Multinational Design Evaluation Programme

Technical Report

TR-VVERWG-09

Technical Report on Long Term Heat Removal from the Containment Under Severe Accident Conditions

Countries involved in the MDEP working group discussions:	HAEA (Hungary), NNSA (People's Republic of China), NDK (Türkiye), Rostechnadzor (Russia)
Countries which support the present TR	HAEA (Hungary), NNSA (People's Republic of China), NDK (Türkiye), Rostechnadzor (Russia)

Contents

List of abbreviations and acronyms

BDBA	Beyond Design Basis Accident
CHRS AIC	Containment Heat Removal System with Alternative Intermediate Circuit
Co PHRS	Passive Containment Heat Removal System
LTCHRS	Long Term Heat Removal from the Containment
LTHR	Long-Term Containment Heat Removal
NPP	Nuclear Power Plant
SA	Severe Accident
TA	Transient and Accident

List of tables and figures

1. Introduction

The purpose of this report is to describe and compare the differences in the approaches for design long-term containment heat removal (LTHR) systems provided in VVER-1200 designs and to highlight the safety aspects that should be considered when assessing safety in severe accident (SA) conditions, while facilitating the exchange of experience, including national rules and recommendations.

In this report, the term "long term heat removal from the containment" means the time during which the design features (without external intervention) ensure heat removal from the containment and maintain its integrity and leak-tightness under severe accident conditions, except for practically eliminated conditions[1].

Ensuring the integrity and leak-tightness of the containment under SA conditions is a key condition for avoiding a large radioactive release, which is a mandatory requirement for all countries' participants. It is important to identify all potential sources of impact that could threaten the integrity of the containment and that need to be mitigated, and to demonstrate that the design features are capable of removing sufficient heat and maintaining the integrity and leak-tightness of the containment under SA conditions.

2. Processes and phenomena in the containment under SA conditions

The thermal loading of the containment shell is determined by the sources of mass and energy that exist in the containment from the moment the accident occurs. Listed below are the sources of mass and energy that determine changes in parameters in the containment shell, including in the long term.

[1] "The possibility of certain conditions arising may be considered to have been 'practically eliminated' if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise", p. 2.11, SSR-2/1 (Rev.1)

Steam generation:

- Due to decay heat in the core and release into the containment, either from a rupture of the primary circuit (low-pressure scenario) or through the relief valves (high-pressure scenario). A rupture of the primary circuit under high pressure and temperature (creep rupture) is also possible,
- due to boiling off the coolant from the reactor vessel in the cold condition, if residual heat removal was lost,
- due to boiling off of the coolant in the spent fuel pool if spent fuel cooling is lost, since in VVER designs the pool is located inside the containment,
- due to evaporation of water from the annular space surrounding the core catcher (after the reactor vessel was destroyed and corium moved into the core catcher, water in the annular space heats up and boils; generated steam comes into the containment),
- due to evaporation of water from the surface of the corium in the core catcher when cooling water supplying there from tanks for inspection of reactor internal equipment, generated steam also comes into the containment.

Steam from all sources after the cooling on colder surfaces of the containment shield and condensate is drained down into the sump, which is connected with annular space around the core catcher. This closes the containment cooling circuit. Over time, the surfaces heat up and steam condensation on it decreases, which leads to an increase of the parameters in the containment. So special cooling measures are necessary to provide heat removal from the containment.

Heat generation:

The increase of parameters in the containment under transient and accident (TA) conditions will be aggravated by generation of additional amount of heat due to:

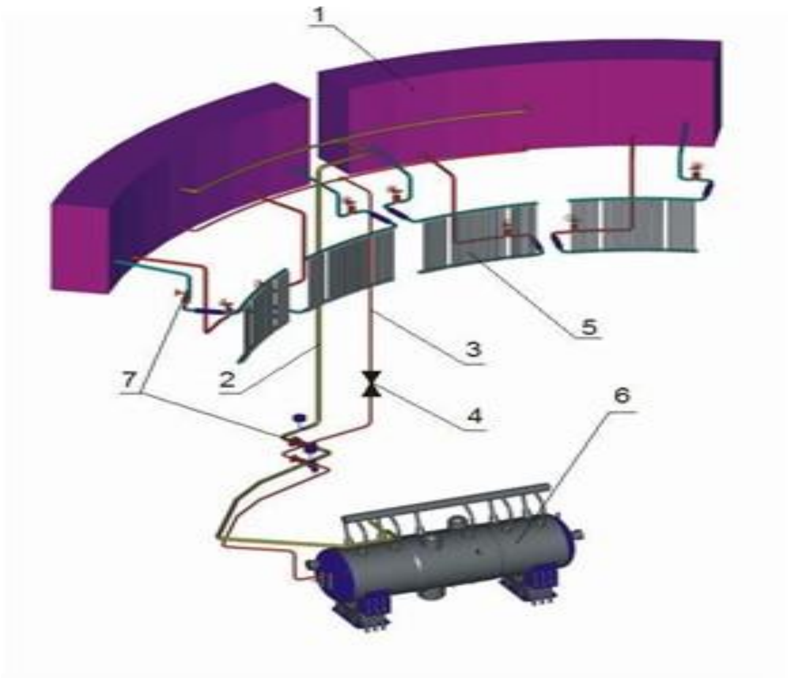
- zirconium and steel oxidation,
- hydrogen recombination,
- hydrogen combustion (deflagration),
- due to the ingress of dispersed fission products in the containment.

3. Special technical means provided for in VVER-1200 designs to ensure long-term heat removal

In different VVER-1200 designs, two kinds of systems for long term heat removal from the containment (LTCHRS) are used. One of them is "passive containment heat removal system (Co PHRS)" and the other one is an active system called "containment heat removal system with alternative intermediate circuit (CHRS AIC)". Both systems perform their heat removal function under DEC-A and DEC-B conditions and provide pressure and temperature reduction in the containment. The table below shows the presence of one or more systems for long-term heat removal from the containment in the different VVER designs.

Table 3. 1. Presence of Heat Removal Systems by VVER Designs. Presence of Heat Removal Systems by VVER Designs

Country	Nuclear Power Plant (NPP)	Design	Power MW (e)	HRS
China	TW, unit 7, 8 XP unit 3, 4	B-491	1200	CoPHRS
Hungary	Paks	B-491	1200	CoPHRS
Russia	LN-2	B-491	1200	CoPHRS
	NV-2	B-392M	1200	CHRS AIC
	KU-2	B-503	1200	CHRS AIC
Türkiye	Akkuyu	B-509	1300	CHRS AIC



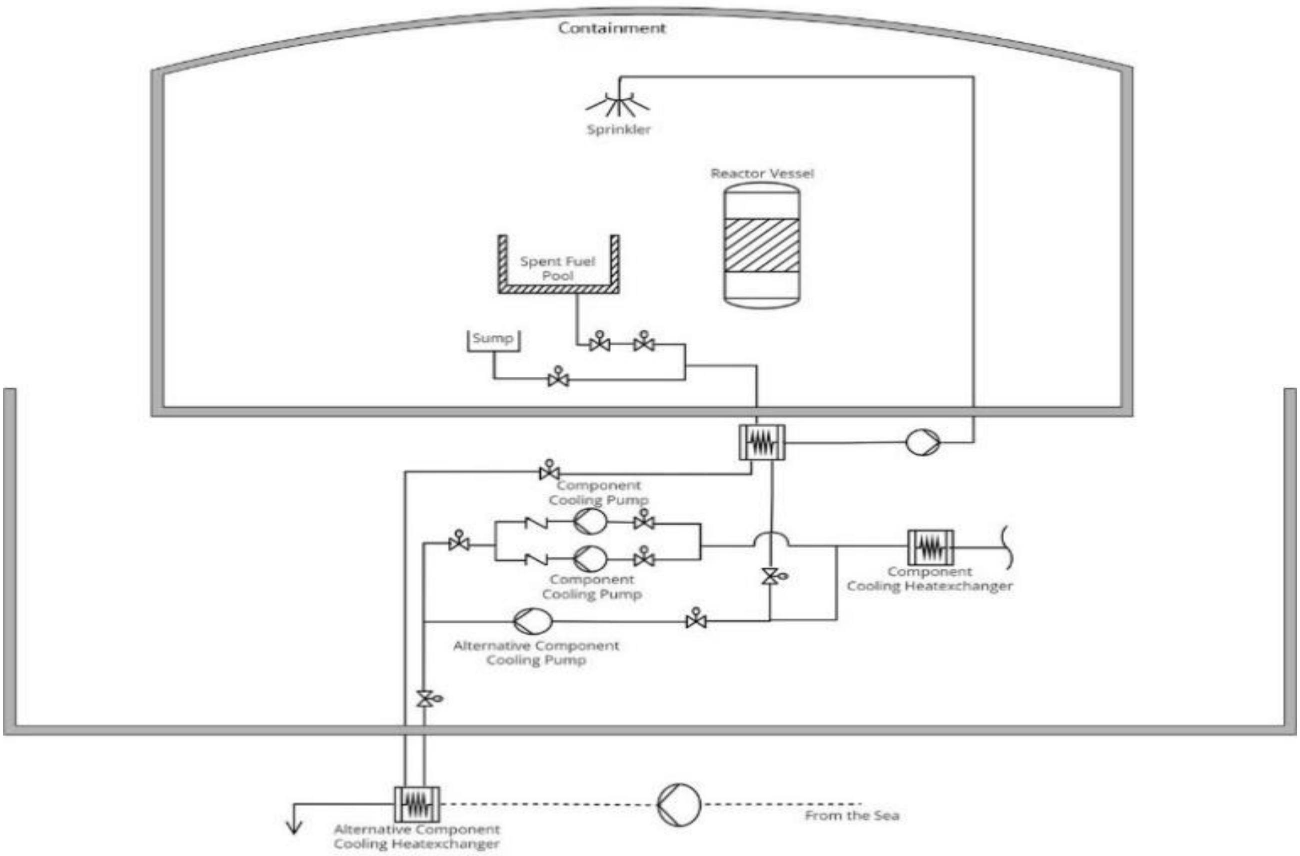
Picture 3. 1. Co PHRS

Heat exchanger-condensers (5) of Co PHRS are located in the upper part of the containment. Steam generated into containment is condensated on the heat exchanger-condensers surface, heated water with lower density raised to containment PHRS tanks (1) by the natural circulation and heat is removed to the ultimate heat sink (atmosphere) by evaporation of water from tanks of exchangers.

The CHRS AIC is part of the active safety system and, in case of beyond design basis accident (BDBA), including severe accidents, ensures heat removal from the containment to the ultimate heat sink. If the NPP is beside the sea, the sea is used as ultimate heat sink and mobile pump provides cooling water from sea via flexible hoses. In other cases, alternative intermediate cooling circuit system provides heat removal to the ultimate heat sink with a fan cooling tower (~20 MW).

CHRS AIC includes a water circulation line with one heat exchanger, one pump and alternative intermediate cooling circuit system via flexible hoses. The power supply to all active components of the heat removal chain is from alternative air-cooled diesel generator

(0.4kW). The design provides water supply from sump to the sprinkler nozzles to reduce the parameters inside the containment under the design limits. The water from the sump is cooled by CHRS AIC heat exchanger through alternative intermediate cooling circuit system.



Picture 3. 2. CHRS AIC

4. Justification of the efficiency of the design features dedicated for long term heat removal under SA conditions

4.1. Deterministic analyses

The main objective of deterministic analyses is to study the behaviour of parameters in the containment compartments for SA conditions that are the most unfavourable from the point of view of maintaining the strength and density of the last physical barrier.

Governing scenarios:

- Total loss of power supply of all AC sources
- Loss of heat removal to ultimate heat sink

Codes used for analysis must be equipped with models that consider the effects of all sources of mass and energy affecting the parameters in the containment.

The duration of the accident calculation must be sufficient to confirm that during the calculation period all possible factors that could lead to an increase in parameters in the containment are considered and that such factors are absent outside the calculation period. The assumptions made when performing the calculations should not lead to a significant decreasing of parameters in the containment.

4.2. Experimental investigations

The functionality of the CoPHRS has been confirmed:

- results of experimental studies on a large-scale experimental installation: /2/;
- results of start-up tests at power units No. 1 and No. 2 of the Leningrad NPP /2/.

The functionality of CHRS AIC should be confirmed by the results of periodic checks, tests and emergency training.

5. Conclusions

The description of two alternative approaches for long term heat removal from the containment (including SA conditions) realized in VVER designs are presented in the current report.

Main sources of heat and masses released in the containment and should be considered in the safety analyses are specified.

The governing scenarios for confirming the efficiency of long-term heat removal from the containment are defined.

References

1. Long Term Containment Heat Removal under Station Blackout in AES-2006. JSC NIAEP-JSC ASE-JSC Atomproekt. Presentation at the seminar WWER WG, Moscow 28/09/2016/
2. Safety of Nuclear Power Plants: Design. Specific Safety Requirements. No. SSR-2/1 Rev.1, IAEA 2016.

Appendix A: System description for country specific design

China:

Tianwan unit 7&8 and Xudapu unit 3&4 (AES-2006):

The containment passive heat removal system is designed for continuous (no less than 24 hours of autonomous mode) heat removal from the containment during DEC. The system reduces and maintains pressure within the design pressure range inside the containment and removes heat released to the containment to the ultimate heat sink under DEC-A and DEC-B. Capacity of the system is selected based on typical DEC accident scenarios considered in the design, the system consists of four totally independent trains with capacity of 4×33.3%. The operation of the system is based on passive principles. The design of the system provides for its completely autonomous operation without any operation for at least 24 hours. Within the period between 24-72 hours, mobile equipment and standby service water available at the site is supposed to be used to ensure the system operation (makeup of the emergency heat removal tanks). The Fukushima nuclear accident relevant mobile measures can also be used in these units.

Hungary:

VVER-1200 (V-527) Paks NPP unit 5&6:

The containment passive heat removal system (Co-PHRS) is a part of technical means for DEC accident management and is designed for continuous (no less than 72 hours in autonomous operation) heat removal from the containment during DEC2. The Co-PHRS enables reduction and maintenance of the pressure in the containment below design values by removing the heat released under the containment under DEC2 to the ultimate heat sink. The Co-PHRS consists of four similar and completely independent trains with a capacity of 4×33.3%. The four-channel structure of the system ensures that single failures in the system do not result in loss of system functions. To ensure makeup of PHRS tanks after 72 hours, Emergency Makeup System for Passive Heat Removal System Tanks is envisaged providing emergency makeup of PHRS tanks from Makeup water system tanks.

Russia:

VVER-1200 (B-491) Leningrad NPP:

In the conditions of postulated SA long-term heat removal from the containment is provided by passive heat removal system (Co-PHRS). The system provides heat removal from the containment for 24 hours in an autonomous mode, due to heat removal to the water of the emergency tank and then to the atmospheric air due to the boiling off of water in the emergency tank. After 24 hours, to maintain the heat removal process, the emergency tank should be replenished from external sources by a mobile pump. There are four independent trains (4x33%) in Co-PHRS. According to the design, three trains are sufficient to remove heat from the containment under BDBA conditions.

VVER-1200 (B-392M) Novovoronezh NPP

A distinctive feature of this design is the second stage of ECCS (passive part), which ensures reliable heat removal from the core for at least 24 hours. Under blackout conditions the core is cooled due to the operation of the passive heat removal system through the SG (SG-PHRS) to the atmosphere air for an almost unlimited time. In the conditions of postulated severe accidents, long-term heat removal from the containment is provided due to heat removal to the atmospheric air by means of fan tower and an intermediate cooling circuit. Using these means, heat removal from the SFP could be provided and, if necessary, the operation of the sprinkler system can be ensured.

VVER-1300 (V-510) Kursk NPP (under construction)

The prototype for this project is the project (B-392M). The main difference from (B-392M) design is the additional, third stage of ECCS (passive part), which ensures reliable heat removal for at least 72 hours. Under SA conditions, heat removal from the containment is carried out in the same way, using the same technical means as in the B-392M project.

Appendix B: National requirements on long-term heat removal from the containment

China: According to Safety regulation of nuclear power plant design (HAF102-2016), provision shall be made to control the pressure and temperature in the containment at a nuclear power plant and to control any build-up of fission products or other gaseous, liquid or solid substances that might be released inside the containment and that could affect the operation of systems important to safety.

6.3.5.3 The capability to remove heat from the containment shall be ensured, in order to reduce the pressure and temperature in the containment, and to maintain them at acceptably low levels after any accidental release of high energy fluids. The systems performing the function of removal of heat from the containment shall have sufficient reliability and redundancy to ensure that this function can be fulfilled.

6.3.5.4 Design provision shall be made to prevent the loss of the structural integrity of the containment in all plant states. The use of this provision shall not lead to an early radioactive release or a large radioactive release.

6.3.5.5 The design shall also include features to enable the safe use of non-permanent equipment for restoring the capability to remove heat from the containment.

Hungary: Nuclear Safety Codes Volume 3a. Design requirements for new NPPs:

3a.2.2.7200. At least the following events shall be practically eliminated by design solutions or the implementation of preventive accident management capabilities, i.e. it shall be demonstrated that their occurrence is physically impossible, or the frequencies of their occurrence are less than 10-7 /year with high certainty:

[...]

c) all loads appearing in the short and long run, which may jeopardise the integrity of the containment, in particular, the dropping of a heavy load, steam and hydrogen explosion, interaction between the molten core and concrete loadbearing structures, and containment overpressurzation,

[...]

3a.2.2.7400. During design, the intended SA management functions and the pressure reduction and hydrogen removal systems performing such functions during severe accidents shall be determined to such an extent that high pressure processes in events causing fuel melting and early damage to the containment can be avoided

3a.4.6.0200. For the performance of the radioactive release restriction or retention and monitored release function of the containment:

[...]

f) heat removal from the containment, protection of the structure against overpressure and the management of combustible gases generated shall be ensured in all operating conditions,

[...]

3a.4.6.1400. The loss of the structural integrity of the containment shall be practically eliminated. To this end, equipment stored on or off site may also be used for controlling the conditions prevailing in the containment.

3a.4.6.1600. The heat removal system of the containment shall ensure the quick reduction of the pressure and temperature in the containment following a loss of coolant event, then it shall ensure their maintenance at a reasonably achievable low level, assuming single failure.

3a.4.6.1800. Technical solutions shall be applied for DEC1-2, for the monitoring and control of pressure and temperature in the containment, for the management of combustible gases and for avoiding a significant deterioration of the leak-tightness of the containment during a reasonable period following such events.

Russia: General provisions for ensuring the safety of nuclear power plants. (NP-001-15):

3.1.3 The NPP design must provide for special technical means to ensure BDBA management.

3.1.4 The special technical means specified in item 3.1.3 used for BDBA management shall include technical means providing basic safety functions for the following BDBA:

- Failure of normal operation systems and safety systems removing heat to the ultimate heat sink,
- Failure of normal operation power supply systems accompanied by failure of the emergency power systems.

NPP design shall envisage means protecting the above special technical means against external effects as well as against effects raised from accidents (including BDBA), for example, mobile means stored in safe places.

3.1.9 In NPP design measures should be considered and justified to protect safety systems, as well as systems and elements of special technical means for BDBA management from common cause failures through the realization of the principles of diversity, redundancy (redundancy) and independency.

3.5.4. As part of protective safety systems, systems for emergency heat removal from the reactor to the ultimate heat sink, consisting of several independent channels, should be provided.

The use of cooling systems (channels) intended for normal operation as systems (channels) for emergency heat removal from the reactor is allowed if they meet the requirements for safety systems.

3.6.2 The reactor and the systems containing radioactive substances must be entirely located within the containment.

Controlled release of radioactive substances outside the containment is allowed in severe accidents only in order to prevent the destruction of the containment, provided that measures are taken to ensure the radiation safety of the population (using filtration system, shelter, evacuation of the population or other measures).

3.6.3 Localizing safety systems must be provided for each NPP unit and perform the specified functions for design basis accidents, as well as beyond design basis accidents accounted according to paragraph 1.2.16 of these General Provisions.

3.6.4 In cases where heat removal systems with active elements (or passive elements with moving parts) are provided to prevent pressure build-up inside the containment, these systems should include several independent trains.

4.5.9 When managing BDBA, it is necessary to take measures to return the NPP unit to a controlled state, in which the fission chain reaction stops, the fuel is constantly cooled, and the radioactive release is kept within the established limits; take actions to prevent the BDBA development and mitigate its consequences, including protecting the containment from destruction and maintaining its operability.

Türkiye: There is no specific requirement for long term heat removal from the containment in Turkish Regulations (requirements for containment are related to design basis accidents and early failure scenarios). Russian regulations are followed.