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Review of Regulatory Standards and Guidelines for Light Water Reactors in terms of Passive Residual Heat Removal System

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1. Introduction

Regulatory Standards and Guidelines for Light Water Reactors (LWRs) [1, 2] published by Korea Institute of Nuclear Safety (KINS), are subordinate regulations to describe in detail or to supplement the nuclear energy safety legislation and the notices of the Nuclear Safety and Security Commission (NSSC).

KINS Regulatory Standards for LWRs [1] deal with interpretation of the technical standards or detailed criteria required to secure the safety of the nuclear reactor facilities, etc. On the other hand, KINS Regulatory Guidelines for LWRs [2] deal with detailed methods, procedures or technical conditions to meet the above KINS Regulatory Standards.

These regulations are mainly focused on the active nuclear power plants. After Fukushima accident, however, a movement grows rapidly to replace the conventional active safety systems with passive ones. SMART (System-integrated Modular Advanced ReacTor) developed by Korea Atomic Energy Research Institute (KAERI), is an integral-type passive reactor. Recently, the pre-project engineering (PPE) was officially launched between KAERI and King Abdullah City for Atomic and Renewable Energy (K.A.CARE) in pursuit of the construction of SMART and training of R&D personnel chosen from Kingdom of Saudi Arabia. In this international cooperation, all the safety systems in SMART are being designed as fully passive ones. Therefore, it looks evident that the present KINS Regulatory Standards and Guidelines cannot be fully applicable to SMART.

In the present study, the applicability of the KINS Regulatory Standards and Guidelines for LWRs to SMART will be reviewed in terms of the Passive Residual Heat Removal System (PRHRS), which is the most important passive safety feature of SMART. And also suggestions will be recommended for those Regulatory Standards and Guidelines so they cope with passive systems as well.

2. Description of the PRHRS

SMART is designed with passive safety systems in order to enhance the safety of the reactor. The PRHRS is one of the passive safety systems, which is activated after an accident to remove the residual heat from the core and the sensible heat of the reactor coolant system (RCS) through the steam generators (SGs). The system consists of four independent trains and each train is composed of one emergency cooldown tank (ECT), one PRHRS heat exchanger (PHX), and one PRHRS makeup tank (PMT). Each train is connected to a set of two SGs.

When an accident occurs, which demands an activation of PRHRS, the main steam isolation valves (MSIVs) and feedwater isolation valves (FIVs) are closed automatically, and the PRHRS outlet isolation valves are open simultaneously. Then a closed loop of natural circulation is formed through the SGs, the PHX, and the connecting pipelines. Only by using natural circulation of two phase flow, the PRHRS removes residual and sensible heat for at least 72 hours since an accident occurs even without any operator's intervention or aid of external AC power. The PRHRS shall be designed to bring the temperature of the RCS below a safe shutdown condition within 36 hours after an accident occurrence and to maintain this state until at least 72 hours. This condition may be continuously maintained beyond 72 hours if the ECT is refilled periodically.

3. General Regulations on RHRS

Regulation on Residual Heat Removal System (RHRS) of Republic of Korea (ROK) can be found in Article 29 of Regulation of the NSSC No. 17 [3]. It is stated that a system capable of removing heat due to fission product's decay heat and other residual heat from the core shall be installed to assure that specified acceptable fuel design limits and the design conditions of the reactor coolant pressure boundary are not exceeded. This statement is almost identical to that of US Nuclear Regulatory Commission (NRC), *i.e.*, General Design Criteria 34 [4].

4. Specific Regulations on RHRS

4.1 Cold shutdown vs. Safe shutdown

KINS Regulatory Standards 6.5.5.1 indicated that the system shall be capable of bringing the reactor to a cold shutdown condition within 36 hours using only safety grade equipment. Cold shutdown condition means 200°F for a PWR or 212°F for a BWR. This KINS Regulatory Standards seems to be implemented by US

NRC Regulatory Guide (RG) 1.139 [5], which was already withdrawn in 2008.

However, in the design of the passive safety system, it is physically impossible to reach the cold shutdown temperature, as the system uses evaporation and condensation. In SMART, core decay heat and sensible heat of the RCS are delivered to the water in the ECT using two phase heat transfer and natural circulation. Therefore, the temperature of the RCS cannot be lowered than the evaporation temperature of ECT water by using the passive safety system only. This is an inherent feature of the passive safety system.

Electric Power Research Institute (EPRI) [6] acknowledged that cold shutdown is not needed in a passive plant to maintain the fuel and reactor coolant pressure boundary within acceptable limits. It also insisted that the passive RHRS can be employed to reach a fully acceptable shutdown condition of about 420°F in 36 hours. In SECY-94-084 [7], it is clearly stated that cold shutdown is not the only safe stable shutdown condition which can maintain the fuel and reactor coolant boundary within acceptable limits, and that the EPRI proposed 215.6°C (420°F) as a safe stable shutdown condition is acceptable on the basis of acceptable passive safety system performance and acceptable resolution of the regulatory treatment of non-safety systems (RTNSS). This regulatory position is endorsed in Standard Review Plan (SRP) 19.3 [8] as stated that the US NRC considers a safe stable shutdown condition for advanced passive LWRs to be a condition by which all plant conditions are stable and within regulatory limits, and the reactor coolant system pressure is stabilized and reactor coolant temperature is less than or equal to 420°F.

Therefore, KINS Regulatory Standards 6.5.5.1 shall be changed to allow safety shutdown condition for passive safety system.

4.2 Mid-loop operation

KINS Regulatory Guidelines 6.9 instructed that RHRS shall provide the safety measures for mid-loop operation. However, SMART does not conduct mid-loop operation at all.

Therefore exception or deletion of KINS Regulatory Guidelines 6.9 is suggested for passive safety system.

4.3 Emergency feedwater system

KINS Regulatory Standards 7.1.4 directed requirements for emergency feedwater system and KINS Regulatory Guidelines 7.2.7 indicated the pump activation. However, in the design of SMART, the PRHRS conducts the emergency feedwater supply without any active pumps.

Therefore exception or deletion of KINS Regulatory Standards and Guidelines for LWRs regarding any active systems or components is suggested for passive safety system.

4.4 Regulatory treatment of non-safety systems

The ECT contains enough water to remove the residual heat from the core and the sensible heat of the RCS. However, after 72 hours since an accident occurs, the ECT needs to be replenished periodically to maintain the safe shutdown condition for a long-term period. This PRHRS ECT refilling system, which is a non-nuclear safety system, shall be designed in accordance with RTNSS.

Regulatory position of US NRC on RTNSS can be found in SECY-94-084 [7], SECY-95-132 [9], RG 1.206, C.IV.9 [10], and SRP 19.3 [8]. However, in ROK, there are no directions regarding RTNSS in both KINS Regulatory Standards and Guidelines for LWRs. Only a few citations to US NRC regarding RTNSS can be found in Safety Review Guidelines for LWRs [11].

Therefore, regulatory body of ROK is currently preparing to build domestic regulations regarding the RTNSS.

5. Conclusions

In this study, discrepancy of current regulation from the passive safety system was briefly touched and several suggestions were made. This review only limited to the design of the PRHRS. There may be more discrepancies among other passive systems as well. Regulatory body of ROK already begun to resolve these issues and therefore cooperation among KAERI, K.A.CARE and KINS is strongly encouraged.

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