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## Water Volume Available for ECCS Sump Recirculation Mode Following a LOCA

*T. Riekert<sup>\*</sup>, H. Rebohm<sup>\*\*</sup>, J. Huber<sup>\*\*\*</sup>, F. Brandes<sup>\*\*\*\*</sup>*

<sup>\*</sup>TÜV NORD SysTec - Germany,  
<sup>\*\*</sup>TÜV NORD EnSys Hannover - Germany  
<sup>\*\*\*</sup>TÜV SÜD IS – Germany  
<sup>\*\*\*\*</sup>TÜV SÜD ET - Germany

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### Abstract:

In this paper we describe the reviews performed in Germany on the water level in the containment sump after a LOCA and the derived actions. Our view on the issue is from the perspective of the independent safety experts – i.e. TÜV SÜD Industrie Service (TÜV SÜD IS), TÜV SÜD Energietechnik GmbH Baden-Württemberg (TÜV SÜD ET), TÜV NORD EnSys Hannover and TÜV NORD SysTec –, which reviewed the analyses of the utilities on behalf of the responsible supervising authorities. Between these expert organizations information were exchanged via the steering committee on nuclear technology of the association of the TÜVs (VdTÜV).

In our paper we describe the analyses on the two safety issues relevant in the connection with the water level in the containment sump: the necessary minimum coverage of suction pipes to avoid inadmissible entrainment of air and the water retention inside the containment after a LOCA. Our description concentrates on PWRs because of the more complex conditions in comparison to BWRs. In conclusion it can be stated that due to the thorough evaluation of operating experience, optimization measures could be derived. In addition, the analyses served the purpose of know-how maintenance.

### 1 INTRODUCTION

In January 2005, the supervising authority of the federal state Baden-Württemberg informed the public and the German federal government about a potential flaw in the safety analyses concerning loss-of-coolant accidents (LOCA) for the nuclear power plant (NPP) Philippsburg, unit 2 (KKP-2) [1]. The information concerned the analysis of a leak in the main coolant line close to the reactor pressure vessel (RPV). For this break location, more water could be retained in the reactor cavity than assumed in the original safety analysis. This could result in a water level in the containment sump that is lower than permissible according to the state-of-the-art to avoid the entrainment of air into the suction pipes of the emergency core cooling system (ECCS). This problem could arise when two out of the four trains of the ECCS were assumed to be unavailable according to the single failure concept (one train in repair, the other failing due to a single failure). To avoid an insufficient water level in the containment sump, restrictions were imposed on the utility concerning repair times of equipment necessary for the emergency core cooling function.

Subsequently, this issue was investigated thoroughly for all German pressurized water reactors (PWRs) on request of the responsible federal ministry (BMU). The analyses were performed by the utilities with support by AREVA NP. Additionally, the relevance for boiling water reactors (BWRs) was evaluated.

The analyses were reviewed by the responsible TÜVs as independent expert organisations – i.e. TÜV SÜD Industrie Service (TÜV SÜD IS), TÜV SÜD Energietechnik GmbH Baden-Württemberg (TÜV SÜD ET), TÜV NORD EnSys Hannover and TÜV NORD SysTec – on behalf of the responsible local state authorities. Between these expert organizations information were exchanged via the steering committee on nuclear technology of the association of the TÜVs (VdTÜV).

The major assessments were completed in 2005. As a result, optimization measures were introduced in various plants, e.g. concerning the operating manuals for LOCA. The safety issue and the performed analyses were also submitted to a review by the German Reactor Safety Commission (RSK). On the basis of the analyses presented by the utilities and AREVA NP, the assessments by the TÜVs as well as internal discussions, the RSK issued in November 2005 a recommendation on the relevant safety aspects and on the further analyses needed [2]. These analyses, which were performed in 2006, supplemented the work done in 2005.

In this paper, the involved TÜVs represented by the authors describe the background for the information by the supervising authority of Baden-Württemberg (BW) concerning KKP-2, the safety issues involved, the assessments performed by the TÜVs and the major results. The assessments are presented in more detail for PWRs because the issue of water retention after a LOCA is more complex for PWRs with their large containments than for BWRs. Finally, the lessons learned are summarized in the conclusions.

## **2 BACKGROUND: ATTAINING KNOWLEDGE AND IMMEDIATE MEASURES AT NPP KKP-2 IN JANUARY 2005**

On January 13th, 2005 the management of the NPP KKP-2 informed the Ministry of the Environment in Baden-Württemberg (BW), as the responsible authority for the supervision of the nuclear installations in BW, that under special conditions a specific LOCA might not be controlled without additional measures.

This insight resulted from the evaluation of the tank inventories and the available emergency coolant water volume initiated by the Ministry of the Environment in BW after an event at KKP 2 in the year 2001.

The problem can be described as follows:

In the original analysis of a LOCA with a leak in the 2m long pipe section between the reactor pressure vessel (RPV) and the support-cylinder of the RPV (see fig. 1), it had been assumed that a volume of 130 m<sup>3</sup> coolant accumulates in the reactor cavity during the event. In new evaluations, it was recognized that the insulation at the wall of the reactor cavity is filled with water during the event, too. This results in an additional lost volume of about 40 m<sup>3</sup>. That means that in total a volume of 170 m<sup>3</sup> has to be considered as a "dead" volume in the reactor cavity during the event, which is not available for the emergency core cooling system (ECCS) after switching from suction from the storage tanks to recirculation.

As a consequence of this scenario, the utility had to demonstrate that there is always sufficient water in the sump so that the ECCS pumps have a net positive suction head and air entrainment into the pumps can be avoided during the whole event. This had to be shown under design conditions, i.e. under consideration of the single failure concept. The single failure concept as applied in Germany assumes that two safety trains are unavailable, one due to repair, the second due to a random failure. Concerning the entrainment of air, it was

not quite clear at this stage whether the formerly employed KSB-Formula from the design phase of the plants or the more conservative, recently issued ANSI-Formula had to be used.

At the very beginning, after gaining knowledge of this problem, the utility could not demonstrate the control of a LOCA under the above mentioned design conditions by using the ANSI-Formula and by a simple calculation of the amount of available emergency cooling water volume considering the contraction of water in the primary circuit during the cooling down period, the refilling of the pressurizer during the event and the dead volumes of the reactor cavity and in the containment.

For that reason, the utility in a first step introduced restrictions concerning repair times and preventive maintenance during power operation affecting the availability of the ECCS. Further, the shift staff was informed about additional available measures, e.g. the opening of a connection between the storage tanks of the ECCS. Through this measure, the water in the storage tanks of a safety train with a failed pump is made available for core cooling.

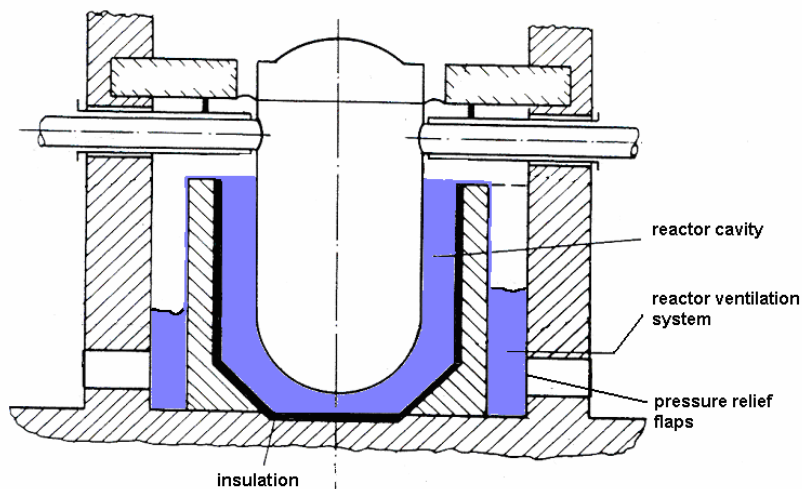


Fig. 1: Filling of the reactor cavity and the ventilation system with closed pressure relief flaps

### 3 SAFETY ISSUES

During the discussion of the information on KKP-2 it became clear that two safety issues had to be analyzed:

- Minimum coverage of suction pipes:  
Apparently, the formula applied during the plant licensing process to determine the minimal necessary coverage of suction pipes was not conservative in each case. The ANSI formula [3] reflecting the state of the art could lead to a higher minimal allowed coverage than the original formula by the pump supplier KSB. This had relevance for the recirculation sump, but also for other suction situations.

- Water retention inside the containment outside the recirculation sump:  
In the original LOCA analyses, the water retention inside the containment had not been analysed completely for each case. There exists a potential that more water is lost in “dead” volumes inside the containment than considered in the original emergency core cooling (ECC) analyses. More generally, this led to the question whether the flow paths from the break location to the containment sump had been analysed in detail for each break location.

The focus of the initiated analyses was laid on LOCA at PWRs. Here, a sufficient water level in the containment sump has to be demonstrated for all break locations, all break sizes and over the whole time of the accident progression. The recirculation operation of the ECCS has to be ensured for months after a LOCA. In contrast, in many other suction situations, a low coverage can only occur in a short operation period before the emptying of a tank. Therefore, we do not cover this aspect in our presentation.

## 4 ASSESSMENT FOR LOCAS AT PWRs

### 4.1 Break locations considered

Referring to the retention of water inside the containment, the break locations can be divided into two groups:

- a) Leakages at the RPV or in the main coolant line which cannot be isolated (incl. breaks near to RPV and other locations)
- b) Leakages in systems connected to the main coolant line (auxiliary systems) which can be isolated (Break location at connecting pipes / auxiliary systems)

#### a) Leakages at RPV or in the main coolant line

These leakages can be distinguished by the different break locations in terms of their effects:

- 1) Leakage positions at the RPV:  
Direct outflow into the reactor cavity
- 2) Leakage positions in the main coolant line close to RPV-nozzles (guard pipe):  
Partial outflow into the reactor cavity via the gap between nozzle and guard pipe
- 3) Other leakage positions in the main coolant line which cannot be isolated:  
Direct outflow into the recirculation sump

#### 1) Leak positions at the RPV

According to the assumptions for pipe breaks and leaks in the Regulatory Guidelines of the German Reactor Safety Commission (RSK) for PWRs (RSK-Leitlinien für DWR), leaks in the RPV have to be assumed for the accident analysis. The analyses of leaks at the RPV are directly connected with the mentioned findings at the NPP KKP2 (“dead volume” of the reactor cavity). Leaks at the RPV lead to an immediate filling of the reactor cavity including the volume of the thermal insulation. As there is no direct connection between the reactor cavity and the recirculation sump, the volume of the reactor cavity has to be classified as a “dead volume”, i.e. this amount of water cannot be used by the ECCS during the recirculation mode (see fig. 1). After the complete filling of the reactor cavity, the leaked water will also flow into the ventilation system around and below the RPV and will lead to at least a partial filling of this system. Some areas of the ventilation system are below the elevation of the intake of the

suction pipes of the ECCS. Thus, the water in these lower volumes is lost for the ECCS and these volumes have to be regarded as “dead volumes”, too.

## 2) Leak positions in the main coolant line close to the RPV-nozzles (guard pipe)

These leaks close to the RPV-nozzle are directly connected to the findings at the NPP KKP2, as well. Just like the described leaks at the RPV, these leaks in the main coolant line near the RVP can lead to a filling of the reactor cavity. Close to the RPV-nozzle, a special guard pipe splits the leaking water between the volume outside of the biological shield and the reactor cavity (see fig. 2). Therefore, the water level in the reactor cavity rises more slowly than in the case of a direct RPV-leakage. This “time-effect” can be considered in the analysis of the water level in the containment sump, if it is necessary to reduce conservatism. Thus, these leak positions can also lead to a complete filling of the reactor cavity and, subsequently, to an overflow from the reactor cavity to the ventilation system. Summarizing these effects, the same “dead volumes” of water losses have to be considered for leaks directly at and close to the RPV.

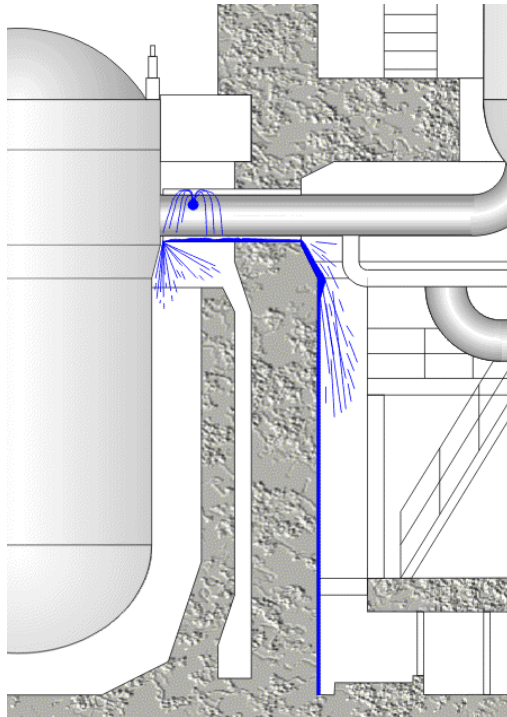


Fig. 2: Distribution of water from a leak in the main coolant line close to the RPV

## 3) Other leak positions in the main coolant line

For leak positions in the main coolant line different from those discussed before, a filling of the reactor cavity does not have to be taken into account. Water does not flow from the sump into the reactor cavity, even for a rising water level in the recirculation sump.

For all leak locations, potential barriers which can hold back the draining water have to be reviewed. If the effect of such barriers is confirmed, the resulting retained volume has to be

classified as “dead volume” and the available water in the recirculation sump is to be reduced accordingly.

#### b) Break location at connecting pipes / auxiliary systems

Only leaks in connecting pipes with the possible consequence of a significant loss of coolant have to be investigated as a LOCA considering the retention of water inside the containment. In German NPPs, such leaks can occur in the volume control system only. Other auxiliary systems are separated from the main coolant line during power operation (e.g. residual heat removal system) or can be neglected because of the small size of their pipes (e.g. sample system). In case of a LOCA, the reactor protection system triggers the safety function “reactor coolant system isolation”. According to this function, all connections between the main coolant line and auxiliary systems (also the outlet line of the volume control system) are closed. Therefore, a relevant leakage in the volume control system has to be taken into account only if the separating valve does not close properly due to a single failure. However, in this special case, a second independent single failure concerning a storage tank of the ECCS is not to be assumed. Consequently, as the mass inventory of a storage tank exceeds the estimated losses within the containment, a larger amount of coolant is available for the recirculation cooling than for a leak location in the main coolant line.

### 4.2 Water retention inside the containment

With respect to the retention of water inside the containment outside the recirculation sump, the following conditions have to be taken in account:

- Unfavourable combinations between leak location and leak size have to be considered by parameter studies.
- For leaks close to the RPV-nozzles, the effect of the guard pipe which distributes the leaking water between the reactor cavity and the sump has to be taken into account. This should be accomplished by using all the available realistic analysis tools. The limiting conditions for these analyses have to be based on the actual geometric dimensions of the NPP in question.
- All possible “dead volumes” inside the containment which cause retentions of condensate have to be considered.

Regarding the retention of water inside the containment, two different effects can be noticed:

- „Dead volumes”
- Water retention in form of vapour and droplets in the containment atmosphere or in form of condensate on surfaces, floors etc.

#### Dead volumes

Referring to the described leak locations in chapter 4.1, different “dead volumes” have to be taken into account. If the time-dependent filling process of the reactor cavity is not considered in detail for leaks close to the PRV-nozzle (guard pipe), the water losses for those leaks can be treated in the same way as those for leakages direct at the RPV. Otherwise, a detailed time-dependent analysis of the different water levels has to be performed. In the following, we neglect the time-dependent filling of the reactor cavity and therefore summarize the leaks close to the RPV-nozzle and the leaks at the RPV under the term “Leaks near the RPV”.

- Leaks near the RPV

The analyses of various leakage locations indicate that the leak positions in the main coolant line close to RPV-nozzles are the crucial locations. For these leak positions, the combination of two unfavourable aspects of water retention is possible: On the one hand, the reactor cavity can be filled completely and, on the other hand, a smooth blow down procedure can leave the pressure-relief-flaps in the biological shield between the ventilation system and the recirculation sump closed (see fig. 1). Thus, the following scenario has to be assumed:

Leaks near the RPV fill up the reactor cavity resulting in a volume of lost water of approximately 135 m<sup>3</sup> to 170 m<sup>3</sup> depending on the different designs of the NPPs. The insulation with a volume of approximately 40 m<sup>3</sup> to 60 m<sup>3</sup> inside the reactor cavity is assumed to be filled with water and is included in these values.

For the pressure relief flaps inside the biological shield between the ventilation system of the RPV and the recirculation sump, completely leak tight flaps have to be assumed as worst case with regard to water retention. It is possible that these flaps remain closed and tight during the whole blow down phase unless the necessary hydrostatic pressure is reached by sufficient water retention in the reactor ventilation system. This water volume necessary for the opening of the flaps of up to 20 m<sup>3</sup> depending on opening conditions is not available in the recirculation sump before the opening of the flaps.

- Other leak positions in the main coolant line

Leaks in the main coolant line far away from the RPV don't lead to a filling of the reactor cavity. For these leak positions, the "worst case scenario" is the assumption that the pressure relief flaps between the ventilation system and the recirculation sump are not leak tight. As a consequence of the LOCA, the filling of parts of the RPV ventilation system has to be considered.

Special inspections in the plants show that there is generally a free flow path for the draining water from the leaks to the recirculation sump. This means that no obstacles like closed upstanding boundary bars or thresholds are present. In the relevant areas, a lot of the floors are designed as gratings supporting the drainage. Thus, only a small amount of "dead volumes" has to be taken into account.

- Leaks in connecting systems (auxiliary systems) which can be isolated

As these leaks are only possible in rooms far away from the recirculation sump, the flow path for the drainage water is seriously obstructed. In order to ensure a proper water flow to the recirculation sump, the existing piping and the flow paths have been reviewed by local inspections. These inspections have shown the need for improvements of the drainage path in some plants. Modifications that have been carried out included the removal of upstanding boundary bars and the creation of additional openings in walls. Nevertheless a specific amount of water – depending on the individual design of the plants – is supposed to remain in rooms along the flow path to the recirculation sump. However, these remaining amounts of water do not affect the analyses of a LOCA crucially due to the larger water volume available in the storage tanks for these leakage locations (single-failure-concept as described above).

### Water retention in form of vapour and droplets in the containment atmosphere and condensate on surfaces, floors etc

During a LOCA process, the leaking coolant is partly discharged as vapour and droplets into the atmosphere of the containment. This causes an increase in the humidity of the atmosphere until saturation is reached. This amount of water in the atmosphere – depending on the temperature – is not available for recirculation cooling. In addition, there is condensate on all cold surfaces within the containment which is also missing in the sump. Because of these effects, it is necessary to have a drainage path from all rooms with condensate on surfaces to the recirculation sump.

Detailed inspections in the plants showed that the flow path is generally provided by the building drainage system. Only some small upgrades of the drainage systems were necessary, e.g. enlarging of strainers at the inlets of the draining system. However, these improvements were of minor importance.

Although the condensate can reach the recirculation sump, it has to be taken into account that vapour and droplets remain in the atmosphere and water sticks as condensate on walls, floors, and other cold structures. The volume of this “blocked” water can be estimated by special codes and is considered in the analyses. Depending on the LOCA circumstances and the special design of the containment and the drainage system, the analyses reveal that about 50 to 100 Mg of coolant mass is kept back as vapour or droplets in the atmosphere and as condensate on surfaces (walls and floors).

### **4.3 Transient analysis of water level in recirculation sump**

For several German NPPs in-depth thermal-hydraulic analyses were carried out for LOCA cases with a possible water loss from the break into the reactor cavity. In the following we describe one example of these analyses to demonstrate the general procedure and main assumptions. However, due to different operating manuals and geometric properties of the plants the analyses had to be adapted for each unit. Also, in some cases more conservatism could be applied so that not each detail had to be modelled.

The weld connecting the main coolant line (hot leg) with the reactor pressure vessel (RPV) was chosen as the break location. The size of the leaks varied in the range of 10 cm<sup>2</sup> to 400 cm<sup>2</sup>. In addition, a leak of 20 cm<sup>2</sup> on the ground of the RPV was considered. These assumptions cover the worst cases to be considered.

The investigations focused on the safe function of the recirculation pumps at any time, taking into account the most unfavourable cooling conditions to be assumed for LOCA and the plant specific dependency of the water level from the water volume in the sump. Hence it was necessary to determine the water mass available for core cooling and the resulting water level in the sump as a function of time.

In general, the following sources are available for core cooling:

- the storage tanks of the ECCS (flooding tanks),
- the accumulators of the ECCS,
- the additional boration system and
- other sources, such as the volume control system and systems activated manually by the reactor operator.

In our described example, conservatively only the resources of the flooding tanks and the accumulators of the ECCS were taken into consideration for the computational. Besides, it

was assumed that because of repair of an emergency diesel generator and a single failure in another emergency diesel generator in two trains of the ECCS neither the high pressure pump nor the low pressure pump are available for safety injection. It should be noted that the practices for preventive maintenance differ between the German NPPs. Hence the assumptions on equipment out of service due to preventive maintenance had to be adapted on the specific situation.

The accumulators feed into the primary circuit, as soon as the primary pressure drops below 25 bar. The injection rate of the accumulators depends on the time-dependent primary pressure. The accumulators at the cold leg are automatically blocked off 500 sec. after detection the leakage by the reactor protection system. Therefore, these accumulators do not inject their content into the primary circuit in case of a small and medium sized leak (i.e. less than 400 cm<sup>2</sup>) with a slow primary pressure drop.

Beside the water volume injected into the primary circuit by the ECCS, the mass of water contained in the primary system at the respective time has to be calculated. Through the water flow out of the leak, the coolant mass in the reactor system decreases at first. Depending on pressure and temperature in the primary circuit, the leak flow and the flow rate of the ECCS, the water mass inventory in the primary circuit varies over time. Furthermore, such phenomena as the development of a steam bubble under the RPV lid and the falling water level in the pressurizer have to be considered. Both effects lead to a decrease of the water mass in the primary circuit corresponding to more water in the sump.

The third component to be considered is the water loss inside the containment. This is described in chapter 4.2.

The recirculation mode of the ECCS begins with the change-over of the low pressure pumps from suction from the storage tanks to suction from the containment sump. The leakage outflow to the sump and the flow rate taken from the sump by the pumps is not equal all the time depending on the break size. The minimum water level is to be determined in the analyses to prove that the safe operation of the ECCS is guaranteed at any time and for all break sizes.

In the described example the code system ATHLET developed by GRS was used for the thermal-hydraulics analyses (in other cases RELAP was applied). For the calculation of the water volume and water level in the sump, we developed an additional Lumped-Parameter-Model, taking into account the volumes in the reactor cavity, in the thermal shield and in the sump. The calculations with the program ATHLET correspond to the standard procedures for LOCA analyses. Therefore, we do not describe this part of the calculation in detail. The calculation model for the water balance is displayed in figure 3 as an overview.

Figures 4 and 5 show an exemplary calculation of the results we obtained. In figure 4 the development of the water level in the sump over time is displayed for a small leakage at the RPV nozzle. The water level in the reactor cavity does not reach the upper edge of the thermal shield during the displayed period, i.e. for long after the start of the recirculation mode. The water level in the sump rises at the beginning of the accident progression due to the flow of water from the leak. Then the switch over to the recirculation mode of the ECCS leads to a reduction of the water level in the sump due to the continuing loss of water into the reactor cavity, until an equilibrium develops. This equilibrium arises in the analysed example with a water level which lies above the upper edge of the concrete cover of the suction chamber of the pumps.

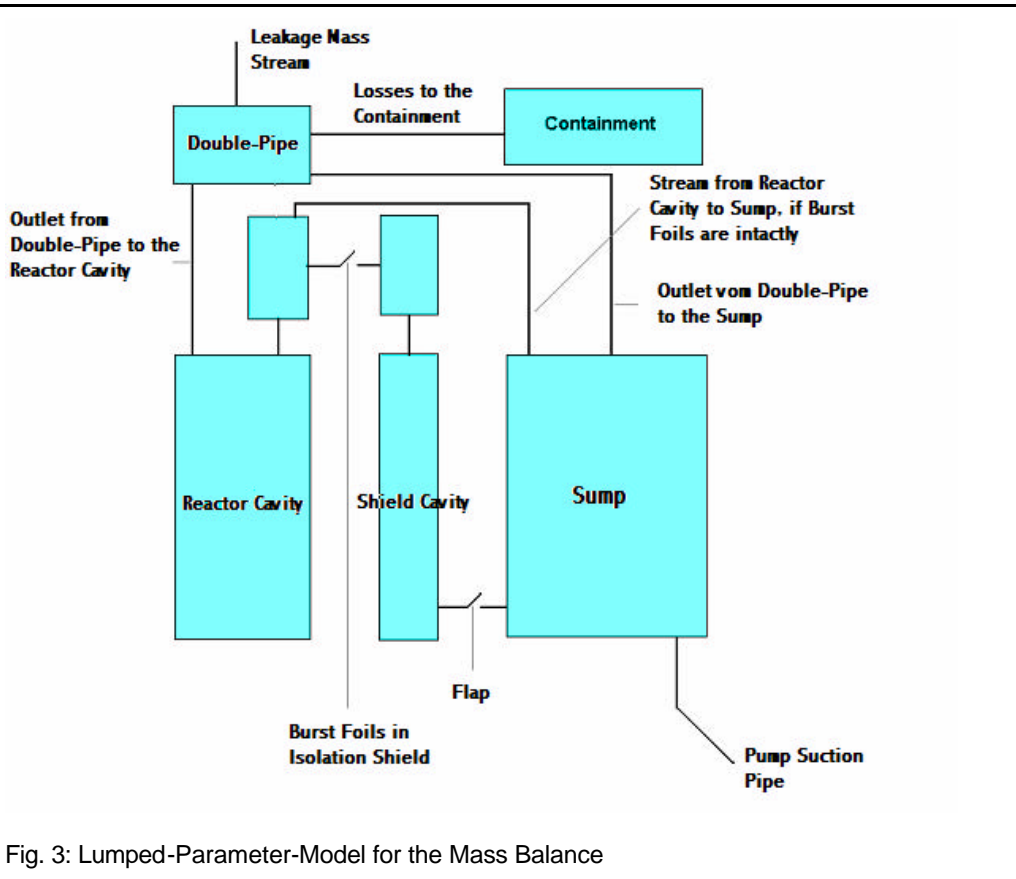


Fig. 3: Lumped-Parameter-Model for the Mass Balance

In figure 5 the results are displayed for a larger leakage. Here, water flows from the reactor cavity into the ring gap of the thermal shield (see fig. 1). When the opening pressure of the flaps in the thermal shield is reached these flaps open. Water flows into the sump leading to corresponding water levels in the ring gap and in the sump. For the example illustrated in figure 5, the water located in the reactor cavity already gets lost into the thermal shield during the displayed period of the emergency cooling. Hence an accordingly lower level appears in the sump after the beginning of the recirculation mode. In the illustrated case, the water level lies at the height of the upper edge of the concrete cover of the suction chamber.

With the calculation method sketched above, the situations in several German NPPs were analyzed and the safety reports of AREVA NP and the utilities were reviewed.

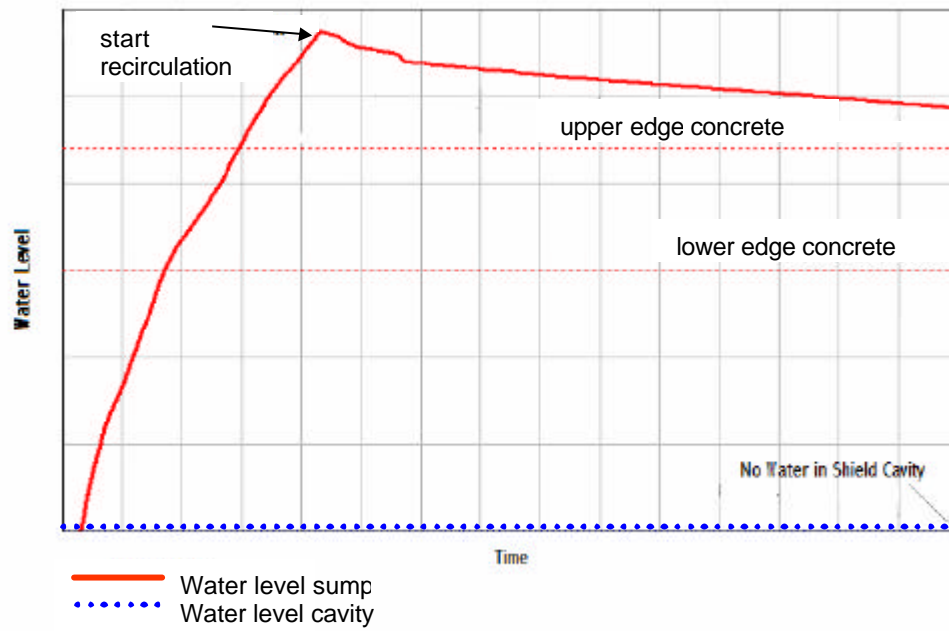


Fig. 4: Water Level in the Ring Gap and the Sump for a Small Leak (example)

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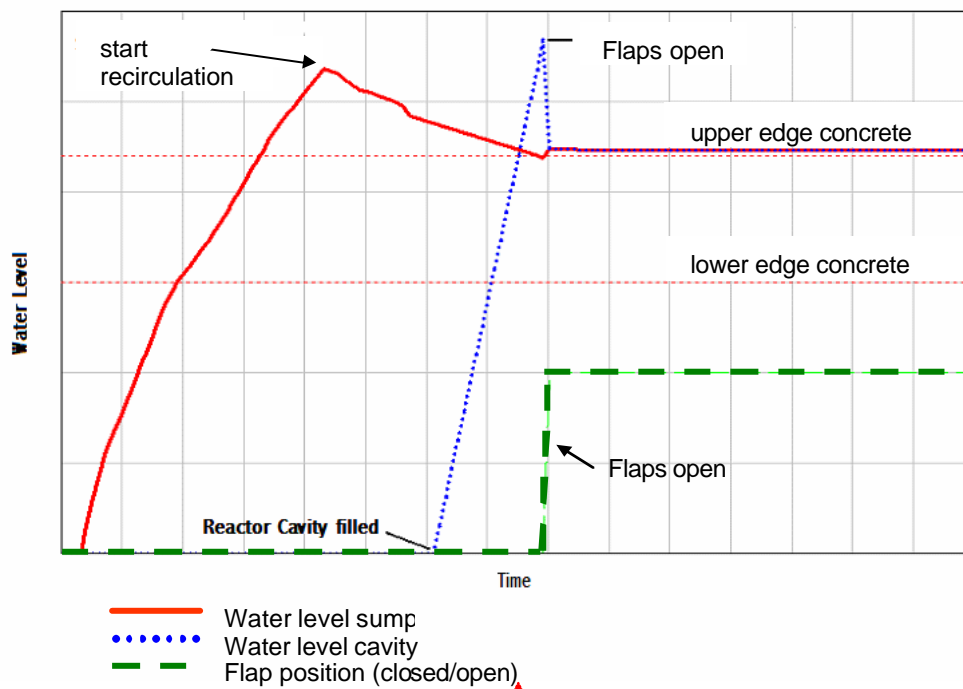


Fig. 5: Water Level in the Ring Gap and the Sump for a Medium Leak (example)

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#### 4.4 Minimal necessary water level in the sump

During the construction of the plants, the issue of air entrainment was discussed in connection with the suction from storage tanks by the low-pressure pumps of the ECCS. At that time, in order to ensure a safe suction, the necessary minimum coverage of the suction nozzles was determined by means of the so-called "KSB formula".

Within the framework of the analyses for the plant KKP 2 mentioned in chapter 2, a calculation method to determine the necessary minimum coverage of the suction pipe in the sump to avoid insufficient entrainment of air was found in the literature (see ANSI-standard [3]). Under the same conditions, the use of the ANSI formula leads to a considerably higher - and thus conservative - necessary minimum coverage of the suction nozzle than the formula given by the pump supplier (e. g. KSB) used during construction of the plants.

In order to clarify these facts, the utility engaged AREVA NP to erect a test facility and to carry out experimental verifications with regard to the necessary minimum coverage. In 2005, numerous scaled experiments were carried out with varying mass flow rates, temperatures, sump levels and partly with additives to minimize the surface tension of the water.

The experiments showed that with a mass flow rate of the ECCS pumps of up to about 240 kg/s -corresponding to medium sized leaks - even a sump water level below the lower edge of the sump ceiling is sufficient to guarantee an air bubble-free suction. Furthermore, the experiments showed that if the rising sump level reaches the lower edge of the sump ceiling, the suction of air is stopped even at maximum injection rates of the ECCS (about 350 kg/s) and thus no intake of air occurred. A sump level reaching this height is therefore an adequate requirement to avoid air entrainment. It should be noted that the review of these experiments is not yet completed.

A comparison of the theoretical calculation methods (KSB and ANSI formula) and the results of the test facility (scale approx. 1:4) shows that the values of a sufficient coverage of the suction nozzles of the low pressure (LP) pumps lie on the one hand above the "KSB values" and on the other hand significantly below the values of the "ANSI formula" (see fig. 6).

#### 4.5 Results

With the analysis methods described above, a sufficient water level in the containment sump could be demonstrated for all German PWRs, taking into account all leak locations and sizes. In most cases, the lower edge of the sump ceiling is covered, preventing air entrainment safely without the need for additional calculations. In some cases, for small leak sizes in combination with unfavourable manual actions (e. g. filling up the pressurizer, closing the accumulator valves and switching one pump into the residual heat removal mode) the water level remains for some time below the sump ceiling. In these cases, the flow rate of the ECCS is small. Hence the necessary coverage of the suction pipes is low according to the cited experiments and lies above the water level calculated with conservative assumptions.

Based on the analyses, the operating procedures for LOCA with small leak size were optimized to mobilize available water reserves. In this way, the water level in the containment sump can be increased. Such measures can be the prescription of a lower target level for the pressurizer level, the renunciation of the isolation of the accumulators of the ECCS when not all ECCS pumps are working and the opening of connecting pipes between the ECCS storage tanks. With these measures, a water level in the sump above the lower edge of the sump ceiling can be reached over the whole time period to be considered.

Because of the obtained results, the restrictions on the preventive maintenance during power operation of safety systems which had been imposed after the distribution of information on the issue by the supervisory authority of Baden-Wurtemberg could be lifted.

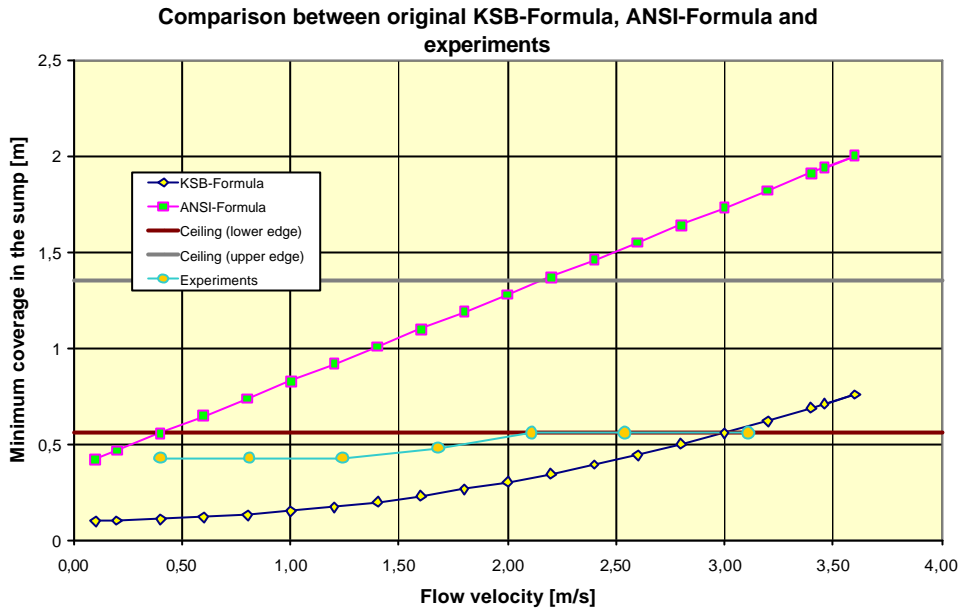


Fig. 6: Results for the minimum necessary coverage for PWR containment sump (sample values for one plant)

### 5 EVALUATION FOR BWRS

In Germany, two generic types of BWRs built by KWU are in operation, the “BWR 69” (4 units) with a pear shaped steel containment and the “BWR 72” with a cylindrical concrete containment. In this paper, the analyses are demonstrated on the example of one of the BWR 69 plants. Due to the difference between the designs of these plants the analyses can not transferred to the other plants.

The layout of the containment is shown in fig. 7. The drywell with the reactor pressure vessel is surrounded by a ring shaped suppression pool. With regard to the considered safety issue, LOCAs inside the containment and leaks from the suppression pool to the exterior of the containment can arise from leakages at connecting pipes leading out of the suppression pool. For the sample plant, small leaks from the suppression pool were also analysed in combination with a LOCA within the licensing process. LOCAs outside the containment are isolated from the RPV by fast closing isolation valves, hence the water loss is small.

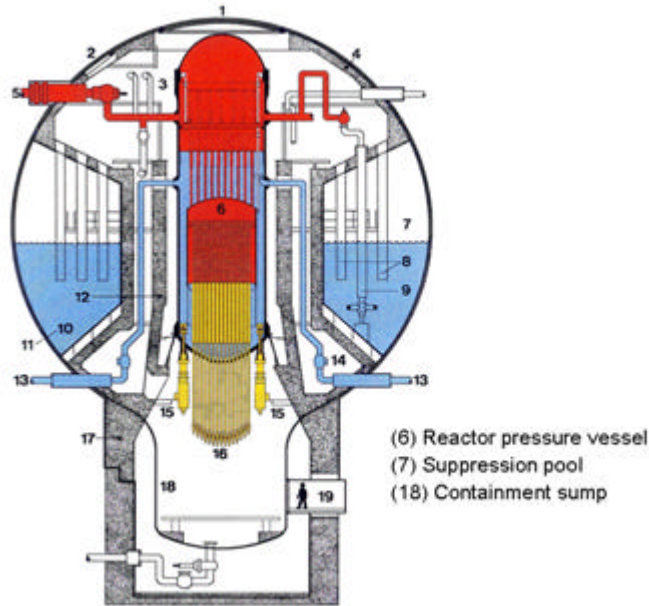


Fig. 7: Overview over BWR-containment (BWR 69)

In case of a LOCA, the ECCS takes the water for the flooding of the RPV and for the cooling of the core from the suppression pool with a huge water volume (3700 m<sup>3</sup>). There the water level decreases, as the leaking water flows into the containment sump. From the sump, it is pumped back into the suppression pool by dedicated safety systems, when a sufficient water level is reached in the containment sump. Also, one train of the ECCS can deliver water from the sump directly into the main feedwater pipes and by this way into the RPV. In addition, at the sample plant water leaking from the suppression pool into the reactor building is pumped back into the containment sump by a specific, two train system.

Therefore, three different suction situations had to be evaluated at the selected plant:

- a) in the suppression pool,
- b) in the containment sump,
- c) in the sump of the reactor building.

For the cases b) and c) the theoretical evaluation showed clearly that no air entrainment had to be feared. In contrast, for the suppression pool, only a small coverage of the ECCS suction pipes exists for the lowest water levels to be considered. However, the intakes of the ECCS are equipped with suction strainers to cope with released insulation material. These suction strainers hamper the creation of vortices so that the ANSI formula [3] could lead to too conservative demands for the minimum coverage of the intakes.

Because of these uncertainties a test was performed in one plant. During one outage, the ECCS train with the highest flow rate was operated at the lowest water level in the suppression pool to be considered. In the test, no vortex was generated and the pump operated smoothly at the specified parameters.

Water retention is no problem for these BWRs because of the small, simply structured containment as compared to PWR containments. For the leaks from the suppression pool into the reactor building the review showed that the water flow paths had been evaluated thoroughly during the licensing process of the plant.

The above description is valid only for the plant selected for this paper. At the other BWRs, the scope of the analyses and their results varied due to the specific situations.

## 6 CONCLUSIONS

In this paper we describe the reviews performed in Germany on the water level in the containment sump after a LOCA and the derived actions. Our view on the issue is from the perspective of the independent safety experts – i.e. TÜV SÜD Industrie Service (TÜV SÜD IS), TÜV SÜD Energietechnik GmbH Baden-Württemberg (TÜV SÜD ET), TÜV NORD EnSys Hannover and TÜV NORD SysTec –, which reviewed the analyses of the utilities on behalf of the responsible supervising authorities. Between these expert organizations information was exchanged via the steering committee on nuclear technology of the association of the TÜVs (VdTÜV).

The analyses were initiated after the information was distributed by the Ministry of the Environment of Baden-Württemberg in January 2005. The evaluation of this information showed that two safety issues had to be considered:

- the minimum coverage of suction pipes,
- the water retention inside the containment after a LOCA.

In our paper, we describe the analyses on these safety issues in detail for PWRs. For PWRs, the water paths inside the containment and the retention of water in cavities and other “dead volumes” as well as the resulting water level in the sump as calculated with the thermal-hydraulic code system have been evaluated for all relevant leak sizes and locations in the main coolant line and connecting pipes. As a result of the evaluation, modifications were made in some plants to optimize the flow paths in the containment. In addition, the operating procedures for LOCA were changed.

Also, the analyses for BWRs are outlined.

In conclusion it can be stated that due to the thorough evaluation of operating experience, optimization measures could be derived. In addition, the analyses served the purpose of maintaining know-how.

## 7 REFERENCES

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