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Evaluation of Improved Fission Product DFs Model in MAAP-ISAAC 4.03 Code during MSGTR Accident

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1. Introduction

Multiple steam generator tube rupture (MSGTR) was chosen as one of the initiating events and the corresponding scenario was analyzed for the Wolsong plants from a view point of severe accident analysis. The frequency of severe core damage for the MSGTR is very low below 5.5 x 10^{-8}/ry [1].

In the case of a severe accident arising from MSGTR, fission products directly bypass the reactor building through the tube break first, then through stuck open main steam safety valves (MSSVs). Therefore, MSGTR can result in severe offsite consequences. However, this scenario affords the possibility for the scrubbing of fission products as they are discharged into Steam Generator (SG) inventory which acts like water pool. In this case, feed-water injection may be resumed to allow for a water pool to be maintained in the ruptured steam generator. Even though the scrubbing of fission products in water pools is an effective way to mitigate fission product releases, the methodology in Level 2 PSA and modeling in MAAP-ISAAC[1] [2] were not developed to analyze realistic fission product retention mechanisms for these sequences.

Therefore, it is necessary to analyze MSGTR event with an improved MAAP-ISAAC model which reflects the above concerns in spite of the low frequency.

2. Background and MAAP-ISAAC Modeling

Characterization of fission product source terms for MSGTR sequences is typically performed using the assumption that fission products released from the primary system through the break are immediately and completely released to the environment.

This assumption is a simple, conservative way to treat releases but neglects many mechanisms which could result in significant fission product retention within the SG. The major mechanisms for fission product retention are identified as deposition within the SG tube and secondary side, and scrubbing of fission products in the water pool.

2.1 ARTIST Tests

In the past, PSA of SGTR or MSGTR takes a conservative approach and rarely credits retention of fission products within the SG. This is done mainly due to a lack of enough experimental evidence for large fission product retention. The situation has changed when the AeRosol Trapping In a STeam generator (ARTIST) experiments operated by Paul Scherrer Institute (PSI) in Switzerland were performed and reported. The experiments were mainly dedicated to fission product retention studies during SGTR. The ARTIST test matrix includes a total of eight phases. Phase 1 tests were dedicated to fission product deposition in a single SG tube with a break, phase 2, 3, 4 and 7 tests to dry SG tests, and phase 5, 6 and 8 tests to wet SG tests, in which the secondary side of the SG was flooded with water [3, 4, 5]. As the ARTIST experiments have revealed, a large decontamination factor (DF) can be achieved. The increased DF is due to the retention of fission product aerosols in both the SG tube with a break and the secondary side. Therefore, the total DF within a SG during SGTR or MSGTR is a product of the three individual DFs as follows:

$$DF_{Total} = DF_{tube} \; x \; DF_{dry\_SG} \; x \; DF_{wet\_SG} \qquad (1)$$

DF_{Total} is defined as the ratio of the mass flow of fission product aerosols entering the SG primary side to the mass flow out of the SG through stuck open valves. DF_{tube} is the DF for fission product retention within a tube with break, and DF_{dry_SG} and DF_{wet_SG} are the DFs for fission product retention in the secondary side of the dry SG and wet SG, respectively.

2.2 Limitations of the MAAP-ISAAC DF Model

The MAAP-ISAAC code only calculates the scrubbing of fission products in water using the aerosol scrubbing model which is essentially an engineering correlation using the results generated by SUPRA [6], coupled to the non-dimensional aerosol particle size spectrum correlation developed by FAI [7]. If there is no water in the secondary side, DF_{pool} which is the DF for gas laden with fission product aerosols passing through a bare pool will be set to 1 by the code. However, it does not mechanistically account for the

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[1] MAAP is an Electric Power Research Institute (EPRI) software program that performs severe accident analysis for nuclear power plants including assessments of core damage and radiological transport. A valid license to MAAP4 and/or MAAP5 from EPRI is required.

enhancement of DF for a flooded tube bundle as has been revealed by ARTIST wet SG tests. The code also does not account for the retention in the primary side of the ruptured SG tube or in a dry SG. SUPRA is a mechanistic suppression pool scrubbing model that is based on extensive studies by EPRI, SAIC, and Battelle Columbus. Pool scrubbing for flow through a break during SGTR or MSGTR into water in the SUPRA model is simulated as a Side Vent. It is worthwhile to note that the Side Vent injection mode only considers pool heights up to 1.8 m. For pool heights greater than 1.8 m, the DF will be calculated assuming a pool height of 1.8 m. This limitation may potentially have a significant impact on pool scrubbing DF for an SGTR or MSGTR.

2.3 Improved Fission Product DFs

In the MAAP-ISAAC code, the DF_{Total} is applied by manipulation of the sequence inputs. DF_{tube} is assumed and applied based on ARTIST phase 1 measurement as below:

$$DF_{tube} = 2, \textit{ without condensation} \qquad (2)$$
$$DF_{tube} = 5, \textit{ with condensation} \qquad (3)$$

An assumption in equations (2) & (3) is that fission product re-vaporization is not a major concern for the type of analysis in consideration. If re-vaporization is indeed a major concern, DF_{tube} should be set to 1, i.e., no credit for fission product retention within SG tubes, for conservative purposes.

Based on ARTIST dry SG test measurements, the value of DF_{dry_SG} is assumed as below:

$$DF_{dry\_SG} = 1, \textit{ PHTS has depressurized} \qquad (4)$$
$$DF_{dry\_SG} = 2, \textit{ PHTS has not depressurized} \qquad (5)$$

In the equation (5), $DF_{dry\_SG} = 2$ for the high pressure SGTR case is the smallest DF measured through the ARTIST experiments. It is more conservative to use the smallest DF of 2 instead of using an average DF based on particle size distribution.

According to comparisons of transport efficiency measured in ARTIST wet SG tests and earlier bare pool and flooded bundle (SGTR) tests [4], the ratio of DF in a flooded SG secondary side to the DF in a bare pool ranges from 33 to 172. Therefore, the value of DF_{wet_SG} is applied as below. The factor 33 is chosen for conservative purposes.

$$DF_{wet\_SG} = 33 \times DF_{pool} \qquad (6)$$

3. Assumptions and Results

3.1 Description of Analyzed Cases and Assumptions

The chosen case is the MSGTR accident. MSGTR is a transient sequence initiated by the rupture of several steam generator tubes, allowing PHTS coolant to discharge into the secondary side of the SG. It is an accident that causes leakage of coolant to the outside of the reactor building. Even though shutdown is successful after MSGTR occurs, it can lead to core damage due to much delayed actuation of ECCS. Once ECCS signal is initiated, SG MSSVs open automatically. If core damage occurs, the radioactive material may be directly released to the environment through the opened MSSVs as shown in Fig. 1. It is assumed that 10 steam generator tubes in loop 1 are ruptured and the maximum break flow rate is 80 kg/s.

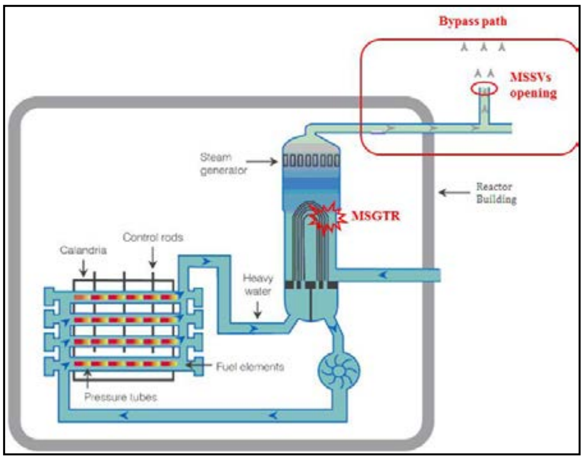

Fig. 1. Reactor Building Bypass Route due to MSGTR [8].

The assumptions regarding the availability of systems are as follows:

- Main & Auxiliary Feed Water System (MFWS & AFWS), Emergency Water Supply (EWS) System, Moderator Cooling System (MCS), Shutdown Cooling System (SCS), End Shield Cooling System (ESCS), and Emergency Core Cooling System (ECCS) including Loop Isolation (LI) are assumed to be not available after reactor trip during the transient.
- Main steam safety valves (MSSVs) are assumed to become stuck open once the valves are open.
- Local Air Coolers (LACs) and Containment Filtered Venting System (CFVS) are assumed to be not available right after the accident.
- All Passive Autocatalytic Recombiners (PARs) are assumed to be available and the Dousing System (DS) and Crash Cooldown (CC) are assumed to work normally.
- Containment isolation is automatically initiated on a high containment pressure signal (3.45 kPa(g)).
- Analysis credits reactor building airlock seal failure which occurs at 262 kPa(g) with a break area of 0.027871 m^2.

To confirm the effect of DF_{wet_SG}, it is assumed that the operator can manually supply feedwater to the broken SG using a portable pump and fire hoses after 4 hours from the time of the accident and the external injection to the secondary side is performed at a flow rate of 5.5 kg/s per SG as mitigation actions.

3.2 Results and Discussion

A comparative analysis has been performed with and without the improved fission product DFs for the steam generator. Table 1 indicates the comparison of the results for the release fraction of each nuclide element. As shown in Figs. 2, 3, and 4, the release of fission products into the environment was significantly reduced.

Table 1: Release Fraction of Each Nuclide Element.

Nuclide	Release Fraction		
	Without DF	With $DF_{Tube\ x\ Dry}$	With $DF_{Tube\ x\ Dry\ x\ Wet}$
Xe	6.98E-01	6.98E-01	5.77E-01
Cs	8.02E-02	4.29E-02	5.76E-03
Ba	7.86E-03	3.93E-03	1.30E-04
I	6.19E-02	3.23E-02	4.95E-03
Te	5.49E-02	2.82E-02	4.97E-03
Ru	2.94E-02	1.47E-02	1.18E-03
Mo	2.94E-02	1.41E-02	1.14E-03
Ce	4.36E-04	3.51E-04	3.10E-06
La	8.91E-05	4.46E-05	1.14E-06
U	5.85E-09	5.40E-09	0.0

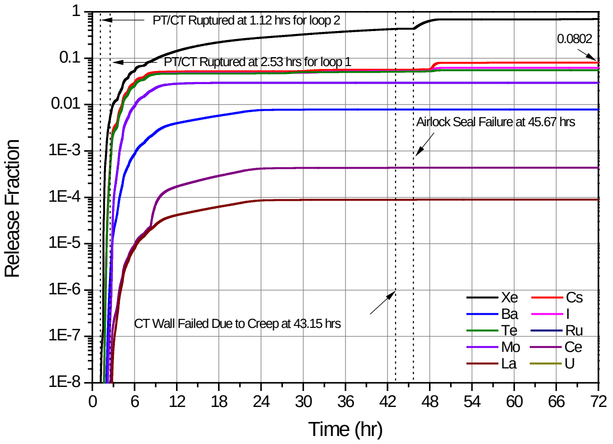

Fig. 2. Release Fraction of Nuclide Element for Dry SG Condition without Steam Generator DFs (Base Case) during MSGTR.

In the case of Cesium which is the representative volatile fission product, it was reduced by about 46.5% from 0.0802 to 0.0429 as shown in Fig. 2 and Fig. 3 because of the deposition effect in the structures; bundle of tubes, and around the break.

In the mitigated case by re-fill of the ruptured SG as shown in Fig. 4, the release fraction of Cs was significantly reduced relative to the case without steam generator DFs by about 92.8% from 0.0802 to 5.76E-03 due to added the pool scrubbing effect. Besides, it was confirmed that mitigation action such as the external injection to the SG secondary side prevented the calandria tank and airlock seal failures.

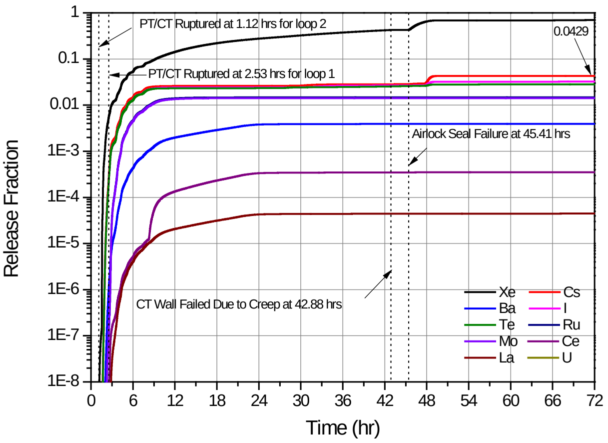

Fig. 3. Release Fraction of Nuclide Element for Dry SG Condition with Steam Generator DFs (DF_{tube} x DF_{dry_SG}) during MSGTR.

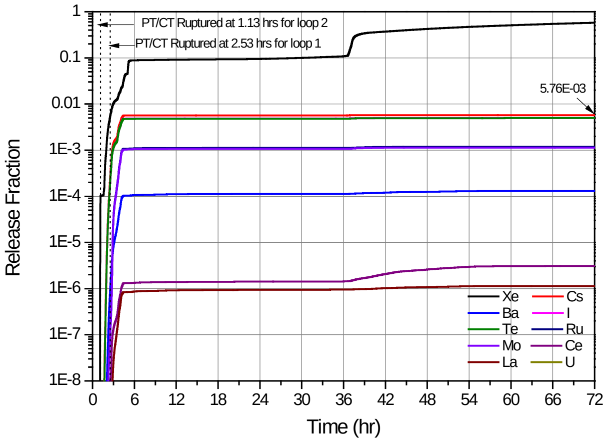

Fig. 4. Release Fraction of Nuclide Element for Wet SG Condition with Steam Generator DFs (DF_{tube} x DF_{dry_SG} x $DF_{wet\ \_SG}$) during MSGTR.

4. Conclusions

The parameters of the MAAP-ISAAC 4.03 severe accident analysis code relevant to steam generator decontamination factor improved and their effects were evaluated based on the currently-available best-practice state of knowledge. As a representative accident, the multiple steam generator tube rupture (MSGTR) in the

Wolsong plant was selected because fission products directly bypass reactor building through main steam safety valves.

As a result of the analysis, it was confirmed that applying the steam generator DFs significantly reduced the release fraction of each nuclide element. Therefore, it may be necessary to improve the parameters relevant to steam generator decontamination factor.

The present analysis result that reflects the improved fission product DFs can provide the valuable insights into the Level 2&3 PSA or severe accident management guidance (SAMG) which uses the result of the severe accident analysis.

ACKNOWLEDGMENTS

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