*Transactions of the Korean Nuclear Society Autumn Meeting*
*Jeju, Korea, October 21-22, 2010*

# Insights from Development of Regulatory PSA Model for SMART

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## 1. Introduction

SMART (System-Integrated Modular Advanced Reactor) is a first-of-the-kind integral reactor with 330 MW thermal power under active development by Korea Atomic Energy Research Institute (KAERI) for power generation and seawater desalination [1]. SMART employs various design features that are not typically found in other nuclear power plants. Examples include a unique passive residual heat removal system (PRHRS), and enclosure of a pressurizer, eight helical steam generators, and eight canned reactor coolant pumps inside the reactor pressure vessel. This paper presents risk insights on the SMART reactor gained during the development of a regulatory PSA model by Korea Institute of Nuclear Safety (KINS) [2].

## 2. Risk Insights on SMART Reactor

The SMART design is not yet finalized but a package, including design description, the results of preliminary safety evaluation (such as the thermal-hydraulic analysis of various design basis events), and so on, has been recently submitted to KINS for regulatory review [1]. A PSA also was performed by KAERI for preliminary SMART design in 2002 and is currently under revision to reflect the latest design features.

A regulatory PSA model is also being developed independently by KINS for the latest SMART design [2], and once completed, will be utilized not only to confirm the risk results obtained by the KAERI's PSA model but also support various regulatory applications.

The insights gained through the process of developing a regulatory PSA model for SMART are discussed below along with the issues that have been identified as needing further investigation in the future.

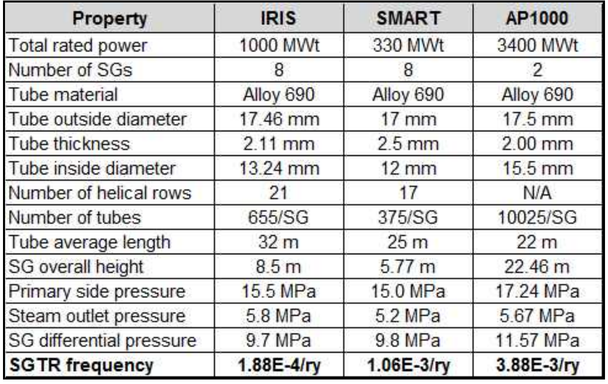
(1) Identification of Potential Initiating Events – In performing PSAs for large-scale light water reactors, it is relatively easy to identify potential initiating events particularly because there exist an extensive list of plant transients and initiating events that actually occurred during operation of such plants throughout the world in the last several decades. Furthermore, the frequencies of most initiating events, other than those that rarely occur (e.g., large-break loss of coolant accident) can also be evaluated with great confidence. However, there exist no such lists for plants like SMART, because small reactors such as NuScale, mPower, Hyperion Power Module, IRIS and 4S are under design [3] but have not been operated yet. Therefore, a master logic diagram for extensive core damage was developed in terms of loss of safety functions with associated initiating events in order to help identify initiating events that may occur uniquely at SMART. This diagram will be also used in checking the completeness of initiating events modeled in the regulatory PSA.

(2) Uniqueness of SGTR Events at SMART – The IRIS, SMART and NuScale plants are quite different from AP1000 in terms of steam generator (SG) characteristics, because: 1) helical tubes are used in IRIS, SMART and NuScale, but straight tubes in AP1000; and 2) the SG tubes are in compression (i.e., the pressure outside of the tubes larger than that inside the tubes) in the cases of IRIS, SMART and NuScale, but on the contrary the SG tubes of AP1000 are subject to tensile forces because the inside pressure is larger than the outside pressure. According to the operating experience of current PWRs, tensile stress corrosion cracking has been responsible for about 70% of SG tube failures [4]. Therefore, the initiating event frequency for SGTR at SMART has been obtained in this study by removing the contribution due to the tensile stress corrosion cracking from the SGTR frequency given in the latest initiator frequency database, i.e., NUREG/CR-6928.

Table I compares the specific parameters for SGs of IRIS [4,5], SMART [1] and AP1000 [6] along with the SGTR frequencies used in the design-specific PSAs. From this table we can note the following among others:

- The same tube material of Alloy 690 is used in all the plants, but the number of SGs is very different (i.e., only 2 SGs in AP1000, but 8 SGs in IRIS and SMART).

Table I: Comparison of SG parameters



| Property | IRIS | SMART | AP1000 |
|---|---|---|---|
| Total rated power | 1000 MWt | 330 MWt | 3400 MWt |
| Number of SGs | 8 | 8 | 2 |
| Tube material | Alloy 690 | Alloy 690 | Alloy 690 |
| Tube outside diameter | 17.46 mm | 17 mm | 17.5 mm |
| Tube thickness | 2.11 mm | 2.5 mm | 2.00 mm |
| Tube inside diameter | 13.24 mm | 12 mm | 15.5 mm |
| Number of helical rows | 21 | 17 | N/A |
| Number of tubes | 655/SG | 375/SG | 10025/SG |
| Tube average length | 32 m | 25 m | 22 m |
| SG overall height | 8.5 m | 5.77 m | 22.46 m |
| Primary side pressure | 15.5 MPa | 15.0 MPa | 17.24 MPa |
| Steam outlet pressure | 5.8 MPa | 5.2 MPa | 5.67 MPa |
| SG differential pressure | 9.7 MPa | 9.8 MPa | 11.57 MPa |
| **SGTR frequency** | **1.88E-4/ry** | **1.06E-3/ry** | **3.88E-3/ry** |

- The SG differential pressure that causes stress to the tubes is very similar in IRIS and SMART, but significantly higher in AP1000. Importantly, the SG tubes in IRIS and SMART are in compression although they are subject to tensile forces as indicated earlier.
- The SG tubes of SMART are thicker than the tubes of IRIS or AP1000.
- The total SG tube length of SMART is more than 2 times shorter than that of IRIS.

Especially considering the similarity and differences in physical characteristics between SMART and IRIS, we can expect that the SGTR initiating event is less likely to occur at SMART as compared to IRIS. Therefore, the SGTR initiator frequency of $1.06\times10^{-3}$ per reactor year adopted to be used in the regulatory PSA model for SMART represents a more conservative estimate as compared to the value used in the IRIS PSA, i.e., $1.88\times10^{-4}$ per reactor year.

(3) Passive Safety System – The PRHRS is designed to remove decay heat through the SGs so that the RCS can be cooled down within 36 hours following the reactor trip to the temperature where the shutdown cooling system can be started. A preliminary evaluation of the PRHRS reliability indicates that the passive system exhibits much higher reliability than a comparable active safety system (e.g., high-pressure or low-pressure safety injection system) especially because only one time alignment of valves is needed for the passive system start-up and once started its failure likelihood is extremely small [7]. However, it is expected that the driving force for natural circulation in the PRHRS will continue to be reduced because of a decrease in density difference between the SG and the condensation heat exchanger of the PRHRS as a consequence of the continued reduction in the core decay heat. What this implies is that the PRHRS will become increasingly vulnerable to the potential flow blockage that may be caused by excessive fouling of heat exchanger piping, introduction of extraneous material into the PRHRS, accumulation of noncondensible gas, etc. All such failure modes that have been identified in the worldwide research thus far [8,9] will be considered in the regulatory SMART PSA model with conservative estimates for their likelihood of occurrence. Caution will be also exercised so that too much conservatism does not distort the risk profile.

(4) Mission Time – In a Level-1 PSA, 24 hours is typically used as a mission time for safety systems under the assumption that once core damage is prevented for 24 hours, extensive core damage will not occur afterwards because the plant will be stabilized in safe state. In the case of SMART, this assumption is less likely to hold true because the PRHRS will be still in operation during the first 24 hours and may not be switched to the shutdown cooling system until the PRHRS is operated for a total of 36 hours. This issue is currently under investigation to evaluate the effect of mission time on the risk.

## 3. Conclusions

A regulatory PSA model is under development by KINS for SMART reactor. Various insights gained during the development process were presented in this paper along with issues identified. These insights or issues will be taken into account in further development of the regulatory PSA model and also in the regulatory review of SMART design safety.

## ACKNOWLEDGMENT

This work has been carried out under the Nuclear R&D program supported by the Ministry of Education, Science and Technology, Republic of Korea.

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