MDEP Common Position CP-EPRWG-04

Related to: EPR Working Group activities

COMMON POSITION ON EPR CONTAINMENT HEAT REMOVAL SYSTEM IN ACCIDENT CONDITIONS

Participation

Countries involved in the MDEP working group discussions:	China, France, Finland, the United Kingdom and the United States
Countries which support the present common position	China, France, Finland, the United Kingdom, and the United States
Countries with no objection:	India, Sweden
Countries which disagree	
Compatible with existing IAEA related documents	

Containment Heat Removal System (CHRS) in Accident Conditions

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Summary

- **General expectations regarding containment integrity**
- **Main EPR design characteristics**
- **EPR common position**
- **Common design criteria**
- **Appendix 1: Design, Arrangements and Configuration of the CHRS - Finland**
- **Appendix 2: Design, Arrangements and Configuration of the CHRS - France**
- **Appendix 3: Design, Arrangements and Configuration of the CHRS - UK**
- **Appendix 4: Design, Arrangements and Configuration of the SAHRS - USA**
- **Appendix 5: Design, Arrangements and Configuration of the CHRS - China**

General expectations regarding containment integrity

The importance of the integrity of the containment as a fundamental barrier to protect the people and environment against the effects of a nuclear accident is well established. In this regard, an essential objective is that the necessity for off-site counter-measures to reduce radiological consequences be limited or even eliminated. The design should provide engineering means to address those sequences which would otherwise lead to large or early[1] releases, even in case of severe external hazards.

The plant shall be designed so that it can be brought into a controlled and stable state and the containment function can be maintained, under accident conditions in which there is a significant amount of radioactive material in the containment, i.e. resulting from severe degradation of the reactor core. It is expected that due consideration to these requirements is to be given while tailoring long term loss of electrical power mitigation strategies.

In order to reliably maintain the containment barrier, the regulators believe that:

- safety features specifically designed for fulfilling safety functions required in core melt accidents shall be independent to the extent reasonably practicable from the Systems, Structures and Components (SSC) of the other levels of defence;
- safety features specifically designed for fulfilling safety functions required in core melt accidents shall be safety classified and adequately qualified for the core melt accident environmental conditions for the time frame for which they are required to operate. In the light of the Fukushima Daiichi accident, the regulators believe that those safety features shall be designed with an adequate margin as compared to the levels of natural hazards considered for the site hazard evaluation;
- the systems and components necessary for ensuring the containment function in a core melt accident shall have reliability commensurate with the function that they are required to fulfil. This may require redundancy of the active parts;
- containment heat removal, including corium cooling, during core melt accidents shall be provided;
- it shall be possible to reduce containment pressure in a controlled manner in the long term taking into account the impact of non-condensable gases;
- there shall be provisions to reduce the amount of fission products in the containment atmosphere in case of the core melt accident.

[1] **"Large radioactive release"**: a release for which off-site protective measures limited in terms of times and areas of application are insufficient to protect people and the environment. **"Early radioactive release"**: release for which off-site protective measures are necessary but are unlikely to be fully effective in due time

Main EPR design characteristics

The generic EPR design includes measures to prevent and mitigate the consequences of severe accidents. The EPR design includes measures to prevent accident situations such as high pressure core melt, global hydrogen detonations, ex-vessel steam explosions and potential containment bypass, which could lead to large or early releases. All EPR are equipped with a core catcher, aiming to stabilize the situation in case of vessel melt-through. The containment is designed to withstand a global hydrogen combustion taking into account the implementation of passive hydrogen recombiners that limit the hydrogen accumulation. The containment heat removal system (CHRS) / severe accident heat removal system (SAHRS) is the primary mean, under severe accident conditions, of drawing heat from the containment and maintaining the pressure inside within the design limits. Its supporting systems, i.e. dedicated cooling chain and the ultimate diesel generator are independent from the systems supporting the design basis accidents (DBA) safety functions.

In China, France, Finland, and the UK, the CHRS is a dedicated two train system each including one passive and one active flooding lines, safety related system used to control the conditions within the containment atmosphere and the in-containment refuelling water storage tank (IRWST) following a severe accident.

In the US, this system is referred to as severe accident heat removal system (SAHRS) which is a dedicated single train with two passive and two active flooding lines, non-safety related system used to control the conditions within the containment atmosphere and IRWST following a severe accident.

Both CHRS and SAHRS have three primary modes of operation: internal spray, core catcher spreading compartment passive flooding and IRWST water heat removal. Except for China and France, CHRS and SAHRS have also a core catcher spreading compartment active flooding mode. Each mode plays a role in controlling pressure and temperature within the containment and IRWST heat removal. Moreover in France and the UK another function of CHRS is to control the IRWST pH.

EPR Common Position

The regulators consider on a best estimate basis that CHRS and SAHRS will maintain the containment atmosphere within the design pressure and temperature, likely to reduce the amount of fission products in the containment atmosphere and cool the corium in the core catcher.

Some regulators continue to evaluate the adequacy of the detailed designs of CHRS and SAHRS, for example for long-term management of the containment atmosphere and credit given to CHRS for a limited set of design extension conditions.

Appendix 1

Containment Heat Removal System (CHRS) in Accident Conditions

FINLAND

Summary

1. Glossary

CHRS: Containment Heat Removal System, called JMQ in Olkiluoto 3

IV – Isolation valve

POR - Passive Outflow Reducer

PFV – Passive flooding valve

2. Injection Lines into the Core Catcher

Regulatory requirements

The main Finnish requirements for systems used to protect containment in severe accidents are:

1) the systems must be independent of the systems used in DBAs,
2) the systems must be single failure tolerant,
3) the systems must be safety classified.

The requirements are given by the following legislation.

Government Decree on the Safety of Nuclear Power Plants 2013/717, Section 14

> "*The plant shall be provided with systems, structures and components for controlling and monitoring severe accidents. These shall be independent of the systems designed for operational conditions and postulated accidents. Systems necessary for ensuring the integrity of the containment building in a severe accident shall be capable of performing their safety functions, even in the case of a single failure.*"

STUK Regulatory Guide on Nuclear Safety YVL B.2, Classification of Systems, Structures and Components of a nuclear facility

> "*Safety Class 3 shall include systems accomplishing safety functions that*
> ...
> *2. are designed for severe reactor accident management*"

Design

Olkiluoto 3 has two identical redundant core catcher flooding valves (JMQ AA003) (see Figure 2) equipped with metallic seals for robustness and to withstand high irradiation doses. The flooding valves are kept closed by a cable, which is connected to the spreading area.

The isolation valves (JMQAA004) are kept open during the normal operation. The position is monitored. The power supply to the motor operated isolation valves is from the emergency power supply bus-bars (not from SBO backed power supply, which is the case for severe accident systems).

The flooding valves and isolation valves are located in the containment in two separated casemates at level -6.30 m between IRWST and the spreading area room.

A flow limiter (POR) is installed in the piping between IRWST and the valves to constrict the bypass flow to IRWST during active flooding.

Design goals

Core melt arrival into the spreading area melts attachment of the cable that keeps the core catcher flooding valve closed. After valve opening, coolant flows into the core catcher by gravity.

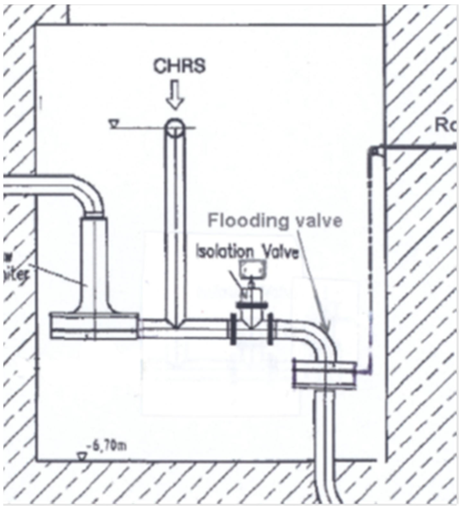


Figure 1. Schematic of the valve configuration.

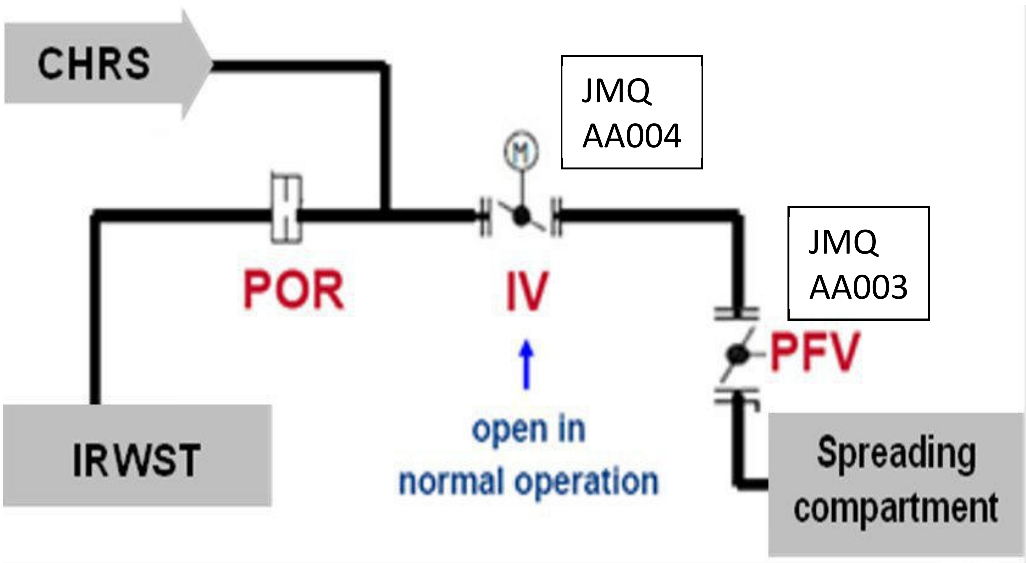


Figure 2. Simplified Olkiluoto 3 flow diagram.

Actuation of the containment spray is manual, decided by the operator based on operating procedures for severe accidents. CHRS is equipped with two parallel trains, each with a capability to keep the containment pressure at acceptable level in a severe accident. The CHRS pumps are powered by the SA power supply backed by the SBO diesels.

Spraying transfers residual heat from the containment atmosphere to the IRWST. Operation of the CHRS system transfers residual heat from IRWST via heat exchangers to the ultimate heat sink (sea).

After containment pressure has sufficiently decreased, the operator can switch one or two CHRS trains in the cooling configuration (active cooling).

Design details

Operation of the CHRS

Actuation of the CHRS consists on the following steps (manual transition):

- Start the dedicated ESWS chain,
- Start the dedicated CCWS chain,
- Open the required CHRS discharge valve,
- Start the CHRS pump,
- Check the flow rate.

Switch between the two operation modes (spraying, active flooding of the core catcher) is done manually by the operator. The CHRS pump cannot sustain operation of spraying and flooding together. Therefore, spraying of the containment must be stopped in the train used for active flooding.

Leaking flooding valve during normal operation

In case of spurious opening (information given by position sensors) or leak of the flooding valve, the operator manually closes the JMQ AA004 isolation valve, if the following criteria are met:

- The plant is in normal operating conditions,
- The other passive valve is still closed.

The objective is to prevent loss of coolant from the IRWST to the melt spreading area by spurious opening or leak. The conditions for this (Technical Specifications) are not determined for Olkiluoto 3 at time of this writing.

Failure of the core melt cooling function

Passive and active flooding of the core melt fails in a train if:

- the valve AA003 fails to open,
- or valve AA004 has been closed during normal operation and it cannot be opened in a severe accident.

Compliance of the valve configuration with regulatory requirements and Safety Authority position

The system fulfils the Finnish severe accident requirements, because:

- the system is independent from the systems used in normal operation or DBAs,
- the system is single failure tolerant,
- the system is classified to Finnish Safety Class 3.

STUK has approved the JMQ (CHRS) system description with some comments on the isolation of the containment pressure measurement lines. The flooding line valve configuration is approved because it does not violate the Finnish severe accident requirements. Consideration of common cause failures or diversity is not required of the severe accident systems.

3. NPSH analysis of the CHRS pumps

The main factors affecting the available NPSH are: the geodetical height, pressure difference between the containment pressure and the coolant saturation pressure and pressure drops in the piping and strainer. The coolant saturation pressure depends on the IRWST temperature. In severe accident conditions without containment venting the containment pressure is the sum of air and steam partial pressures. 2 bar containment pressure corresponds ~20 m height in the NPSH calculation, and the available net pump suction head exceeds the required pump suction head by a large margin.

The situation might be different, if containment pressure has been decreased by filtered venting, or if the calculation is done as required in the U.S. Regulatory Guide 1.82 [paragraphs 1.3.1.1 & 2.3.1.1: "*ECC and the containment heat removal system should be designed so that sufficient available NPSH is provided to the system pumps, assuming maximum expected temperature of pumped fluid* ***and no increase in containment pressure from that present prior to the postulated LOCA***"].

The plant vendor has conducted an analysis of available NPSH for Olkiluoto 3 in case of operation near saturation conditions. The available suction head is in that case determined by:

+geodetical height between pump centreline and minimum water level

-pressure losses on piping

- pressure losses on strainer

= available pump suction head

The calculation still shows margin between the available and required suction heads, but this margin is much smaller (~0.5 m) compared with the margin (~10 m) obtained taking credit of the containment pressure.

4. Use of the containment filtered venting system as a diverse decay heat removal system

The main function of the containment filtered venting system in Olkiluoto 3 is to decrease the containment pressure due to non-condensable gases that may be produced during a severe accident. Opening of the vent is designed as a late phase action of a severe accident (after several days). The Olkiluoto 3 containment filtered venting system should not be used as the primary method of containment pressure control/decay heat removal. Therefore, the system capacity has not been designed for decay heat levels early after accident initiation.

The system may be used for decay heat removal in a DEC case involving loss of the ultimate heat sink (LUHS) in a shutdown state. In this case, RPV lid is open and heat transfer to secondary side is not available. Core cooling is done by LHSI which is assumed available. Decay heat is removed by steaming into the containment and steam release into the atmosphere through the filtered venting system. Because the core is covered, release of fission products remains small. The plant vendor has conducted analyses of the case with and without containment venting. Without venting, the containment design pressure (5.3 bar) would be reached after ~60 h. If the filtered venting system is opened after 24 h, it would take more than 10 days to reach the containment design pressure.

Technical Research Centre of Finland (VTT) has performed for STUK a study to investigate whether the filtered venting system could also be used beyond its original purpose, for containment heat removal in cases when the containment spray is not available. Two accident scenarios were analysed: station blackout and loss of ultimate heat sink. Several cases with various start times of the containment spray and of the venting system were calculated.

It was found out that the containment filtered venting system is able to prevent containment overpressure failure in the station blackout and loss of ultimate heat sink scenarios. If the containment spray is not available and venting is not performed, the assumed containment failure pressure (10.75 bar) would be reached about 49 h after a station blackout. Opening of the vent line turns the containment pressure into decline and stabilizes the pressure at around 5 bar. If water injection to the containment is not successful, all water in the core catcher and in the IRWST evaporates in about six days after the station blackout. This would eventually lead to core catcher and venting scrubber dry-out. Loss of the scrubbing liquid would significantly increase the releases to the environment.

As a conclusion, it was found that the containment filtered venting system is able to prevent containment overpressure failure in all the calculated cases. The system has the potential to reduce the Cesium release to the environment by a factor of 400 to 3500 compared to containment failure.

Appendix 2

Containment Heat Removal System (CHRS) in Accident Conditions

FRANCE

Summary

1. Glossary

CCWS: Component Cooling Water System

CHRS: Containment Heat Removal System

CSBVS: Controlled Safeguard Building Ventilation System

CVCS: Chemical and Volume Control System

EOPs: Emergency Operating Procedures

I&C: Instrumentation and Controls

IRWST: In-containment Refueling Water Storage Tank

IV: Isolation Valve

FA3: Flamanville 3

FPCS: Fuel Pool Cooling (and Purification) System

NVDS: Nuclear Vents and Drains System

OSSAs: Operating Strategies for Severe Accidents

POR: Passive Outflow Reducer

PCC: Plant Condition Category 1 to 4 (design basis accident)

PFV: Passive Flooding Valve

RCS: Reactor Coolant System

RCC-A: Risk Reduction Category A (prevention of core melt, in particular in case of multiple failure events)

RCC-B: Risk Reduction Category B (severe accident)

SBO: Station Black-Out

SIS: Safety Injection System

RPV: Reactor Pressure Vessel

TG: Technical Guidelines

TSO: Technical Safety Organisation

UCWS: Ultimate Cooling Water System

2. Regulatory requirements

In France, the regulatory requirements for the EPR reactor are mainly contained in a document called "Technical guidelines for the design and construction of the next generation of nuclear power plants" (TG).

General safety objectives for low pressure core melt sequences

The TG outlines general safety objectives, in particular:

- *"Low pressure core melt sequences have to be dealt with so that the associated maximum conceivable releases would necessitate only very limited protective measures in area and in time for the public".*
- *"Due consideration must be paid to the different aspects of a spray system inside the containment building for severe accident situations".*
- *"The residual heat must be removed from the containment building without venting devices. For this function, a last-resort heat removal system must be installed".*
- *"The penetration of the basemat of the containment building by a «corium» must be avoided*[…]. *Moreover, adequate provisions have to be implemented to prevent leakage of contaminated water and gases to the sub-soil via cracks in the basemat".*
- "*The design pressure and design temperature of the containment inner wall must be such to allow a grace period of at least 12 hours without containment heat removal after a severe accident".*

Requirements concerning the Containment Heat Removal function

The TG details the requirements concerning specific safety functions, notably the containment heat removal function (CHRS):

"*The containment heat removal function in low pressure core melt conditions can be performed by a system achieving containment spray and corium cooling, subdivided in two trains, one train being sufficient after 15 days to maintain the containment pressure below the design pressure. These trains would be cooled by a dedicated chain as a diverse system to the component cooling water system used for the systems related to core melt prevention. The two trains of this dedicated cooling chain would be power supplied by small diesel generators* […]*."*

3. Design

The CHRS:

1. provides the capability to remove the residual heat from the containment atmosphere during a severe accident (RRC-B), in order to maintain the containment pressure at values which ensure its integrity and meet the qualification pressure profile for components inside containment and used under severe accident:
   - actuation of two CHRS trains after a grace period of 12 hours (this 12 hours grace period is not the CHRS system start-up criterion but is used to design the containment and the CHRS) must reduce the containment pressure below 2 bar (0.2 MPa) within 12 additional hours,
   - actuation of one CHRS train after a grace period of 12 hours must maintain the containment pressure below its design pressure (5.5 abs bar) (0.55 MPa),
   - one CHRS train only must maintain the containment pressure below 2 bar (0.2 MPa) in the long term period,
2. provides thermal insulation between the spreading area and the structural basemat of the reactor building during a severe accident (RRC-B),
3. performs a passive flooding by IRWST water when corium is spread in the spreading area during a severe accident (RRC-B).

   Warning: in the original design, during a severe accident, the CHRS also performed an active flooding by IRWST water when corium is spread in the spreading area. Nevertheless, this active corium cooling mode was not required for safety demonstration. At time of this report writing, EDF decided to change the CHRS-strainer component from "plane vertical filtering surface-type" to "pocket-type". As a consequence of this CHRS strainer component change, EDF decided to suppress the use of the active flooding function in the operating strategies for severe accident (OSSAs) because the "pocket-type" strainers are not designed for the small reverse water flow coming from the passive outflow reducer (POR) in case of active cooling actuation. Moreover, EDF decided to suppress the backflushing function (and lines) of the CHRS of the original design (this function was designed to remove the debris from the strainer surface in case of strainer clogging) because the "pocket-type" strainers are assumed by EDF to prevent clogging. At time of this report writing, the French Safety authority position regarding these changes is not known.
4. participates in containment isolation during accidents that do not require its operation,

5. ensures, with the part of the CHRS located outside the containment, a containment barrier during an accident that requires its operation,
6. reduces the production and the release of gaseous iodine from IRWST to the containment atmosphere by injecting Sodium Hydroxide in the IRWST water in case of severe accident (IRWST water pH must be alkaline).

    Warning: compared to the original design, in order to ensure an alkaline IRWST water in case of severe accident with station black-out (SBO) independently of the recovery time for power supply, EDF has decided, for each CHRS train, to add a line allowing direct Sodium Hydroxide injection into the IRWST water by means of a pump power supplied by the 12 h batteries using the severe accident I&C.

In addition, the CHRS is also used for some specific events which are not RRC-B:

- the cooling capacity of the CHRS must be sufficient to ensure, in case of some RCC-A accident, the residual heat transfer from the IRWST to the Ultimate Cooling Water System (UCWS) and to maintain the IRWST temperature below 120°C (393 K) (design temperature of safety injection system pumps),
- the CHRS train 1 of the dedicated intermediate cooling chain must operate when the third line of the Fuel Pool Cooling (and Purification) System (FPCS) is started.

Single failure criterion

For components performing F1[2] functions in case of RRC-B (containment isolation of CHRS), the single failure criterion must be postulated in order to ensure a sufficient degree of redundancy.

Diversification

The two FA3 CHRS trains are geographically separated within two independent divisions of the safeguard building.
The UCWS is also diversified. In normal operation, UCWS is fed by the pumping station, but in case of total loss of normal feeding, the UCWS is fed by the water outfall structure.

Emergency power supplies

The two CHRS trains (main and intermediate chains of each train), the UCWS and the Sodium Hydroxide injection dedicated pumps are power supplied by two separate electrical divisions. All those components are emergency power supplied by the main diesel generators in case of loss of off-site power and by the two ultimate emergency

[2] F1A function: all safety functions, including supporting functions, which are needed to reach the controlled state (the fast transient is finished and the plant is stabilized) after any internal events PCC-2 to PCC-4.
F1B function: all safety functions needed beyond achievement of the controlled state to reach the safe shutdown state (the three basic safety functions are durably met), and to maintain it after any internal events PCC-2 to PCC-4.
F1 function: by definition F1 function is F1A or F1B function.
F2 function: functions necessary to prevent large releases in RRC-B scenarios.

diesels generators in case of SBO. The Sodium Hydroxide injection dedicated pumps are also power supplied by the 12 h batteries using the severe accident I&C.

Operating strategies during a severe accident

The operating strategies during a severe accident described in this appendix are coming from the FA3 OSSAs version dated 2009.

OSSAs immediate actions

Once transition is made to FA3 OSSAs, systematic actions so-called "immediate actions" are performed by the main control room staff and do not require evaluation from the technical support center. The immediate actions concerning the CHRS are summarized hereafter:

- deactivation of the Nuclear Vents and Drains System (NVDS) pumps in CHRS rooms to prevent NVDS pump start-up in case of leakage in these rooms during the SA,
- confirmation of the isolation of the CHRS/CVCS (Chemical and Volume Control System) connection valves,
- preparation of the UCWS trains for operation in severe accident,
- preparation of the CHRS configuration for Sodium Hydroxide injection.

CHRS passive cooling mode

As it is fully passive, no operating strategy is foreseen for this mode.

CHRS spray mode

The management of the CHRS spray mode is performed manually by the operator. Before using the CHRS, some actions must be performed:

- it is recommended to isolate the CHRS rooms and to actuate the Controlled Safeguard Building Ventilation System (CSBVS) cooling units in order to cool the CHRS rooms,
- additionally, if it has not been performed before in EOPs, to prepare Sodium Hydroxide injection.

CHRS spray mode activation criteria

- when the containment pressure exceeds 2 bar (0.2 MPa). This action limits the containment pressure,
- when a leak in the containment is detected. This action enables to catch fission products into the IRWST and thus to decrease potential releases.

CHRS spray mode stopping criteria

- it is recommended to stop the spray mode when the containment pressure falls below 1.8 bar (0.18 MPa).

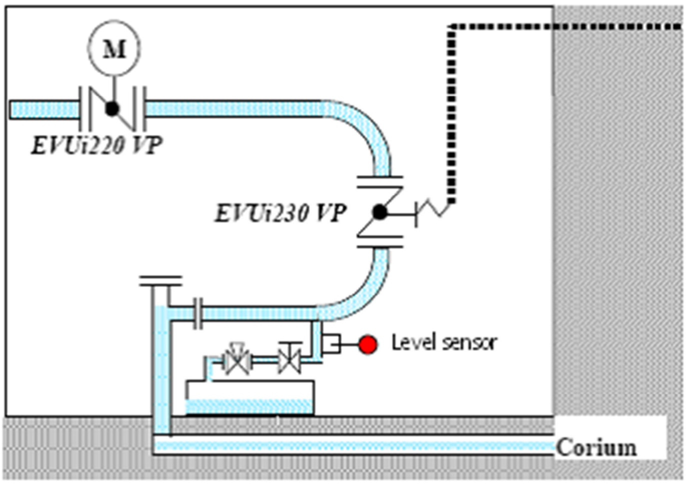
CHRS leak management

In case of leakage in one CHRS train, the operator must:

- stop the CHRS pump and isolate the leak,
- ensure that the available CHRS train is in operation or start it,
- introduce recovery actions on the unavailable CHRS train as soon as dose rates in the CHRS rooms are in compliance with workers entrance.

Case of a leak of one of the two CHRS passive flooding valves

In case of a leak of one of the two CHRS passive flooding valves (here EVU i230 VP) with high leak rate during normal operation, the motorized isolation valve (here EVU i220 VP) is closed.



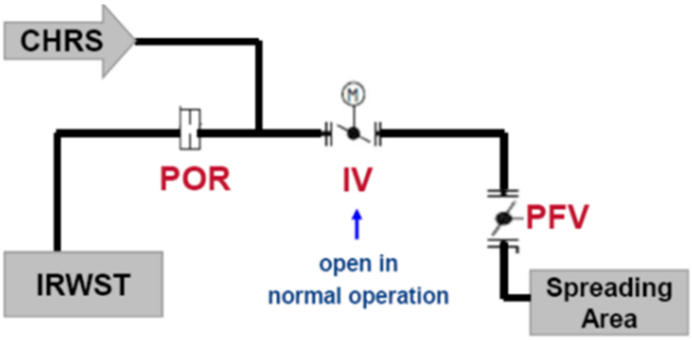
FA3 OSSAs alternative strategy using CHRS

A severe accident sequence in which the severe accident systems perform as designed is described as following the "mitigation path". Otherwise, some alternative actions ("alternative strategies") are defined in the FA3 OSSAs.

Failure of the opening of both passive flooding valves

In the original design, for each FA3 CHRS train, the active flooding injection line was introduced upstream of the isolation valve (IV) (opened in normal operation) and of the passive flooding valve (PFV) (closed in normal operation). Nevertheless, the active cooling mode was not required for safety demonstration.
EDF pointed out that the FA3 CHRS configuration of the active water injection lines introduced upstream of the motorized isolation valve and of the PFV in the same line was chosen in order to avoid, during a severe accident, due to a spurious opening of the

motorized isolation valve by the operators, the presence of water in the spreading area before the corium arrival in this area.



At time of this report writing, EDF decided to change the CHRS-strainer component from “plane vertical filtering surface-type” to “pocket-type”. As a consequence of this CHRS strainer component change, EDF kept the active flooding lines but decided to suppress the use of the active flooding function in the operating strategies for severe accident (OSSAs) because the “pocket-type” strainers are not designed for the small reverse water flow coming from the passive outflow reducer (POR) in case of active cooling actuation.

Passive flooding of the core melt fails in one CHRS train if:

- the CHRS passive flooding valve (PFV) fails to open,
- or the motorized isolation valve has been closed during normal operation (because of a spurious opening of the PFV or a leak with high leak rate of the PFV) and it cannot be opened in a severe accident.

In case of:

- failure of the opening of the two CHRS passive flooding valves,
- or if a motorized isolation valve closed during normal operation cannot be opened in a severe accident and the other CHRS train is under preventive maintenance (presently planned during normal operation),

the CHRS passive cooling mode is no more available to flood and cool the corium.

To cope with these cases, in-vessel injection is proposed as alternative strategy in the FA3 OSSAs. Water is supplied to the core catcher spreading area via the RCS, the breached RPV and then the transfer channel. Heat is removed to the containment atmosphere by evaporation first, then directly to the IRWST due to flooding of the spreading area and its chimney. The heat that was first transferred to the containment atmosphere by evaporation can now be removed by using the CHRS spray lines or SIS recirculation lines that do not depend on position of passive flooding valves.

4. Compliance with the regulatory requirements and Safety authority (or TSO) position

The review of FA3 CHRS is still ongoing and the French Safety Authority has not taken its position. Such position is expected beginning 2016.

Appendix 3

Containment Heat Removal System (CHRS) in Accident Conditions

UK

Summary

1. Glossary
2. Regulatory requirements
3. Design
4. Compliance with the regulatory requirements and Safety Authority position

1. Glossary

ALARP – As Low As Reasonably Practicable

CHRS - Containment Heat Removal System

FA3 – Flamanville 3

GDA – Generic Design Assessment

HSE – Health and Safety Executive

HSWA – Health and Safety at Work Act (1974)

IRWST – In-containment Refuelling Water Storage Tank

NIA – Nuclear Installations Act (1965)

ONR – Office for Nuclear Regulation

PCSR – Pre-Construction Safety Report

POR - Passive Outflow Reducer

SAP – Safety Assessment Principle

SFAIRP – So Far As Is Reasonably Practicable

TAG – Technical Assessment Guide

2. Regulatory Requirements

The UK regulatory regime is “goal setting, none prescriptive” and therefore the fundamental regulatory requirement is to ensure that risks are reduced “As Low As is Reasonably Practicable” (ALARP).

The Health and Safety at Work etc. Act 1974 [HSWA] is the basic legal requirement concerning health and safety related to work activities in the UK. Other legislation such as the Nuclear Installations Act 1965 (as amended) [NIA] are subordinate to it. The HSWA places duties on employers to ensure the health, safety and welfare of their employees (Section 2) and to conduct their operations so that persons not in their employment are not exposed to risks to their health and safety (Section 3). The employer is required to ensure that these duties are met “so far as is reasonably practicable”. This principle, abbreviated to SFAIRP, is therefore the basic legal requirement to which an employer needs to conform. ALARP and SFAIRP require the same tests to be applied and are effectively the same thing.

The Office for Nuclear Regulation (ONR) is responsible for judging whether measures put in place or proposed, by those who are under a duty to control and reduce risks ALARP, are acceptable.

The ONR Safety Assessment Principles (SAPs) provide ONR inspectors with a framework for making consistent regulatory judgements on nuclear safety cases. The principles are supported by Technical Assessment Guides (TAGs), and other guidance, to further assist decision making by the nuclear safety regulatory process. The SAPs also provide nuclear site duty holders with information on the regulatory principles against which their safety provisions will be judged. However, they are not intended or sufficient to be used as design or operational standards, reflecting the non-prescriptive nature of the UK's nuclear regulatory system. In most cases the SAPs are guidance to inspectors, but where guidance refers to legal requirements they can be mandatory depending on the circumstances.

The SAPs describe the numerical targets and legal limits that ONR inspectors should use when judging whether the duty holder is controlling radiological hazards adequately and reducing risks ALARP. The targets and legal limits are defined for normal operations, design basis analysis, individual risk and societal risk. The targets are not mandatory, but in some circumstances may be legal limits. The targets are guides to ONR inspectors to indicate where there is the need for consideration of additional safety measures.

3. Design

The Containment Heat Removal System (CHRS) is described in the Pre-Construction Safety Report (PCSR). The CHRS is used to control the containment pressure and achieve long-term cooling of the IRWST and the molten corium in the spreading compartment. The CHRS also provides a function to scrub fission products from the containment atmosphere. Two trains of CHRS are included in the UK EPR design, both taking supply from the IRWST. Each train consists of a pump and heat exchanger (cooled by a dedicated cooling system) which supply the dome spray system (when operated to remove FPs) or two other outlets can be used, depending on the accident conditions. In all cases the water is returned to the IRWST.

4. Compliance with the regulatory requirements and Safety Authority position

ONR have considered the CHRS during accident conditions as part of the Generic Design Assessment (GDA) for UK EPR in both the severe accident and chemistry technical areas.

The UK EPR design incorporates a Containment Heat Removal System which includes a dedicated spray system with heat exchangers and dedicated heat sink to control the pressure rise inside the containment. In severe accident conditions, although the initiating set point is the containment pressure, the spray system can be activated by operators within 12 hours after entry into severe accident conditions. Besides assisting to limit containment pressures and temperatures the spray system helps to wash fission products into the IRWST where decontamination may occur at high pH. The second mode "active cooling" of operation of the containment heat removal system enables the water to flow directly into the spreading compartment via the other available line or instead of the spray system. The introduction of sub-cooled water over the corium is intended to provide cooling and leads to a reduction of steaming production.

The above flow is important to cool the debris, but it is strictly controlled in accordance with the overall severe accident progression management, and to minimise the relevant hazard of steam explosion ex-vessel. EDF and AREVA recognise that there are uncertainties, and the phenomena governing occurrence of steam explosion are complex. EDF and AREVA have therefore made probabilistic arguments and claim evidence from experimental research and development work supports their assertion that in-vessel or ex-vessel steam explosion have a very low probability of occurrence.

The water delivery from the IRWST to the core catcher is via two independent lines within the CHRS. The IRWST water injection is triggered by the thermal destruction of metallic receptors which relief pre-stressed steel cables linked to the passive flooding valves. The safety submission indicates that the time taken to fill the passages from these valves to the top of the melt, under gravity, is in the order of a few minutes to minimise local melt-through and excessive damage to the supporting structure. On each line, the design includes a motor-operated isolation valve (normally open) located upstream of the passive flooding valve. The safety objectives of the IRWST injection into spreading room are:

- delayed IRWST water injection onto the molten pool for the prescribed duration to allow completion of the spreading process, and
- flooding the molten pool to promote superficial fragmentation to improve coolability.

Passive Outflow Reducer

The Passive Outflow Reducer (POR), located on the line between IRWST and spreading compartment, is required to prevent the flow of water into the IRWST during active cooling mode, when water circulation is driven by CHRS pump.

The POR is a novel design feature which replaces the use of a non-return valve and offers a higher reliability in severe accident conditions.

The POR does not include any internal moving parts, and thus the flow resistance offered by this device is dominated by its shape.

The low flow resistance of the POR in the forward direction will favour the gravity-driven flooding of the spreading room from the IRWST. EDF and AREVA have demonstrated that the spreading room is adequately flooded when water flow from the IRWST is affected due to reduced hydrostatic pressure and a pressure increase in the spreading room due to steam generation. EDF and AREVA have also provided calculations to justify that the backward flow resistance includes sufficient margins to prevent the flow into the IRWST for the bounding (lowest) water level within the IRWST. This justification for the reverse flow resistance is relevant to the active cooling mode.

Passive and Isolation Valves

The water injection line includes a dedicated “leak recovery tank” that is housed within the same room as the passive and isolation valves. The dedicated tank houses a water detection sensor which initiates an alarm for the operator. In case of a leaking passive valve, the operator would have the option of using the isolation valves to isolate the line.

The closure of the isolation valve will prevent the discharge of the IRWST water on demand. In addition, the successful opening of the passive valves could also be hindered by fouling of these valves, severely restricting the flow into the spreading compartment on demand.

It is understood that maintenance of these valves cover:

- Tests that will be performed periodically to verify the functionality of these valves.
- In the case of leakage rate higher than 1000 l/year from one valve, the injection line is isolated; and, for leakage rate lower than 1000 l/year the water is stored in a corresponding dedicated tank.

There are only two cases when an isolation valve may be closed: either there is maintenance on the passive valve on the same line or this passive valve has a leak which is with a rate higher than 1000 l/year. Water leakage greater than 1000 l/year from the passive valves will lead to the closure of both isolation valves; consequently EDF and AREVA have stated the reactor will be shutdown in order to repair the leaks.

Initial Corium Cooling due to Flooding

The introduction of IRWST water onto the corium within the spreading compartment and quenching of the upper melt surface will lead to a significant generation of steam that will be released into the containment. This release of steam will cause a major pressure peak within the containment that may pose a threat to its integrity. The safety objective is to ensure such pressure increases will remain within the containment design pressure limits.

Long Term Cooling of the Melt in the Spreading Compartment

At the end of spreading, the corium is expected to be contained within the engineered cooling structure in the spreading compartment and ultimately re-solidify. The long term cooling of the melt calls on both CHRS trains. Each train is capable of meeting the expected cooling requirements, and is intended to operate for 12 months before maintenance is required.

The safety objectives of the long term cooling are the following:

- Corium is safely enclosed within the spreading compartment, long-term, allowing the containment liner and basement integrity to be preserved.
- Decay heat is removed from the melt, long term.

Use of CHRS Trains for Long-term Cooling

The distribution of energy during the long-tem cooling is a key aspect of the severe accident management strategy. The main system used by the operator is the Containment Heat Removal System, equipped with two trains. This system has two main functions: provision of the spray within the containment to reduce the pressure, and supply of water to the core catcher in the active cooling mode. In addition, the strainers back-flushing function also utilises the same system. The ultimate heat sink is through a heat exchanger on each train located externally to the containment.

EDF and AREVA have provided additional information that active cooling mode is used to avoid generation of saturated water in the spreading compartment limiting fission product release into the containment atmosphere. It is also claimed that if one CHRS train is used the water temperature is lower than the saturation temperature.

In conclusion, ONR considered that further work was necessary in relation to CHRS and the pretension of the corium within the spreading compartment. There is also a need to consider the specific features of the UK EPR design and the accident mitigation approach decided upon by the Licensee, as well as further consideration of longer term accidents which has resulted in additional related Assessment Findings.

Further assessment will be required of Licensee responses to these Assessment Findings.

Appendix 4

Containment Heat Removal System (SAHRS) in Accident Conditions

USA

Summary

1. Glossary

CMSS: Core Melt Stabilization System

ECC: Emergency Core Coolant

IRWST: In-containment Refueling Water Storage Tank

2. System Function

The SAHRS is a dedicated single-train, non-safety related, thermal-fluid system used to control the environmental conditions within the containment following a severe accident. SAHRS has four primary modes of operation, each playing a role in controlling the environmental conditions within the containment so that its fission product retention function is maintained.

3. Regulatory Requirements and Guidance

For Severe Accidents

SECY 90-016. Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements

> The containment should maintain its role as a reliable leak tight barrier by ensuring that containment stresses do not exceed ASME service level C limits for a minimum period of 24 hours following the onset of core damage and that following this 24 hour period the containment should continue to provide a barrier against the uncontrolled release of fission products. During the first 24 hours the containment integrity should be provided to the extent practicable by passive design features, after which the design may rely on the restoration of normal containment heat removal capability.

SECY 93-087. Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advance Light-Water Reactor (ALWR) Designs

> Provide reactor cavity floor space to enhance debris spreading and provide a means to flood the reactor cavity to assist in the cooling process.

For Design Basis Accidents

10 CFR 50, Appendix A, Criterion 35—Emergency core cooling.

A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.
Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

One of the requirements is to demonstrate that the MHSI pumps and the LHSI pumps have sufficient net positive suction head (NPSH) available during postulated DBAs (U.S. Regulatory Guide 1.82 - paragraphs 1.3.1.1 & 2.3.1.1- *"ECC and the containment heat removal system should be designed so that sufficient available NPSH is provided to the system pumps, assuming maximum expected temperature of pumped fluid and no increase in containment pressure from that present prior to the postulated LOCA").*

4. Design

Design evolution

One of the primary modes of the SAHRS is cooling of molten core debris in the spreading area of the core melt stabilization system (CMSS), via the passive flooding lines.
The original design of the passive flooding lines consisted of two normally open isolation valves in each passive flooding line connecting the in-containment refueling water storage tank (IRWST) to the spreading area. Each passive flooding line would take suction from a strainer in the IRWST directing gravity-driven emergency core coolant (ECC) flow through a flow limiter upstream of the two motorized isolation valves. Downstream of the motorized isolation valves is a normally closed passive flooding device held closed by a cable. Within the spreading compartment, the cable is attached to a thermal actuator. When the thermal actuator melts from contact with molten debris, the tension in the cable is released and the spring-loaded passive flooding device opens, initiating the gravity-driven ECC flow from the IRWST into the spreading compartment.
In order to address the safety related function of protecting the IRWST water inventory and to provide sufficient net positive suction head (NPSH) for the safety injection system

and residual heat removal pumps for a design basis LOCA, the following changes have been made to the design of the passive flooding lines:

- One of the motorized isolation valves in each of the passive flooding lines was removed.
- The normal operating position of the remaining motorized isolation valves was changed from “normally open” to “normally closed”.
- The motorized isolation valve in each remaining passive flooding line is powered from a separate electrical division and backed by 12-hour uninterruptible power supplies. The valves are deactivated during normal operation with their electrical supply breakers open to remove electrical power.

Based on the above changes, the isolation valves are normally closed and disconnected from the power system to maintain a condition in which a single failure cannot result in the loss of a safety function. This is accomplished by opening the isolation valves’ electrical supply breaker to prevent spurious opening of these valves.

With the passive flooding device normally closed and the power removed from the motorized isolation valves, no single failure can result in the loss of the safety function to maintain the water level of the IRWST at an appropriate level for emergency core cooling system pump NPSH.

Current Design

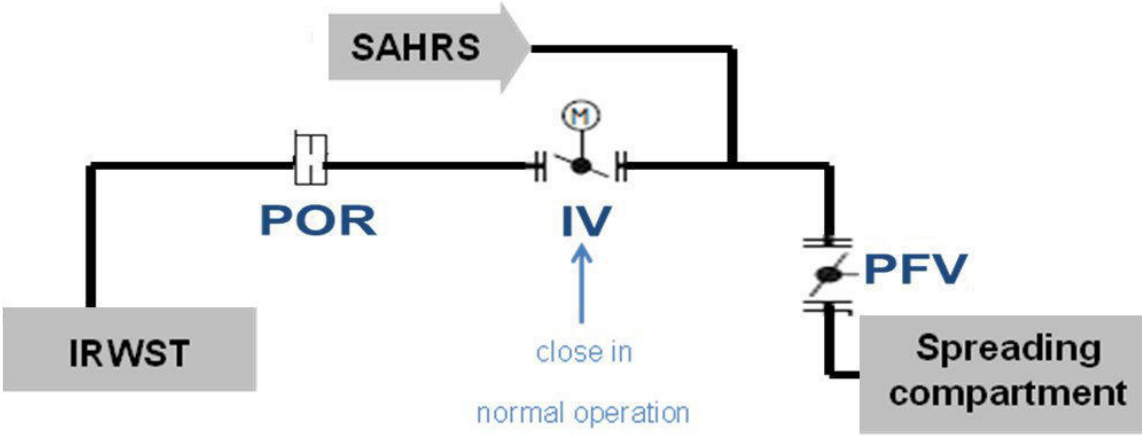
The SAHRS modes of operation for cooling the molten debris in the core spreading area of the CMSS are passive cooling and active recirculation cooling.

For the passive cooling mode, once the core outlet temperature reaches 1200ºF (650°C), the operator will close the breaker to allow the motor operated valves in the passive flooding lines to be powered and operated in the open position.

Each passive flooding line would take suction from a strainer in the IRWST directing gravity-driven emergency core coolant (ECC) flow through a flow limiter upstream of the single motorized isolation valve. Downstream of the motorized isolation valves is a normally closed passive flooding device held closed by a cable. Within the spreading compartment, the cable is attached to a thermal actuator. When the thermal actuator melts from contact with molten debris, the tension in the cable is released and the spring-loaded passive flooding device opens, initiating the gravity-driven ECC flow from the IRWST into the spreading compartment.

For the passive flooding mode to succeed, the operator must energize and open the motor operated valve in either train, and the passive flooding valve must open (N.B. The phrase “passive flooding” continues to be used, design change notwithstanding).

In the active recirculation cooling mode, after the containment spray has sufficiently reduced containment pressure, the SAHRS can be switched to a long-term recirculation mode where the SAHRS feeds water directly into the spreading area. The success of this mode is not dependent on the motor operated valves being opened, as shown below.



Part of SAHRS (USA): connection of the active line

(this figure shows only one active and one passive lines)

5. Compliance with Regulatory Guidance

For Severe Accidents

The U.S. EPR design feature for addressing the guidance of SECY 93-087 for core coolability is the CMSS, which provides floor space for debris spreading and the SAHRS for both passive cooling and long term active capability to cool the debris. The design provides retention and long-term stabilization of the molten core inside the containment. And the decay heat removal by the active recirculation cooling, following the SAHRS containment spray mode, reduce containment pressure and maintain containment integrity, addressing the guidance of SECY 90-016.

For Design Basis Accidents

With the passive flooding device normally closed and the power removed from the motorized isolation valves, no single failure of the SAHRS can result in the loss of the safety function to maintain the water level of the IRWST at an appropriate level for emergency core cooling system pump NPSH.

Appendix 5

Containment Heat Removal System (CHRS) in Accident Conditions

CHINA

Summary

1. Glossary

RRI: Component Cooling Water System

EVU: Containment Heat Removal System

CSBVS: Controlled Safeguard Building Ventilation System

RCV: Chemical and Volume Control System

EOPs: Emergency Operating Procedures

IRWST: In-containment Refueling Water Storage Tank

IV: Isolation Valve

PTR: Fuel Pool Cooling (and Purification) System

NVDS: Nuclear Vents and Drains System

OSSAs: Operating Strategies for Severe Accidents

POR: Passive Outflow Reducer

DBC: Design Based Condition 1 to 4 (design basis accident)

PFV: Passive Flooding Valve

RCS: Reactor Coolant System

DEC-A: Design Extension Condition A (prevention of core melt, in particular in case of multiple failure events)

DEC-B: Design Extension Condition B (severe accident)

SBO: Station Black-Out

SIS: Safety Injection System

RPV: Reactor Pressure Vessel

TSO: Technical Safety Organisation

SRU: Ultimate Cooling Water System

2. Regulatory requirements

In China, the regulatory requirements for the Containment Heat Removal System are HAF/HAD.

HAF 102, Safety of Nuclear Power Plants: Design

- *Adequate consideration shall be given to the capability to remove heat from the reactor containment in the event of a severe accident.*

HAD 102/06, Design of the Reactor Containments for Nuclear Power Plants (Draft, IAEA No. NS-G-1.10)

- *6.1.5: For new plants, possible severe accidents should be considered at the design stage of the containment systems. The consideration of severe accidents should be aimed at practically eliminating the following conditions:*
  - i. *Severe accident conditions that could damage the containment in an early phase as a result of direct containment heating, steam explosion or hydrogen detonation,*
  - ii. *Severe accident conditions that could damage the containment in a late phase as a result of basemat melt-through or containment overpressurization,*
  - iii. *Severe accident conditions with an open containment - notably in shutdown states,*
  - iv. *Severe accident conditions with containment bypass, such as conditions relating to the rupture of a steam generator tube or an interfacing system LOCA.*
- *6.2.3: For new plants, the integrity and leaktightness of the containment structure should be ensured for those severe accidents that cannot be practically eliminated (para. 6.1.5). The long term pressurization of the containment should be limited to a pressure below the value corresponding to Level II for structural integrity.*
- *6.3.5: For new plants an energy management system should be incorporated as the primary means of meeting the Level II acceptance criteria for structural integrity for loads derived from the pressures in the containment during accidents, as discussed in para. 6.2.3.*
- *6.3.5: In severe accidents, the systems for energy management in the containment and their support systems (the cooling water systems and power supply systems) should be independent of the systems used to prevent melting of the core. If this is not the case, the design of the containment should provide a sufficient period of time for measures to recover failed systems for energy management so as to be able to guarantee the operability of the energy management system under severe accident conditions.*

3. Design

The design of Taishan CHRS (called EVU system) is similar with FA3 design:

1. the EVU system provides the capability to remove the residual heat from the containment atmosphere during a severe accident (DEC-B), in order to maintain the containment pressure at values which ensure its integrity and meet the qualification pressure profile for components inside containment and used under severe accident:
    - actuation of two EVU trains after a grace period of 12 hours (this 12 hours grace period is not the EVU system start-up criterion but is used to design the containment and the EVU system) must reduce the containment pressure below 2 bar (0.2 MPa) within 12 additional hours,
    - actuation of one EVU train after a grace period of 12 hours must maintain the containment pressure below its design pressure (5.5 abs bar) (0.55 MPa),
   - one EVU train only must maintain the containment pressure below 2 bar (0.2 MPa) in the long term period,
2. the EVU system carries out flooding of the corium spreading compartment with water from the IRWST during a severe accident (DEC-B),
3. the EVU system ensures cooling of the Reactor Building (HRA) foundation raft during a severe accident (DEC-B).
4. the EVU system participates in containment isolation during accidents that do not require its operation,
5. the EVU system ensures, with the part of the EVU located outside the containment, a containment barrier during an accident that requires its operation.

In addition, the EVU system is also used for some specific events which are not DEC-B:

- in case of some DEC-A accident, the cooling capacity of the EVU system must be sufficient to ensure the residual heat transfer from the IRWST to the Ultimate Cooling Water System (SRU) and to maintain the IRWST temperature below 120°C,
- in DEC-A and DBC, the EVU train 1 of the dedicated intermediate cooling chain must operate when the third line of the Fuel Pool Cooling (and Purification) System (PTR) is started.

Single failure criterion

For components performing F1[3] functions in case of DEC-B (containment isolation), the single failure criterion must be postulated in order to ensure a sufficient degree of redundancy.

[3] F1A function: all safety functions, including supporting functions, which are needed to reach the controlled state (the fast transient is finished and the plant is stabilized) after any internal events PCC-2 to PCC-4.
F1B function: all safety functions needed beyond achievement of the controlled state to reach the safe shutdown state (the three basic safety functions are durably met), and to maintain it after any internal events PCC-2 to PCC-4.

Diversification

The common mode failure of EVU system is prevented by diversified design and geographically separation.

Emergency power supplies

The EVU system is power supplied by ultimate emergency diesels generators in case of SBO.

Operating strategies during a severe accident

The operating strategies during a severe accident described in this appendix are coming from the Taishan OSSAs.

OSSAs immediate actions

Once transition is made to Taishan OSSAs, systematic actions so-called "immediate actions" are performed by the main control room staff and do not require evaluation from the technical support center. The immediate actions concerning the EVU system are summarized hereafter:

- deactivation of the Nuclear Vents and Drains System (NVDS) pumps in EVU rooms to prevent NVDS pump start-up in case of leakage in these rooms during the SA,
- confirmation of the isolation of the EVU/RCV (Chemical and Volume Control System) connection valves,
- preparation of the SRU trains for operation in severe accident.

EVU passive cooling mode

As it is fully passive, no operating strategy is foreseen for this mode.

EVU spray mode

The management of the EVU spray mode is performed manually by the operator. Before using the EVU system, it is recommended to isolate the EVU rooms and to actuate the Controlled Safeguard Building Ventilation System (CSBVS) cooling units in order to cool the EVU rooms.

EVU spray mode activation criteria

- when the containment pressure exceeds 2 bar (0.2 MPa). This action limits the containment pressure,
- when a leak in the containment is detected. This action enables to catch fission products into the IRWST and thus to decrease potential releases.

F1 function: by definition F1 function is F1A or F1B function.
F2 function: functions necessary to prevent large releases in RRC-B scenarios.

EVU spray mode stopping criteria

- it is recommended to stop the spray mode when the containment pressure falls below 1.8 bar (0.18 MPa).

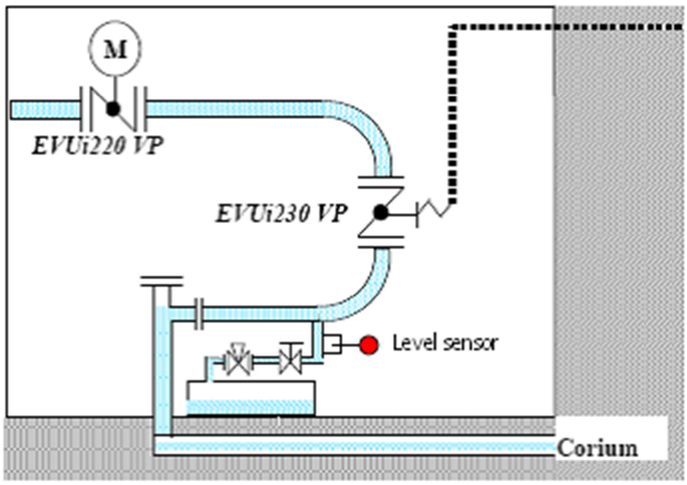
EVU leak management

In case of leakage in one EVU train, the operator must:

- stop the EVU pump and isolate the leak,
- ensure that the available EVU train is in operation or start it,
- introduce recovery actions on the unavailable EVU train as soon as dose rates in the EVU rooms are in compliance with workers entrance.

Case of a leak of one of the two EVU passive flooding valves

In case of a leak of one of the two EVU passive flooding valves (here EVU i230 VP) with high leak rate during normal operation, the motorized isolation valve (here EVU i220 VP) is closed.



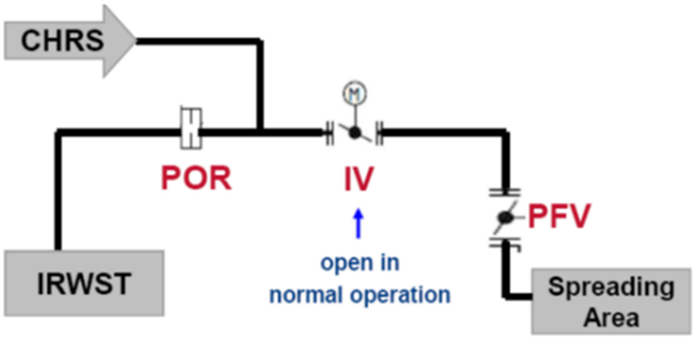
Taishan OSSAs alternative strategy using EVU system

A severe accident sequence in which the severe accident systems perform as designed is described as following the “mitigation path”. Otherwise, some alternative actions (“alternative strategies”) are defined in the TAISHAN OSSAs.

Failure of the opening of both passive flooding valves

In the original design, for each TAISHAN EVU train, the active flooding injection line was introduced upstream of the isolation valve (IV) (opened in normal operation) and of the passive flooding valve (PFV) (closed in normal operation). Nevertheless, the active cooling mode was not required for safety demonstration.

EDF pointed out that the TAISHAN EVU configuration of the active water injection lines introduced upstream of the motorized isolation valve and of the PFV in the same line was chosen in order to avoid, during a severe accident, due to a spurious opening of the motorized isolation valve by the operators, the presence of water in the spreading area before the corium arrival in this area.



At time of this report writing, EDF decided to change the EVU-strainer component from "plane vertical filtering surface-type" to "pocket-type". As a consequence of this EVU strainer component change, EDF kept the active flooding lines but decided to suppress the use of the active flooding function in the operating strategies for severe accident (OSSAs) because the "pocket-type" strainers are not designed for the small reverse water flow coming from the passive outflow reducer (POR) in case of active cooling actuation.

Passive flooding of the core melt fails in one EVU train if:

- the EVU passive flooding valve (PFV) fails to open,
- or the motorized isolation valve has been closed during normal operation (because of a spurious opening of the PFV or a leak with high leak rate of the PFV) and it cannot be opened in a severe accident.

In case of:

- failure of the opening of the two EVU passive flooding valves,
- or if a motorized isolation valve closed during normal operation cannot be opened in a severe accident and the other EVU train is under preventive maintenance(presently planned during normal operation),

the EVU passive cooling mode is no more available to flood and cool the corium.

To cope with these cases, in-vessel injection is proposed as alternative strategy in the Taishan OSSAs. Water is supplied to the core catcher spreading area via the RCS, the breached RPV and then the transfer channel. Heat is removed to the containment atmosphere by evaporation first, then directly to the IRWST due to flooding of the spreading area and its chimney. The heat that was first transferred to the containment atmosphere by evaporation can now be removed by using the EVU spray lines or SIS recirculation lines that do not depend on position of passive flooding valves.

4. Compliance with the regulatory requirements and Safety authority (or TSO) position

The review of TAISHAN EVU system is still ongoing. Such position is expected in 2015. NNSA will review this item according to HAF/HAD, based on the analysis result.