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Development of an Ultimate Heat Sink for a Passive Integral Reactor

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1. Introduction

As defined in US Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.27 [1], an Ultimate Heat Sink (UHS) is the system of structures and components and associated assured water supply and atmospheric condition(s) credited for functioning as a heat sink to absorb reactor residual heat and essential station heat loads after a normal reactor shutdown or a shutdown following an accident or transient including a loss-of-coolant accident (LOCA).

There are three principal safety functions of the UHS [1]: (1) dissipation of residual heat after reactor shutdown, (2) dissipation of residual heat after an accident such as a LOCA and (3) dissipation of maximum expected decay heat from the spent fuel pool to ensure the pool temperature remains within the design bounds for the structure. For a single nuclear power unit, the UHS should be capable of providing sufficient cooling water to accomplish these safety functions.

In conventional nuclear power plants that use active systems, the capacity of the UHS shall be sufficient to provide cooling for a period of 30 days to evaluate the situation and take corrective action. However, this is not applicable to passive plants as stated in the above RG [1], because passive light water reactors have significantly different design bases for the UHS.

In this study, development of the UHS for a passive integral reactor, SMART (System-integrated Modular Advanced ReacTor) is presented. Design features of the UHS in SMART are introduced briefly and conformance to the currently applicable regulations is examined.

2. System Description

In the design of SMART, the UHS is provided by the Emergency Cooldown Tank (ECT), which provides the heat transfer mechanism for the reactor and containment to the atmosphere. The capacity of the ECT is determined to remove the decay core heat and sensible heat from the Reactor Coolant System (RCS) and/or the Lower Containment Area (LCA) during 72 hours after an accident. The ECT may be replenished periodically by the ECT makeup tank, which enables the safety function of the UHS to be maintained for long-term period beyond 72 hours.

The ECT makeup tank provides post-72 hour makeup to the ECT through seismic category I piping. The ECT makeup tank also belongs to seismic category I. The ECT makeup operation is performed by gravity caused by the height difference between the ECT makeup tank and the ECT. The ECT makeup tank is provided to replenish the ECT periodically in emergency situations.

2.1 Passive Residual Heat Removal System

The heat sink for the Passive Residual Heat Removal System (PRHRS) is the ECT. During the operation period of the PRHRS, the heat from the RCS is removed by the PRHRS heat exchanger (PHX), which is submerged in the ECT cooling water. The cooling water capacity in the ECT needed for the operation of the PRHRS is calculated to perform the RCS heat removal without being exposed to the atmosphere at the top of the heat transfer tube in the PHX without the operator's action for at least 72 hours.

2.2 Containment Pressure and Radioactivity Suppression System

The heat sink for the Containment Pressure and Radioactivity Suppression System (CPRSS) is also the ECT. During the operation period of the CPRSS, the heat from the LCA is removed by the ECT heat exchanger (ECTHX), which is also submerged in the ECT cooling water. The cooling water capacity in the ECT needed for the operation of the CPRSS is calculated to perform the containment heat removal without being exposed to the atmosphere at the top of the heat transfer tube in the ECTHX without the operator's action for at least 72 hours.

3. Conformance to Regulations

In the design of UHS, the following regulations are considered:

(1) Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the Code of Federal Regulations, Part 50 (10 CFR Part 50) [2]
(2) Regulations on Technical Standards for Nuclear Reactor Facilities, Etc. [3]
(3) IAEA Safety Guide, "Safety of Nuclear Power Plants: Design" [4].

Standard Review Plan 9.2.5 [5] and Regulatory Guide 1.27 [1] are also relevant but they are not intended for passive plants. Conformance to each regulation [2-4] is reported in this section.

3.1 General Design Criteria

General Design Criteria (GDC) 2, 5, 44, 45, and 46, were considered in the design of the UHS. Detailed requirements for each GDC can be found in Reference 2.

3.1.1 General Design Criterion 2

The UHS meets GDC 2, by compliance with RG 1.29 [6]. The applicable sections of RG 1.29 [6] include Positions C.1 and C.2. The UHS is designed to remain functional by withstanding the effects of natural phenomena.

3.1.2 General Design Criterion 5

The UHS meets GDC 5 for shared structures, systems and components (SSC) important to safety. The UHS design for SMART does not share any SSC with other unit.

3.1.3 General Design Criterion 44

The requirements of GDC 44 for heat transfer to the UHS are met. The SMART UHS is the ECT. In the event of a design basis accident, heat is transferred to the ECT through either the PRHRS or the CPRSS. The water in the ECT is allowed to boil and the resulting steam is vented to the environment. The water in the ECT is sufficient to perform the safety related function of transferring heat to the atmosphere for the initial 72 hours of an accident.

3.1.4 General Design Criterion 45

The features of the UHS meet the requirements of GDC 45. The UHS is located in auxiliary area outside containment and is accessible for periodic inspections. Redundancy and isolation are provided to allow periodic inspections of the UHS.

3.1.5 General Design Criterion 46

The design of the UHS meets the requirements of GDC 46. Functional testing to assure structural leak-tight integrity is accomplished by maintaining the UHS water level and monitoring for leaks during periodic walkdowns.

3.2 Regulations on Technical Standards for Nuclear Reactor Facilities, Etc.

This regulation is one of the Korean nuclear legislation, *i.e.* “Regulation of the Nuclear Safety and Security Commission No. 17 [3].” This regulation is mainly based on the GDC of Appendix A to 10 CFR 50.

Articles 13, 16, 31, and 41, were considered in the design of the UHS. The whole contents of this regulation are easily accessible at the National Law Information Center (http://www.law.go.kr).

3.2.1 Article 13

This Article 13 is correspondent to GDC 2. The design of the UHS conforms to the above regulation.

3.2.2 Article 16

This Article 16 is correspondent to GDC 5. The design of the UHS conforms to the above regulation.

3.2.3 Article 31

This Article 31 is correspondent to GDC 44. The design of the UHS conforms to the above regulation.

3.2.4 Article 41

This Article 41 is correspondent to GDC 45 and 46. The design of the UHS conforms to the above regulation.

3.3 IAEA Safety Guide

3.3.1 Requirement 53: Heat transfer to an ultimate heat sink

IAEA produces many safety standards series, such as Safety Fundamentals, Safety Requirements, and Safety Guides. In Reference 4, there is a requirement regarding the UHS: “The capability to transfer heat to an ultimate heat sink shall be ensured for all plant states.” It means that “systems for transferring heat shall have adequate reliability for the plant states in which they have to fulfill the heat transfer function.” [4] The design features of the UHS for SMART meet the above requirement as well.

4. Conclusions

In the present study, a brief description of the UHS for SMART was presented. Design features and requirements of the UHS are investigated. Conformance to the currently applicable regulations was also examined. It was revealed that they were well satisfied. However, in the near future, new regulations may be needed for specific design features of passive plants.

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