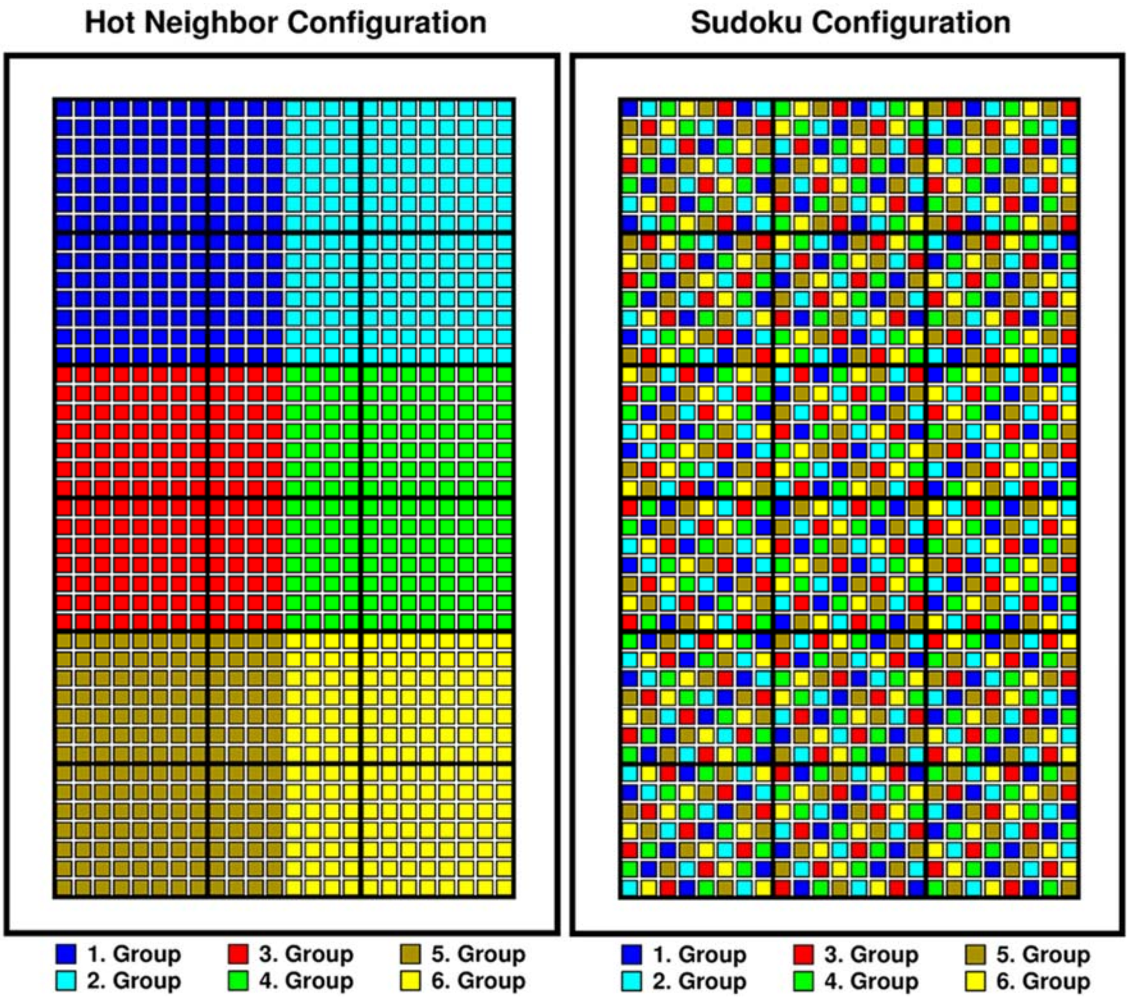

Figure 2: Hot (left) and cold (right) neighbor storage pattern for full wet storage pool

With the MELCOR2.1 code up to 300 days of accident sequence were calculated for all cases from the initiation of the accident until the end of the calculation.

3 RESULTS

The base calculations performed for the different heat loads of the wet storage pool show, as expected, a strong dependency of the heat up rate of the pool water. The highest allowed heat load of 1.5 MW of the spent fuel needs almost 4 days to reach boiling conditions in the pool (Fig. 3). The heat up curves of the water are no straight lines because of the heat conduction of the concrete walls which takes heat from the water especially at higher temperatures close to boiling conditions.

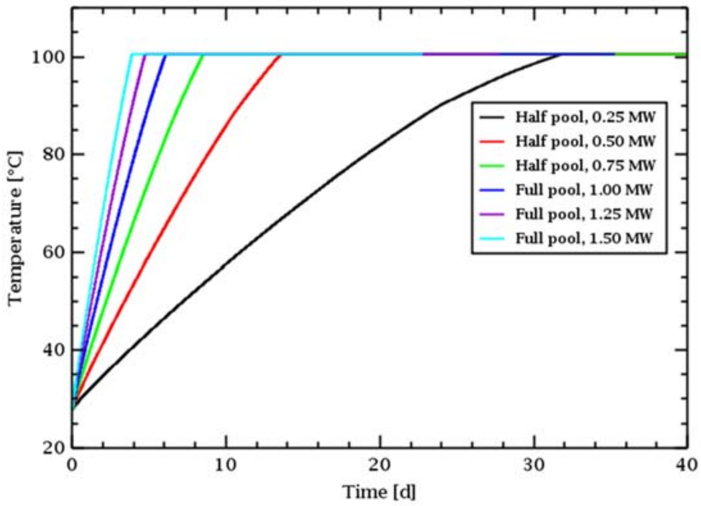

Figure 3: Temperature history of pool water for different heat load of the spent fuel

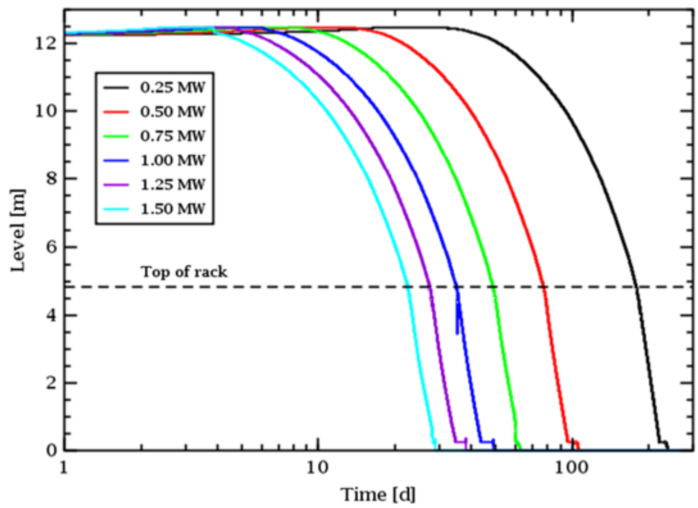

Figure 4: Water level in wet storage pool for base cases with different heat load

The water level (Fig. 4) rises due to the density change during heat up and after reaching boiling conditions the water evaporates according the heat load of the spent fuel and level decreases below the top of the racks (dashed line) after several days. Even with the highest heat load more than three weeks passes until top of the racks is reached. The calculations with hot and cold neighbor storage did not show visible differences, because the heat load difference between the hottest group and the group stored longest in the wet storage pool was not more as a factor of two. In a spent fuel pool, where also recently unloaded fuel is stored, the differences can be easily a factor of ten and more. In a spent fuel pool the storage policy can have a reasonable influence on the fuel degradation [2].

The results for the lowest heat load and the highest heat load will be presented on the following pages. The case with 0.25 MW

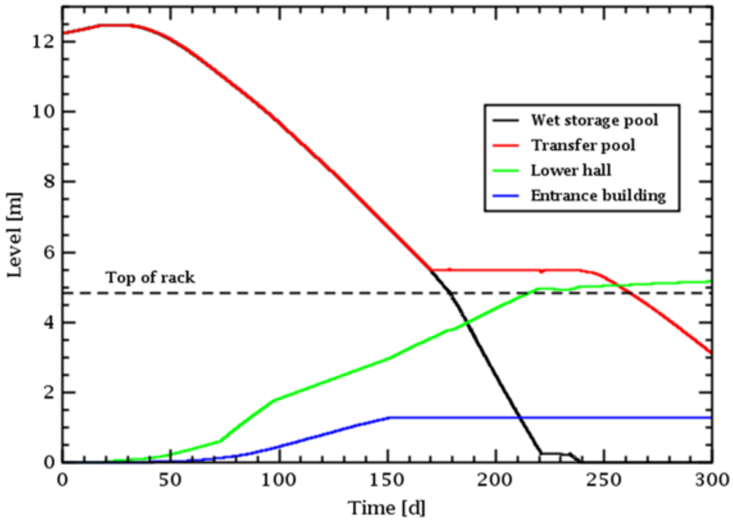

Figure 5: Water levels at different locations in the wet storage building for 0.25 MW case

and 504 FA's stored in the wet storage pool shows a very low accident progression with boiling of the pool after about one month (Fig. 5). The low steam production leads to condensation on the walls of the building and almost all steam remains inside the building. Part of the condensed water flows back into the pool and part of the water flows into the lower hall of the wet storage building. The heat conduction through the concrete walls removes most of the decay heat produced by the spent fuel. The water level of the wet storage pool reaches top of active fuel after about half a year of boil down. Between 200 and 240 days from the onset of the accident the cladding starts to heat up and oxidizes in steam atmosphere. Due to the large amount of steam produced during the boil down of the pool water, the air inside the building is replaced by steam and therefore the hydrogen production does not produce enhanced possibility of deflagration because of the missing oxygen. The oxidation of the cladding results in degradation of the fuel as up to 90% of the cladding thickness is oxidized. This happens for the lowermost axial fuel node and therefore the program changes the state of the fuel from intact geometry to debris. The temperatures reached by the degraded fuel are far below the melting temperature of the steel liner of the wet storage pool, so that core concrete interaction cannot start in this accident simulation. The final state after 300 days of accident progression (Fig. 6) shows water in the lower building and in the transfer pool, but not any more in the wet storage pool.

Figure 6: Final state of the wet storage building for the 0.25 MW case after 300 days of accident progression (orange: debris, blue: water)

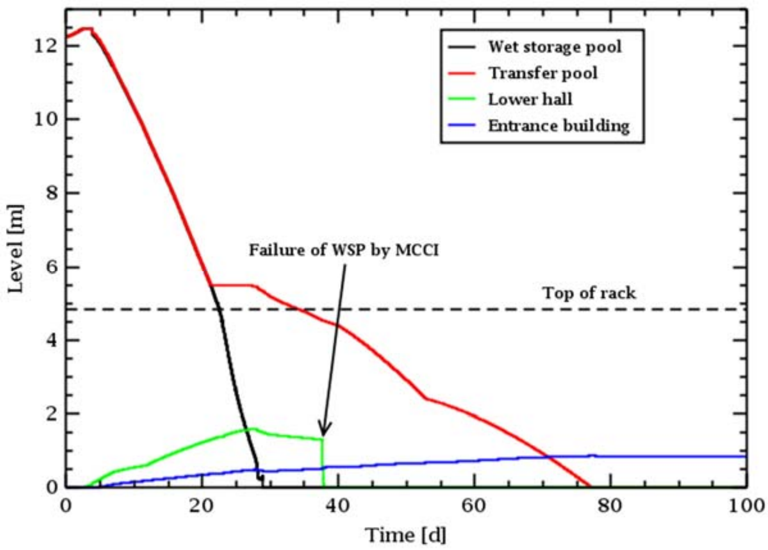

Figure 7: Water levels in wet storage building for the 1.5 MW

For the base case with 1.5 MW decay heat of the spent fuel, a full pool with 1008 fuel assemblies was modeled. Again the fuel was organized in six groups with different heat load to represent the different storing time of the spent fuel in the wet storage pool. The heat up of the pool water is now much faster because of the six times higher decay heat and leads also to a faster boil down of the pool water. The steam production is higher by about a factor of six and therefore the condensation capacity of the wet storage building is strongly exceeded. The steam mostly escapes into the environment which means, that less condensed water can flow back into the wet storage pool. The time of core uncovery (Fig. 7) is reached in this case after about three weeks and then the cladding heat up and oxidation starts in steam atmosphere. The chemical energy generated by cladding oxidation added to the nuclear decay heat leads to a strong temperature excursion which results in melting of the corium and onset of a dry molten-core-concrete-interaction (MCCI) inside the wet storage pool. After more than one week the bottom of the pool is eroded in the MELCOR calculation (Fig. 8) and the corium is released into the lower part of the building which was modeled as second cavity.

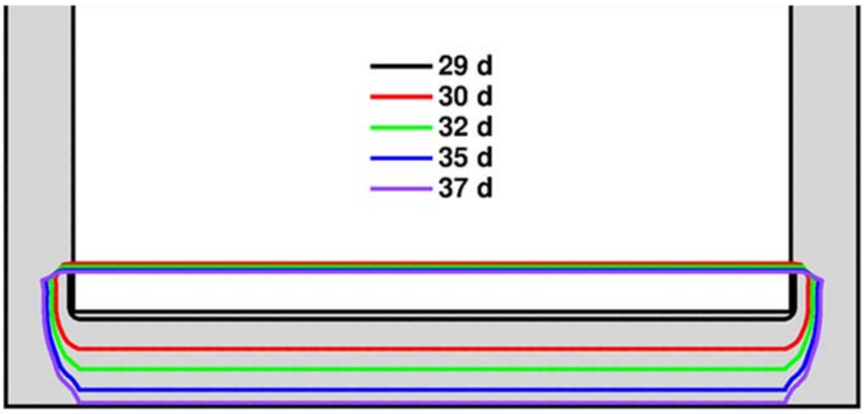

Figure 8: Core-Concrete-interaction in wet storage pool for the 1.5 MW case after melting of the steel liner

The amount of water condensed in the building and flowing to the floor of the building is lower than in the case with 0.25 MW decay heat due to the extensive steam release into the environment, but it is still enough to cool down and arrest the corium after failure of the wet storage pool (Fig. 9).

The final state of the accident calculation for the 1.5 MW case (Fig. 10) with the arrested corium in the lower part of the wet storage pool building and a small amount of water in the entrance area of the building. The temperature of the corium very slowly increases after the cool down after failure of the wet storage pool due to MCCI, but could not reach temperatures to reactivate the core-concrete-interaction in the 300 days until end of the calculation.

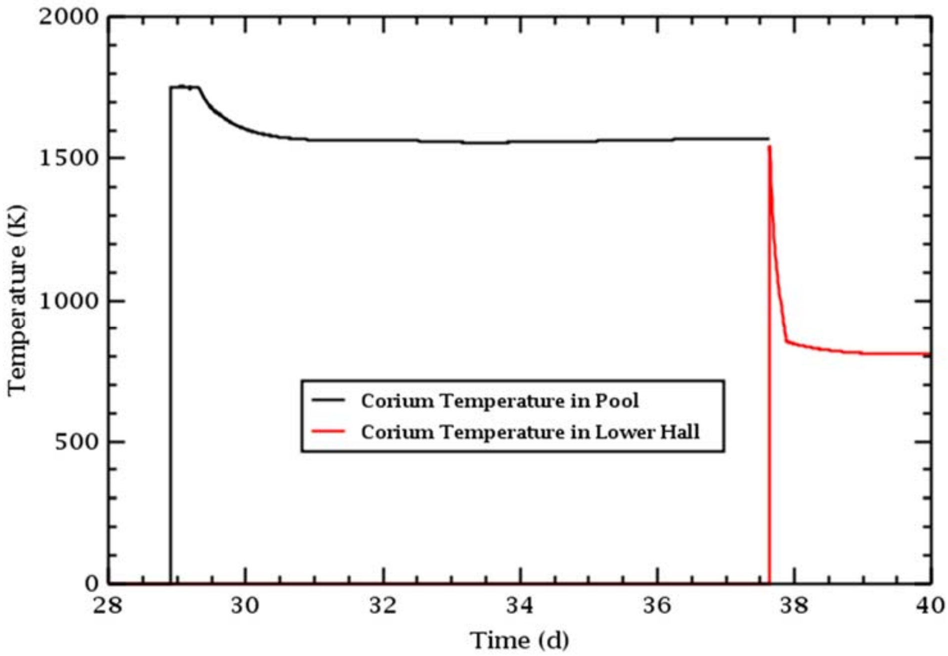

Fig 9: Corium temperature history in wet storage pool and lower hall

Figure 10: Final state of the wet storage building for the 1.5 MW case after 300 days of accident progression (red: corium, blue: water)

4 DISCUSSION

The postulated severe accident calculations for the wet storage building of Gösgen/Däniken nuclear power plant have shown that the scenarios with given boundary conditions can be calculated with the MELCOR 2.1 severe accident code. The calculations have to be interpreted carefully having in mind that some results might be uncertain because of the extrapolation of models used in the code. Especially the corium-concrete interaction might be uncertain because of the low temperature of the corium.

The main goal of this study was the definition of time frames for accident management measures to prevent fuel damage. As shown for different heat loads in the wet storage pool plenty of time is available (Tab. 1) before water has to be added into the pool to stop the accident progression. The amount of water needed to replace the water loss by steam production is in all cases less than 1 kg/s, which can easily be delivered by fire water pumps.

Table 1: Timetable of important events during severe accidents in a wet storage pool

Power/Event	Onset of Boiling	7 m	Water loss at boil down	Top of rack	Top of active fuel
0.25 MW	31.8 d	145 d	0.092 kg/s	178 d	186 d
0.50 MW	13.5 d	62 d	0.20 kg/s	76 d	80 d
0.75 MW	8.5 d	39 d	0.32 kg/s	49 d	51 d
1.00 MW	6.1 d	28 d	0.42 kg/s	35 d	36 d
1.25 MW	4.7 d	21.9 d	0.53 kg/s	27.4 d	28.4 d
1.50 MW	3.8 d	17.9 d	0.64 kg/s	22.4 d	23.3 d

The sensitivity calculations with different storage configurations, hot neighbor storage or cold neighbor storage, did not show large differences because of the small change in the heat load for the different fuel groups.

The atmospheric composition in the late phase of the unmitigated accident is very uncertain because the wet storage building is not a closed containment. Air ingression into the building may happen by change of the weather conditions (environmental temperature) or by open doors. In the present calculation only the failed ventilation system (0.6 m^2) was used for exchange of the building atmosphere and the environment.

REFERENCES

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[2] B. S. Jäckel, J. C. Birchley, L. Fernandez-Moguel, Spent Fuel Pool Under Severe Accident Conditions, 22nd ICONE Conference, 2014, http://dx.doi.org/10.1115/ICONE22-30729