Note:
This is a translation of the RSK statement entitled “Ausfall der Primären Wärmesenke”.
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK Statement
(446th meeting on 05.04.2012)

Loss of the ultimate heat sink

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Contents

1 Cause and course of discussions

Based on a request by the German Bundestag, the Federal Environment Ministry (BMU) asked the Reactor Safety Commission (RSK) at its 433rd meeting on 17.03.2011 to first subject the German power reactors to a safety review due to the events in the Japanese nuclear power plant in Fukushima I. The related RSK statement "Plant-specific safety review (RSK-SÜ) of German research reactors in the light of the events in Fukushima-I (Japan)" /1/ of 16.05.2011 was adopted at the 437th RSK meeting from 11. to 14.05.2011 and is published on the website of the RSK (http://www.rskonline.de).

As another step to meet the request by the BMU, the RSK identified topics of consultations at its 438th meeting on 09.06.2011, which will be discussed in depth as a follow-up to the safety reviews of the German nuclear power plants. In this context, it was decided to consider the robustness of the existing design of the essential service water supply, taking into account recent operating experience. At its 439th meeting held on 07.07.2011, the RSK adopted a consultation concept on this issue and requested the Committee on REACTOR OPERATION (RB) to deal with this question. To this end, the RSK Committee RB launched the ad hoc working group on the loss of the essential service water supply (AUSFALL NEBENKÜHLWASSER - AG NKW) at its 204th meeting on 27.07.2011.

At its 1st meeting on 09.09.2011, the AG NKW first sought information from GRS on the preliminary results of a report requested from GRS on the impairment of the essential service water supply by blockage of the cooling water intake structure ("*Beeinträchtigung des Nebenkühlwassers durch Blockierung des Kühlwassereinlaufbauwerkes*"), which gives an overview of the current national and international operating experience in this field. Based on it, relevant scenarios and possible event causes were derived for further consultations. In the course of the 2nd meeting on 02.12.2011, the basic structure of a statement has been agreed upon and international developments with regard to future requirements for the design of the essential service water supply identified. The 3rd meeting of the ad hoc working group AG NKW on 07.02.2012 served to discuss a first draft statement within the working group. Meanwhile, at its 444th meeting on 12.01.2012, the RSK decided that the results of the consultations of the ad hoc working group AG NKW are to be presented and discussed directly within the RSK. Accordingly, the draft statement was discussed at the 445th RSK meeting on 29.02./01.03.2012 and then adopted at the 446th RSK meeting on 05.04.2012.

2 Terms and scope

The waste heat produced in a nuclear power plant is discharged into the environment via technical installations. The heat losses from the thermodynamic process and the heat from the cooling of the components are usually either transferred to water (into a river or the sea, the so-called receiving water) or dissipated into the environment via wet cooling towers or cells coolers. The heat is transferred to water via a heat exchanger. For the effectiveness of the single-phase heat transfer, a considerable flow of water is required, so that for heat dissipation it is necessary to withdraw large amounts of water from the river. In case of heat dissipation via evaporation in cooling towers, a comparatively small supply of water is required, so that, at least for a few hour heat can be removed with system-internal inventories.

These considerations show that for heat dissipation into the environment - the heat sink of the power plant - technical installations and environmental conditions have to interact. In this statement, the term loss of the heat sink is referred to if heat dissipation into the environment is prevented, for example, by impairment of the necessary technical installations for heat transfer (as in Fukushima by flooding of the pumps) or by obstructed water intake. The heat sink itself will usually not get lost.

Neither nationally nor internationally terms associated with heat sinks are used in a uniform manner. The terms used in connection with this statement, are therefore defined as follows.

Heat removal systems:

The heat to be removed has to be transported from the heat source (reactor, turbine condenser, etc.) to the heat sink. For this purpose, heat removal systems are used. Accordingly, protected heat removal always requires a functioning heat removal system, which transports the heat from the origin to the heat sink, <u>and</u> the availability of a heat sink.

Main heat sink:

The main heat sink is used to remove the heat lost during electrical power generation – in case of nuclear power plants, this is usually the turbine condenser. The main cooling water system serves the purpose of heat transfer from the main heat sink into the environment. The main heat sink mainly has operational tasks and therefore does not belong to the safety installations. As per design, the loss of the main heat sink is an event of abnormal operation ("transient") and is to be controlled.

Ultimate heat sink[1]:

In connection with this statement, the ultimate heat sink is the safety-relevant heat sink to which the decay heat of the reactor after shutdown and the heat loss from the safety systems during normal operation and incidents is ultimately transferred. In connection with incidents, the removal of the decay heat of the fuel assemblies in the reactor and spent fuel pool is of high safety significance to prevent destruction of the reactor core and the activity barriers due to overheating. In accordance with the German plant concept, the heat transfer from the reactor to the ultimate heat sink required for it is designed as the so-called "residual heat removal chain", which essentially consists of three systems, the "emergency core cooling and residual heat removal system" and the pool cooling system integrated in it, the “component cooling system for protected systems” and the "essential service water system for protected installations". The latter transports the waste

[1] Also referred to as “primary ultimate heat sink”

heat from the component cooling system for protected systems to the ultimate heat sink via heat exchangers (component cooler). Here, in most plants, the same ultimate heat sink is used as for the main heat sink.

In connection with this statement, the structure, function and the failure possibilities that may result in a loss of the last link of the safety-relevant the residual heat removal chain, i. e. the essential service water system for protected installations and the related heat sink, are of relevance.

For the sake of completeness it should be mentioned that there are other heat removal chains in nuclear power plants, for example, the "essential cooling water system for conventional installations" These cooling systems are usually interconnected with the main heat sink and the primary heat sink; they have no safety significance and are not considered in this statement.

Alternate heat sink[2]:

Another safety-relevant heat sink that is capable, independent of the ultimate heat sink, of dissipating the decay heat of the reactor after shutdown and the heat losses from safety-relevant systems during normal operation and incidents. Diverse concepts use, e.g. another heat sink (air instead of water; well instead of river) than the ultimate heat sink. Full diversity is achieved if, in addition to the alternate heat sink, diverse systems (technically or functionally) are also used for heat transport.

3 National and international operating experience

The loss of the ultimate heat sink due to flooding by a tsunami in Fukushima, mentioned at the beginning, led to a re-assessment of the safety-relevant cooling water supply due to the disastrous impacts on the cooling of the reactors. This re-assessment does not only comprise the causes in Fukushima "flooding" with consequential loss of power supply systems, but also other failure causes known from operating experience, such as blockage the cooling water supply or loss of the coolant of the heat sink. Upon request of the RSK, GRS evaluated relevant national and international incident reports /1/. Sources of this list are the reportable events in Germany according to the Nuclear Safety Officer and Reporting Ordinance (AtSMV) and the IRS database of the IAEA. It should be noted that some reports in the IRS cover several events and the number of events on which the report is based is not stated.

Altogether, impairment of the heat sink in nuclear power plants does not occur very rarely at all. However, problems with the cooling water supply in the first place (in about 80% of cases) lead to a loss of the main heat sink and, as a consequence, impairment of power generation.
Since the ultimate heat sink requires significantly smaller amounts of cooling water than the main heat sink, the purification systems could in most cases still provide sufficient amounts of cooling water after power

[2] Also referred to as “alternate ultimate heat sink” or “diverse heat sink”

reductions or after plant shutdown for the supply of the safety-relevant service water supply trains. In about 20% of cases, however, the service water supply trains were also affected.

With the above information, there is comprehensive experience concerning failure phenomena related to heat sinks of nuclear power plants according to which the reliability of the ultimate heat sink requires re-assessment not only due to the incident in Fukushima, but also with respect to other failure mechanisms.

4 Potential causes that may lead to a loss of the ultimate heat sink

Based on the above-mentioned operating experience and the consideration of potential mechanisms, seven typical causes of impairment of the ultimate heat sink can be derived, where blockage events dominate with regard to occurrence frequency.

a Blockage of the intake structures by foreign particles in the receiving water and blockage of the intake structures by ice formation.

b Formation of biological foreign matter in the cooling water systems.

c Impairment of the heat exchanger effectiveness due to deterioration of the heat transfer at the heat exchanger surfaces (deposits, fouling).

d Flooding of the intake or pump structures by internal events.

e Flooding of the intake or pump structures by external events.

f Lack of cooling water or blockage of the intake or discharge structures as a result of event-induced external impacts.

These mechanisms are considered below regarding their probability of occurrence and their consequences for safety. To what extent these aspects mentioned apply to a facility, depends on the geographical location of the site as well as on the applied technology of the heat sink.

The Fukushima incident

The essential service water supply to the Fukushima units was affected by the tsunami in two respects: the flooding led to both the failure of the systems of essential service water - especially of the pump systems - and the failure of the power supply for the service water pumps.

Each of these failure causes alone would have led to a failure of heat removal to the ultimate heat sink. The special circumstance of the events at Fukushima was that both failure causes occurred almost simultaneously and were due to the same initiating event, i.e. a tsunami. For this reason, a significant new aspect in assessing the potential causes for the loss of the ultimate heat sink is the consideration of superposed failure causes, especially when, to a certain extent, inevitability has to be assumed.

Blockage of the intake structures by foreign matter in the receiving water

It can be concluded from operating experience that the blockage of intake structures and the related system components is the most common cause of impairment of the ultimate heat sink.

The cooling water taken from the receiving streams is usually filtered by coarse and fine screens as well as small-mesh screens (travelling screen units, drum screens) in order to protect downstream components from contamination. Fine screens, however, are not used at all sites due to local conditions.

Vulnerable components in cooling systems are

- cooling water pumps, and
- downstream condensers and heat exchangers, also including the safety relevant "nuclear component cooler" belonging to the ultimate heat sink.

The capacity of the filtering devices is limited, especially when the receiving water contains large amounts of foreign matter. This may lead to blockage of the cooling water supply. For this case, some systems have by-pass gates to protect the filters. These gates, however, when opened - usually suddenly –lead to unwanted intrusion of large amounts of foreign matter into the cooling water circuits. Both blockage of the purification equipment as well as the entry of large amounts of foreign matter due to the actuation of by-pass gates or a failure of the filter screens may lead to a loss of one or more redundancies of the essential service water system, depending on the actual system configuration.

As outlined in the GRS report /1/, blockage of cooling water intake structures have occurred repeatedly both at coastal and at river sites. At river sites, high pollution loads of the receiving water are mainly due to leaves, grass and other solids, often in connection with extreme weather or flood situations. Coastal sites are primarily endangered by vegetable or animal material in the receiving water, such as algae, seaweed, jellyfish or shoals of fish.

The removal of heat through **cooling towers** is generally little affected by high pollution loads in the receiving water, especially when the supply of cooling towers with evaporation water is not impaired by the loss of the related supply systems for longer periods, because inventories of clean water are available to replace the evaporated water. However, there is a potential for impairment of the effectiveness of cooling towers (especially of those with less capacity) by blocking of draught due to foils, paper or similar foreign bodies flying around, e.g. during storms or due to the failure of cooling tower internals, e.g. in the case of an earthquake or fire.

Blockage of the intake structures due to ice formation in the receiving water or at purification equipment

Ice formation in the cooling water inlet structures may result in blockage of the cooling water intake and, in turn, in the failure of the ultimate heat sink. Here, different types of ice formations are to be considered.

Slush ice is a conglomeration of millimetre-sized ice particles, which are formed in subcooled water. As a loose ice-water mixture it can accumulate at structures, freeze over and, under certain conditions (e.g. change in salinity of tidal waters), solidify so rapidly that it can lead to blockage of inlet chambers or impairment of the cooling water purification. In some cases, blocking of cooling water purification (coarse screens, fine screens, travelling screen units, drum screens) by icing resulted in the loss of several trains of different cooling water systems.

If water temperatures fall below the freezing point, there is a danger of ice formation also in the form of large ice chunks. These may lead to damages to the cooling water purification system, especially to the coarse screens. As has been shown, strong wind can break an existing ice sheet and press the ice chunks formed into the intake structure. This may result in severe impairment of the cooling water supply by blocking of purification equipment.

Even at water temperatures above the freezing point, **icing** may occur at various locations in the area of the cooling water pumps which, above the water surface, are in contact with the ambient air. Here, there is a danger of blocking of intake ducts. Such icing may also block impulse lines for measurements resulting in protective shutdown of cooling water pumps.

As a countermeasure, in some plants there is the possibility to redirect heated return water into the inlet area in order to prevent the formation of ice. The switching operations required for it are carried out preventively before reaching low cooling water temperatures. The measure, however, can only be performed effectively during power operation of the plant. With regard to the cooling of spent fuel pools, which will probably be required for several years in shut down plants, this aspect is also of particular relevance for these plants.

Formation of biological foreign matter (mussels) in the cooling water systems

A phenomenon increasingly observed in recent years is the growth of shells in the cooling water systems of the plants. The screens do not hold back mussel larvae and the larvae grow - often in considerable amounts - in the systems. These mussels can enter the coolers of the plant and reduce their cooling effect or block the coolers. A chemical treatment, e.g. by shock chlorination treatment, is prohibited for environmental reasons, so that this phenomenon can only be mastered by careful observation of the system state, and timely removal of such shellfish stocks.

Impairment of heat exchanger effectiveness surfaces due to degradation of heat transfer at the heat exchanger surfaces

Besides the aforementioned rather more sporadic events, phenomena developing slowly and gradually may impair the effectiveness of the safety-relevant cooling points. These include, for example, the slow and gradual entry of solids at the screens of the cooling water intake or "macro fouling" (degradation of heat transfer) of the heat exchanger tubes. The heat transfer of the cooling tubes may also be impaired by dissolved substances, such as oil. Pipe cleaning systems (e.g. sponge balls) are often used to prevent deposits in the heat exchanger tubes. In case of imminent clogging of the coolers, however, these balls may accelerate clogging of the heat exchanger.

Flooding of the intake or pump structures by internal events

Events that caused flooding in the area of the essential service water systems due to internal events are relatively frequent. Causes were both component failure and human error, in some cases, the leakage quantities were considerable. In the case of component failure, corrosion and other ageing mechanisms (e.g. embrittlement of rubber expansion joints and seals) are the dominant failure mechanisms.

Flooding of the intake or pump structures by external events

Safety-relevant installations that serve the control of external events are to be protected against these influences. Since the pumps systems of the ultimate heat sink are generally installed in the immediate area of influence of the receiving water, special attention has to be paid to the aspect of flooding caused by external flooding events. The required measures depend on the location of the plant (coastal or inland sites). Incoming tidal waves, e.g. in the case of dam breaks, landslides or sudden storms, can, when they hit the intake structures, reach dynamically increased water levels, which can lead to short-term flooding of the pump structures. It is therefore recommended to verify the design of the cooling water pump structures with regard to flood safety, also under such boundary conditions and, if necessary, to make the most exposed installations flood resistant. Alternatively, pumps can be used which can also be operated under water.

Lack of cooling water or blockage of the intake or discharge structures as a result of event-induced impacts

Besides the aforementioned phenomena, there are a number of other plant-external events that may lead to the loss of the ultimate heat sink. These include, in particular, events leading to the lack of cooling water in the receiving water. This mainly concerns sites at rivers. Such an event may be caused by the break of a downstream weir or dam. Silting and deposits in the cooling water systems can occur slowly, rapidly occurring burials and blockages due to work in the vicinity of intake structures, due to earthquake events or other geological events such as landslide. Under certain boundary conditions, interference by third parties cannot be excluded as the initiating cause.

5 The ultimate heat sink in German plants

In most cases, receiving water (river or sea) is used as ultimate heat sink, in two plants, air-cooled cooling towers are used as a ultimate heat sink according to /2. The German regulations do not require an alternate heat sink that is independent from the ultimate heat sink. An essential part of the systems technology, which is required for the transport of heat from the safety-relevant cooling points to the heat sink, is the essential service water system for protected installations (see also 5.2).

Therefore, the essential service water system for protected installations belongs to the safety systems and is designed accordingly. Among other things, safety systems have a degree of redundancy of n+2 and have to be designed so that a failure due to common mode events is not to be expected. Requirements for the systems of the residual heat removal chain, and the essential service water system counts for protected installations is one of these systems, are in included in nuclear safety standard KTA 3301.

The essential service water system for protected installations (PWR) usually has four trains (4 x 50% with regard to the initial residual heat removal and the storage heat to be dissipated), its cooling capacity is determined by the design basis accidents, mainly the LOCA events and, since the essential service water system for protected installations according to the German system concept also has to fulfil operational functions, by operational requirements (mainly shutdown gradients).

Residual heat removal and cooling of safety-relevant components are also required for the management of external hazards, such as aircraft crash or blast waves. For the management of such events, the regulations require /7, 8/ protection against the postulated impacts, so that at least once 100% are available. In some newer plants, there is a dual-train emergency residual heat removal chain. However, these emergency residual heat removal chains generally share components with the essential service water systems of ultimate heat sink that are used for the management of design basis accidents, e.g. the heat exchangers for the heat transfer from the component cooling circuits to the essential service water supply trains (nuclear component cooler).

In most cases, the heat to be removed by the emergency residual heat removal chain is also dissipated to the ultimate heat sink, i.e. the respective receiving water. The previously mentioned plants, which use cooling towers as ultimate heat sink, have an alternate heat sink (river) to which the residual heat is dissipated through a dual-train emergency essential service water system. The plants KRB-B/C, whose ultimate heat sink is a river, each have a single-train alternate heat sink (cooling tower), KKP-2 a dual-train additional emergency essential service water supply from a well.

While the basic structure of the essential service water systems for protected installations is almost identical, there are relevant differences regarding the cooling water intake structures due to site-specific boundary conditions and according to the progressive state of the art at the time of plant construction. This mainly applies to the physical separation of the redundancies, the design of the cooling water cleaning, here, in particular, the use of common components for the purification of the main cooling water and the essential service water. So far, there are no typical common characteristics here; a detailed assessment of these installations in terms of reliability and possible sources of systematic errors that can lead to complete loss of ultimate heat sink must therefore be made plant-specifically.

Another decisive factor for the assessment of the consequences of a loss of the ultimate heat sink is which systems are affected by the failure of the cooling. Usually, some of the essential service water for protected installations is used for cooling of emergency diesel generators and/or for cooling of safety-relevant refrigerating units and ventilation systems. This may result in consequential failures in other safety installations so that the effects of multiple concurrent failure phenomena have to be considered analogous to Fukushima.

6 Potential consequences of a loss of the ultimate heat sink

In German plants, as part of the ultimate heat sink, the essential service water system for protected installations is usually a combined system that has operational as well as safety-related tasks.

The operational tasks comprise

- component cooling of the plant auxiliary and supporting systems,
- cooling of the ventilation and air conditioning systems in the nuclear part of the plant,
- cooling of the chilled water systems (refrigerating units),
- removal of the decay heat in several low-power and shutdown states, and
- cooling of the spent fuel pools.

The safety-related tasks comprise

- residual heat removal for all design basis accidents and external hazards (e.g. aircraft crash or blast waves),
- cooling of all systems relevant for the management of the events mentioned and their components, including the emergency diesel generators (not in all plants), and
- maintenance of the ambient conditions in the plant required for the operability of the safety systems (level of defence 3) and the emergency residual heat removal chain (level of defence 4a).

A loss of the ultimate heat sink has therefore a significant impact on the plant. If the plant is in power operation, essential components required for the operation of the plant fail in a short period of time due to insufficient cooling, as for example, the reactor coolant pumps, reactor recirculation pumps, various plant auxiliary and supporting systems such as the volume control system and heat removal through the ventilation and air conditioning systems large areas of the nuclear facilities. These component failures subsequently lead to automatic shutdown of the plant, i.e. to the initiation of transients and accidents even if no other initiating event, such as a loss of the ultimate heat sink or a LOCA, occurred.

If the plant is in low-power and shutdown operation, a loss of the ultimate heat sink also leads to the loss of operational and safety-relevant functions, such as the cooling of the spent fuel pool, and in some phases of operation also the cooling of fuel assemblies in the reactor pressure vessel and to impairment of ventilation and air conditioning systems and component cooling.

If the ultimate heat sink is also used for cooling of emergency diesel generators, such a loss will lead to the unavailability of these aggregates.

For German PWR plants, the external hazards concept does not provide cooling of the sealing areas of the reactor coolant pumps (RCPs) through a cooling system for some events (e.g. aircraft crash, loss of offsite power (LOOP) with loss of the D1 diesel). However, the failure of the cooling function can only be controlled for a limited period of time. If this period is exceeded, seal failure is to be expected and consequential loss of coolant. At present, the RSK neither has information on the system behaviour for failures of seal cooling at RCPs >> 10 h nor on the failure behaviour of the seals of reactor recirculation pumps in BWR plants.

With regard to a failure of the ultimate heat sink it is to be considered that, due to the jointly used installations, there is a high probability that the cooling water supply of the conventional service water will also no longer be available, resulting in a loss of the auxiliary power supply via the generator transformer. If power supply to the plant is provided through an air-cooled auxiliary power transformer, power supply to the plant is ensured. Only if the standby grid or auxiliary power transformer fail, the emergency diesel generators (D1 system) have to fulfil the function of auxiliary power supply, but these may also be unavailable due to the loss of the ultimate heat sink. If such an event occurs during power operation in PWR plants, this will lead to the event “external hazard during power operation” with challenge of the diversitary emergency power supply (D2 system) and the external-hazard-protected steam generator power supply.

During low-power and shutdown operation (open RPV), the residual heat removal chain alone ensures residual heat removal; a loss of the primary heat sink therefore leads to the loss of fuel cooling.

With the existing concept, this can then only be done by means of accident management measures.

The assessment of risks resulting from the loss of the ultimate heat sink therefore requires very differentiated considerations, starting from the respective plant concept and the initial state at the time of event occurrence, since the heat to be removed, the available systems, available accident management measures, etc. differ. The plant manufacturer made assessments on the consequences and the controllability of a loss of the ultimate heat sink, the auxiliary power supply and the D1 emergency power supply by the example of a German PWR plant. With the current conditions (technology, procedures) it is determined that the plant has significant potential to control the loss of the ultimate heat sink for a period of about 24 hours if the event occurs during power operation. During low-power and shutdown operation, such a scenario may - especially in case of open primary circuit and a low coolant inventory in the reactor - lead to shorter grace times.

From this, it is concluded that for the control of a longer-term failure of the ultimate heat sink during power operation and for the control of such a failure in some low-power and shutdown states, further measures are needed. Possible measures include systems engineering enhancements and/or additional procedures and accident management measures. Relevant for the results are, in particular, the provision of supplies and materials, cooling water inventories, and ensuring energy supply in the long term.

7 EU stress test: status and considerations in other countries

Within the framework of the EU stress tests, reports of the participating countries have been available since the beginning of January 2012. Within the framework of this statement, the reports from Germany /2/, France /3/, Great Britain /4/ and from Finland /5/ and Switzerland /6/ were reviewed. Thus, the majority of nuclear installations in Central Europe and in the immediate vicinity of Germany is covered.

First of all, in this respect, it is to be noted that according to the ENSREG specifications, all countries mentioned report on the loss of the ultimate heat sink to countries, but with different degrees of depth and informative value. They deal largely with the causes of a loss described in Chapter 3, i.e., the reports are not only limited to the flooding scenario occurred in Fukushima.

The following table summarises the report, statements with respect to design requirements and the current situation with respect to the scenario “Loss of Ultimate Heat Sink”.

Country	**Alternate heat sink**	**Accident management measure**	**Remarks**
Germany	No requirement Existing in some cases	Yes for loss of ultimate heat sink	Information that the RSK is still preparing a detailed statement
France	No requirement Existing in some cases	Yes for loss of ultimate heat sink	Requirements on additional verifications /reports including studies on the implementation of an alternate heat sink
Great Britain	Design requirement All plants have alternate heat sinks	Yes for loss of <u>both</u> heat sinks	
Switzerland	Existing, except for the Mühleberg nuclear power plant (KKM), there, backfitting required	Yes for loss of both heat sinks	Backfitting of a diverse heat sink for KKM required, additional studies on blockages in rivers with regard to flooding aspects required
Finland	No requirement Existing for Olkiluoto 3 (under construction)	Yes for loss of ultimate heat sink	Additional verifications required and in progress, including studies on the implementation of an alternate heat sink

Table 1: Statements on the loss of the "Ultimate Heat Sink" within the framework of the EU stress tests

From the reports, the following statements and trends can be derived:

1 In recent years, backfitting measures have already been implemented in plants due to precursor events with a focus on measures to cope with high pollution loads in the receiving water and to prevent entry of oil into the cooling systems. These measures were therefore mainly used to increase the reliability of the ultimate heat sink during normal operation and anticipated operational occurrences (level of defence 1).

2 Alternate heat sinks for the control of design basis accidents and external hazard events are currently required per design in only a few countries. In the light of the Fukushima event, such a requirement is generally discussed, and in Switzerland, backfitting has been requested where it not already exists.

3 In all countries, the total loss of the ultimate heat sink is considered within the framework of the stress tests; for its control, accident management measures are generally available or are being developed. In the countries that have an alternate heat sink per design or have requested backfitting where it not existed (Great Britain, Switzerland) the loss of both heat sinks, i.e. the primary and the alternate heat sink, are considered and accident management measures provided for it.

4 The accident management measures implemented for the loss of the ultimate heat sink emergency measures are checked for effectiveness and feasibility in the light of the Fukushima event. The impacts on other operational and safety-relevant systems associated with the loss of the ultimate heat sink are considered.

5 In countries where alternate heat sinks are currently not installed, the operators were requested to check the feasibility of backfitting of alternate heat sinks with effectiveness in all phases of operation. Whether, and if so in what period of time, backfitting requirements result from it not clear, but it is to be expected that in new regulations requirements for the provision of an alternate heat sink will be included. In Finland, the draft YVL B1 draft 2 “Safety Design of a Nuclear Power Plant” already contains such requirements.

6 In the context of failure scenarios, the EU stress test also considers a superposition of the loss of the ultimate heat sink with the loss of power supply (station blackout), and the simultaneous unavailability of other operational cooling trains which are also supplied by the ultimate heat sink and the main heat sink.

8 Assessment

The RSK dealt with the risks associated with the loss of the ultimate heat sink and, in this context, considered and evaluated

- the experience from the event in Fukushima,
- the wide range of national and international operating experience associated with the impairment of the ultimate heat sink,
- the potential consequences of such a loss with regard to the compliance with the protection goals, and
- first results from generic studies on consequences and possibilities of control of a simultaneous loss of the ultimate heat sink and power supply in a PWR plant.

Furthermore, previously published partial results of the EU stress tests and identifiable trends with regard to the further development of the international state of the art were included in the assessment.

The following conclusions are drawn:

1 The operating experience according to /1/ shows that there is a potential with respect to the loss of the primary heat sink that is not to be neglected. One of the most likely causes include blockage of intake structures by foreign particles and ice as well as failures of pump systems due to internal or external

flooding. Further, it is to be noted that the system and plant technology in the area of cooling water withdrawal and cooling water recirculation is very site-specific.

2 In four of the nine plants which are still in operation, there are alternate heat sinks in addition to the ultimate heat sink for the control of man-made hazards. In some cases, such heat sinks had been installed in the shut down plants in the context of backfitting measures for the control of rare external hazards (e.g. KKB).

3 Alternate heat sinks, whose systems design generally has a degree of redundancy of 2 x 100%, exist in three PWR plants. Here, the heat is removed to a different heat sink in each case; in the KONVIO plants KKE and GKN 2 to the receiving water instead of via the cell coolers of the ultimate heat sink (air cooling), in KKP 2 to a well system instead of the receiving water. The related essential service water systems partially have diverse system components, but shared are the nuclear component coolers. In case of loss of the ultimate heat sink during power operation of the plants, there is an alternate heat sink by means of main steam removal to the atmosphere and make-up feeding from the protected emergency feedwater inventories at all PWR plants for at least several hours. However, heat removal via the steam generators is not available in all plant operating states. One of the relevant aspects in case of a longer-term loss of essential service water supply in PWR and BWR plants is the cooling of the sealing areas of the reactor coolant pumps and reactor recirculation pumps, since failure of the sealing function is to be assumed in case of not lowered coolant temperatures and longer lasting cooling failure.

4 Each unit of the BWR plant KRB II has a single-train diverse additional residual heat removal and injection system. With this system, the RPV can be fed with water from the wetwell; from the RPV, the water is returned to the wetwell via the safety and relief valves. Heat removal from the circuit takes place via a dedicated, downstream train of the essential service water system with cell coolers. Evaporated water can be replaced in accordance with /2/ from various sources.

5 The effectiveness of existing alternate heat sinks, such as the use of wells and their cooling capacity, cannot be assessed in detail – since it is very plant-specific - by the RSK. However, as far as these were installed in connection with the concept for the control of rare external events, it is to be assumed that the cooling capacities for longer-term removal of decay heat are sufficient. Regarding the long-term cooling of safety-relevant installations, such as the reactor coolant pump seals in PWR plants or the seals of reactor recirculation pumps of BWR plants, the RSK has no detailed information.

6 All plants have accident management measures that are able to control some of the relevant causes of failure mentioned above, so that the protection goals can be met for most of the plant states. A proof that, for example, the loss of the ultimate heat sink (LUHS) in combination with a loss of offsite power (LOOP) can be controlled with the existing accident management measures for longer periods of time (> 10 h), is currently not available. A potential for improvement exists from the RSK's point of view,

for example, with regard to losses during low-power and shutdown operation and with regard to the periods of time over which a loss of the ultimate heat sink remains controllable.

7 With the information currently available to the RSK, a statement on the efficiency, the reliability and the effectiveness of planned accident management measures for the control of losses of the ultimate heat sink is not possible either, since conclusive information on the related analyses and an implementation of additional emergency procedures derived from them for bridging longer-term losses of heat sinks and of power supply are not available yet. The applicability and effectiveness of the existing accident management measures will also be assessed in a separate statement.

8 The documents /2-6/ reviewed show that the international state of the art with the aim of increasing the reliability of the ultimate heat sink has undergone further development.

Based on this review, the RSK derives the recommendations made in Chapter 9 with regard to the optimisation of the ultimate heat sink in the plants still being operated.

9 Recommendations

9.1 Measures to review and possibly improve the reliability of the ultimate heat sink with regard to blockage of cooling water intake

Experience shows that major contamination or icing in the a receiving water cannot be excluded. In recent years, there has rather been an increase in the number of such events internationally due to changing environmental conditions. Accordingly, it is to be ensured that such impacts will not lead to redundancy-wide losses of cooling water supply up to a total loss of the ultimate heat sink.

The RSK considers it necessary to re-asses the ultimate and, if existing, the alternate heat sink site-specifically, taking into consideration the operating experience gained in Fukushima and in other plants. In this respect, at least the phenomena listed in Chapter 2 and their relevance for the particular site as well as the following aspects have to be considered:

- The potential for blockage of cooling water supply due to high pollution loads of the receiving water or slowly developing effects, such as the silting of water-conducting channels, is to be considered site-specifically and, where required, appropriate measures are to be provided to prevent the loss of the ultimate heat sink provided.

- For smaller cooling towers, it should be checked if there is a site-specific potential that coolability may be impaired as a result of the entry of airborne contaminants (foils).

- Possible failure of filtering or screening devices (e.g. screen damage or opening of by-pass gates) leading to sudden and massive entry of dirt into the cooling systems, particularly in connection with high pollution loads of the receiving water, must be reliably prevented by taking appropriate measures, e.g. by shutdown of the main cooling water pumps at high differential pressure at the screening devices. If, due to the systems technology installed, a simultaneous failure of more than one cooling train (redundancies) caused by the sudden entry of large pollution loads can no longer be excluded, effective remedial measures are to be provided.

- Measures to prevent ice formation in the receiving water, and on or in components of the cooling systems are to be assessed particularly under the boundary conditions of low-power and shutdown states. This re-assessment should also be performed for the plants that are no longer in power operation.

- It must be possible to monitor the operability of the safety-relevant heat exchangers by an appropriate instrumentation. This also includes the timely detectability of influences which inadmissibly impair the heat transfer of the heat exchangers, e.g. due to fouling, sudden or gradual blocking of the heat exchanger tubes, shell deposits, etc.

- It is to be ensured by appropriate provisions and stipulations that weather events, such as storms, floods or storm surges, are reported to the operation management in good time so that organisational measures can be taken to control the impacts on the ultimate heat sink to be expected. The measures to be taken with a specific alarm actuation are to be specified for the operating personnel (for example, increasing the operating team in the intake structure, limits for the mode of operation of the plant, etc.). The stipulations and conditions for power and shutdown operation have to include clear specifications for which limits measures have to be taken and, if necessary, into what operating condition the plant has to be brought.

- If of site-specific relevance, an accidental entry of oil and other substances, which may impair the operability of the ultimate heat sink, has to be considered. Where appropriate, precautions must be taken to prevent such an entry.

- The inspection, maintenance and repair programmes of safety-relevant cooling systems have to be reviewed for their completeness and effectiveness to prevent damage to or functional losses of the ultimate and, if existing, the alternate heat sink. Although the components of the purification systems partially rather belong to “conventional mechanical engineering” and do not comply with the usual nuclear design standards, such standards are to be set for maintenance and modification of the systems that they do not determine the availability of the essential service water supply. The maintenance programmes must also ensure that natural or man-made silting or soiling in the cooling water systems can be detected in a timely manner and then be removed.

- The specifications for the planning of maintenance and modification activities in the area of the cooling water systems should be reviewed, taking into account the risks associated with the measures of a loss of the ultimate heat sink, particularly during plant shutdown states.

- The stipulations and conditions for power and shutdown operation have to be reviewed to determine whether appropriate requirements for the availability of the ultimate heat sink have been specified under consideration of potential causes of failure and the controllability of a loss in the respective operating phase.

9.2 Measures to strengthen the reliability of the ultimate heat sink with regard to the occurrence of rare external hazards

Rare external hazards may lead to the loss of cooling water supply to the plant. Here too, especially such events are to be considered which may lead to a blockage of the cooling water intake or to the flooding of the cooling water intake structures. In this regard, the RSK recommends the following:

- It is to be checked whether the assumptions for flood events also take into account the dynamic peak loads of incoming tidal waves to be expected in the area of the cooling water intake. If necessary, the active components in the areas at risk should be technically designed such that these remain operational even in case of flooding.

In connection with the re-assessment of flood protection as well as of the design against earthquakes and other very rare events, such as aircraft crashes and their impacts in the vicinity of the plant, it is to be determined if all failure causes that may result from these events have been considered in the design of the ultimate heat sink to the extent required. These include

- the loss of ultimate heat sink (of the receiving water), e.g. caused by breaks of dams/weirs,

- blockage of the cooling water supply or the cooling water return in the receiving water itself or of the intake structures, e.g. due to coarse gravel and mudslides or destruction of building structures by aircraft crashes, earthquakes, etc.

  and

- impairment of the cooling systems resulting from the loss of the screening function of the coolant water purification system and the intake of unpurified cooling water.

The potential for such failure causes must be considered site-specifically; where required, effective measures are to be provided to ensure unhindered cooling water supply. In connection with such scenarios, the operability of cooling water discharge must also be considered in addition to cooling water supply. A potential for the failure of cooling water discharge exists particularly with regard to seismic impact and aircraft crash.

9.3 Measures to control the loss of the ultimate heat sink

It is beyond doubt that the installation of an alternate heat sink is the most effective measure to cope with a loss of the ultimate heat sink, in particular if the heat sink itself is diverse (e.g. air instead of receiving water) and if its energy supply is appropriately reliable and not affected by the loss of the ultimate heat sink. Although with appropriate technical system design, a loss of the ultimate heat sink is very unlikely, but cannot be ruled out.

The RSK recommends:

Residual heat removal from the plant and the spent fuel pool must be ensured in all plant operating states also in case of loss of the ultimate heat sink due to failure causes in the area of cooling water intake and cooling water return by an alternate heat sink (possibly also different heat sinks in combination). The installations required for it must at least meet the requirements for accident management measures and their effectiveness is to be demonstrated.

The safety analysis should be performed under the following conditions. It is to be demonstrated

- that a loss of the ultimate heat sink and the emergency diesel generators cooled by it and a simultaneous loss of power supply can be controlled. In this respect, all relevant operating conditions as well as the cooling of the spent fuel pool is to be considered.

- that for at least 72 hours the necessary technical installations as well as supplies and materials are available at the plant and can be used effectively. The feasibility of the measures is to be demonstrated under the event-induced conditions.

- that the protection goals can be maintained until restoration of power supply (also offsite-power supply), for at least 7 days. After the expiry of 72 hours can reliably prepared and available external assistance in the verification process will be credited.

- that measures generally can only be credited if the required power supply and availability of the necessary supplies and materials is demonstrably ensured. Furthermore, the boundary conditions during a loss of the ultimate heat sink (e.g. failure of room and component cooling, especially the cooling of the reactor coolant pump seals in PWR plants, or of the seals of reactor recirculation pumps of BWR plants) are to be considered.

The RSK recommends - if not already implemented – introducing an additional accident management measure so that cooling water can be supplied to the nuclear component cooling systems and be discharged again. Supply can be provided through mobile devices. The quantities supplied must be sufficient for the removal of decay heat from the reactor and spent fuel pool and of the lost heat of the components required for such a cooling operation.

The RSK recommends providing appropriate accident management measures to ensure cooling water return for plants having a CCF potential due to the redundancy-wide merging the cooling water return lines.

10 References

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/9/ KTA 3301 Nachwärmeabfuhrsysteme von Leichtwasserreaktoren