Note:
This is a translation of the RSK recommendation entitled “Anforderungen an die Brennelement-Lagerbeckenkühlung”.
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK recommendation
(479th meeting of the Reactor Safety Commission (RSK) on 09.12.2015)

Requirements with respect to spent fuel pool cooling

1 Background

By letter dated 22.07.2014, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Building (BMUB) requested the Reactor Safety Commission (RSK) to prepare a statement on the requirements with respect to spent fuel pool cooling in response to discussions regarding the implementation of the Safety Requirements for Nuclear Power Plants (*Sicherheitsanforderungen an Kernkraftwerke* – SiAnf) [1] in the KTA safety standards (in particular KTA 3303 [2]) and to focus on answering the following three questions:

1 Are there fundamental concerns to carry out planned maintenance measures on the trains of the spent fuel pool cooling system in plants with authorisation for power operation during full core unloading?

2 If so, which plant operating states are recommended from the point of view of safety for carrying out such maintenance measures?

3 Is it necessary to provide additional explanations on the Safety Requirements for Nuclear Power Plants with regard to spent fuel pool cooling, in particular the accidents listed therein, as well as their appropriate practical implementation in terms of safety?

2 Consultations

At its 468th meeting on 04.09.2014, the RSK commissioned the RSK Committee on REACTOR OPERATION (RB) to address the request for advice of the BMUB and to prepare a draft statement. At its 229th meeting of 30.10.2014, the Committee RB set up a working group and asked to deal with the questions. Since the issues raised fall within the competence of various committees, members of the RSK Committee on PLANT AND SYSTEMS ENGINEERING (AST) as well as a staff member of the Gesellschaft für Anlagen- und Reaktorsicherheit mbH (GRS) were asked to join the working group. Within the framework of nine meetings and telephone conferences, the working group prepared a draft recommendation, which was adopted by the Committee RB at its 236th meeting on 10.09.2015. RSK concluded the discussions on the recommendation at its 479th meeting on 09.12 2015 and then adopted it by way of circulation.

3 Design of the spent fuel pool cooling systems

PWR

The spent fuel pool cooling system (SFPC system) in German pressurised water reactors with authorisation for power operation has three trains. Parts of trains 10 and 40 are part of the emergency cooling and residual heat removal chains and designed as interconnected trains, with the components being primarily used in case of demand for emergency core cooling and residual heat removal from the reactor core (redundants 1 and 4). These two residual heat removal trains can also be used for spent fuel pool cooling. In the interconnected trains and the downstream cooling systems (component cooling water and service water systems), the pumps are available in duplicate, one of the two pumps being assigned to the residual heat removal chain and the other one to the emergency residual heat removal chain. The major part of the pipes, valves and coolers as well as the associated component cooling water and service water systems are used by both the residual heat removal system and the emergency residual heat removal system. The operating mode (residual heat removal or spent fuel pool cooling) is selected as required, using the common coolers and one of the two pumps. In the event of failure of or maintenance work on components required for both operating modes, such as coolers, valves or pipes, a complete interconnected spent fuel pool cooling train is not available.

The emergency residual heat removal chains with the spent fuel pool cooling pumps are supplied by the D2 system, and the residual heat removal chains by the D1 system.

The heat removal capacity of each of the two interconnected spent fuel pool cooling trains is designed in such a way that 100% of the heat generated in the spent fuel pool (SFP) can be removed in all operating phases (A to F) at levels of defence 2 and 3 as well as in the case of external hazards. According to [1], the following operating phases are permissible for PWRs:

A: Nuclear power and start-up operation (plant during power operation or ready to start power operation, keff ≥0.99)
B: Hot subcritical (residual-heat removal via residual heat removal system not possible, keff < 0.99)
C: Cold subcritical, primary system pressure-tight closed (residual heat removal via residual heat removal system, primary system pressure-tight closed, k_{eff} <0.99 in case of a control-element-free reactor core)
D: Cold subcritical, primary system not pressure-tight closed (primary system not pressure-tight closed and refuelling cavity not completely flooded, k_{eff} <0.95 in case of a control-element-free reactor core)
E: Refuelling (refuelling cavity completely flooded, k_{eff} < 0.95 in case of a control-element-free reactor core)
F: Fuel assembly storage (all fuel assemblies in the spent fuel pool separated from the refuelling cavity, fuel assembly cooling via spent fuel pool cooling system, k_{eff} <0.95)

If one of the subsystems is used, 100% of the heat generated in the SFP can also be removed in emergency situations. In addition, there is a third SFP cooling train. The third SFP cooling train is supplied with emergency power via the D1 system of redundant 2 or 3. On the cooling water side, it is supplied by the operational part of the nuclear component cooling system. The third SFP cooling train is of particular safety significance since it serves to prevent repeated switching of the interconnected SFP cooling trains from residual heat removal to the SFP cooling mode in the event of a loss-of-coolant accident (LOCA) in the reactor coolant system. In some plants, the third SFP cooling train has a lower heat removal capacity than the interconnected SFP cooling trains. The functional capacity of the third train for cooling of the fuel pool has not been demonstrated with respect to the design basis earthquake. Likewise, the part of the nuclear component cooling system, which supplies the third SFP cooling train, is not designed against earthquakes and emergency situations so that in such scenarios, availability of the third SFP cooling train is not credited.

During power operation, the heat generated in the SFP is typically in the order of 5 MW. Compared to this, there is a heat output of approx. 15 MW at the time of a fully unloaded core during plant outage for refuelling and annual inspection.

BWR

In German boiling water reactors with authorisation for power operation (BWR 72), cooling of the SFP can be carried out by means of the following systems:

- <u>the 2-train operational SFPC System</u>:

One train is sufficient to meet the requirement of normal operation (maximum pool water temperature: 45°C) under the most unfavourable condition after refuelling (with a maximum of approx. 6.5 MW in the SFP); with fully unloaded core (max. approx. 13 MW in the SFP), both trains are required for this. With one train, 100% of the heat generated in the SFP can be removed in each operating phase A to F), while maintaining the acceptance criterion of level of defence 3. According to [1], the following operating phases are permissible for BWRs:

A: Nuclear power and start-up operation (plant during power operation or during start-up operation from the start of control element withdrawal, keff ≥0.99)
B: Hot subcritical (control elements completely inserted and residual heat removal via residual heat removal system <u>not</u> possible, k_{eff} < 0.99)
C: Cold subcritical, reactor cooling system pressure-tight closed (residual-heat removal via residual-heat removal system, reactor coolant circuit pressure-tight closed, k_{eff} <0.99)
D: Cold subcritical, reactor cooling system not pressure-tight closed (reactor coolant circuit not pressure-tight closed and refuelling cavity not completely flooded, k_{eff} <0.99)
E: Refuelling (refuelling cavity completely flooded, fuel assemblies in the reactor and in the spent fuel pool, k_{eff} < 0,99 for reactor and < 0.95 for spent fuel pool)
F: Fuel assembly storage (<u>all</u> fuel assemblies in the spent fuel pool separated from the refuelling cavity, Fuel assembly cooling via spent fuel pool cooling system, k_{eff} <0,95)

The components and piping of the operational SFPC system are designed in such a way that integrity is maintained in case of loads from a design basis earthquake. Since, however, the associated systems of component cooling water and service water supply and the emergency power supply (availability emergency busbars) of the system are not designed against the design basis earthquake, an earthquake may cause a loss of the operational SFPC system.

- the TH2 train of the residual heat removal system in the operating mode “direct pool cooling”
  This TH train can be directly used for pool cooling and maintains the pool water temperature below 40°C also when the core is fully unloaded.

- the three trains TH1 to 3 of the residual heat removal system in the “overflow operating mode”
  (with depressurised RPV at a RPV temperature < 100°C, SFP cooling in parallel to suppression pool cooling:

With this operating mode, the SFP can be cooled with each of the TH trains in parallel to suppression pool cooling, and even under the most unfavourable condition after refuelling (max. approx. 6.5 MW) or when the core is fully unloaded (max. approx. 13 MW), at least the technical specifications limit for design basis accident (DBA) conditions (limitation of fuel pool water temperature) can be complied with.

For this operating mode, suppression pool cooling must be available since coolant is taken from there and fed back into the SFP via TH. In the overflow operating mode, the water flows back from the SFP into the suppression pool.

Regarding the availability of trains TH1 to TH3, it should be noted that this operating mode requires the use of passive components (pipe sections) of the operational SFPC system and thus, correspondingly associated failures may occur event-specifically (in the event of leaks in these pipe sections).

- trains TH1 to TH3 of the residual heat removal system in the operating mode “suction from the set-down pool” and the additional independent RHR system (ZUNA) in the operating mode “reactor well cooling”
  (with depressurised RPV and opened refuelling slot gate):

According to the plant operator, the maximum amount of decay heat generated can be removed via one train of TH1 to TH3 and the additional independent RHR system (ZUNA) with depressurised RPV as well as opened refuelling slot gate. The operating mode with TH1 to TH3 is independent of the availability of the suppression pool. The operating mode with ZUNA takes place using pipes of one of the three trains TH1 to TH3 each and requires availability of suppression pool cooling.

Thus, in the BWR, two operational SFP cooling trains and three trains of the component cooling system are available for cooling of the SFP. For the overflow operating mode, however, the operating rules stipulate that the use of residual heat removal trains is only permissible after having brought the plant into a depressurised condition. Each of these trains is able to remove 100% of the decay heat generated in the pool while maintaining the temperature limits in the pool water that are permissible for design basis accidents. When the refuelling slot gate is open, the ZUNA system can be used additionally for SFP cooling.

After a design basis earthquake, only trains TH2 and TH3 are available as specified by design. During operating phase E with open refuelling slot gate, ZUNA is available additionally.

4 Assessment criteria

The following event of level of defence 3 has been introduced in the event category "reduced heat removal from the spent fuel pool" in Annex 2, Table 5.3 of the Safety Requirements for Nuclear Power Plants *(Sicherheitsanforderungen an Kernkraftwerke - SiAnf)* [1]:

B3-01: 'Loss of two trains of the spent fuel pool cooling system for a longer period (> 30 min.)'
For the safety demonstration, grace times and repair possibilities might be taken into account.

For this event, Interpretation I-5, Section 5 [4] of the SiAnf specifies the following:

A system train shall be understood to be a complete residual heat removal chain of the spent fuel pool.

Regarding event B3-01, it shall be demonstrated for all operating phases that for compliance with the protection goal 'fuel cooling', a limitation of the pool water temperature to levels below the design temperature of the pool is achieved to ensure pool integrity.

The event sets in with the loss of a train in operation during the unavailability of a second train due to maintenance measures.

Further, with regard to the redundancy requirements for equipment of level of defence 3, the SiAnf, Annex 4, Section 2.2.3 specify the following:

For the safety equipment required to cope with events on level of defence 3, a single failure generally combined with a maintenance outage shall be postulated when demanded (degree of redundancy n+2). For exceptions, see below.

If for a safety equipment, only a redundancy degree of n+1 is realised (e.g. for primary circuit or containment isolation valves), repair is only allowed if during repair on such an equipment, its safety function can be reliably ensured by other measures (e.g. closure of the 2nd isolation valve), or the repair is sufficiently limited in time und the permissible unavailability is specified in the operational plant documentation.

Regarding maintenance, all types of maintenance permitted and possible to be performed during an operating phase shall be considered. Details about the permissibility of maintenance during different operating phases are provided in Section 3.

In addition, the SiAnf, Annex 4, Section 2.3 define redundancy requirements for safety-relevant equipment in operating phases C to F:

2.3 (1): For the periods of planned maintenance during operating phases C to F (outage, shut-down states) on equipment of level of defence 3 required for these operating phases, a single failure shall be postulated without an additional maintenance (degree of redundancy n+1).

2.3 (2): A degree of redundancy n+0 is permissible in the operating phases E and F if in case of a loss of function of the safety-relevant equipment, relevant acceptance criteria are not exceeded within 10 hours and the active safety-relevant equipment failed or being under maintenance can be made functional within this time frame."

The relevant provisions are specified in Interpretation I-5, Section 4.1 of the SiAnf. Accordingly, the requirements of the SiAnf, Annex 4, Subsection 2.3 (2) regarding the installations for cooling the spent fuel pool are also applicable to operating phases A to D, and the following applies:

Note: Operating experience has shown that it is possible to make at least one pool cooling system train available within 10 hours if sufficient maintenance resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) are provided at the plant.

With regard to the implementation of preventive maintenance measures, the SiAnf, Annex 4, Subsection 3.3.1 (1) specify the following:

Preventive maintenance beyond the scope of servicing activities according to Section 3.2.2, and resulting in unavailability of safety-relevant equipment, according to Subsection 3.1 (1), shall be performed in general during operating phases in which an actuation of this equipment is not necessary or is rather unlikely, as a rule during the operating phases C to F.

For maintenance measure in terms of the SiAnf, Annex 4, Section 3.3.2 stipulates the following:

If servicing is required for ensuring the functional operability of safety-relevant equipment, it can be performed in all operating phases if the following conditions are met:

- *The servicing requires only unavailability of the safety-relevant equipment for less than 8 hours, and*
- *the safety-relevant equipment can be brought back to functionality in short time in case of a necessary demand, this shall also be possible under the conditions of an accident happened, and*
- *the servicing activities are limited to one redundant only and all other redundants remain fully available during this period, and*
- *during start-up and shutdown of the plant, servicing is limited to unavoidable cases.*

The following applies according to draft safety standard of KTA 3303 (revision), [2], 4.2.4 (1):

A pool water temperature of less than or equal to T_3 must be maintained for the events of level of defence 3 ... postulated according to the SiAnf.
Note: In contrast to design basis accidents whose occurrence is postulated for the reactor during power operation, graded safety requirements apply to postulated failures of the SFPC systems. ... A significantly longer grace time is therefore always available for corrective measures for event-independent single failures occurring in the SFPC systems ... . In addition, fuel pool cooling is an essential continuous operational function requiring continuous availability of the SFPC system.

According to KTA 3303 4.2.5 (1), the limit temperature T_3 also applies to natural external hazards and internal hazards (see also [3]).

In addition, KTA 3303, 4.2.4 (2)[1] applies:

If a grace time of at least 10 hours ... can be demonstrated for the design basis events ... applying the single failure concept, one of the unavailable trains may be assumed to be available again after 10 hours.

Further, KTA 3303, 4.2.4 (4) states:

Substitute measures or measures to restore availability may be taken into account in the event analysis if these measures can be carried out event-specifically before T_3 is reached.

5 Consultation results

Preliminary remarks

IAEA Safety Standard SSG-15 “Storage of Spent Nuclear Fuel” recommends using the deterministic single failure criterion for the design of heat removal systems of the wet spent fuel storage facility. This recommendation is complied with in the SiAnf [1] with the definition of events of level of defence 3 in the “Event list fuel storage PWR and BWR”. It should be noted that in accordance with the German single failure concept in [1], for safety equipment required to cope with events of level of defence 3, a single failure generally combined with a maintenance outage shall be postulated when this equipment is demanded.

From the description in Chapter 2 on the available trains of the SFPC system of the PWR and BWR plants in power operation, it follows that in the case of a postulated event-induced loss of an SFPC train (e.g. due to event B3-01 or as consequential loss of a design basis earthquake), the application of the single failure concept according to [1] to the remaining SFPC trains may have the effect that initially there will be no more active functions available for SFP cooling.

The application of the single failure concept to the safety function “fuel cooling in the spent fuel pool” had not been required in the nuclear rules and regulations before the SiAnf [1] entered into force. Since accident progression in the SFPC system is generally much slower at low pressures and temperatures as well as with regard to the temperature development than in the case of accidents in the reactor and since there is a comparatively good accessibility to the relevant installations in case of demand, the option of taking credit of a grace time of 10 hours was introduced with the definition of events of level of defence 3 in the SiAnf [1]. If sufficient maintenance resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) are

[1] In its comments on the revision of the existing KTA 3303 (draft safety standard), the RSK proposed the following passage for amendment:
If a grace time of at least 10 hours before reaching T_3 can be demonstrated for the design basis events of the SFPC systems applying the single failure concept, one of the unavailable trains may ***be assumed to be available again after 10 hours if it is shown that sufficient resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) are provided at the plant****.*

provided at the plant under the given boundary conditions of the postulated events, restoration of availability of at least one active train can be assumed within the available grace time [4].

In its advisory request to the RSK dated 22.07.2014, the BMUB focused on event B3-01 “Loss of two trains of the spent fuel pool cooling system for a longer period (>30 min.)” from [1] since the implementation of the related requirements in [1] into the subordinate regulations [2] has led to discussions. Questions 1 and 2 of the BMUB’s request for advice therefore relate to the point in time for the implementation of planned maintenance measures most suitable from a safety perspective since the loss of a train in operation during unavailability of a second train due to planned maintenance measures is to be postulated as occurrence of a B3-01 event.

Against this background, the RSK focusses on this event. However, the assessments derived from this event when answering Questions 1 and 2 of the BMUB and recommendations on the prevention of inadmissible conditions apply to all accidents relevant with regard to heat removal from the SFP as well as consequential losses resulting from a design basis earthquake as far as applicable. Within the framework of the answers to Question 3 of the BMUB, Sections 5.3.3 and 5.3.4 also explicitly address other events of level of defence 3 of Annex 2 in [1] relating to heat removal from the SFP, as well as the design basis earthquake.

Based on its consultations and the above preliminary remarks, the RSK answers the questions of the BMUB as follows:

5.1 Answer to Question 1 of the BMUB:

Are there fundamental concerns to carry out planned maintenance measures on the trains of the spent fuel pool cooling system in plants with authorisation for power operation during full core unloading?

The RSK is concerned about the implementation of planned maintenance measures during operating conditions in which a grace time of 10 hours (after which, according to [4], restored availability of one train can be assumed) until reaching design basis temperature T_3 is not ensured in the case of event-induced losses applying the single failure concept according to the SiAnf, Annex 4. This is to be expected especially during the first days with a fully unloaded core.

The reasons for these concerns are explained in more detail below in the context of the answer to Question 2 of the BMUB.

The concerns do not relate to maintenance measures that meet the requirements of the SiAnf, Annex 4, Section 3.3.2. Under these conditions, maintenance work (inspections, in-service inspections) can be carried out whenever it is shown that the required fast restoration of availability of the train under maintenance is short in relation to the actual grace time. In this case, restoration of availability after the respective period of time can be credited in the safety analyses.

5.2 Answer to Question 2 of the BMUB:

If so, which plant operating states are recommended from the point of view of safety for carrying out such maintenance measures?

In Annex 4, Section 3.3.1, the SiAnf stipulate with regard to preventive maintenance measures (corresponding to the planned maintenance in terms of the question of the BMUB) that these shall be performed in general during operating phases in which an actuation of this equipment is not necessary or is rather unlikely. In contrast to many other safety-relevant installations, the fuel pool cooling equipment is always required in all operating phases, but due to the differing number of fuel assemblies in the fuel pool with different levels of requirements regarding the effectiveness of the cooling systems.

The highest effectiveness requirements with respect to spent fuel pool cooling are to be met in operating phases E and F according to Annex 2, Section 4 of the SiAnf [1]. Since the duration of operating phase E is essentially determined by the time required for unloading or loading, and the heat to be removed from the fuel pool depends on the loading concept (e.g. shuffling), the actual conditions resulting from partial unloading of the core or during movement of fuel assemblies in the core inside the reactor pressure vessel (shuffling) are to be considered with their respective residual heat in the SFP.

With regard to operating conditions under which a temperature of T_3 can be maintained in the case of planned maintenance on a train and a postulated loss of a train of the SFPC system with remaining active SFPC trains applying the single failure concept, planned maintenance on this train presents no safety concern.

As far as this requirement is not fulfilled with regard to event B3-01 (as for the 3-train design concept of the PWR plants), the RSK arrives at the following conclusions:

Planned maintenance procedures during which the function of an SFPC train (necessary auxiliary and supply functions are to be taken into account) is not available, should be carried out under operating conditions where there is a grace time of at least 10 hours until excess of T_3 after occurrence of event B3-01 in combination with a single failure. The necessary maintenance resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) for restoring the availability of SFPC components within the available grace time are to be ensured for the period of planned maintenance **(Recommendation 1a).**

With regard to Recommendation 1a, the following has to be taken into account:

- The RSK takes the view that under consideration of the availability requirements with respect to core cooling (e.g. loss of coolant, external hazards, internal hazards, and emergency situations) as well as additional requirements if necessary, appropriate operating conditions for planned maintenance measures on the SFPC system are to be selected plant-specifically, provided that the condition of a 10h grace time for the SFP can be complied with.

- For the BWR, it is to be noted that not all of the cooling possibilities mentioned above are immediately available with the residual heat removal trains in all operating phases. It should therefore be shown that the timely restoration of the availability conditions for trains that become necessary is possible. Otherwise, planned maintenance measures on SFPC trains are to be carried out during operating conditions where the necessary trains are available in a timely manner.

If in the individual case for important reasons, planned maintenance measures during which the function of an SFPC train is not available are carried out with grace times of less than 10h, the following conditions are to be met during the maintenance measures:

- It is to be shown that for event B3-01, assuming an additional single failure, sufficient heat removal capacity can be reliably provided by completion of maintenance or by means of prepared repairs and substitute measures within the actual grace time in order to keep the fuel pool temperature below T_3.
  Note: To determine the grace time, the boundary conditions to be expected for this individual case can be taken into account (e.g. decay heat generation and temperature in the spent fuel pool).
- The resources required for repairs and substitute measures (sufficient and qualified maintenance personnel, stocks of spare parts, special equipment for restart of cooling) are provided at the plant.
- Measures are to be taken to minimise the probability of occurrence of a single failure of equipment for heat removal from the SFP during maintenance.
- The required procedures and boundary conditions must be described in operating documents (e.g. shift instructions) **(Recommendation 1b)**.

5.3 Answer to Question 3 of the BMUB:

Is it necessary to provide additional explanations on the Safety Requirements for Nuclear Power Plants with regard to spent fuel pool cooling, in particular the accidents listed therein, as well as their appropriate practical implementation in terms of safety?

Based on its consultations, the RSK has drawn the conclusion that the provisions of the SiAnf [1] leave room for interpretation with regard to SFP cooling and therefore considers the following explanations to be essential and derives further recommendations from it.

Question 3 of the BMUB is answered according to the following sections:

Section 5.3.1 General explanations (not event specific)
Section 5.3.2 Additional explanations on event B 3-01
Section 5.3.3 Explanations on other events in spent fuel pool cooling (leakages)
Section 5.3.4 Explanations on the design basis earthquake

5.3.1 General explanations (not event specific)

Consideration of operational installations:

Taking into account the preliminary remarks in Chapter 5, the RSK considers crediting of operational trains of the SFPC system to be generally admissible as a substitute measure in the event analysis as far as their reliable function is shown under the respective event boundary conditions (see also [2]).

The RSK emphasises, however, that crediting of installations in this statement that are not part of the safety system (e.g. the third SFP cooling train of the PWR plants), in the safety analysis on the control of events in the SFPC system exclusively refers to this system. To which extent installations that are not part of the safety system can generally be credited in safety analyses of level of defence 3 is a generic question which is the subject of other RSK consultations.

Consideration of repair outage

According to [1], a single failure and unavailability due to maintenance measures are to be postulated for equipment for the control of events of level of defence 3 in case of demand. Here, no distinction is made between planned or unplanned maintenance outages. According to [1] (Annex 4, 2.3 (1)), however, no additional maintenance outage is to be postulated, i.e. in particular no unplanned maintenance outage (repair outage) either, in operating phases C to F for the periods of planned maintenance measures. For periods outside of planned maintenance measures, however, a repair outage is to be postulated for all operating phases.[2]

Just as in the case of planned maintenance, longer term unavailability of a train of the SFPC system due to a repair outage in the case of a postulated event-induced loss of an SFPC train (e.g. as consequential loss of a design basis earthquake) and a postulated single failure may lead to a situation where active equipment is no longer available for SFP cooling.

To be able crediting the possibility of restoring the availability of a train of the SFPC system within the available grace time also in this case, the necessary maintenance resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) for the postulated restoration of the availability of SFPC components within the available grace time are to be provided in a timely manner for a repair outage where the function of an SFPC train (necessary auxiliary and supply functions are to be taken into account) is not available **(see <u>Recommendation 2 below</u>)**.

Thus, there are periods of times due to repair outages during which there can be no single-failure-proof condition with respect to fuel pool cooling.

[2] This differentiation in the SiAnf [1] takes into account the operating experience according to which planned maintenance and inspection/testing measures are carried out in operating phases C to F, e.g. on the emergency cooling and residual heat removal systems and their energy supply, i.e. it can be assumed that, as a rule, maintenance on parts of these systems is planned. Simultaneous occurrence of another i.e. unplanned maintenance case is not postulated during the execution of such planned maintenance measures since this would contradict the single failure concept (no simultaneous occurrence of several independent maintenance cases).

According to [1] (Annex 4, 2.2.3), a no longer given single-failure-proof condition in the safety system in operating phases A and B due to a repair outage can be tolerated if the repair-related unavailability is sufficiently limited in time and the permissible unavailability is specified in the operational documentation or the necessary safety function is reliably ensured otherwise by means of substitute measures. This results in measures that are to be taken when the permissible unavailability is exceeded, e.g. power reductions or plant shutdown. Accordingly, no proof of event control with simultaneous single failure must be provided for the condition of a sufficiently limited repair time.

This requirement applies to power operation of the plant and relates to ensuring the minimum availability of safety systems in power operation (“repair time regulations”). Here, operating conditions with a redundancy degree of n+0 are permitted for a short time against the background that time is required for transferring the plant into a safe state, for example by operational shutdown. In order to prevent processes related with the shutdown which may lead to transients, it can be considered as advantageous from a safety perspective to continued operation of the plant for a period of time which corresponds to the time required for the transfer into a safe state, provided that the single failure-proof condition can be restored within this time.

These boundary conditions of the repair time regulations are not applicable to the trains of the SFPC system, but the RSK holds the view that the basic approach of limiting repair times can also be used for the trains of the SFPC system regarding the issue of simultaneous occurrence of a single failure. Thus, no simultaneous occurrence of a single failure has to be considered in the safety analysis on the control of events for a sufficiently limited repair time, provided that the repair time is minimised as far as possible in such a case. If a single-failure-proof condition in the SFPC system is no longer given due to a repair outage, the fastest possible rectification of this condition must therefore be ensured primarily.

According to [1], Annex 4, Subsection 3.2.1 (1), it is generally applicable that in case of identified deficiencies on safety-relevant equipment resulting in unavailability of the equipment in case of demand, immediate actions to identify the cause of the deficiency and for the elimination of the deficiency shall be initiated. In the case of the SFPC systems, however, additional measures should also be taken in the event of a train loss, such as

- ensuring sufficient resources to restore availability of SFPC trains, and
- minimising the probability of occurrence of further failures in the SFPC system,

Against this background, the RSK makes the following recommendation:

The relevant requirements regarding the availability of the spent fuel pool cooling systems and the measures in the case of unplanned outages should be specified in the requirements and conditions for safe operation.

In situations where the resistance of the SFPC systems to a single failure is not given, the provision of sufficient resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) in a timely manner must be ensured for restoring the availability of failed SFPC trains. Moreover, measures are to be defined to reduce the probability of further failures in the SFPC system **(<u>Recommendation 2</u>**).

Concurrent loss of offsite power:

For events of level of defence 3, loss of offsite power is to be postulated. When switching on the devices supplied with emergency power, manual measures can be credited in the analyses under the boundary conditions to be observed in the event of an accident.

Consideration of real parameter values:
In the case of planned and unplanned maintenance measures, real parameter values (e.g. decay heat, initial pool water temperature and service water temperature, heat storage capacity of the pool internals) can be used for determining the grace times.

5.3.2 Additional explanations on event B 3-01

General boundary conditions:
In the SiAnf, event B3-01 is described as the loss of two trains of the spent fuel pool cooling system for a longer period. Interpretation I-5, Section 5 of the SiAnf [4] provides a specification on this event by defining that the event sets in with the loss of a train in operation during the unavailability of a second train due to planned maintenance measures. Therefore, the simultaneous loss (due to a common mode) of two trains of the SFPC systems is not to be postulated, but there is already a maintenance outage at the time of the event.

For the safety analysis according to SiAnf, Annex 4, Section 2.3, a single failure shall be postulated for the periods of planned maintenance. Occurrence of a single fail is therefore also to be postulated for the SFPC systems in addition to the loss of a train in operation during the unavailability of a second train due to planned maintenance measures.

The loss of a train of the SFPC system postulated in event B3-01 and the planned maintenance of another train refer to all trains, including those which are not part of the safety system. Accordingly, all SFPC trains must be included in the considerations.

Event B3-01 during planned maintenance measures:
According to the SiAnf, event B3-01 is to be postulated under the boundary condition that a complete SFP cooling train is unavailable due to planned maintenance measures. In the case of planned maintenance measures on the interconnected SFP cooling trains of the PWR, these are only to be considered as unavailable if the function of spent fuel pool cooling is not available during the planned maintenance measures. Pool cooling may remain available via such a train during planned maintenance measures on redundant components (e.g. redundantly available pumps of the interconnected trains) so that the unavailability of this train would not have to be postulated.

Event B3-01 without planned maintenance measures:
There is a consensus within the RSK that by refraining from carrying out a planned maintenance, the boundary condition of event B3-01 "Unavailability of a second train due to planned maintenance measures" can be excluded. For the purpose of an overall consideration, however, the "loss of one train of the SFPC system in operation for a longer period" should be considered under the assumption of a single failure. By refraining

from carrying out a planned maintenance, the SFPC train thus remaining available can be credited for ensuring correct temperature and available grace time.

With regard to a repair outage to be postulated, see the explanations in Chapter 5.3.1.

If an available train is able to ensure long-term maintenance of temperature T_3, no further measures are necessary in this case.

When considering failure combinations where only one train remains available but which is not able to ensure the permissible condition (T_3) in the long term, it is to be shown that with the remaining train and taking into account the heat capacity of the fuel pool, there will be a grace time of at least 10 hours left until reaching T_3. In this case as well, the required maintenance resources should be kept available in accordance with the SiAnf, Interpretation I-5, Section 5 **(see Recommendations 1 and 2)**.

Operating conditions without planned maintenance, for which a grace time of more than 10 hours is not given, taking into account the heat capacity of the fuel pool as well as after occurrence of an event, taking into account a single failure at remaining trains of the SFPC system, are to be prevented by limiting the energy inventory of the spent fuel pool by appropriate workflow planning. The boundary conditions required for it should be specified in the requirements and conditions for the operation of the plant **(Recommendation 3)**.

5.3.3 Explanations on other events in spent fuel pool cooling

Annex 2 of [1] also includes the following events, which also concern the function of the SFPC system:

- B3-02: Loss of coolant from the spent fuel pool due to leaks with a cross section > DN25 up to the largest connecting pipe
- B3-03: Leak at the reactor well or setdown pool with opened refuelling slot gate[3]
- B3-04: Internal leak in heat exchangers of the spent fuel pool carrying coolant

As in the case of event B3-01, events B3-02 und B3-04 may lead to the loss of an SFPC train due to the initiating event postulated for all operating phases and to the unavailability of two further trains when applying the single failure concept (single failure and maintenance).

In the case of the PWR, this has the effect, as in event B3-01, that initially there will be no more active functions available for SFP cooling.

This is not the case for the BWR – except for leak events which would result in a loss of three trains – or in operating phases A and B, during which not all trains are immediately available, only until restoration of the availability conditions for trains that become necessary.

[3] see additional boundary conditions and notes in Annex 2, Table 5.3, on event B3-03 in [1].

The following considerations are limited to event B3-02, serving as an example.

Leak sizes and leak positions to be postulated:

Event B3-02 (loss of coolant from the spent fuel pool due to leaks with a cross section > DN25 up to the largest connecting pipe) as well as the additional boundary condition for this event stated in [1] “Maximum cross-sectional area: area of the largest connecting pipe” refer to a leak size up to the largest connecting pipe to the SFP. Furthermore, according to [1], where applicable, the conditions for other pipes of the external systems of PWRs and BWRs (ibid Annex 2, Appendix 2, Section 4.2) can be of relevance or also the conditions for operational systems (2A leaks of pipes) in case of appropriate design. According to these boundary conditions, the leak sizes and leak positions are to be defined plant-specifically.

Supported by international experience [6] and in German plants, for example [7], the RSK holds the view that leaks on the SFPC systems are caused by maintenance procedures or other human errors rather than by inherent failures of pipes. In order to minimise such leak events, the RSK recommends to generally apply the principle of double shut-off when working on SFPC systems (shut-off of the pipes connected to the fuel pool by means of two reliable shut-off devices (e.g. valves or qualified plugs)). Exceptions to this principle should be limited to work on the first source shut-off valves in the piping downstream of the fuel pool **(Recommendation 4)**.

Also when considering double shut-off, maintenance-induced leaks at SFPC trains as well as their possible leak positions must be taken into account when defining the leak sizes to be postulated.[4]

Furthermore, from the RSK's point of view, it follows from the context of the previous and current rules and regulations [3] that event B3-02 relates to leaks in the pipes of the SFPC system and not to leaks in the structural components of the spent fuel pool (lining or concrete structure) themselves.

Event sequence to be considered specifically for B3-02 and B3-03:

During the course of event B3-02, the leak results in lowering of the water level in the SFP in both the PWR and the BWR. Insofar as a correspondingly unfavourable leak position is postulated or leak shut-off, possibly due to a single failure, is to be postulated to be ineffective, the water level in case of event B3-02 may fall below the lowest suction pipe of the SFPC trains or, in case of event B3-03, down to the lower edge of the refuelling slot gate, with the effect that there will be no more active functions available for SFP cooling independently of the loss of trains to be postulated according to the single failure concept. In this case, it is to be shown that possibly necessary leak isolation, the necessary refilling of the SFP to a level which restores cooling possibility via one of the SFPC trains, and the activation of an available train can be effected in time before reaching T_3. The assessment of the feasibility of the necessary activities to isolate the leak and to refill the SFP shall consider the local ambient conditions (temperature, humidity, visual conditions, radiation level) that may occur.[5]

[4] Double shut-off of pipes of the SFPC systems connected to the fuel pool is also to be considered, depending on the place of work and activity, under the aspects of “barrier integrity containment” and “plant-internal flooding”.

[5] In some PWRs, there are no shut-off valves for isolating leaks in the SFPC systems within the containment (e.g. in the feed lines of the connected SFPC systems). This is also to be taken into account when defining leak size and leak position as well as a single failure and the measures for restart of the SFPC systems.

Against this background, the RSK takes the view that for events with loss of water from the SFP,

- equipment and measures should be kept available for sufficiently fast leak isolation,
  and
- full core unloading into the SFP should only take place if the resulting grace time until reaching T_3 is larger than the time required for leak isolation and restart of cooling, taking into account the reduced coolant volume due to the leak **(Recommendation 5)**.

5.3.4 Explanations on the design basis earthquake

It is to be postulated that after a design basis earthquake (DBE) only those trains of the SFPC system are available whose functional capability has been demonstrated for the DBE. Accordingly, two trains are to be assumed to be still available each for PWRs and BWRs (see Section 3; for the PWR, these are the two interconnected SFP cooling trains and, for the BWR, the two trains TH2 and 3 of the emergency cooling and residual heat removal system designed to withstand a DBE, where the ZUNA system can be used additionally for SFP cooling in case of opened refuelling slot gate[6]). The application of the single failure concept according to [1] to these remaining SFPC trains has the effect that in case of a maintenance measure which leads to the availability of only one remaining SFPC designed to withstand a design basis earthquake, there will be no more active functions available for SFP cooling (in the case of the BWR if ZUNA is not available for the SFP cooling function either).[7]

With regard to <u>(planned or unplanned)</u> maintenance measures, the following additional aspects are to be considered:

The measures to be provided according to Recommendations 1 and 2 for restoring the availability of an SFPC train within the available grace time must be initiated when there is only one DBE-qualified SFP cooling train left and must be effective under the boundary conditions of an earthquake **(<u>Recommendation 6</u>)**.

In the case of the BWR, the closure of the refuelling slot gate (which involves unavailability of the ZUNA system for SFP cooling) should only be carried out if there will be a grace time of more than 10 hours until reaching design basis temperature T_3 after a design basis earthquake, applying the single failure concept (i.e. in case of loss of TH2 and TH3 postulated by it) **(<u>Recommendation 7</u>)**.

[6] In this statement, the ZUNA system is credited by the RSK in terms of a sufficiently reliable substitute measure. The RSK, however, did not carry out its own reviews of the quality or reliability of this system.

[7] Since integrity of pipe sections of the third train in the annulus has not been proven for the PWR, a leak is to be postulated in this train in the event of a design basis earthquake. For the BWR, no earthquake-induced leak is to be postulated for one of the SFPC trains as specified by design.

6 Recommendations

The following recommendations are made on the basis of the investigations carried out within the framework of this recommendation with regard to existing system configurations and designs. Explanations on the recommendations are given in the respective chapters. The extent to which the principles of the assessment have been implemented in the different plants must be verified in the individual supervisory and licensing procedures.

Recommendation 1:

a) Planned maintenance procedures during which the function of an SFPC train (necessary auxiliary and supply functions are to be taken into account) is not available, should be carried out during operating conditions where there is a grace time of at least 10 hours until excess of T_3 after occurrence of event B3-01 in combination with a single failure. The necessary maintenance resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) for restoring the availability of SFPC components within the available grace time are to be ensured for the period of planned maintenance.

b) If in the individual case for important reasons, planned maintenance measures during which the function of an SFPC train is not available are carried out with grace times of less than 10h, the following conditions are to be met during the maintenance measures:

- It is to be shown that for event B3-01, assuming an additional single failure, sufficient heat removal capacity can be reliably provided by completion of maintenance or by means of prepared repairs and substitute measures within the actual grace time in order to keep the fuel pool temperature below T_3.
  Note: To determine the grace time, the boundary conditions to be expected for this individual case can be taken into account (e.g. decay heat generation and temperature in the fuel pool).
- The resources required for repairs and substitute measures (sufficient and qualified maintenance personnel, stocks of spare parts, special equipment for restart of cooling) are provided at the plant.
- Measures are to be taken to minimise the probability of occurrence of a single failure of the equipment for heat removal from the SFP during maintenance.
- The required procedures and boundary conditions must be described in operating documents (e.g. shift instructions).

Recommendation 2:

The relevant requirements regarding the availability of the spent fuel pool cooling systems and the measures in the case of unplanned outages should be specified in the requirements and conditions for safe operation.

In situations where the resistance of the SFPC systems to a single failure is not given, the damage must be rectified as soon as possible by the provision of sufficient resources (sufficient and qualified maintenance personnel, stocks of spare parts, etc.) for restoring the availability of failed SFPC trains. Moreover, measures are to be defined to reduce the probability of further failures in the SFPC system and substitute measures to be provided for their control.

Recommendation 3:

Operating conditions without planned maintenance, for which a grace time of more than 10 hours is not given, taking into account the heat capacity of the fuel pool as well as after occurrence of an event, taking into account a single failure at remaining trains of the SFPC system, are to be prevented by limiting the energy inventory of the fuel pool by appropriate workflow planning. The boundary conditions required for it should be specified in the requirements and conditions for the operation of the plant.

Recommendation 4:

Supported by international experience [6] and in German plants, for example [7], the RSK holds the view that leaks on the SFPC systems are caused by maintenance procedures or other human errors rather than by inherent failures of pipes. In order to minimise such leak events, the RSK recommends to generally apply the principle of double shut-off when working on SFPC systems (shut-off of the pipes connected to the fuel pool by means of two reliable shut-off devices (e.g. valves or qualified plugs)). Exceptions to this principle should be limited to work on the first source shut-off valves in the piping downstream of the fuel pool.

Recommendation 5:

The RSK takes the view that for events with loss of water from the SFP,

- equipment and measures should be kept available for sufficiently fast leak isolation,
  and
- full core unloading into the SFP should only take place if the resulting grace time until reaching T_3 is larger than the time required for leak isolation and restart of cooling, taking into account the reduced coolant volume due to the leak.

Recommendation 6:

With regard to (planned or unplanned) maintenance measures, the following additional aspects are to be considered:

The measures to be provided according to Recommendations 1 and 2 for restoring the availability of an SFPC train within the available grace time must be initiated when there is only one DBE-qualified SFP cooling train left and must be effective under the boundary conditions of an earth-quake.

Recommendation 7:

In the case of the BWR, the closure of the refuelling slot gate (which involves unavailability of the ZUNA system for SFP cooling) should only be carried out if there will be a grace time of more than 10 hours until reaching design basis temperature T_3 after a design basis earthquake, applying the single failure concept (i.e. in case of loss of TH2 and TH3 postulated by it).

5 References

[1] Sicherheitsanforderungen an Kernkraftwerke, 03. März 2015, BAnz AT 30.03.2015 B2

[2] KTA 3303, Wärmeabfuhrsysteme für Brennelementlagerbecken von Kernkraftwerken mit Leichtwasserreaktoren ‚Regeländerungsentwurf - Fassung 2014-11

[3] KTA 2502, Mechanische Auslegung von Brennelementlagerbecken in Kernkraftwerken mit Leichtwasserreaktoren, Fassung 2011-11

[4] Interpretationen zu den „Sicherheitsanforderungen an KKW vom 22. November 2012“, Änderung der Bekanntmachung der Interpretationen zu den Sicherheitsanforderungen an Kernkraftwerke vom 22. November 2012, 3. März 2015

[5] IAEA Safety Standards No. SSG-15 “Storage of Spent Nuclear Fuel”, February 2012

[6] NEA/CSNI/R (2015) 2 “Status Report on Spent Fuel Pools under Loss-of-Cooling and Loss-of-Coolant Accident Conditions”; Nuclear Safety, May 2015

[7] KKP 2, Sicherheitstechnische Bewertung des Ereignisses „Wasserverlust aus dem Brennelementlagerbecken (Ereignisdatum: 17.6.2010)“