Note:
This is a translation of the RSK statement entitled
“Anforderungen bei einer passiven Kühlung der Brennelemente im Lagerbecken”
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK statement
(509th meeting of the Reactor Safety Commission (RSK) on 27 March 2019)

Requirements in connection with passive spent fuel pool cooling

1 BMU advisory request and consultations

In a letter dated 9 February 2018 [1], the BMU asked the RSK to answer the question:

In the opinion of the RSK, which systems are necessary to ensure cooling of the fuel still present in the spent fuel pool after transition to the decommissioning phase?

In addition to the cooling and injection systems, systems such as ventilation systems, isolation valves and emergency power supply systems should also be considered, also including aspects of robustness considerations, emergency conditions and in the area of design extension conditions.

At the 130th meeting of the Committee on PLANT AND SYSTEMS ENGINEERING (AST) on 28 March 2018, the advisory request from the BMU was discussed. To prepare further consultations, an ad hoc working group dealt with this advisory request on 26 April 2018 in Hanover and prepared a draft statement. The AST Committee discussed this draft at its 131st, 132nd and 133rd meeting on 17 May 2018, 5 July 2018 and 13 September 2018. On 26 September 2018, the ad hoc working group met in Cologne to revise the draft statement, which was adopted at the 134th AST meeting on 25 October 2018. The RSK discussed the statement at the 506th to the 508th meeting and adopted it at its 509th meeting on 27 March 2019.

2 Background

Based on the 13th Act Amending the Atomic Energy Act (AtG), the power operation licences for commercial generation of electricity expire at the latest on the dates specified in the Act. With the last shutdown for permanent cessation of power operation, the plants are entering the post-operational phase. Until granting of the decommissioning and dismantling licence in accordance with § 7(3) AtG, operation of the plants in this phase shall be carried out in accordance with the applicable operating licence and, in particular, in accordance with the provisions on non-power operation (plant shutdown). With the granting and utilisation of a decommissioning and dismantling licence, residual operation commences. For the remaining plant components still in use, the operating licence shall, in general, initially continue to apply. Residual operation can be structured in several phases, e.g. “residual operation with active or passive spent fuel cooling” or "with or without fuel assemblies/fuel”.

3 Requirements of nuclear rules and regulations / assessment criteria

For residual operation (starting with the utilisation of the decommissioning licence) and dismantling, the "Guide to the decommissioning, the safe enclosure and the dismantling of facilities or parts thereof as defined in § 7 of the Atomic Energy Act" is particularly relevant.

It states: *If there are still fuel assemblies in the nuclear facility, it is to be shown for planned dismantling measures that these will have no retroactive effects on the safe operation of systems and components necessary for compliance with the protection goals.* and *As long as there is still nuclear fuel in the facility during decommissioning exceeding the masses or concentrations mentioned in § 2(3) AtG, all necessary safety precautions must continue to be observed and must be included in the corresponding considerations.*

For the safety assessment of events, the guideline states that it must be oriented towards "the provisions set out in §§ 46, 47, 50 StrlSchV and all other protective requirements of the StrlSchV."[1]

Annex 2 of this guide classifies the rules and regulations in terms of their applicability to decommissioning procedures. The safety requirements for nuclear power plants (*Sicherheitsanforderungen an Kernkraftwerke* – SiAnf) and their interpretations are classified as follows:

The rule is applicable after adaptation to the protection goals or partially applicable to decommissioning procedures, taking account of the changed and in many respects reduced potential hazard and the modified requirements compared to construction and operation.

Annex 3 of this guide states:

The safety requirements for nuclear power plants are to be applied as appropriate to the requirements of decommissioning.
The defence-in-depth concept as presented in the safety requirements for nuclear power plants is not applicable to decommissioning. However, the technical requirements described are to be applied for compliance with the protection goals stated and with the radiological safety objectives, adapted to the events still to be postulated during the decommissioning phase so that these events can be avoided or controlled. Requirement 3.11 (7)[2] *refers to decommissioning.*

If there are still fuel assemblies in the nuclear facility, the following event categories (based on the safety requirements for nuclear power plants) are also relevant:

- *reduced heat removal from the spent fuel pool,*
- *loss of coolant from the spent fuel pool,*
- *reactivity changes in the spent fuel pool and criticality accident, and*
- *events during handling and storage of fuel assemblies*

[1] The amendment of the radiation protection law in 2018 did not lead to a change in content of the relevant requirements.
[2] "*The condition of nuclear power plants shall be such that they can be decommissioned in compliance with the radiation protection regulations. A concept shall exist for their removal after final decommissioning in compliance with the radiation protection regulations.*"

The applicability of the various KTA safety standards to residual operation and dismantling is also specified. Accordingly, the requirements of the KTA safety standards of the KTA 3500 series, KTA 3601, KTA 3602 and the KTA 3700 series shall be applied within the scope of decommissioning while there is still nuclear fuel in the plant.

Finally, the ESK Guidelines for the decommissioning of nuclear facilities define fundamental safety functions (subcriticality and residual heat removal) as well as events and refer again to the SiAnf:
As far as required from a safety point of view, the relevant requirements of the "Safety Requirements for Nuclear Power Plants" are also to be taken into account.

4 Consultation results

4.1 Scope

The advisory request [1] relates to residual operation with fuel assemblies or fuel rods still stored in the spent fuel pool. In order to answer the question in [1], which systems are required to ensure cooling, it is helpful from the RSK's point of view to subdivide this phase of residual operation into different phases depending on the residual heat to be removed.

This statement deals with the phase of residual operation in which the residual heat (resulting from remaining fuel assemblies and/or remaining individual fuel rods) to be removed is reduced to such an extent that the following condition is met:

> In the event of a failure of the active systems, a fuel pool temperature of 60 °C will not be exceeded by utilisation of passive cooling in the long term (corresponding to temperature T2 from KTA 3303).

For the case that in this phase of residual operation (hereinafter referred to as the phase with possible passive cooling) changes to availability requirements are to be made for systems for residual heat removal or spent fuel pool water make-up, the events to be considered, the fundamental safety functions and acceptance criteria as well as safety demonstration requirements are described below and the minimum requirements for the scope and type of systems to be kept available are derived.

4.2 Fundamental safety functions and events to be considered

For the phase with possible passive cooling as defined in Section 4.1, the fundamental safety functions according to Section 2.3 of the SiAnf

- reactivity control (R),
- fuel cooling (K), and
- confinement of radioactive material (B),

and according to Section 2.5 of the SiAnf

- the radiological safety objectives (S)

are to be fulfilled and maintained. To verify fulfilment of these functions, the following event categories are to be considered according to the "Guide to the decommissioning, the safe enclosure and the dismantling of facilities or parts thereof as defined in § 7 of the Atomic Energy Act" (Annex 3) (if fuel assemblies or fuel are still in storage there):

- reduced heat removal from the spent fuel pool,
- loss of coolant from the spent fuel pool,
- reactivity change in the spent fuel pool and criticality accident,
- events during handling and storage of fuel assemblies.

These event categories are also to be considered for the phase with possible passive cooling as defined in Section 4.1.

According to the Radiation Protection Ordinance (StrlSchV), specified normal operation and safety-relevant events (design basis accidents) shall be considered. In accordance with the advisory request [1], considerations on emergency conditions as well as on robustness and in the area of design extension conditions are supplemented.

4.3 Acceptance criteria

The safety demonstrations for the following event categories stated in Section 4.2

- reactivity change in the spent fuel pool and criticality accident, and
- events during handling and storage of fuel assemblies

are to be performed in accordance with the SiAnf. Subcriticality in the spent fuel pool is to be demonstrated for all plants, even if the core is fully unloaded. Alternatively, this can be provided by boron credit or under consideration of an actually existing minimum burn-up of the fuel in the spent fuel pool and this demonstration covers the possible conditions during residual operation.

For the radiological safety objectives S regarding events during handling and storage of fuel assemblies, the relevant limits of the StrlSchV apply. Compared to the condition of a fully unloaded core after power operation, handling during residual operation may result in lower technical system requirements due to the radioactive decay of dose-relevant nuclides.

Furthermore, it is to be shown for fundamental safety function B and safety objectives S that the radiological limits are not violated by the activity released as a result of evaporation.

In any case, sufficient water coverage and cooling of the fuel assemblies is a prerequisite for the fulfilment of fundamental safety function B and the safety objectives S. On the basis of the above explanations, the statement concentrates on fundamental safety function K “fuel cooling” and the related event categories

- reduced heat removal from the spent fuel pool, and
- loss of coolant from the spent fuel pool.

According to the SiAnf (Annex 2, Table 3.2), fundamental safety function K is fulfilled if the spent fuel pool water temperature on the second level of defence remains limited to values which ensure accessibility of the pool area by customary measures and if the water coverage is sufficient to ensure the required inlet conditions for the pool pumps. It shall be demonstrated on the third level of defence that the spent fuel pool water temperature remains below the design temperature of the spent fuel pool and that the water coverage is sufficient for ensuring fuel assembly cooling. These objectives are considered to have been met if specified spent fuel pool water temperatures are demonstrated. The admissible spent fuel pool water temperatures are listed in KTA 3303 according to the levels of defence and are 45, 60 and 80 °C, respectively.

If in the phase with possible passive cooling as defined in Section 4.1 changes to the availability requirements for systems for residual heat removal or spent fuel pool water make-up are intended, compliance with the following acceptance criteria is to be demonstrated with regard to fundamental safety function K:

- During specified normal operation, a maximum fuel pool water temperature of 45 °C and the operationally required minimum water level in the spent fuel pool must continue to be maintained (assignment to the first level of defence according to the SiAnf).

- For all events to be postulated on the second level of defence according to the SiAnf, it is to be demonstrated that without the use of any active equipment (i.e. “passive cooling”) the acceptance criteria of the second level of defence are met. Thus, a maximum spent fuel pool water temperature of 60 °C is to be maintained.

- For the initiating events on the third level of defence according to the SiAnf it has to be shown that the passive heat transport prevents a spent fuel pool water temperature of 60°C to be exceeded, taking the requirements in Section 4.4 into consideration. The acceptance criteria on the second level of defence are also not exceeded if all boundary conditions to be applied in accordance with the SiAnf for safety demonstration on the third level of defence are taken into account.

  Notes:
  Compliance with this spent fuel pool water temperature also ensures that the reactor service floor is generally accessible for the performance of measures[3].

  The requirement regarding the inlet conditions for the pool pumps is not relevant in the operating condition under consideration since no credit is taken from the operation of the pool pumps.

[3] KTA 3303: *“T2 is the temperature of an abnormal fuel pool operation. It is specified as 60°C because it can be assumed that, up to 60°C with the associated steam moisture [...] necessary tasks can be performed.”*

- The water coverage required for cooling is given if the fuel rods are completely covered with water. However, a higher water level (radiation shielding) is required to ensure that the reactor service floor can be accessed. Under this aspect, a radiologically required minimum spent fuel pool level of approx. 3 m above the upper edge of the fuel assemblies (approx. 2.7 m below the deepest fuel pool connecting pipe in a PWR) is assessed to be an appropriate acceptance criterion[4]. The issue of fuel pool water make-up is dealt with in Section 4.4 under the event category "Loss of coolant from the spent fuel pool".

4.4 Specific requirements for fundamental safety function K

Specified normal operation

Compliance with a maximum spent fuel pool water temperature of 45 °C[5] can be demonstrated by using active cooling systems (fuel pool cooling systems, recirculation coolers and ventilation systems). Evaporation losses are compensated by a water make-up system.

For the safety demonstration, external boundary conditions are applied in accordance with KTA 3303 (e.g. outdoor air temperature, humidity).

Event category: Reduced heat removal from the spent fuel pool

The failure of all active cooling systems is postulated. In this case, it is to be shown that the decay heat is passively transferred to the environment up to a maximum spent fuel pool water temperature of 60 °C (by evaporation, convection, heat conduction in and through concrete to the atmosphere or soil). The safety demonstration is to be based on the boundary conditions for the heat sink in accordance with Section 4.3 of KTA 3303.

The water volume of the spent fuel pool is dimensioned in such a way that a safety-relevant decrease of the water inventory by evaporation in the periods to be considered for event control is not to be expected, taking into account the maximum decay heat power to be postulated for the phase of residual operation under consideration here. The evaporation losses are less than 5 m^3 per day at a spent fuel pool temperature of 60 °C in the case of a failure or intentional deactivation of the ventilation system (determined e.g. in accordance with VDI 2089[6] [2] or [3]). Air humidity in the area of the spent fuel pool rises rapidly without active ventilation and reduces evaporation losses. This means that compensation of evaporation losses to maintain the radiologically required minimum water level specified in Section 4.3 is only required in the very long term (in the range of weeks).

4 Accident mitigation manual *(Handbuch mitigativer Notfallmaßnahmen)* for PWR 1,300 MW: For full core unloading with a decay time of 300 days, a dose rate of less than 0.01 mSV results for a pool level of approx. 3 m above the upper edge of the fuel assemblies (visual contact FAs).

5 In practice, a value of max. 30°C is targeted for operational reasons.

6 Example calculation: with an air temperature above the fuel pool of 50°C at 80 % relative humidity, a 105 m^2 pool surface and a conservatively high evaporation coefficient (ε=15), the amount of evaporation is 3.8 m^3 per day.

Thus, the plant is passively transferred to a controlled plant state according to [6] for this event category. This means that no requirements have to be applied for active cooling systems or make-up systems that go beyond the operational requirements. In this case, emergency power supply for the necessary equipment is not required either.

Event category: Loss of coolant from the spent fuel pool

For demonstrating passive cooling, loss of coolant via connecting pipes of the spent fuel pool cooling system (see SiAnf event B3-02) is to be postulated and superimposed with a failure of active systems. A leak in these pipes results in a maximum level drop to the lower edge of the connecting pipe. Thus, the water level (>3 m above the upper edge of the fuel assemblies) will be sufficient to ensure accessibility in the area of the spent fuel pool (i.e. for radiation shielding). In this case, too, it is to be shown that the decay heat is passively transferred to the environment up to a maximum spent fuel pool water temperature of 60 °C.

The grace period for compensating evaporation losses to maintain a radiologically required minimum water level is reduced due to the leakage-related level drop. As for the compensation of evaporation losses to maintain the radiologically required minimum water level specified in Section 4.3, compensation in this case is only required in the very long term (in the range of weeks) due to the limited maximum decay heat generated in the spent fuel pool for the phase of residual operation under consideration here with passive cooling capability. This means that no requirements arise for active cooling systems or make-up systems that go beyond the operational requirements. In this case, emergency power supply for the necessary equipment is not required either.

A relevant water loss via lower leak positions must continue to be excluded by precautionary measures. For the event of a leakage in the spent fuel pool liner, reliable level monitoring and the possibility of timely isolating the leakage collection pipes is to be maintained.

Earthquake

For the initiating event “earthquake”, a level drop as in the preceding event category as well as a failure of the existing make-up system may be assumed due to a failure of non-earthquake resistant pipe sections of the spent fuel pool cooling system. In this case, an additional possibility of make-up water injection shall be provided that is also available after an earthquake. In the opinion of the RSK, substitute measures can also be credited (e.g. injection from an emergency feed water tank or fire extinguishing system, among others by mobile pumps on installed pipes leading to the spent fuel pool), provided that their effectiveness after an earthquake has been demonstrated. Furthermore, if one of the installed fuel pool cooling trains designed against earthquakes continues to be used for the purpose of operational fuel pool cooling, a loss of active spent fuel pool cooling as well as of the possibility of make-up water injection can be prevented in the event category earthquake. For this fuel pool cooling train, emergency power backup is not required. Further requirements for make-up water injection result from considerations regarding robustness or beyond-design-basis events (see next section).

According to KTA 2502, a loss of integrity of the spent fuel pool during an earthquake with resulting relevant water losses from the spent fuel pool is to be excluded by design.

Emergency conditions

The impacts of emergencies on the spent fuel pool are controlled by the design of the reactor building and do not lead to any plant states with a greater level drop than in the event of a loss of coolant as initiating event. With regard to make-up water injection, credit can also be taken from the above-mentioned substitute measures.

4.5 Robustness considerations, area of design extension conditions

With regard to robustness and the area of design extension conditions, impacts on the spent fuel pool are to be considered that could lead to more severe water losses from the fuel pool than those assumed in Section 4.4.

With the exception of the crash of a fuel assembly transport cask into the spent fuel pool or the cask loading pool, no impacts from internal or external hazards[7] on the spent fuel pool have been identified by the robustness considerations in the context of power operation of the plants which would lead to more severe water losses than postulated for the event category "Loss of coolant from the spent fuel pool", or for the control of which the entirety of the spent fuel pool make-up systems available during power operation is required.

With regard to the crash of a fuel assembly transport cask into the spent fuel pool, the RSK [4] states that for PWRs "loss of spent fuel pool water" should be analysed. In this context, the possibility of overfeeding a fuel pool water leakage should be checked and specific accident management measures should be introduced, if necessary. Alternatively, it is to be demonstrated in more detail by which measures crashing or falling over of a fuel assembly transport cask into the spent fuel pool is prevented so reliably that it can be excluded (with regard to cliff edge effects). Therefore, the fulfilment of this RSK recommendation is to be demonstrated under the conditions of decommissioning too. For BWRs, crashing of a fuel assembly transport cask into the fuel pool can be excluded according to [4].

In the case of a postulated crash of a fuel assembly transport cask into the cask loading pool according to [4], for PWRs, a maximum level drop to the upper edge of the separating wall (threshold) between cask loading pool and spent fuel pool can occur due to leakages, which will not lead to uncovering of fuel assemblies. In this case, there will be higher water losses from the fuel pool than in the event category loss of coolant. Under the boundary conditions on which this statement is based, a grace period of at least one week is available for measures until the water level decreases due to evaporation, leading to uncovering of fuel assemblies. During this time, the necessary measures for the injection of make-up water and maintaining the water level can be taken. For make-up water injection and maintaining the water level at the height of this separating wall upper edge, the injection options specified in Section 4.4 are available. In this context, it must be noted that the water level in the fuel pool may drop to about only 35 cm above the fuel assemblies so that, for this reason, increased radiological loads in the area of the reactor service floor are to be expected.

[7] With regard to a beyond-design-basis aircraft crash, the RSK refers to the RSK statement [5] as regards Konvoi plants and, as regards pre-Konvoi and SWR 72 plants, to still ongoing consultations of the RSK.

In order to ensure injection of make-up water into the spent fuel pool in the long term, the RSK is of the opinion that a measure for recirculating leakage water from the containment sump to the spent fuel pool has to be implemented. Here, boundary conditions during plant dismantling that may deviate from power operation have to be considered (e.g. increased ingress of dirt and foreign matter into the containment sump). The possibility of implementing these options regarding make-up water injection and recirculation must therefore also be demonstrated under these aforementioned boundary conditions.

According to [4], relevant damages leading to leakages can be excluded for BWRs due to the design of the cask loading pool.

4.6 Basic requirements

The above consultation results of the RSK presuppose that

- the requirements of KTA 3602, Section 4 – as far as applicable to this phase – are met,
- all measures credited in the course of event control are described in written operating procedures,
- also during the decommissioning phase, there is still sufficient qualified personnel available at the plant to ensure that the substitute measures can be carried out within the specified grace period,
- no activities are carried out during decommissioning that could have a retroactive effect on the safe storage and handling of fuel assemblies in the spent fuel pool,
- in particular, the handling of heavy loads in the phase of residual operation does not change, relevant precautionary measures are maintained where necessary, and thus there will be no handling of large components above the spent fuel pool (e.g. steam generator dismantling) in this plant state and the inspection concept for the relevant plant components will be continued, and
- leakages at the spent fuel pool liner can still be sealed.

5 References

[1] Beratungsauftrag des BMUB
(AZ RS I 3 (M) - 17018 / 1), 09.02.2018

[2] Richtlinie VDI 2089
Technische Gebäudeausrüstung von Schwimmbädern; Hallenbäder

[3] Methods for Calculation of Evaporation from Swimming Pools and Other Water Surfaces
Energy and Buildings (June 2012), Published in ASHRAE Transactions, Volume 120, Part 2.

[4] RSK-Stellungnahme (496. Sitzung der Reaktor-Sicherheitskommission (RSK) am 06.09.2017), Bewertung der Umsetzung von RSK-Empfehlungen im Nachgang zu Fukushima

[5] Zusammenfassende Stellungnahme der RSK zu zivilisatorisch bedingten Einwirkungen, Flugzeugabsturz, Teilbericht: Festlegung der Lastannahmen und Bewertung der Konvoi-Anlagen, RSK 499, 30.11.2017

[6] RSK-Stellungnahme (439. Sitzung der Reaktor-Sicherheitskommission (RSK) am 07.07.2011), Regelungen zu Anlagenzuständen nach Eintritt eines Störfalls