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

RSK statement

(518th meeting of the Reactor Safety Commission (RSK) on 21 October 2020)

Requirements for the cooling of the fuel assemblies in the spent fuel pool during residual operation

Statement

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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 make-up feeding systems, systems such as ventilation systems, isolating valves and the emergency power supply should also be considered. Aspects of robustness considerations, emergency situations and the beyond-design-basis range must also be taken into account.

At the 130th meeting of the Committee on PLANT AND SYSTEMS ENGINEERING (AST) on 28 March 2018, the BMU's advisory request was discussed. In preparation of the further consultations, an ad hoc working group convened in Hanover on 26 April 2018 exchanged views on the present advisory request and initially prepared a draft statement that was limited to plant conditions in which the after-power can be dissipated without active systems in such a way that temperatures of 60° C are not exceeded in the spent fuel pool (passive cooling). The AST Committee discussed this draft at its 131st, 132nd and 133rd meetings on 17 May 2018, 05 July 2018, and 13 September 2018. On 26 September 2018, the ad hoc working group met again in Cologne to revise the draft statement, and the draft was adopted at the 134th AST meeting on 25 October 2018. The RSK discussed the statement at its 506th to 508th meetings and adopted it at its 509th meeting on 27 March 2019 [2].

At the 135th and 136th meetings of the AST Committee, further discussions were held on plant conditions in residual operation that require active heat removal due to the after-power to be removed. An ad hoc working group was asked to prepare a draft statement to conclude the BMU advisory request. The AST Committee discussed this draft at its 137th meeting on 02 May 2019 and continued the consultation at its 139th, 140th, 141st 142nd, 143rd and 144th meetings during the period 09 July 2019 to 14 May 2020 and in editorial group consultations between these meetings. It adopted this document as a draft for the RSK at its 145th meeting on 02 July 2020. The RSK discussed and adopted the statement at its 518th meeting on 21 October 2020.

2 Background

With the 13th Amendment Act to the Atomic Energy Act (AtG), the licences to operate nuclear power plants for the commercial generation of electricity expire at the latest on the dates specified in the Act. With the last shutdown for permanent termination of power operation, the plants enter the post-operational phase. Until the decommissioning and dismantling licence (Stilllegungs- und Abbaugenehmigung - SAG) is granted in accordance with Section 7 (3) of the Atomic Energy Act, the post-operation of the plants has to be carried out in accordance with the valid operating licence and, in particular, in accordance with the provisions on low-power and shutdown operation (plant standstill). Residual operation begins with the take-up of an SAG. Residual operation can be structured in several phases, e.g. "residual operation with active or passive cooling of fuel assemblies" or "with or without fuel assemblies/fuel". Requirements for the phase with passive cooling of the fuel assemblies (FA) were formulated by the RSK in [2]. The following explanations refer to the period of residual operation in which active cooling of the fuel assemblies is required not only on level of defence 1, but also on levels of defence 2 and 3 to maintain temperature criteria in the spent fuel pool.

3 Requirements of nuclear regulations / assessment criteria

3.1 Overriding requirements of nuclear regulations

Essential requirements of the nuclear rules and regulations on spent fuel pool cooling during residual operation have already been presented in Chapter 3 of the RSK statement on passive cooling [2]:

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” (hereinafter referred to as “Guide”), *all necessary safety precautions must continue to be observed as long as there is still nuclear fuel in relevant amounts in the spent fuel pools.*

Accordingly, the "Safety requirements for nuclear power plants" (SiAnf) and various KTA Safety Standards "*remain applicable after adaptation according to the fundamental safety functions or partially applicable, taking account of the changed and in many respects reduced potential hazard and the modified requirements compared to construction and operation*.“

Furthermore, the "ESK Guidelines on the Decommissioning of Nuclear Facilities" define fundamental safety functions (subcriticality and residual-heat removal) and events and again refer 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.“*

According to the Guidelines, the following event categories are also to be considered in residual operation with fuel still present in the plant

- *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, and*
- *events during handling and storage of fuel assemblies.*

According to the SiAnf, normal operation, anticipated operational occurrences and design basis accidents have to be taken into account.

3.2 Acceptance criteria

The main acceptance criteria for the passive cooling phase were formulated by the RSK in Chapter 4 of the RSK statement [2]; these are also applicable to the phase with active pool cooling; if necessary, they are supplemented in the following (e.g. with regard to spent fuel pool temperatures above 60°C):

Reactivity control (fundamental safety function R):

During residual operation, too, the safety demonstrations regarding subcriticality for the event categories

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

have to be performed in accordance with the SiAnf and have to cover all conditions that are still possible in the spent fuel pool during residual operation.

Fuel cooling (fundamental safety function K):

The fundamental safety function K is fulfilled if specified spent fuel pool water temperatures are maintained. These permissible pool water temperatures are listed in KTA 3303 according to the levels of defence (level of defence 1: T_1 = 45° C, level of defence 2: T_2 = 60° C, level of defence 3: T_3 = 80° C).

In the context of beyond-design-basis considerations, it must be shown that even at boiling temperature in the spent fuel pool (approx. 100° C), the decay heat can be removed without causing damage to the FAs [4].

Accidents involving leaks in the spent fuel pool (in particular events B3-02 and B3-03) must be controlled in accordance with the SiAnf. It must therefore also be shown for the conditions of residual operation that for all possible leak locations that can lead to a loss of water from the spent fuel pool (incl. drain lines)

- either a leak can be excluded (VM),
- the leak is isolable within the non-intervention time[1] (e.g. by a plug) and cooling can be resumed, if necessary by make-up water supply,
- or cooling with the existing engineered system and procedures can be resumed despite the leak (e.g. overflow operation with recirculation feeding from the reactor building sump in the case of a PWR).

If additional coolant inventory is necessary for event control, it must be available within the non-intervention time. A relevant water loss via leak locations below the top edge of the FAs must also be excluded during residual operation (VM), e.g. it must still be possible to shut off the leak detection system for the spent fuel pool lining.

Confinement of the radioactive materials and radiological safety objectives (fundamental safety function B and safety objective S):

For the radiological safety objectives S in case of events during the handling and storage of fuel assemblies, the safety-related assessment criteria of the SiAnf apply. Due to the radioactive decay of dose-relevant nuclides,

[1] According to KTA 3303, Section 5.1, the non-intervention time is defined as the time required for the pool to heat up from the operationally intended maximum temperature to the respective permissible temperature, e.g. marked by a "Temperature high" alarm, to the respective permissible pool water temperature T_2 or T_3.

lower requirements in view of systems engineering may result for handling during residual operation compared to conditions with the core fully unloaded after power operation.

In any case, sufficient water coverage and cooling of the fuel assemblies is a prerequisite for compliance with fundamental safety function B and safety objective S.

4 Consultation results

4.1 Potential hazard, safety-related boundary conditions and verifications

As described in the "Guide", the SiAnf "*remain applicable after adaptation according to the fundamental safety functions or partially applicable, taking account of the changed and in many respects reduced potential hazard and the modified requirements compared to construction and operation*."

For the application of this statement, it is assumed that the after-power decay heat is reduced to such an extent that the operation of one spent fuel pool cooling pump (in the case of PWRs, one of the two emergency residual-heat removal pumps) is sufficient to keep the spent fuel pool temperature below the design operational maximum temperature and that, without the operation of active cooling systems, the time required for the spent fuel pool cooling water to heat up from the maximum temperature to reach 80° C (T_3 according to KTA 3303) is > 24 hours.

Note: It is estimated that this boundary condition will be reached at the latest about 150 days after shutdown, even if the spent fuel pool is still completely filled with irradiated FAs.

From the RSK's point of view, the following aspects are particularly relevant with regard to the potential hazard and changed boundary conditions compared to power operation or low-power and shutdown operation:

Reactivity control (fundamental safety function R):

With regard to criticality safety, the requirements of KTA Safety Standard 3602, Section 4.2.6 Criticality Safety, continue to apply. As far as, in the case of PWRs, boron treatment of the pool water is no longer to be taken into account in the verification, it is possible, as already described in [2], to verify subcriticality by taking into account the actual burn-up of the fuel assemblies in the spent fuel pool and possibly reduced fuel quantities.

Confinement of the radioactive materials and radiological safety objectives (fundamental safety function B and safety objective S):

For the plants in operation, the consequential dose for design basis accidents in the spent fuel pool with FA damage is determined by radioisotopes that are easily released from the water, in particular isotopes of iodine, krypton and xenon. After a decay time of about 150 days, the radioactive I-131 (half-life about eight days) and xenon have largely decayed in the plant. If the handling error still to be assumed for fuel assembly handling (design basis accident) is taken as a basis, the activity that can be released into the room air by I-131 has already fallen significantly below the daily limit for discharges at the time considered. For the radiation exposure in the environment, the consequential dose is determined by the remaining amounts of I-131 and the long-lived radionuclides I-129 and Kr-85. However, the consequential dose from these radionuclides in the design basis accident is not only several orders of magnitude below the accident planning levels, but also more than a factor of 1,000 below the limit for specified normal operation (air path).

With regard to the sufficient covering of the fuel assemblies with water, it must be ensured that the maximum radioactive inventory in the spent fuel pool after accidents is maintained at the radiologically required minimum level, which sufficiently limits the dose burden of the plant personnel during work (stay in the hourly range). In [2], a minimum water level of 3 m above the top edge of the fuel assemblies was conservatively postulated. However, from the point of view of the RSK, the minimum level to be maintained can also be determined for concrete boundary conditions.

Fuel cooling (fundamental safety function K):

- In residual operation, there are no requirements to be taken into account for the residual-heat removal chains to remove the decay heat from the reactor core or for emergency core cooling in case of loss-of-coolant accidents. The "linked" cooling trains available in both the PWR and the BWR 72, which are primarily credited for emergency core cooling and residual-heat removal in power and low-power and shutdown operation, are thus available without restriction for pool cooling operation.

- In residual operation, the decay heat to be removed from the spent fuel pool is significantly lower than in the case of a full core load after power operation. 150 days after shutdown of a plant, the maximum power from decay heat is typically about 3 MW. In contrast, at the time of full core load during the maintenance and refuelling outage of a PWR plant, a thermal power of more than 20 MW may occur (13 MW for a BWR 72). The reduced after-power is beneficial for the cooling of the fuel assemblies in several respects:

    - In the case of the BWR 72, the temperature in the spent fuel pool can be kept below the criterion for normal operation (T_1 = 45° C) with each of the cooling trains present in residual operation (two operational pool cooling trains, two emergency core cooling and residual-heat removal trains).

    - In the case of the PWR, the permissible temperature in normal operation T_1 can be maintained by each of the two linked trains for pool cooling with operation of only one emergency residual-heat removal pump, and with the third operational pool cooling train (one pool cooling pump), it is possible to maintain at least the value for abnormal operation (T_2 = 60° C).

    - Compared with conditions in power operation, there are considerably longer non-intervention times, i.e. the transients to be assumed develop comparatively slowly.

As the non-intervention time increases, it will also be possible to credit more complex measures to make failed equipment or equipment undergoing maintenance available again.[2].

- According to KTA 3303 and the RSK recommendation "Requirements for spent fuel pool cooling" of 09 December 2015 [3], substitute measures may also be credited instead of safety systems on level of defence 3, provided that they can be reliably made available within the actual non-intervention time in order to maintain the pool temperature below T_3. With increasing non-intervention times, it will thus also be possible to credit operational and mobile facilities, provided that the effectiveness of these measures is demonstrated under the boundary conditions of the design basis accident under consideration.

- Within the framework of robustness analyses, it was shown under realistic boundary conditions that the integrity of the spent fuel pools is ensured up to 120°C (PWR) and 100°C (BWR 72), respectively. Thus, in the case of beyond-design-basis events, the decay heat can also be removed from the pool by boiling ("evaporation cooling"). Lower after-power in residual operation leads to longer non-intervention times until the pool inventory has to be made up and limits the required make-up rates (approx. 0.5 kg/s per MW of after-power). Due to the small inventory of relevant radioisotopes in the vapour, the latter can also be released into the environment without filter sections, if necessary. (cf. the above considerations on fundamental safety function B and safety objective S).

Requirements for concepts to ensure cooling with consideration of the above points are dealt with in Chap. 4.2.

4.2 Staggering the requirements for the active pool cooling systems depending on the available non-intervention times

4.2.1 Fundamental considerations

As described above, in residual operation there will be a reduction of the potential hazard, leading to increasingly longer non-intervention times for event control.

From the RSK's point of view, it is therefore not necessary from a safety point of view to maintain all pool cooling systems (operational systems and safety systems) provided for power and low-power and shutdown operation until the possible transition to passive cooling of the fuel assemblies. It is rather also possible to demonstrate compliance with the requirements of the defence-in-depth concept as well as the reliable fulfilment

[2] See SiAnf, Annex 4, 2.3 (2): *„A degree of redundancy n+0 is permissible in the operational modes 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.“*
See also KTA 3303, 4.2.4 (2) 1: *"If it can be demonstrated for the design-basis accidents ... including the application of the single failure concept that the non-intervention time ... is at least 10 hours, it may be assumed that one of the unavailable trains is again available".*

of the acceptance criteria on the individual levels with increasing non-intervention times by crediting repairs or re-availabilities as well as substitute measures.

Key aspects regarding

- the defence-in-depth concept,
- the non-intervention times and
- the repair and substitute measures

are explained in more detail below.

In Sections 4.2.2 and 4.2.3, a staggering of the requirements for the active pool cooling systems in the non-intervention time phases, recommended from the point of view of the RSK, is presented in more detail.

Similarly, for the systems of the cooling chain to which the spent fuel pool cooling systems discharge heat, it must be shown which substitute measures are provided for failures that have to be postulated. The measures for the water supply to compensate for losses through humidification and leakages as well as for evaporation losses in robustness analyses are discussed in Sections 4.3 und 4.4.

4.2.1.1 Defence-in-depth concept

The defence-in-depth concept has to be maintained in such a way that event sequences that may not be controlled on one level of defence can be sufficiently reliably controlled on the next level of defence (cf. RSK statement [6] on reference values for the occurrence frequencies of events):

- Level of defence 1:

The temperature in the spent fuel pool has to be kept below T_1 (45°C). Preventive maintenance on pool cooling systems has to be planned in such a way that the temperature will not rise above T_1 (45°C) during the work. If such planning is not possible, measures have to be provided that lead to a resumption of cooling within the non-intervention times until T_1 (45°C) is reached. The corresponding measures have to be carried out before the temperature that has been set as the maximum operational pool water temperature is reached (see Section 4.2.1.2).

Furthermore, the operationally required minimum water level in the spent fuel pool must be maintained.

- Level of defence 2:

If pool cooling should fail due to a cause to be postulated for anticipated operational occurrences (e.g. failure of a train) or if the measures provided for level of defence 1 should not become effective for a resumption of cooling during planned maintenance, measures have to be provided that lead to a sufficiently reliable resumption of cooling before T_2 (60° C) is reached.

- Level of defence 3 as well as internal hazards, external hazards, and very rare human-induced external hazards:

If cooling cannot be resumed and T_2 is exceeded or cooling fails due to other events, further measures must be provided to prevent T_3 (80° C) from being exceeded. According to [3], a loss-of-offsite-power event is to be assumed for events on level of defence 3 and thus also for events affecting the spent fuel pool. The restoration of cooling under these conditions is discussed in more detail in Sections 4.2.2 and 4.2.3.

- Level of defence 4 as well as robustness analyses

Finally, within the framework of robustness analyses, measures for the make-up feeding of water into the pool and thus for sufficient cooling of the fuel assemblies must also be provided under the conditions of a pool at boiling point, cf. Sections 4.3 and 4.4.

Independence of measures

The measures and equipment credited on the different levels of defence have to be independent of each other in such a way that failures on one level of defence will not jeopardise the safe control of the event on the next level (cf. [6]). However, this does not mean that the various measures and equipment for pool cooling in residual operation must be clearly assignable to one level of defence. For example, from the point of view of the RSK, it is permissible to credit equipment that is not classified as a safety system not only on levels of defence 1 and 2, but also as a substitute measure on level of defence 3, provided its reliable function under the respective event boundary conditions is demonstrated (cf. Section 5.3.1 in [3]). In this context, it is necessary that the existing measures and equipment are sufficient in total under all event boundary conditions to fulfil the requirements described above with regard to the defence-in-depth concept.

4.2.1.2 Non-intervention times

When grading requirements with increasing non-intervention times, only a small number of non-intervention time levels should be provided for the sake of clear conditions in residual operation, which can be assigned to corresponding "phases" in residual operation. The following two non-intervention time levels are recommended, each characterised by the non-intervention time until 80° C is reached: > 24 hours or > 3 days.

The following boundary conditions have to be applied for the determination of the non-intervention times and thus for the determination of the maximum after-power permissible for the respective non-intervention time level:

- assumption of a complete loss of pool cooling,

- maximum operationally intended spent fuel pool temperature as initial temperature, e.g. marked by a warning signal "Temperature high" (cf. KTA 3303, 5.1),

- water inventory in the pool: For events (including internal hazards, external hazards, and very rare human-induced external hazards) with the potential for a loss of coolant, the level reached after the pool has emptied to the lowest connection pipe has to be assumed. Otherwise, the operational minimum water level is to be assumed below which the level is indicated by a suitable warning signal in the control room.

- use of validated calculation methods to determine heat input into building structures and heat removal through humidification.

As an example, the following table shows non-intervention times for PWRs in the event of leakage accidents and an initial temperature of 30°C for the pool water. Higher initial temperatures would require a later point in time with lower after-power levels for entering into one of the above-mentioned non-intervention time levels.

Phase	**Non-intervention time until reaching T_3 (80° C)**	*Corresponding after-power*	*Derived non-intervention time up to 45° C (level of defence 1)*	*Derived non-intervention time up to 60° C (level of defence 2)*
1	**> 24 h**	*< 2.7 MW*	*> 9 h*	*> 18 h*
2	**> 3 d**	*< 1.2 MW*	*> 19 h*	*> 2.1 d*

Notes:

- *The after-power levels as well as the non-intervention times up to 45° and 60° C are used here for illustration purposes. Only the non-intervention time until reaching T_3 (80° C) is decisive for the allocation to the phases.*
- *With regard to the non-intervention times, the operational minimum water level is assumed on levels of defence 1 and 2.*
- *For BWRs, there will be longer non-intervention times for events without loss of coolant due to the open swivel gate.*

4.2.1.3 Completion of preventive maintenance, repairs and execution of substitute measures

Already in power operation with non-intervention times of > 10 h up to T_3, the crediting of the completion of preventive maintenance, repairs and substitute measures was permissible in the accident analyses (cf. [3]). The RSK is of the opinion that in residual operation with non-intervention times > 24 h after an accident, repairs on an extended scale as well as equipment not classified as a safety system may generally be credited as substitute measures under the following conditions:

- The measures must be reliably effective under the respective event boundary conditions and must be feasible within the respective non-intervention time at the longest.
  Feasibility and time requirements should be proven by experience, exercises or analyses; the time requirements should be determined conservatively, taking into account uncertainties and any event-specific aggravating boundary conditions.

- A single failure in one substitute measure must not lead to the unavailability of another substitute measure.

- The measure, including the procedures to be applied with initiation criteria as well as the resources to be provided, is described in appropriate written operating rules in sufficient depth for evaluation and implementation.

- Regular plant walkdowns or checks with visual inspections and, if necessary, in-service inspections and surveillance tests or drills are provided to ensure the availability and functionality of the tools required for the measure and the feasibility of the measure.

- Measures that require an on-site inspection of the spent fuel pool service floor may only be credited if the pool water temperature is below 60° C and the water level in the pool sufficiently limits the dose rate (see Section 4.1).

To ensure the execution of substitute measures, the loss-of-offsite-power case on level of defence 3 is assumed to last 3 d (according to KTA 3702 diesel supplies for 72 h). For robustness analyses, the unavailability of the offsite power supply of up to 7 d is assumed.

4.2.2 Requirements for the active pool cooling systems in phase 1 (non-intervention time until T_3 > 24 h)

From the RSK's point of view, safe event control in this phase can be demonstrated on the basis of the following minimum system configurations:

Requirements for the system function 'pool cooling' in phase 1		
Provisions for cooling	**Design to withstand design basis earthquake**	**Emergency power supply**
Two emergency residual-heat removal trains	Yes	Two D2 diesels (PWR) or two emergency diesels (BWR)
One operational pool cooling train	No requirements	Emergency diesel or mobile diesel (to be provided on site)
Prepared measures for cooling train repair in < 24 h	Available after design basis earthquake	Doable under loss-of-offsite-power conditions

With this configuration it is possible to

- keep the temperature in the spent fuel pool reliably below T_1 or T_2 even with the planned maintenance of an emergency residual-heat removal train on levels of defence 1 and 2. The non-intervention time until T_2 is reached is more than 18 h, so that the demonstration of compliance with the temperature criterion for a loss-of-offsite-power case on level of defence 2 (< 10 h) can also be provided without taking the emergency diesel supply into account.

- demonstrate event control on level of defence 3 through
  - crediting of the operational pool cooling train,
  - under design basis earthquake conditions: crediting of the re-availability (completion of maintenance or repair of single failures) of at least one of the two emergency residual-heat removal trains designed to withstand a design basis earthquake if these are assumed to be initially unavailable due to maintenance or single failures, before reaching T_3 (cf. recommendation 6 in [3]).

4.2.3 Requirements for the active pool cooling systems in phase 2 (non-intervention time until reaching T_3 > 3 d)

Essential boundary conditions in this phase are as follows:

- The operational, "third" pool cooling train of the PWR is also sufficiently dimensioned at this level of after-power to keep the maximum pool temperature at a value below 45° C.

- The non-intervention time until T_2 (60° C) is reached is more than two days. Accordingly, the repair of a failed train is possible with increased probability before reaching T_2.

Under these boundary conditions, the RSK is of the opinion that even more complex measures to make failed trains available again as well as substitute measures can be reliably implemented before T_3 is reached (> 3 days).

From the RSK's point of view, safe event control can be demonstrated on the basis of the following minimum system configurations:

Requirements for the system function 'pool cooling' in phase 2		
Provisions for cooling	**Design to withstand design basis earthquake**	**Emergency power supply**
One emergency residual-heat removal trains	Yes	One D2 diesel (PWR) or emergency diesel (BWR)
One operational pool cooling train	No requirements	Emergency diesel or mobile diesel (to be provided on site)
One substitute measure for pool cooling < 3 d	Yes	Mobile diesel or diesel-powered pump
Prepared measures for cooling train repair in < 3 d	Available after design basis earthquake	Doable under loss-of-offsite-power conditions

Notes:

- *Events on level of defence 3 are controlled by the two available pool cooling trains, if necessary by crediting the re-availability of one of the two trains.*

- *Particularly with regard to earthquakes with possible consequential damage in the operational train, an earthquake-resistant substitute measure for cooling must be provided (e.g. mobile pool cooling pump with installed connections to restore a recirculation mode) to prevent T_3 from being exceeded.*

4.2.4 Further considerations

The above consultation results are summarised in Table 1 below. They assume that

- the requirements of KTA 3602, Section 4 - as far as applicable for these phases - are met;
- sufficient skilled personnel is available at the plant, even during residual operation, to reliably carry out manual measures, substitute measures and, if necessary, the restoration of unavailable equipment within the specified non-intervention times;
- the proper functioning of the equipment credited in the demonstrations of accident control is also regularly checked;
- in the course of decommissioning and dismantling, no activities are carried out that may have a retroactive effect on the safe storage and handling of fuel assemblies in the spent fuel pool;
- in particular, there is no change in the handling of heavy loads during residual operation, relevant precautionary measures continue to be maintained if necessary, and the handling of large components above the spent fuel pool does not take place in this plant condition, and the inspection concept for the relevant plant components is upheld.

The requirements listed in the table refer to the removal of residual heat from the spent fuel pool. Further requirements for the equipment mentioned may arise due to other aspects.

Table 1: Pool cooling in the phases of residual operation

Not listed in the table are the measures to be taken for repair in order to make unavailable or failed equipment available again within the respective non-intervention time.

Non-interv. time up to 80° C	**Requirements for the system function 'pool cooling'** [1]			**Configuration example**	
	Number	**Design to withstand design basis earthquake**	**Emergency power supply**	**PWR**	**BWR**
≤ 24 h	*PWR: three trains (five pumps)* *BWR: four trains (four pumps)*	*Two trains*	*All trains*	*Like previous operation (SiAnf and RSK Statement [3])* *No change in the requirements* *Measures to restore availability creditable to a certain extent*	
> 24 h < 3d	Three trains (three pumps)	Two trains	Three trains or two trains and provision of mobile diesels (to be provided on the plant premises)	Two emergency RHR trains (two D2 diesels), third pool cooling train (D1 diesel or mobile diesels)	Two emergency RHR trains (two NS diesels), one pool cooling train (one operational NS diesel or mobile diesel)
> 3 d	Two trains (two pumps) + 1 SM < 3 d	One train + 1 SM < 3 d	Two trains or one train and provision of mobile diesels (to be provided on the plant premises)	One emergency RHR trains (D2 diesel), third pool cooling train (D1 diesel or mobile diesels) + 1 SM < 3 d	One emergency RHR trains (one NS diesel), one pool cooling train (one operational NS diesel or mobile diesel) + 1 SM < 3 d
∞ up to 60° C	*1* [2]	*none*	*none*	*„Passive cooling“* [2]	

1) In addition, up to the "passive cooling" phase, the following has to be provided: measures and equipment for leak isolation and refilling of the pool or sump recirculation mode on level of defence 3; measures and equipment on level of defence 4 ("evaporation cooling" and long-term make-up feeding of the spent fuel).

2) Cf. RSK Statement [2], in case of failure, long-term repair is credited.

4.3 Water injection into the spent fuel pool

In normal specified operation (level of defence 1 and 2), the water injection serves to supplement evaporation losses and water recirculation from the water purification system or for make-up feeding in the event of water losses due to leakages (see event B2-02 of the SiAnf).

In events on level of defence 3 involving a loss of water from the spent fuel pool, refilling of the pool is necessary to ensure active cooling of the fuel assemblies again before T_3 is reached (either by means of leak isolation and resumption of closed-circuit operation or by means of sump recirculation mode).

In the beyond-design-basis case that no resumption of pool cooling is possible before T_3 is reached, the temperature in the pool would rise to max. approx. 100° C without countermeasures and the level would continue to fall slowly through evaporation. Under the given boundary conditions in view of systems design, evaporation cooling is possible and sufficient to avoid damage to the fuel assemblies stored. Make-up feeding of the pool is only necessary in the very long term to ensure cooling of the fuel stored. For example, the corresponding non-intervention time for 2.7 MW of after-power to be removed via evaporation/vaporisation with heating to 100° C is > 6 days in total. In this case, the water injection rate required to compensate for the evaporation losses would be approx. 1.5 l/s.

In the above-mentioned cases, there are no more stringent requirements than operational requirements for the injection to make up supplement water losses in view of the long non-intervention times. In the event that the operational injection should not be available, at least two diverse substitute measures have to be provided, e.g. injection via a remaining injection line of the pool cooling systems, a fixed pipeline with mobile injection, or also a connection to the fire extinguishing system. At least one of these substitute measures has to be available after an earthquake.

4.4 Robustness analyses, beyond-design-basis range

The water injection required to control scenarios in the context of robustness analyses and beyond-design-basis considerations is dealt with in Section 4.3.

Damage to the auxiliary service water supply cannot be ruled out for the very rare human induced external hazards (especially aircraft crash and blast wave). Furthermore, the failure of the heat sink may also have to be considered for robustness analyses [8]. For these cases, the equipment for a shortened residual-heat removal chain with a diverse heat sink, which was introduced within the scope of the robustness analyses, can be credited as a substitute measure. However, this presupposes that this equipment is appropriately physically separated from the equipment of the cooling chains and stored in a protected manner. In addition, evaporation cooling is available.

With regard to robustness, no internal or external impacts that would lead to more serious water losses than those assumed in the event category "loss of coolant from the spent fuel pool" were identified during the analyses of the power operation of the plants, with the exception of the drop of a fuel assembly transport cask into the spent fuel pool or into the transport cask storage pool:

BWR 72:

According to [4], the possibility of a fuel assembly transport cask dropping into the storage pool can be ruled out for the BWR 72 type. Furthermore, due to the design of the transport cask storage pool, relevant damage resulting in leakage can be ruled out even in the event of an assumed drop.

PWR:

According to the RSK statement [4], the "loss of pool water" has to be analysed for the PWR with regard to the drop of a fuel transport cask into the fuel pool. The overfeeding capability of any loss of pool water that occurs has to be checked and, if necessary, specific emergency measures have to be provided. Alternatively, it must be explained in more detail by which measures the dropping or tipping of a FA transport cask into the spent fuel pool is prevented so reliably that it can be ruled out (with regard to cliff edge effects). In this case, it can be assumed that any leaks in the pool liner can be shut off as before, so that there is no additional requirement for water injection. Compliance with this RSK recommendation also has to be demonstrated under the conditions of decommissioning.

In the event of a postulated drop of the cask into the transport cask storage pool in the PWR, it was considered possible in [4] that there could be damage to the transport cask storage pool involving a loss of water. If, as things stand today, it cannot be shown that no such damage will occur, the consequences of the loss of water must be considered.

With the swivel gate open, the level would drop to the upper edge of the partition wall (threshold) between the transport cask storage pool and the spent fuel pool (corresponds to a level of approx. 35 cm above the fuel assemblies). This would not expose any fuel elements, but it would result in increased dose rates in the area of the pool floor.

In this case, measures have to be prepared, depending on the after-power, with which make-up feeding of water can be realised within the time available so that the level will not drop down to the upper edge of the fuel assemblies due to evaporation/vaporisation. In addition, measures have to be provided to raise the level in the pool again to such an extent that the reactor service floor can be walked on again safely from a radiation protection point of view.

PWR and BWR 72

A scenario that a leak in a connecting pipe should occur just during a FA transport operation with a FA lifted from the storage pool to be transferred to the transport cask set-down pool is extremely unlikely (no work on pool cooling systems is permitted in this situation, the time for a raised FA is typically about five minutes). If it were assumed, then - due to the limited outflow rate from a leak and thus the correspondingly limited speed for the water level to drop - the loading machine operator would have the time to place the FA either in its original position or in the transport cask before the dose rate on the loading machine would increase significantly. If an evacuation or escape alarm is assumed due to excessive local dose rate caused by the reduced shielding effect of the water cover, it will be possible to seal the leak temporarily (leak location in the shielded area) and to raise the pool level again. With an increased shielding effect, it would also be possible to man the loading machine again.

In order to limit the coolant inventory in the containment sump at the PWR in the long term, from the point of view of the RSK, an additional measure for recirculating leakages from the containment sump into the spent fuel pool has to be provided. For this purpose, one of the already existing pool cooling trains equipped to allow sump recirculation can be used. In this case, boundary conditions during plant dismantling that deviate from power operation may have to be taken into account (e.g. increased entry of dirt and foreign bodies into the containment sump). The feasibility of the make-up and return options must therefore also be demonstrated under these boundary conditions.

4.5 Requirements for other systems

Requirements for the minimum system configuration of the pool cooling systems were presented in Section 4.2. As a matter of principle, all functionally required auxiliary systems of the systems or system trains credited in each case in the verifications must also be kept in operation with the same redundancy (e.g. instrumentation and control equipment for electro-technical excitation and monitoring, electric power supply, coolant supply and safeguarding defined ambient conditions). Alternatively, it has to be demonstrated that the respective auxiliary systems are no longer required against the background of the boundary conditions prevailing during residual operation.

In the following, essential requirements are presented in more detail.

Ventilation systems

Conventional ventilation systems:

The ventilation systems or chilled water systems in the emergency diesel building or in the building housing the emergency diesel supplying the emergency feedwater system (PWR), in the switchgear building and, if applicable, in the buildings for auxiliary service water supply have to be kept available in such a way that the long-term availability of the systems credited in accordance with Section 4.2 is ensured even at the maximum or minimum outside temperatures to be assumed. This includes the ventilation systems for the control room and the supplementary control room.

Nuclear ventilation systems:

In the reactor building and in the reactor building annulus (PWR), the permissible ambient conditions must still be complied with.

Electric power supply

Auxiliary power supply

Since many large consumers no longer need to be supplied in residual operation, the connection to the main grid is no longer necessary. However, two different fixed supplies must be provided (e.g. standby grid connection and third grid connection).

Emergency power supply and uninterruptible power supply

Requirements for the emergency power supply of the pool cooling systems were explained in Section 4.2. It has to be ensured that for mutually redundant electrical consumers, e.g. pumps used for pool cooling, redundant diesel generators (permanently installed or mobile) are also assigned. In addition, other necessary emergency power consumers also have to be taken into account (e.g. chargers for the batteries of physical protection systems, emergency lighting, and other necessary instrumentation as well as ventilation equipment and fire extinguishing equipment).

Instrumentation and control

Automatic excitation of the components intended for pool cooling or water supply was already not necessary in power operation. The excitation of the components for pool cooling or water supply as well as the associated emergency power supply can be carried out from the control room or directly at the associated switchgear if the corresponding procedures exist.

The monitoring devices for temperature and fill level in the spent fuel pool as well as for the power supply must be emergency-power-supplied in a redundant and qualified manner, with a corresponding display in the control room.

Furthermore, the reliable detection of leakage or flooding events (in particular, submergence monitoring in the reactor building annulus for the PWR and compartment protection for the BWR 72) as well as sufficiently fast shut-off of the relevant flooding sources have to be ensured.

With regard to very rare human-induced external hazards, monitoring must also be possible from the supplementary control room/control unit for operation and monitoring in case of specific external hazards.

5 Documents

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

[2] RSK-Stellungnahme
Anforderungen bei einer passiven Kühlung der Brennelemente im Lagerbecken, Anlage zum Ergebnisprotokoll der 509. Sitzung der Reaktor-Sicherheitskommission (RSK) am 27.3.2019

[3] RSK-Empfehlung „Anforderungen an die Brennelement-Lagerbeckenkühlung“, Anlage 2 zum Ergebnisprotokoll der 479. Sitzung der Reaktor-Sicherheitskommission (RSK) am 09.12.2015

[4] RSK-Stellungnahme, Bewertung der Umsetzung von RSK-Empfehlungen im Nachgang zu Fukushima, Anlage 1 zum Ergebnisprotokoll der 496. Sitzung der Reaktor-Sicherheitskommission (RSK) am 06.09.2017

[5] RSK, Zusammenfassende Stellungnahme der RSK zu zivilisatorisch bedingten Einwirkungen, Flugzeugabsturz, Anlage zum Ergebnisprotokoll der 499. Sitzung der Reaktor-Sicherheitskommission (RSK) am 06.12.2017

[6] RSK-Stellungnahme, Verständnis der Sicherheitsphilosophie, Anlage zum Ergebnisprotokoll der 460. Sitzung der Reaktor-Sicherheitskommission (RSK) am 29.08.2013

[7] EPRI NP-6041, Revision 1, “A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1), Electric Power Research Institute, August 1991

[8] RSK-Stellungnahme, Ausfall der Primären Wärmesenke, Anlage zum Ergebnisprotokoll der 446. Sitzung der Reaktor-Sicherheitskommission (RSK) am 05.02.2012