Experience with the influence of both high summer air and cooling water temperatures and low river levels on the safety and availability of German and French NPP

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Abstract: The effects of different weather conditions are considered in the design of nuclear power plants. Extreme values, based on empirical data from the weather statistics, are used for calculating the design parameters and estimating the impact loads from severe weather conditions. But the apparent increase of frequency and intensity of extreme weather conditions in the past few years has resulted in a re-assessment of the potential consequences of such effects. As an illustration of the current situation, the experiences made at French and German nuclear power plant sites during the exceptional heat wave in summer 2003 and during the summer flood of the Elbe River in 2002 are outlined. Although nuclear safety was not impaired at any plant due to these events, analyses of suitable countermeasures and available safety margins with respect to effects of extreme weather conditions were launched in France as well as in Germany, because the remaining margins were limited in some cases. A draft outline of these assessments is additionally given in this paper.

PART 1
Operating Feedback on the Impact of the 2003 Heat Wave on the Operation of French Pressurized Water Reactors

1 INTRODUCTION

The summer 2003 was the one with the highest temperatures recorded in France for the last fifty years. The heat wave was exceptional in both intensity and duration. The summer of 2003 saw three reports of external climate-related hazards with a potential impact on the safety level of French nuclear plant (NPP) units: high air temperature, high cooling water temperature, and low cooling water level. These three hazards occurred concomitantly on some sites. It is also of interest to note that some French sites have experienced this type of situation in the past, even though over shorter periods and to a lower degree.

After providing a factual account of the operating feedback and lessons learned, this article presents the short-term measures implemented for the summer 2004, together with the safety assessments required over the longer term.

2 OPERATING FEEDBACK FROM 2003: FACTS AND LESSONS LEARNED

2.1 Facts

The experience of the summer 2003 revealed that certain design values taken into consideration in the safety demonstration could be reached, or even exceeded. Values of particular concern were the cooling water temperature, the temperature of the air taken from outside, the room temperature, and the level of water taken from the river.

Regarding the cooling water, the design value of some systems was exceeded on certain sites. This was the case, for example, in the cooling system of the containment spray system in the CP0-series plants, where the design temperature given in the Safety Analysis Report was exceeded. Subsequent checks revealed that system performance in the event of an accident situation was adequate. The availability of heat exchangers between the service water systems and the cooling systems of the nuclear auxiliaries also gave cause for concern. Fouling in these exchangers is measured, and compared to a cleaning limit that decreases with the cooling water temperature. The exchanger concerned becomes unavailable during cleaning. The total downtime is limited by technical operating requirements. Cleaning operations are made more frequently by the high temperature of the cooling water (at such high temperatures, the current safety limit requires an almost perfectly clean exchanger). Some operators initially asked to extend the authorized total downtime annual limit. As the need for cleaning operations was open to debate (only very small quantities of matter were retrieved during cleaning work), operators proposed fouling limits to be temporarily adjusted to avoid real lockout on exchangers due to cleaning jobs that did not significantly improve their performance. Last not least, the general operating rules recommend a cold temperature limit of 35 °C for the component cooling system. It was revealed that observing this limit could be difficult during a heat wave. The limit can be avoided by load-shedding on certain power consuming equipment not required for safety purposes. EDF has nevertheless reported cases of some sites operating temporarily with a component cooling system cold temperature higher than 35 °C, despite of such load shedding and even though heat exchange fouling limits were observed.

EDF also encountered problems ensuring the continued operation of electrical power transmission (transformers, AC generators) and auxiliary systems (compressed air, de-mineralized water and de-aerated water supplies). These problems, which can have a direct impact on the production tool availability, also induce safety related difficulties (reliability of electric power network, availability of coolant reserves, etc.).

The main consequence of the high air temperature is a temperature increase in rooms containing safety related equipment and, in particular, to the reactor building. In this respect, the limits currently mentioned in design or operating documents are relatively low (usually around 40 °C, or even 35 °C in battery rooms) given the ambient air temperatures prevailing during summer 2003. In addition, some ventilation systems are cooled by the component cooling system, which was itself close to its operating limit in terms of temperature (see previous point concerning the cooling water). In order to overcome this situation, operators resorted to the use of backup devices (emergency fans or chillers ranging from portable air-conditioners to 50 kW, high power, portable cooling systems) or alternative solutions, such as adjusting the air renewal rate in the rooms affected according to the time (day or night). On some sites, mist humidifier devices were installed at the intake of some ventilation systems, steps were taken to turn off lighting, and insulation quality inspections were carried out on high energy pipes. One example was at Fessenheim, where the operator tried – without success – to decrease the temperature inside the reactor building by spraying the outside wall. The ventilation systems used to renew the air in the reactor containment were also actuated some nights but with only limited success. One last example that can be mentioned was when an emergency generator tripped during a periodic test, after the high temperature threshold was reached on a "non-priority" protective device on the coolant system. For IRSN, this temperature could have reached a value close to the diesel generator's operating limit, if the use of the generator had been prolonged.

The drought that accompanied the heat wave in summer 2003 resulted in a longer and more severe low-water period than that usually observed. In particular, the operating feedback underlined risks to reach the low operating limit on the suction side of the service water pumps. This often occurred because water intake structures had been silted up more quickly than intended. Other problems occurred when water approached the normal and safe low water levels). This was the situation at Chinon B when, following a drop in the water level of the Loire River, the operator was faced with an increased risk of loss of cooling water due to low water levels. This contingency has been taken into consideration in the Safety Analysis Report (use of riprap) since first operation. However, the practical and administrative provisions accompanying this change, which is liable to have a negative impact on the environment, had never been examined until then. Last not least, regarding the amounts of water taken from and released to the river, the temperature and flow rates encountered sometimes reached the regulatory limits defined in the administrative orders governing water intake and effluent release during normal operation of nuclear facilities. In order to comply with these orders, EDF reduced its electricity production (by reducing power and/or shutting down a production unit). Some sites were granted an exceptional waiver to get through this period.

2.2 Lessons Learned

Plant operating conditions during the heat wave were verified after the event. Despite of the problems to be overcome, overall safety level was generally maintained in the facilities. The difficulties encountered do, however, indicate that French nuclear power plants were in a more vulnerable position regarding accidents than usual. Among the problems reported were those relating to fire (overloading on some electrical switchboards owing to the installation of additional air conditioning equipment, less stringent fire sectorization to allow heat removal), exceptional loading on some systems (aging, etc.), the use of devices inducing particular risks such as corrosion, internal flooding (e.g. mist humidifiers), operating at facility design limits (cooling water, ventilation systems, etc.).

Plant operators had to respond rapidly to the problems encountered during the 2003 summer heat wave. This resulted in the installation of temporary equipment and "degraded" operating modes in facilities. Analyses of the potential risks arising from the implementation of such measures and verifications of continued compliance with safety requirements were conducted urgently.

The first lesson that IRSN drew from the summer of 2003 was the need to anticipate the hazards mentioned above and to determine, in particular, if a warning system should be designed.

Secondly, site operating feedback was analyzed by EDF and IRSN after the summer 2003, focusing on the difficulties encountered and the measures taken by the NPPs. The aim of the analysis was to ensure long-term application of best practices. From its conclusions, EDF wrote down recommendations to be put into action rapidly in the event of another heat wave. These include: a) abandoning certain counter-measures, b) renewing provisions that have proven to be effective and acceptable, c) conducting further studies on the acceptability and/or possible long-term adoption of certain solutions, and d) initiating additional studies to address a few weak points specific to some sites.

Moreover, facility design should be reviewed in light of the limits observed in 2003. Looking specifically at the cooling water problem, the design of heat exchangers between essential service water systems (SEC) and component cooling systems (RRI) should be examined, together with the RRI system's permissible operating limit of 35 °C and its impact on equipment using the system. Regarding air temperature, the design of ventilation and air conditioning systems used for equipment cooling should be examined, and the permissible operating temperature limit should be reviewed to identify any possible underestimation and/or to calculate existing margins. Last not least, with respect to the problem of low river water levels, the events in 2003 resulted in investigations by IRSN regarding the possible total loss of cooling water ("H1" situation) over a long period. The following actions were taken in response to this situation:

- Analysis of weak points at certain riverside facilities,
- Anticipation of severe low water situations in terms of water resource management and from the reactor unit management viewpoint in the event of severe low level conditions in the cooling water.

Flow rates and water levels in the pumping stations on riverside sites remained adequate in 2003. It should be stressed, however, that these flow rates partially depend on operations carried out by the departments responsible for managing the various dams. Operating feedback from events in 2003 shows the importance of suitable agreements to be reached between the various waterway users. Activities of dam operators liable to affect cooling water availability should be coordinated and planned in advance. IRSN considers it necessary to ensure that such agreements exist.

3 ACTIONS TAKEN

Based on the operating feedback from the summer 2003 and in reply to the Safety Authority, EDF put forward a number of operational provisions for summer 2004 to deal with a similar situation. In addition, medium-term external hazards studies are scheduled, particularly within the framework of periodic safety reviews, with a view to implement modifications, if needed.

3.1 Short-term

3.1.1 Monitoring and Warning Procedure

A weather warning system was installed to anticipate problems relating to heat waves or droughts. The system is based on continuous measurements of the climatic conditions observed at plants and on forward-looking studies to trigger appropriate actions at four predefined levels of seriousness, ranging from standby to warning. Each warning level is associated with a local organizational structure and instructions implemented when predefined limits are met. These limits take into account the specific features of the site (technical characteristics and regulations).

3.1.2 Special Operating Procedure and Temporary Measures

As part of the operating feedback on the actions taken at facilities to solve the problems encountered in 2003, EDF drew up a list of effective temporary measures, complying with certain safety requirements. As a result, normal operating instructions (special operating rules (RPC) for "exceptional heat" and "low water" conditions) were set up at facilities with a twofold purpose, on the one hand to make provisions at the reactor units (checking ventilation systems and chiller performance, making sure that heat exchangers are clean, checking the availability of backup air conditioning, etc.) and, on the other hand, to implement these temporary measures when necessary or to bring the reactor units to a safe shutdown state following an approved procedure.

3.1.3 Changes in Safety Requirements

Although, the heat wave's real impact on safety was controlled, facilities did in fact operate with very low safety margins. In this respect, EDF launched an initiative to detect any margins in current system design and, where possible, make certain requirements less stringent to give greater latitude. Within this context, EDF suggested reconsidering certain safety limits concerning high air and water temperatures, ensuring that such action was compatible with the safety demonstration.

The proposed changes concerned maximum permissible temperatures in the reactor buildings of CP0- and N4-series plants, and in certain rooms housing safety related equipment, regardless of series. It was also recommended to lighten the restrictions on the authorized annual limit on total downtime allowed for cleaning exchangers between essential service water systems and component cooling systems.

IRSN replied favourably to EDF's proposed changes to reactor building temperatures. The new temperature limits are compatible with equipment operation and should allow EDF to avoid problems regarding compliance with assumptions made in accident studies.

However, concerning temperatures in auxiliary building rooms, the institute recommended that the envelope temperatures to be taken into account in ventilation system design should be re-examined to check adequacy of the current performance of these systems.

IRSN also considered that the proposal to lighten the restrictions on the authorized annual limit on total downtime allowed for cleaning exchangers between essential service water systems and component cooling systems was not sufficiently supported. The supporting arguments presented were based on probabilistic studies, for which assumptions made could not be confirmed by the operating feedback.

3.1.4 Changes in Applications for Water Intake and Effluent Release Permits (DARPE)

EDF requested changes to thermal release permits for the three most sensitive sites to avoid the need for operation under exceptional conditions. The permits were modified in June 2004.

3.2 Medium-term

The safety review of 900 MW_e reactors, which will be carried out during their third-series ten-year inspection (VD3 900), provides for an assessment of how reactors and facilities in general withstand climate related hazards, including: "high cooling water temperature", "high air temperature" and "low cooling water level". As a consequence of the 2003 heat wave, the Safety Authority requested a similar review for the other plant series.

The resistance of reactor units and facilities with regard to climate related hazards will be assessed adopting a three-phase approach. This involves:

- Identifying and collecting documentary support for the loads involved,
- Drawing up a summary of implemented or planned on-site measures to provide protection against possible hazards,
- Conducting a safety impact analysis of the hazards concerned, making allowance for relevant combinations. Additional preventive measures concerning such hazards should be studied where necessary or solutions found to control their effects.

The operating feedback from the summer 2003 heat wave will be of use in calculating maximum permissible cooling water and air temperatures and in consolidating methods for defining and calculating the water level required to ensure reactor unit safety (safe low water levels).

In addition, the VD3 900 safety review program includes an assessment of how reactor units and facilities respond to hazards integrating a common-mode risk (hazards affecting several units or downtime on several systems due to a single cause). This study focuses on medium- and long-term facility control and is aimed at:

- Identifying hazards liable to have an adverse effect on cooling water and/or external electric power supply availability,
- Characterizing possible ensuing situations (total loss of cooling water and/or total loss of external electric power supplies) and their duration,
- Analyzing the resistance of facilities in terms of secondary reserve capacity and the reliability of internal electric sources, and identifying possible improvements,
- Checking that equipment requirements provide adequate guarantees against hazards.

The initial results of this assessment should be available by the end of 2004.

4 CONCLUSIONS

Operating feedback for 2003 demonstrated that the overall safety levels of facilities were maintained at a time when electric power production capacity was tightly stretched. It also revealed, however, that reactor units could be stretched to their normal operating limits. Operators had to respond rapidly to the problems encountered. This resulted in the installation of temporary equipment and "degraded" operating modes in facilities. Analysis of the possible risks arising from the implementation of such measures and verifications of continued compliance with safety requirements were conducted urgently. It has now become clear that the design and operation of nuclear facilities should be reinforced with regard to such hazards to guarantee a satisfactory safety level.

In the short-term (summer 2004), IRSN examined requests to get certain requirements laid down in the General Operating Rules less stringent and to give greater latitude regarding some restrictive safety criteria in the event of a heat wave. At the same time, the operator took monitoring measures (warning system) and preventive actions (checking the availability and efficiency of critical systems) to make its facilities better prepared for similar climatic conditions in the future. The operator also took steps (in terms of organization and equipment) to control the impact of these hazards. Most of these measures come from site operating feedback in 2003 and were analyzed afterwards to determine their true effectiveness and acceptability with regard to safety.

In the medium-term, IRSN intends to conduct assessments of how facilities withstand heat wave conditions. These assessments will be included in a safety review. This review, initiated on the 900 MW_e series before the summer 2003 and extended to all EDF sites, must also include an assessment of all the combined hazards liable to lead to lasting upset conditions (total loss of cooling water on site). It must be demonstrated that reactor units and sites respond to these common mode hazards in a satisfactory manner.

PART 2
Severer Weather Conditions and Their Impact on the Safety of German Nuclear Power Plants

5 INTRODUCTION

The influence of various weather conditions is considered in the design of nuclear power plants (NPP). The respective requirements are included in the design parameters for safety systems, such as the maximum circulating water intake temperature or the maximum allowed room temperature in the emergency diesel building. In addition, extreme weather conditions, e. g. flooding or lightning, are separately considered in the design. Extreme values, based on empirical data from the weather statistics, are used for defining design parameters and estimating impact loads from severe weather conditions.

The extreme weather conditions having occurred in the past few years, such as the extreme storm in France end of December 1999 resulting in the flooding of the NPP Blayais (INES 2 event), the summer floods at the German Oder River in 1997 and the Elbe River in 2002, as well as the long lasting extreme drought and heat in summer 2003 resulting in operational limitations of nuclear and non-nuclear power plants all over Europe are the cause for a review of German NPPs with respect to the potential impact of exceptional weather conditions.

In 2000, a survey was carried out by the German Federal State Nuclear Authority BMU (Ministry for the Environment, Nature Conservation and Reactor Safety) in the German Federal States regarding the design of German NPP against flooding. Another survey has been started by BMU in 2003 on the effects of an extreme increase of the river water temperatures on the safe operation of German NPP. Both surveys have been analyzed and assessed by GRS. Furthermore, GRS performs a systematic review of weather induced impacts to German NPP. Similar reviews are additionally being carried out by some of the Federal States authorities and the licensees. All these activities have not yet been finished.

Although there are no validated insights, if the intensity and frequency of weather induced impacts will change in the future in Europe, meteorologists and climatologists point out that there is a possibility of more frequent and more intense extreme weather conditions resulting from climate changes.

The major goal of the review with respect to weather induced effects on German NPP is to check if the requirements implemented in the design are still state-of-the-art with regard to extreme weather conditions. Furthermore, existing safety margins in the design with respect to potential changes in the weather conditions shall be demonstrated. The German review includes analyses for all types of extreme weather conditions, the potential impact on the nuclear safety, a comparison of the design and demonstration parameters (representing the basis for safety demonstrations) with extreme values observed up to now, an audit of administrative controls for extreme weather conditions in the instruction manuals, as well as a review of the plant state regarding retrofits, changes in the nuclear design codes and ageing.

In the following, an overview on the impact of extreme weather conditions on nuclear power plants is given.

5.1 Lightning

German nuclear power plants are provided with a protection system against lightning effects. The lightning protection system consists of an external lightning protection, an internal lightning protection, and a protection against the electromagnetic lightning impulse:

- The external lightning protection includes all measures and devices to intercept and divert lightning.

- The internal lightning protection includes all measures and devices against the effects of lightning on conductive installations and electrical systems inside buildings.

- The protection against an electromagnetic lightning impulse includes all measures and devices for grounding, electromagnetic shielding and potential equalization.

The KTA Safety Standard 2206 [1] on the design of nuclear power plants against lightning effects was updated in June 2000. In the meantime, several backfitting measures have been performed at the plants.

Due to the large number of long and manifold cable and pipe routings within and outside NPP buildings, electric potential increases resulting from lightning strikes are a special hazard potential. Electronic systems, such as digital I&C, are particularly susceptible to induced voltage due to their frequency characteristics.

The parameters for lightning strike considered in the design are mainly oriented towards the design values achieved for lightning protection of domestic or industrial buildings. To which extent exceptional extreme values are also covered by the design according to the KTA safety standard is not known.

In the past, several lightning strikes with consequential events were reported from German as well as from foreign NPPs. The most noteworthy consequential events were losses of several redundancies of the neutron flux measuring chains, of the oil supply of a main coolant pump, or of the activity monitoring systems. One of the typical effects is a grid failure due to overvoltage caused by lightning strikes on overhead lines

From German operating experience during the past years, there are no indications of an increase of lightning strikes with consequential events at NPPs.

5.2 Storms

All structures of German NPPs are designed against wind load effects according to conventional civil engineering regulations. Furthermore, the guideline of the Federal Ministry of the Interior (BMI) on the protection of NPP against blast waves from chemical explosions of 1976 [2] is referred to for safety related buildings. By this design against explosion blast waves, effects of extreme wind velocities are covered. For NPPs built before establishment of the guideline, corresponding analyses and demonstrations and, where required, backfitting measures were performed subsequently.

The grid connections of NPPs and the respective high-voltage grid are not provided with a special structural protection but have to withstand extreme weather conditions with storms or hurricanes for reasons of ensured power supply. The design of high-voltage overhead lines against wind loads is based on the industrial standard DIN VDE 0210 [3]. This structural design is not object of the nuclear licensing and supervision procedure.

From GRS point of view due it does not have to be assumed that the stability of safety related NPP buildings will be impaired by extreme wind loads due to their massive construction. However, impacts by wind driven objects falling on parts of the auxiliary power supply or the coolant supply should be taken into consideration, as recent experiences show.

Until now, disturbances in the overhead grid system caused by wind loads on conductor wires and pylons have occurred very seldom in Germany. Typical storm-induced grid disturbances are earth faults, flash-over and short circuits caused by objects blown into overhead lines by storm.

For the determination of the wind load for the design of high-voltage overhead lines, wind velocities of up to 160 km/h are assumed. Higher wind velocities, as they occurred in France, could lead to material breaks. An increase in intensity and frequency of storms or hurricanes could also increase the occurrence frequency of grid failures with longer lasting losses of offsite power. In case of such increases, the effects would have to be reconsidered.

5.3 Extreme Snowfall

In accordance with the conventional civil engineering regulations on which the design is based upon, all structures of German NPPs have to be design against snow loads. Moreover, safety related buildings also have design margins due to their design against explosion blast waves providing stability even under snow loads greater than those taken as a basis for the conventional civil engineering regulations. Effects of extreme snowfall on the NPP safety could rather be induced by grid failures resulting from impairment of the grid connection.

5.4 Extreme Temperatures

Extreme temperatures may impair important safety systems. In the following, both cases, extremely low temperatures and extremely high temperatures, are dealt with separately, because they are very different with regard to their impact paths.

5.4.1 Low Ambient and Water Temperatures

Weather conditions with extremely low temperatures and longer frost periods mainly have an impact on NPP cooling water systems. An impairment of their function is to be feared, particularly, by icing effects. The major part of safety related systems is protected against icing in buildings. However, icing may occur in the area of the on-site pre-flooder or in the area of cooling towers or cooling tower cells. Safety significant consequences may be induced by impaired function of the secured auxiliary service water system due to icing. Depending on the plant, icing may occur in the intake structure or in the cooling tower cells. Corresponding countermeasures, such as the reduction of cooling surfaces in cooling towers or the injection of warm water into the intake structure, are specified in the instruction manuals of German plants and are initiated, if temperatures fall below specified limits.

At German plants, only few events in connection with low ambient temperatures occurred. Experiences in countries such as in USA or Canada with lower temperatures show that events, such as icing of intake structures caused by formation of floating ice, may lead to common mode failures. Such failures can be prevented by maintenance and, where appropriate, by temporary measures.

5.4.2 High Ambient and Water Temperatures

The impact of weather conditions with extremely high temperatures on the safety of NPP can generally take place via two paths: high river water temperatures and high ambient temperatures.

A loss of the main heat sink due to excess of the maximum cooling water intake temperature practically is not to be feared because of the very slow development of the potential transient. In case of excess of a specified temperature rise (exit temperature intake temperature) or a specified exit temperature countermeasures have to be taken for reasons related to water utilization legislation. A power reduction or even the shutdown of the plant may also be required due to an excess of the maximum auxiliary service water temperature for safety demonstrations on the emergency core cooling and the residual heat removal system. In this respect, there was a power reduction at seven German NPPs during the extremely hot summer 2003. The power of four of these seven plants was reduced for reasons related to water utilization legislation and of three by order of the competent authority due to excess of the maximum auxiliary service water temperature. This issue will be addressed more detailed in Chapter 6.2.

The design of the secured auxiliary service water system and the systems connected to it, such as the residual heat removal system, the cooling system of the emergency diesel generators, the room coolers of the switchgear building and the emergency diesel building and the condensers for cooling compressors, is based on a maximum cooling water intake temperature.

The effects of extremely high river water temperatures on the function of the emergency core cooling and residual heat removal system requires a plant specific examination, as not all German NPPs exclusively use river water as heat sink for residual heat removal. At some NPPs, the heat of the secured auxiliary service water system is removed via cooling tower cells and some of these plants also use well water instead of river water for the operation of the cooling tower cells. In addition, German nuclear power plants have, with regard to these cooling systems, different design margins which would enable safe plant operation even in case of higher river water temperatures. The margin between the specified limit temperatures used for safety demonstration and the maximum river water temperatures measured in summer 2003 are presented in Chapter 6.2.

The analysis of the effects of high river water temperatures on diesel cooling has not been finished yet. Therefore, results are not yet available.

In addition to the impact of high river water temperatures, the analysis of the impairment of the function of the room coolers of the switchgear building and the emergency diesel building and the refrigerating unit for the ventilation system also has to consider the impact of high ambient temperatures. If these safety related ventilation systems do not have sufficient design margins, the impact of higher room temperatures on heat-sensitive components, such as electronic elements, have to be analyzed.

5.5 Low Water Levels

Intake and pump structures at German plants are designed such that the required cooling water intake for power operation can even be ensured in case of extreme river water levels. Of special safety significance is ensuring water supply for the auxiliary service water system for residual heat removal in case of incidents or shut down operation. But even if events are assumed where water supply via the intake structures fails, these do not represent a hazard situation, early shutdown provided. The required cooling water supply can be ensured by provisional measures. The amount of cooling water needed for residual heat removal is small even compared to the water volume of a river with low water level. In this respect, it can be assumed that sufficient time is available for necessary measures due to the slow development until reaching such river water levels.

5.6 Floods

Extremely high river water levels may endanger the safety of NPP by inundation of the plant site with subsequent flooding of safety related buildings. Flooding may result in a failure of safety -related components, such as auxiliary service water pumps, and also may lead to short circuits, if electrical equipment is flooded. Furthermore, the accessibility of the plant and the supply with important operating materials may be interrupted due to flooding.

German NPPs are designed against flooding according to the requirements of the KTA Safety Standard 2207 [4]. The design flood to be considered according to this safety standard is the flooding with an occurrence probability of 10^{-4}/a. The plants in coastal regions and those at river sites are protected by location at respective elevations or adequately designed dikes. In a further design step, the potential consequential effects of dike bursting are considered. Here, the intrusion of water into safety-relevant buildings is prevented by the elevated location of the plant site and/or the impermeability of the lower plant areas. In addition, temporary flood protection measures can be taken, such as the installation of stop logs in flood-endangered reveals. All these measures also cover potential effects of extreme precipitations. Some instruction manuals include specifications on plant shut-down and bringing the plant to a safe shutdown state, e. g., when reaching a specified water level below the design flood level. For adaptation to the state of the art in science and technology, the version of KTA Safety Standard 2207 of June 1992 was amended. The most important part of the amended version of KTA 2207 [5] refers to the definition and determination of the design flood and the design flood level. For the determination of the design flood, two different methods are applied; one for inland sites and one for sites in coastal regions.

6 EXAMPLES FROM THE GERMAN OPERATING EXPERIENCE REGARDING EXTREME WEATHER CONDITONS

6.1 Floods

In August 2002, extreme flood events occurred at the rivers Oder and Elbe due to heavy precipitation over Central Europe between 1 and 12 August 2002. In a band, extending from Berlin via Dresden and Prague to Salzburg, a precipitation of more than 100 mm was measured within 13 days, which is more than the medium precipitation volume expected for the entire month of August. Since the affected regions belong to the catchment basin of the Elbe River, the drainage of the precipitations took place via the Elbe and its tributaries. This led to drainage rates in the range of 4'000 m^3/s (normal average drainage 320 m^3/s in Dresden) and thus to considerably high water levels which caused 12 dike breaks along the German part of the Elbe in spite of controlled flooding and other protection measures.

This flood disaster affected the four nuclear power plants located at the lower reaches of the Elbe River to a different degree. For three of these power plants, potential flooding is not primarily dependent on the drainage of precipitations via the Elbe River but mainly is a result of a storm surge of the North Sea and its influence in the lower reaches of the Elbe River. During the flooding in summer 2002, none of these plants was affected by a water level which would have impaired normal operation.

At the fourth site (ELBE-3), the draining of precipitation from the catchment basin of the Elbe River is the determining parameter for a potential flooding. The highest water level reached in August 2002 was approximately one meter below the NPP ground level. This triggered the preparation of flood protection measures foreseen in the plant operational manual, but these measures were finally not applied, because of the favourable development of the situation.

Although none of the four NPP was really compromised by the catastrophic flood in August 2002, this extreme flood was of utmost importance with respect to the protection of German NPPs against flooding: The Elbe river water level of the year 1845, which had been assumed to be a gauge of 10^{-3}/a probability was not only reached but significantly exceeded within less than 150 years. This event as well as the fact that the water level measured at the ELBE-3 site in January 2003 was only insignificantly lower than the one of August 2002, and furthermore that extreme flood water levels have been measured during the last years for various Central European rivers, demonstrate clearly the necessity to check the assessment methods for extreme water levels.

The questionnaire regarding the design of German NPPs against flooding set up by BMU in 2000 (against the background of the severe weather conditions in France end of 1999) and distributed to all Federal State authorities gained even more attention after the flooding in August 2002.

In this questionnaire the following aspects were considered:

- Determination of the design flood,
- Extent of protection and load assumptions,
- Flood protection measures,
- Regular in-service inspections, and

- Applicability of findings and results from the Blayais flooding event to German NPP.

The evaluation of the questionnaire by GRS did not allow for a final assessment of the actual state of German NPPs with respect to flooding protection because of different methodologies and approaches for estimating the design flood level, which were not described in all details, and due to missing requirements and recommendations in the nuclear standards and guidelines.

The amended nuclear Standard KTA 2207 "Protection of NPP against flooding, in preparation" provides an approach for determining the design flood level in compliance with state-of-the-art methods for estimating extreme flood levels and low exceeding probabilities respectively for water levels at river sites as well as at costal sites. This standardized approach will enable the analysts to compare the design water levels considering nuclear safety aspects. KTA 2207 in its amended version also requires a plant specific comprehensive concept for flood protection, demonstrating the appropriateness of the combination of the individual measures, if necessary depending on different flooding water levels up to the design water level for all buildings and structures, which have to be protected. Furthermore, the concept has to consider load combinations like flooding with simultaneous occurrence of an earthquake.

With regard to the applicability of the Blayais event consequences to German NPPs, further analyses are necessary to assess the possibility of an intrusion of water via ducts connecting different buildings and to evaluate the pressure resistance and quality of barriers, penetrations, and separations of rooms taking into account in particular ageing aspects.

Administrative measures for assumed plant isolation due to flooding of the surrounding area ("isle situation") as well as the support with technical supply means in such an extreme situations have especially to be considered for the plants ELBE-2, RHEIN-3, and RHEIN-4.

6.2 High Ambient and Cooling Water Temperatures

The summer 2003 is well known for its long lasting very dry period of high temperatures in Central Europe resulting in an increase of the river water temperatures and significantly low water levels.

With regard to the emergency core cooling and residual-heat removal system, the BMU requested the Federal States with letter of 25 August 2003 to answer the following questions:

- Which temperatures were measured at the intake of the auxiliary service water pumps in August 2003?

- Up to which maximum temperature are demonstrations available on the operability of the emergency core cooling and residual-heat removal system?

- Which cooling water volumes are necessary in the intake building for emergency core cooling and residual-heat removal at the above temperatures and how far were these available at any time?

- Which values are specified in the respective plant operating procedures with regard to the above temperatures and water volumes?

The demonstrations for the emergency core cooling and residual-heat removal refer to plant conditions with special requirements on the cooling chain, in particular loss-of-coolant accidents (LOCA), where no secondary-side heat removal is possible.

Table 1 gives a summary of the numerical values mentioned in response to the first three questions.

Table 1: Service water temperatures at German NPP sites in summer 2003
w = power reduction due to water utilization legislation
r = power reduction due to regulatory requirement

NPP	Power reduction	T_{SW} [°C] reached in August 2003	T_{SW} [°C] safety demonstration	F_{SW} [m³/s] necessary
DONAU-1	-	19…22	22	1.9
DONAU-2	-	19…22	22	1.9
ELBE-1	w	≤ 25.2	26	1.0
ELBE-2	w	≤ 24.9	**24** [(1)]	1.9
ELBE-3	w	≤ 27.2	**25** [(4)]	5.0
ELBE-4	w/r	20.4…27.0	30	0.4
EMS-1 [(2)]	-	18.3…26.9	28	0.6
ISAR-1	w	21…25	**23** [(3)]	1.3
ISAR-2	-	21…24	28	2.3
MAIN-1	-	22…26	29	2.0
NECKAR-1 [(7)]	r	≤ 29.1	**26.2**	2.5
NECKAR-2	r	≤ 29.1	31.0	4.0
NECKAR-3 [(5)]	w	≤ 26.9	**25.0**	1.7
RHEIN-1	?	?	?	?
RHEIN-2	w	24.2...29.1	30.8	1.5
RHEIN-3 [(7)]	r	≤ 27..0	**24.7** (29)	4.7
RHEIN-4 [(7)]	r	≤ 27.0	**25.0** (29)	8.0
WESER-1	-	17.5…25.1	28	2.0
WESER-2	w	21.2…26.0	28 [(6)]	1.4

(1) Safety margins up to 26,2°C at rated power and up to 27.5 °C for LOCA
(2) Emergency service water cooled via river water, auxiliary service water cooled via multiple-cell cooling tower
(3) Up to 29 °C at reduced power
(4) The coolers of the diesel generator units are designed with 15 % safety margins.
(5) Plant shut down for maintenance inspection
(6) Power reduction required due to legal water rights at 20 °C
(7) In August 2003, operational safety has been verified for temperatures up to the values given in brackets.

In August 2003, the auxiliary service water temperatures exceeded the temperatures, for which demonstrations on the safe operation were available, at seven plants. These are the plants ELBE-2, ELBE-3, ISAR-1, NECKAR-1, NECKAR-3, RHEIN-3 und RHEIN-4. For the NECKAR-2 plant, it was demonstrated subsequently that the design already considered a river water temperature of 31 °C (as given in table 1) and not, as initially stated, 26.3 °C.

Except for NECKAR-3, all plants where the demonstration temperature for the auxiliary service water had been exceeded submitted new demonstrations on safe operation for higher temperature. At all these plants, the power was reduced; at four for reasons related to water utilization legislation and at three by order of the competent authority due to excess of the maximum auxiliary service water temperature.

The cooling water volumes necessary for residual heat removal were available at all plants at any time.

In the plant operating procedures of the German plants, limit values for the service water temperature and volumes are only specified with regard to water utilization regulations (nature conservation), in connection with the nominal flow rates of the auxiliary service water pumps and as condition for the complete unloading of the core. The latter means that if a complete core unloading is intended, it has to be demonstrated that the residual heat can be removed from the spent fuel pool via the fuel pool cooling system at the existing river conditions. The removal of the residual heat from the reactor pressure vessel is not concerned by this. As shown in table 1, river water temperatures of up to 29.1 °C were reached at four plant sites (RHEIN-1, RHEIN-2, NECKAR-1, and NECKAR-2) in summer 2003. These are temperature values that are not far away from the design temperature of 32 °C for diesel cooling. To which extent the design of the diesel coolers has margins beyond this value, does not have been examined yet.

7 CONCLUSIONS

Although the safety of German NPPs was not actually impaired by extreme weather conditions in the past, the limited margins in terms of the temperatures used for the safety demonstrations of the emergency core cooling and residual heat removal systems during the heat wave in summer 2003 and the frequency and intensity of floods at the Elbe River in the last few years revealed the necessity to review the status of German NPPs with respect to weather induced effects.

Potential impacts of even worse weather conditions should be anticipated to ensure the safe operation of NPPs also in the long-term. This requires a precise assessment of existing reserves in the current design of safety systems and, if necessary, an amendment of the load assumptions in the safety demonstrations. Special attention should also be paid to measures and procedures to prevent or mitigate weather induced effects. Particular aspects to be considered are the availability and effectiveness of the intended measures as well as the appropriate synchronisation with the time sequence of the particular weather conditions.

The systematic review of the possible impacts of severe weather conditions on German NPPs up to now revealed two effects which should be analyzed more in detail: On the one hand these are events related to heat waves and drought periods, on the other hand events related to floods.

8 REFERENCES

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