NPP Krško Alternative Residual Heat Removal (ARHR) System)

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ABSTRACT

Nuclear Power Plant Krško (NEK) decided to take steps for upgrade of safety measures to prevent severe accidents, and to improve the means to successfully mitigate their consequences. The content of the program for the NEK Safety Upgrade (SUP) is consistent with the nuclear industry response to Fukushima accident, which revealed many new insights into severe accidents. Therefore, NEK carried out a series of accident analyses involving design extension conditions, addressed the combinations of accidents, based on which an additional upgrade of the nuclear power plant was required (Design Extension Conditions – DEC). The new additional systems installed within the SUP, ensure that NEK will manage beyond design basis accidents using the extended range of equipment and upgrades.

Part of the Safety Upgrade Program is extension of exiting Residual Heat Removal (RHR) system, as a safety system, with Alternative Residual Heat Removal (ARHR) system, provided for decay heat removal in Design Extension Conditions (DEC A) and Beyond Design Bases Accidents (BDBA or DEC B). The Alternative Residual Heat Removal (ARHR) System represent alternative cooling of the RCS and the RB sump water, to remove decay heat from the heat source (reactor core and containment) to the heat sink (Sava River).

The design function of the ARHRS is to remove decay heat from the Reactor Coolant System (RCS) and Containment (CNT) under DEC conditions, when the RCS is intact. This function is similar to the primary function of the exiting RHR system except that the ARHR only operates as a backup to the unavailable RHRS (in part or in whole) under DEC conditions.

The secondary function of the ARHR is to provide means, under DEC condition, for an Alternate Core Cooling (ACC) and Containment cooling, in case that the DEC event causes a Loss-of-Coolant Accident (LOCA) or any other accident, making the Emergency Core Cooling System (ECCS) unavailable, and requiring RCS depressurization followed by an alternate core cooling system operation. This secondary function, performed under DEC conditions, is implemented by aligning the ARHR into various configurations with exiting NEK systems. For each configuration, the ARHR pump is used in conjunction with either one of the RHR heat exchanger or the ARHR heat exchanger, depending on accident circumstances and equipment availability.

Keywords: *Alternative Residual Heat Removal, Design Extension Condition (DEC), Krško NPP*

1 INTRODUCTION

Following the Fukushima accident, Nuclear Power Plant Krško (NEK) carried out a series of accident analyses involving design extension conditions. These accidents were not addressed in the original design of the power plant and/or as part of the design basis accidents. The analyses addressed the combinations of accidents, based on which an additional upgrade of the nuclear power plant was required (Design Extension Conditions – DEC). The upgrade took place as part of the Safety Upgrade Program (SUP). The new additional systems installed within the SUP, ensure that Krško NPP manages beyond design basis accidents using the extended range of equipment and upgrades. The equipment was divided into DEC-A and DEC-B equipment.

A set of Design Extension Condition (DEC) is derived based on engineering judgment, deterministic assessments and probabilistic assessments based on references IAEA SSR-2/1 document [1], NEK IPE evaluation [2] and NPP KRŠKO Analyses of Potential Safety Improvements [3]. The combination of events, more severe that design basis accidents, was defined and are considered as design extension requirements.

The one of the combination of events was unavailability of both RHR pumps scenario, which assumes unavailability of both RHR pumps and availability of DB UHS systems (SW and CC systems) and DEC A equipment. Since the water inventory is required for long term decay heat removal to prevent core damage (DEC-A category) or for mitigation of core damage (DEC-B category), the new Alternative RHR system has been introduced. The focus of this scenario is to use ARHR pump for Reactor Coolant System (RCS) cooldown, and RCS cold leg or RCS hot leg recirculation with one train RHR train. In case, that all DB equipment is not available, long term decay heat removal will be performed through ARHR HX using ARHR pump. The other scenarios imply using ARHR for long term (30 days) decay heat removal.

The ARHR system is planned to be used for reactor decay heat removal either from the RCS or from the containment once the core and RCS are severely damaged if the RHR system unavailable.

2 DESIGN REQUIREMENTS

Heat removal from the core to an ultimate heat sink is essential for nuclear safety. In case of a DEC event, the RHR pumps and heat exchangers may not be available, resulting in the loss of residual heat removal capabilities. The ARHR is designed to remove decay heat from the heat source (the core) to a heat sink (Sava River), under both DEC-A and DEC-B conditions.

The Alternative Residual Heat removal system is designed considering different design extension conditions, as follows:

- Large break LOCA without available Emergency Core Cooling System (ECCS) and with Station Blackout (SBO),
- Loss of the secondary heat sink (without the auxiliary feedwater pump and Condensate Water Tanks)
- Loss of the final heat sink (unavailable Essential Service Water and Component Cooling systems),
- Aircraft Crash of the plane (unavailable auxiliary feed water pumps and condensate water tanks)
- both RHR pumps are unavailable (SW and CC systems and DECA equipment available).

Consistently with the design basis for the DEC systems, the Alternative Residual Heat Removal System (ARHRS) is separated from the existing plant systems and fully independent from those systems. As the ARHRS is a back-up system, the single failure criterion is not applicable. The system consists of fixed installed components and permanently installed piping inside existing buildings. The ARHR pump and heat exchanger are located in the Auxiliary Building, at a different elevation than the RHR pumps and heat exchangers. The ARHR pump and the active components of the system will be powered through Safety Class bus supplied by the Emergency Diesel Generator 3 (EDG3) of the NPP Krško.

The exiting Residual Heat Removal System (RHRS), as a safety system, is extended with equipment for decay heat removal in Design Extension Conditions (DEC A) and Beyond Design Bases Accidents (BDBA or DEC B). The classification of the part of the system interconnecting with the existing system is in accordance with the original Classification Criteria as described in the USAR Section 3, in accordance with the applicable criterions.

2.1 Seismic design

The newly upgraded safety equipment in the existing Safety-Related Buildings and new DEC equipment in the yard has been designed for an increased seismic loading of 0.6g PGA at free field (the existing design basis for Krško NPP is 0.3g PGA (e.g., SSE)). This increased seismic load (0.6 g) has been used to increase the margin of safety related to the availability and operability of these systems designed for extreme natural events (DEC equipment) and for the preventing and mitigation of the Beyond Design Bases Accident (BDBA). Increased seismic loading has also been applied to new Safety-Related piping/tubing and new piping/tubing supports associated with the new equipment

2.2 Environmental design

The ARHR system's components are qualified to perform its safety functions through DEC-A and DEC-B periods during plant design lifetime or will not fail in manner to prevent mitigation of sever accident when it may be exposed to severe accident harsh environmental. The ARHR system’s components are installed in Auxiliary Building, which is defined as harsh environmental conditions, in accordance with FER-ZVNE/SA/DA-TR04/18 [4] and EQTR-18 [5] reports. Environmental conditions such as radiation value, environmental temperature and pressure value have been used in design of ARHR components. Some equipment can be exposed to significantly higher radiation doses, due to ARH pipes gamma shining based on the report, mentioned above.

3 ARHR SYSTEM’S FUNCTION

Heat removal from the core to an ultimate heat sink is essential for nuclear safety. In case of a DEC event, the existing RHR pumps or the entire RHR system (RHRS) may be unavailable, resulting in the loss of residual heat removal capabilities. The ARHR system has been installed for alternative cooling of the RCS coolant (and in addition the reactor building (RB) sump water), with the purpose of removing the decay heat from the core and transferring it to the available heat sink (Sava River).

3.1 ARHR Design Function - RCS Decay Heat Removal

The primary function of ARHR system is to remove decay heat from the core and RCS under DEC conditions, when the RCS is intact. This function is like the primary function of the RHR system, except that the ARHRS operates under DEC conditions. In this case, the ARHR system takes suction from the RCS HLs (hot legs) and re-inject the cooled reactor coolant into the RCS CLs (cold legs), either by using the RHR heat exchanger (under DEC-A events) or by using a dedicated ARHR heat exchanger (under DEC-B events). The system can start to operate at 30 bar(g) and 160°C (like RHR system cut-in conditions).

3.2 ARHR Secondary Functions

A secondary function of the ARHR system is to provide Alternate Core Cooling (ACC) under DEC conditions, in case a DEC event causes a loss of coolant accident (LOCA) resulting from a break in the primary RCS or any other accident making the Emergency Core Cooling System (ECCS) components unavailable that would require short term RCS depressurization followed by longer term Alternate Core Cooling system operation. This latter function is similar to the primary function of the Low Head Safety Injection (LHSI) system, except that the ARHR operates under DEC conditions. Hence when the ECCS (LHSI and HHSI) and/or the CI are in operation, the connection of the ARHR to those systems is not allowed.

In case of intact RCS, RCS cooldown can be performed with two possible system alignments at the ARHR pump discharge, as described in the following subsections. The ARHR system consists of one train with the capability to be aligned on the suction side to the RWST, the containment sump and to the RCS HLs, and on the discharge side to the containment sump, to the containment spray system (CI train A), and to the RCS HLs, CLs and RV injection lines. For each configuration, the ARHR pump is used in conjunction with either one of the RHR heat exchanger or the ARHR heat exchanger, depending on accident circumstances and equipment availability, as described below.

3.2.1 RV Injection

For this function, the ARHR pump suction line is connected to existing RHR system train A or train B, through the open isolation valve, upstream of RHR system pumps A and B, and takes suction from the RCS (HL1 or HL2) through open RHRS valves. The primary function of the ARHR during Reactor Vessel (RV) injection phase is directed towards minimizing or preventing further damage to the core (in case core damage has already occurred) by rapidly refilling the RV and hence re-flooding the core once the RCS pressure is low enough to allow injection.

The RV injection phase is defined as that period during which borated water from the RWST is delivered to the RCS RV either via one of the RHR HXs to both RV injection lines or via the ARHR HX to any one injection line.

3.2.2 RV Recirculation

The primary function of the ARHR during RV recirculation phase is to remove the decay heat from the core. In case boiling has occurred in the RV, the function of the ARHR would be to provide makeup water to replace coolant losses due to boiling.

The RV recirculation phase is defined as that period during which borated water is recirculated from the containment sump (RB sump) either through one of the RHR HXs directly to the RCS RV or through the ARHR HX directly to the RV.

3.2.3 HL Recirculation

The primary function of the ARHR during HL recirculation phase is to terminate boiling and prevent boron precipitation in the core. The HL recirculation phase is that period during which borated water is recirculated from the containment sump (RB sump) either through one of the RHR HXs, to the RCS HLs or through the ARHR HX directly to the HLs.

Additional alignments combinations enable the ARHRS to fulfill the following accident mitigating functions:

a) <u>RB Sump Water Cooling</u>

The ARHR system is used to recirculate water from the RB sump, through the ARHR HX and back into the RB sump to cooldown the reactor vessel cavity in case of DEC-B conditions (i.e., core melt). Heat is transferred from the RB sump water to the Sava River water circulating on the shell side of the ARHR HX.

b) <u>RB Sump Flooding</u>

The ARHR system is used to inject water from the RWST into the RB sump under DEC events. Heat is transferred from the RB sump water to the Sava River water circulating on the shell side of the ARHR HX.

c) Containment Spray

The ARHR system delivers water from the RB sump (cooled down by the ARHR HX) or from the RWST (cold water) to the Containment Spray System (CI Train A). The ARHR system is designed such that it has the capability to perform the CI function under DEC conditions.

The ARHR is aligned manually from the ECR or from the MCR. The operator can manually start the ARHR pump and open suction and discharge valves. Independent DEC instrumentation, controls, alarms, and protective equipment are provided to ensure that the various ARHR systems and components' parameters, such as pump suction and discharge pressures, temperatures, and flows, can be controlled and monitored by the operator. The primary location for the actuation and operation of the ARHR pump and motorized control valves is the DEC Panel in the MCR. The backup and ultimate control location for the ARHR active components is from the EMCB in the Emergency Control Room (ECR).

4 ARHR SYSTEM OPERATION

During normal plant operation, the ARHR system is idle and in standby condition. Per design, all ARHR isolation valves are maintained in closed position to isolate the ARHRS from the Safety Injection system, existing Residual Heat Removal system, Containment Injection system and RB atmosphere. In standby position, the ARHRS primary side piping is filled with borated water. The permanent piping that supplies Sava River water to the ARHR HX shell side is filled with demineralized water.

Following any DEC event causing the unavailability of the RHR pumps (i.e., intact RHR system piping and cooling chain CC – SWS – UHS available) or unavailability of the RHR system, the ARHR system is used according to the applicable procedure, which provides guidance necessary for placing ARHR system in service to establish alternate cooling for ARH pump and ARH heat exchanger in case of inoperability of RHR system. The Emergency Operating Procedures (EOP's) are used together with System Operating Procedure (SOP) for ARHR system.

The alternative functions of the ARHR system (RB Sump Water Cooling, RB Sump Flooding and Containment Spray) are performed in accordance with applicable EOP procedure and/or Severe Accident Management Guidelines (SAMG).

5 CONCLUSION

In case of a DEC A event (Design Extension Condition A) causing a loss of both RHR pumps A and B (but with component cooling available), the ARHR pump will be capable to establish flow through the existing RHR heat exchangers. In case of a DEC B event (Design Extension Condition B) the RHR system (existing RHR heat exchangers and RHR pumps) is postulated to be unavailable, resulting in the loss of RCS residual heat removal. Under those conditions, the new ARHR pump and alternative heat exchanger are be used, independent from the existing RHR system, to remove decay heat from the core to an UHS. In case of severe accident, the Alternative Heat Removal system is also can be used to supply the containment spray pumps to reduce in-containment source term in Krško.

Following the implementation of the Safety Upgrade Program, Krško NPP is comparable, in terms of safety, with the newer types of nuclear power plants that are currently being built around the world and the plant's safety is higher, even in the most extreme beyond-design basis events (extreme earthquake, floods, other extreme natural calamities).

6 REFERENCES

[1] IAEA Specific Safety Requirements, SSR-2/1, January 2012.

[2] Krško Individual Plant Examination – Level 2, Westinghouse Energy Systems Europe, August 1995.

[3] NPP KRŠKO Analyses of Potential Safety Improvements, NEK ESD-TR-09/11, Rev. 0.

[4] ZVNE/SA/DA-TR04/18, »NEK ES Assessmnet of Thermal Hydraulic and Radiological Conditions in Aucxiliary Building«

[5] EQTR-18, »Qualification requirements – estimated, environmental Conditions for Equipment survivability (ES) evaluations«

[6] ARHR-NEK-DS-00001, »Krško RCS and CNT Alternative Cooling System (Alternate RHRS) - System Design Description«