Multinational Design Evaluation Programme
Design-Specific Common Position
CP-AP1000WG-03

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MDEP Design-Specific Common Position CP-AP1000WG-03

Common Position on AP1000

In-containment Refuelling Water Storage Tank (IRWST)

Condensate Return Modelling

Participation

Regulators involved in the MDEP working group discussions:	CNSC (Canada), NNSA (China), AERB (India), ONR (UK), NRC (U.S.)
Regulators that support the present Common Position:	CNSC (Canada), NNSA (China), AERB (India), ONR (UK), NRC (U.S.)
Regulators with no objection:	none
Regulators that disagree:	none

Objectives

This report explains how the members of the MDEP AP1000WG with active regulatory assessments of the AP1000® reactor cooperated and shared information on issues associated with the return of condensate to the In-containment Refuelling Water Storage Tank (IRWST) in postulated fault conditions. It also captures common positions reached by the regulators on work done by the Westinghouse Electric Company (Westinghouse or the designer) to address the identified issues that were equally applicable to the AP1000 designs proposed for each country.

Introduction

The key safety innovation identified by the designer for the AP1000 reactor is the provision of a Passive Core Cooling System (PXS) to provide core cooling following certain design basis accidents. The PXS is designed for core residual heat removal, safety injection, and depressurisation without the use of active equipment such as pumps and AC power sources.

A notable aspect of the PXS is the Passive Residual Heat Removal (PRHR) heat exchanger. The PRHR heat exchanger is located in the IRWST at an elevation above the reactor core. The inlet to the heat exchanger is connected to one of the two hot legs of the primary circuit while the outlet is connected to the outlet plenum on one of the two steam generators (the steam generator on the loop with the PRHR heat exchanger inlet). Following a design basis reactor fault where the primary circuit remains intact and there is not a Loss of Coolant Accident (LOCA), the PRHR heat exchanger plays a vital role in decay heat removal, transferring heat from the Reactor Coolant System (RCS) into the IRWST. This transfer of heat causes the water in the IRWST to heat up, eventually becoming saturated, and resulting in steaming from the tank.

Eventually, the heat in the steam needs to be transferred to an ultimate heat sink. In the case of the AP1000, this is the outside atmosphere. This is achieved by another passive safety system, the Passive Containment Cooling System (PCS), working in conjunction with the PXS. This feature is designed to provide heat removal from the containment shell to the environment via natural circulation of air and evaporative cooling of water flowing from the Passive Containment Cooling Water Storage Tank (PCCWST) under gravity. The steam released from the IRWST condenses on the inner surface of the containment vessel, giving up heat originating in the RCS, and (by design) it forms a thin film of water which runs down the inner containment wall surface. Provisions are made to collect and channel condensate to the IRWST, replenishing the steam losses and allowing the passive heat removal process to continue. Refer to Figure 1 for an overview of the AP1000 PCS.

The individual components of the PXS and how they combine together to deliver the necessary safety functions have been substantiated by many years of analysis and experimental test rig work undertaken by the designer, some of which has its origins in a previous reactor design, the AP600 pressurized water reactor. The majority of this substantiation has been subject to detailed regulatory review by the United States (US) Nuclear Regulatory Commission (NRC) and has been performed in accordance with its requirements such as Regulatory Guide 1.203 (Ref. 1).

The regulators, members of the AP1000WG, acknowledge that the effectiveness of numerous aspects of the PXS has been demonstrated through many years of analysis and experimental work performed by the designer, undertaken consistent with US NRC's requirements.

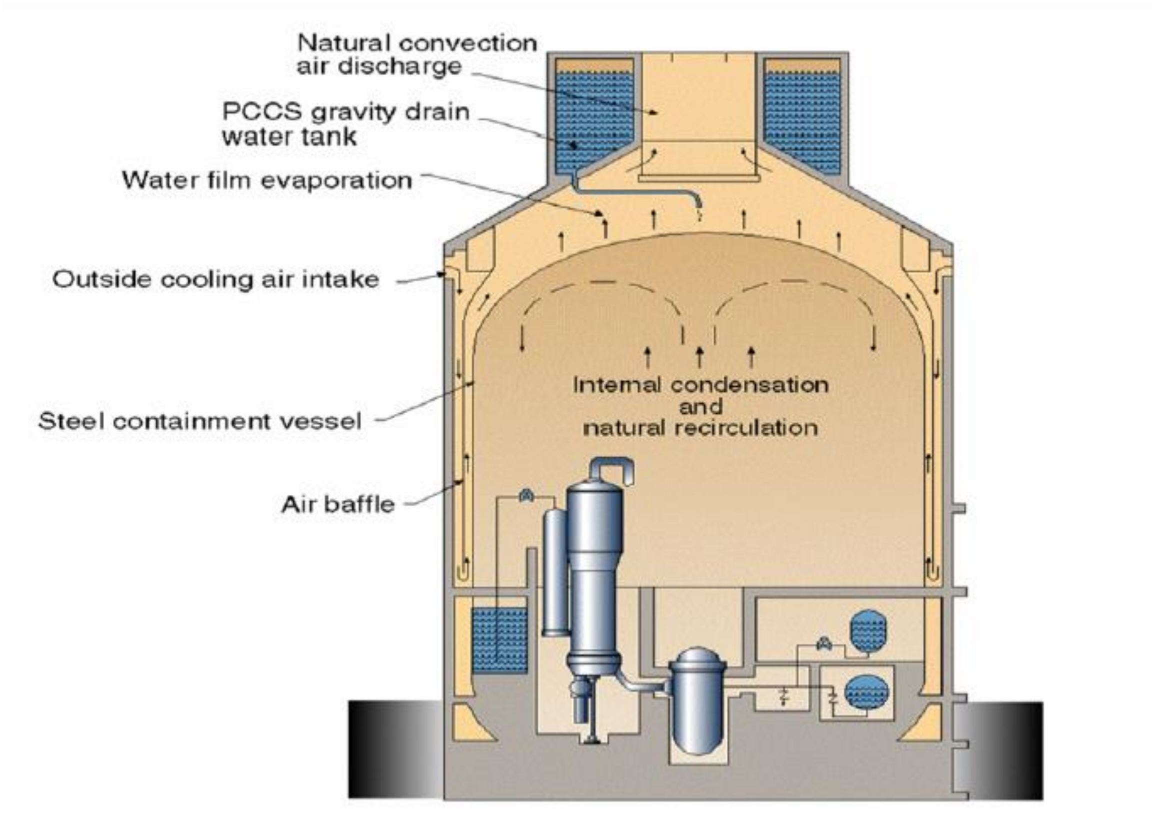

Figure 1: Overview of AP1000 PCS

In 2007, Westinghouse submitted its AP1000 reactor design to the UK nuclear safety regulator (at the time, the Nuclear Directorate of the Health and Safety Executive; it has since become Office for Nuclear Regulation (ONR) for consideration by its Generic Design Assessment (GDA) process. The main submission ultimately considered by ONR was Revision 1 of the European Design Control Document (EDCD) (Ref. 2) which was broadly consistent with Revision 18 of the AP1000 Design Control Document (DCD) supplied to the NRC. The ONR was satisfied with the majority of the PXS substantiation evidence identified in the EDCD (identical to that provided to the other regulators in the AP1000WG).

However, the EDCD/DCD stated that for intact circuit faults, the PXS would be capable of removing decay heat from the RCS indefinitely. To achieve this, high efficiency would be required from the PXS but it is unavoidable that not all the condensate will be returned to the IRWST. Some of the steam will condense and get trapped on other structures within the containment. Alternatively, it could drain to the containment sump and therefore bypass the IRWST (See Figure 2). Over a period of time (that time being dependent on the magnitude of the condensate losses), the PRHR heat exchanger could uncover and cease to be effective. The designer was unable to provide to ONR any detailed justification for how much of the condensate forming on surfaces within the containment during an intact circuit fault would be returned to the IRWST, and therefore support its claim on how long the PXS would be effective for.

As a result of this lack of justification, at the end of 2011 ONR wrote the GDA Issue GI-AP1000-FS-06 requiring the designer to provide validation that the IRWST is functionally capable of cooling the PRHR during intact circuit faults for 72 hours, or propose a design change to rectify the situation (Ref. 3). The ONR brought this GDA Issue to attention of the other regulators on the AP1000WG through MDEP.

At this point, Westinghouse pause its activities in the UK (subsequently resuming again in 2014). However, it recognised that the GDA Issue initially raised in the UK context had implications for all AP1000 designs, and it commenced a programme of work to address the underlying technical concerns for the benefit of continuing AP1000 projects in the US and the People's Republic of China.

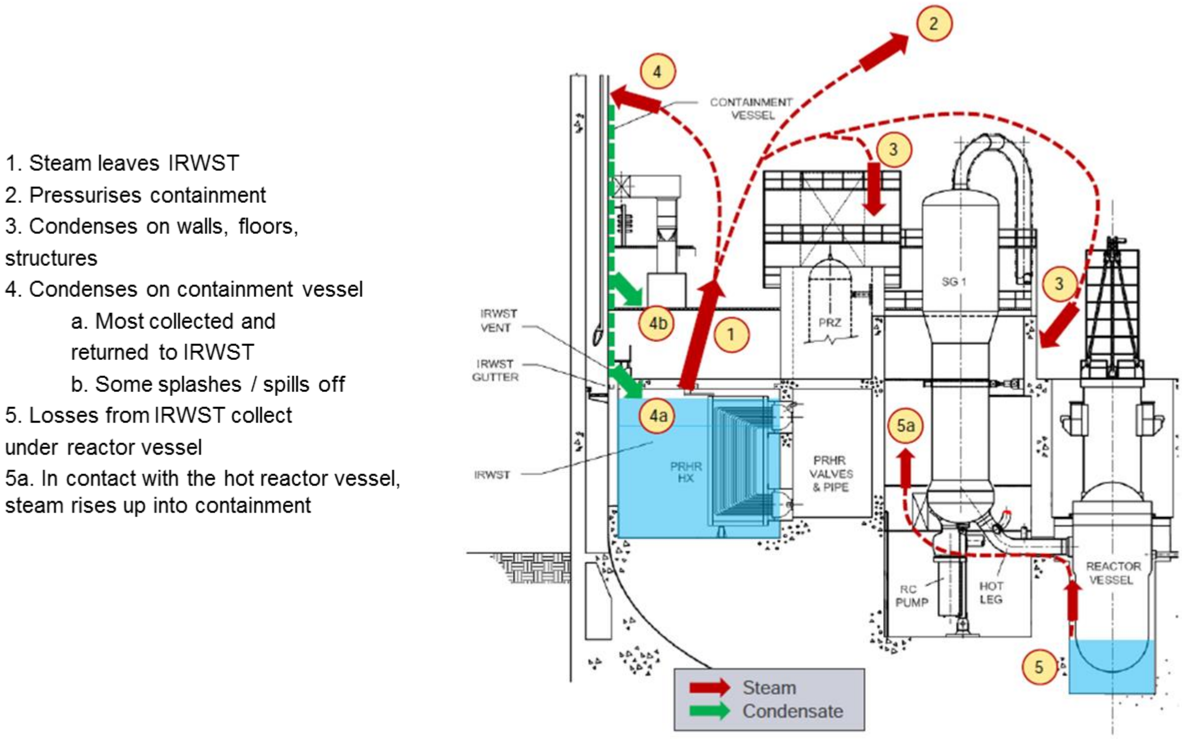

Figure 2: Steam / condensate cycle within the containment

The designer's response to the regulatory challenge

To address the issue, over a period of several years and informed by interactions with the regulators and (in the case of the US) scrutiny from the Advisory Committee on Reactor Safeguards (ACRS), the designer did the following:

- Systematically attempted to identify and quantify the important phenomena that influence the condensate return rate to the IRWST, assembling the findings in a Phenomena Identification and Ranking Table (PIRT).

- Performed a series of physical tests to investigate the behaviour of a condensate film as it flows down the vertical side wall of the containment shell. This had been identified in the PIRT as a phenomenon with a high importance but a low state of knowledge.

- Proposed and implemented design changes (identified following the test work) to facilitate water collection. These design changes were to the polar crane girder, internal stiffener and IRWST gutter, as well as the addition of a downspout piping system.

- Proposed and implemented a reduction in the number of PRHR heat exchanger tubes; it is permissible to plug (down from 8% to 5%).

- Developed a new analysis methodology specifically to consider the condensate return issue. The methodology included the following:

  - Containment response analysis using the designer's version of the GOTHIC code which tracks the condensation that bypasses the PXS gutter arrangement.

  - Hand calculations which evaluate the overall percentage of steam condensation that is lost from the containment vessel shell (used to justify the basis for a bounding containment vessel shell bypass as an input into the containment response analysis).

  - Analyses using the LOFTRAN code to evaluate the RCS cooldown following the PRHR heat exchanger operation with three objectives: 1) to demonstrate the capability of the PRHR heat exchanger to cool the RCS core average temperature to 215.6°C (420°F) in 36 hours on a realistic basis; 2) to demonstrate that conservative design basis analyses of events considered in Chapter 15 of the DCD / Final Safety Analysis Report (FSAR) can be extended out to 72 hours with all safety criteria met; and, 3) to demonstrate that the PRHR heat exchanger can effectively match the decay heat and keep the RCS temperature below 215.6°C (420°F) for an extended period of time (eventually claimed to be at least 14 days).

  - Analyses using the RELAP code to independently confirm that the conclusions reached from the LOFTRAN calculations are appropriate despite two known simplifications: 1) LOFTRAN neglects ambient heat losses to maximise the RCS energy; and, 2) LOFTRAN has a limited capability to model two-phase flow and therefore the performance of the PRHR when sub-cooling is lost.

In the US, the required changes are documented in the combined license applications for Levy Units 1 and 2, William States Lee Units 1 and 2, and Turkey Point Units 6 and 7, and in License Amendments 72 and 71 for the Vogtle Units 3 and 4 (Refs 4, 5, 6, and 7). In the UK, the modifications are incorporated into the reference design through a number of design change proposals and the revised safety case arguments are presented in Chapter 9 of the AP1000 Pre-Construction Safety Report (Ref. 8). In China, the required changes have been incorporated into the FSAR revisions approved by NNSA for initial fuel load at Sanmen and Haiyang Units 1 and 2.

Regulators' activities and cooperation through MDEP

Although there were some differences in the final high level documentation and submissions provided to different countries, the supporting experimental work, analysis and changes to the AP1000 design were common. The MDEP AP1000WG was vital to establishing this commonality and facilitating cooperation between the different regulators.

The designer's approach was to treat the US design as the lead review to take forward the revised analysis methodology, with submissions to other countries following slightly behind. The MDEP AP1000WG forum allowed member countries to hear simultaneously from both the designer and the NRC what progress was being made and to what timescales.

Through MDEP AP1000WG interactions, the NRC was able to explain the confirmatory analysis it performed with RELAP code to gain extra confidence in the designer's analyses. It was also able to provide the other regulators with additional positive assurances on the adequacy of the designer's analysis documentation following audits it performed. All participating regulators benefited from the collaboration on completion of the first review.

The MDEP AP1000WG provided an ideal forum for NRC to explain the historic basis for the AP1000 design's objectives for achieving a safe shutdown state through the PXS, usefully explaining the involvement of Electric Power Research Institute (EPRI) and the ACRS, as well as the status of its policy for safe shutdown in passive plants as defined in SECY-94-084, Item C (Ref. 9).

The National Nuclear Safety Administration (NNSA) shared its areas of regulatory attention and review conclusions on the IRWST Condensate Return issue with the MDEP AP1000WG, and introduced the progress of the design changes performed on Sanmen and Haiyang Unit 1. Through the MDEP AP1000WG, all countries discussed NNSA's review experience to the benefit of all member countries.

In 2016, NRC, NNSA, and ONR were all able to confirm that they had no outstanding significant concerns. Each regulator made their own regulatory judgements on the adequacy of Westinghouse's design and submissions. However, they were able to do this with the benefit of a high level of understanding of the conclusions of other regulators in the AP1000WG through their involvement with MDEP.

Common Position

The AP1000WG members are satisfied that:

- The AP1000 designer has adequately investigated the issue of condensate return through PIRT analysis and experimental test rigs.

- The AP1000 designer has made appropriate design changes to common aspects of the AP1000 that improve the efficiency and effectiveness of condensate collection and returning it to the IRWST.

- The AP1000 designer has demonstrated the capability of the PRHR heat exchanger to cool the RCS core average temperature to 215.6°C (420°F) in 36 hours on a realistic basis.

- The AP1000 designer has performed appropriate analysis to demonstrate the PXS can take the plant to a safe, stable state for at least 72 hours following a design basis accident without additional makeup water. A long-term stable condition can be maintained beyond 72 hours by simple, unambiguous operator actions, easily accomplished with non-safety / lower safety class equipment (provided onsite or potentially brought in from off-site).

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