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# Predictability Assessment of SPACE using an ATLAS test 'Prolonged SBO with SGTR'

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## 1. Introduction

Korea has developed the system transient analysis code of SPACE (Safety and Performance Analysis Code for NPP) [1] and the code was permitted to be used for the safety analyses for postulated accidents belonged to DBE(Design basis events). Recently the ability of SPACE code must be broadened to handle a more severe accidents as a regulation in Korea after the Fukushima nuclear reactor accident has place it's emphasize on the accidents belonged to DEC (Design extension condition).

In the above light KAERI (Korea atomic energy research institute) has carried out a test for 'Prolonged station blackout (SBO) with multiple tube rupture' [2] and the test was used for the validation of SPACE code. The SBO can be developed to a total loss of the heat sink leading to core uncover, core damage, and ultimately, a core melt-down under high pressure without a proper operator action. During the long transient of the SBO, a SGTR (steam generator tube rupture) accident can occur when a steam generator tubes are exposed to a superheated steam flow.

## 2. Calculation Results

In this section some of the techniques used to simulate the ATLAS [3] test are described.

### *2.1 Nodalization*

As shown in Figure 1, the downcomer of pressure vessel is azimuthally divided into 6 channels to model the asymmetry of temperature and flow in the region. Bottom node of the downcomer is connected with the lower plenum node by the cross-flow junction that represents the six holes on divide plate between downcomer and lower plenum. The core region is modeled by the two sub-regions of heater rods and guide tubes. Upper plenum is connected with two hot legs which liaise between pressure vessel and steam generators. The U-tubes inside of steam generators thermally connect the primary side with the secondary side and transfer the heat of core to the secondary side. 169 U-tubes are modeled into the single tube with heat transfer area corresponding to the same number of tubes.

The pressure valve component of SPACE code was used to model the POSRV (pilot operated safety relief valve) which prevent the system over-pressurization and is installed at the pressure top head. The main steam safety valves are consisted of 3 different valves which are operated at the different pressure set points. First stage MSSV of which the open/close pressures are 7.7/8.1 MPa was operated at this test. The MSSVs of other stages were not operated at this test.

The SGTR line connects the SG inlet plenum (primary side) to the middle of SG riser (secondary side). The number of hypothetically ruptured tubes is 5 and the tube diameter is 1.756 mm.

The heat loss to the environmental atmosphere should be reflected at the simulation of this test because of its effect on the other phenomena. The sensitivity study for heat loss should be performed due to the unknown heat loss. The atmosphere is modeled by the large volume and boundary condition filled with the non-condensable gas of 1 bar and 300 K. and this volume is connected with the heat structure component at the systems boundaries.

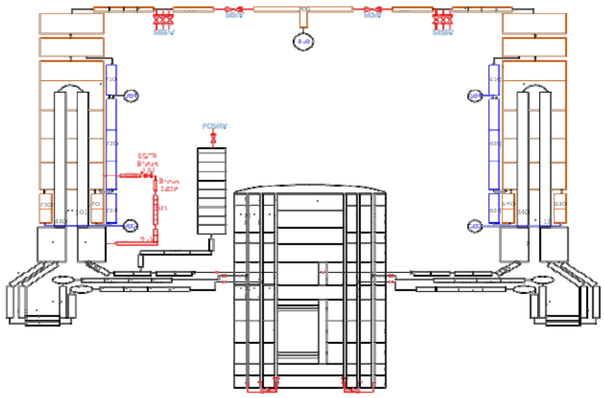

Figure 1. SPACE Nodalization for ATLAS facility

### *2.2 Steady-state calculation*

Table 1 compares the SPACE calculation results with the test data for the steady state. The primary coolant was heated by two locations of core and pressurizer to compensate the unusual depressurization in the pressurizer. The total power given in primary coolant was 1.653 MW while the heat removed by two steam generator was 1.606 MW in the calculation and 1.5 MW in the test. The difference between the given power and the removed heat is the heat loss to atmosphere. The heat loss in the test is slightly large compared to it in the calculation. The exact modeling for the coolant boundary heat structures is difficult because of the information absence of insulation materials. The geometry difference in steam lines from both steam generators also caused the asymmetric results.

| **Parameter** | **Value** | |
|---|---|---|
| | **Test** | **SPACE** |
| *Primary System* | | |
| Power (Core, PRZ), MW | 1.639, 0.014 | 1.639, 0.014 |
| Pressurizer pressure, MPa | 15.47 | 15.51 |
| Core I/O temperature, ℃ | 290.7/326.3 | 290.5/326.5 |
| Cold leg flow rate, kg/s | 2.0 | 1.92~1.95 |
| *Secondary System* | | |
| SG heat (SG1, SG2), MW | 0.75/0.75 | 0.800/0.806 |
| Steam flow rate, kg/s | 0.387/0.423 | 0.437/0.442 |
| Feedwater flow rate, kg/s | 0.420/0.419 | 0.438/0.442 |
| Feedwater temperature, ℃ | 232.1/232.6 | 234.3/235.3 |
| Steam pressure, MPa | 7.83/7.83 | 7.91/7.91 |
| Steam temperature, ℃ | 292.9/292.4 | 294.1/294.1 |
| Secondary side level, m | 5.0/5.0 | 5.0/5.0 |

*2.3 Transient simulation (Base case)*

Base case means that the heat transfer multiplication factor of single phase vapor at the heat structure model of coolant boundary is 1.0. Figure 2 shows that the primary flow is decreased according to the decay heat reduction, but the natural circulation flow corresponding to the decay heat is formed after 500.0 seconds. The wide range level of SG reached the bottom of riser at 4,000.0 seconds due to the release of steam through MSSV (Figure 6). The calculation results agree well with the test data by this time, but, the natural circulation flow is rapidly decreased after the dry-out. The flow was maintained ~1,000.0 seconds more in the test than in the calculation.

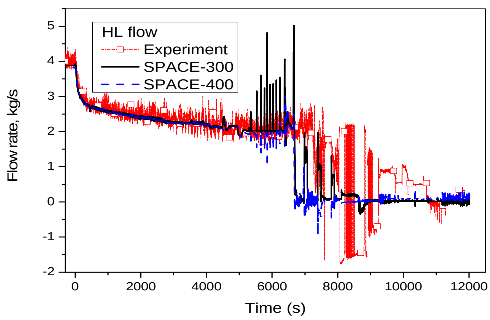


Figure 2. Flow of hot legs

After the SG dry-out the POSRV iterates the open and close at set pressures to prevent the system over pressurization. The first open of POSRV was started at 6,156.0 seconds in the test while 5,530.0 seconds in the calculation. The time that the level of pressure vessel reached set point of SGTR 2.477 m was 8,172 seconds in the calculation while 9,247 seconds in the test (Figure 7). The SPACE code generally predicts early the sequences of the test, which is due to the inaccurate modeling of heat loss to atmosphere.

Fig. 3 shows the SG pressure behaviors, which decrease after the steam generator dry-out due to the MSSV leak. The pressure again increases at the SG-1 because of inflow through the ruptured tube while at the SG-2 because of auxiliary feed-water. The SGTR and the supply of auxiliary feed-water cause the primary pressure decrease.

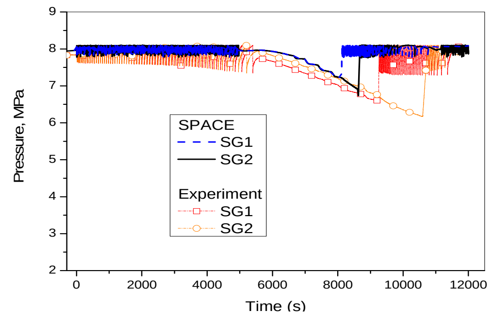


Figure 3. SG pressures

The integration of flow through POSRV of pressurizer which was represented in Fig. 4 was 655.35 kg in the calculation, 605 kg in the test. The cumulating behavior was very similar to the test data except the starting time. The level of pressure vessel is reduced by the discharge through POSRV. This caused the temperature peak of heater rod in Fig. 5. However, the core level was shortly recovered by the core flow increase due to flow path change from the pressurizer to the steam generator with SGTR. The continued break flow through SGTR line reduces the core level and finally the heater rod temperature continues to increase.

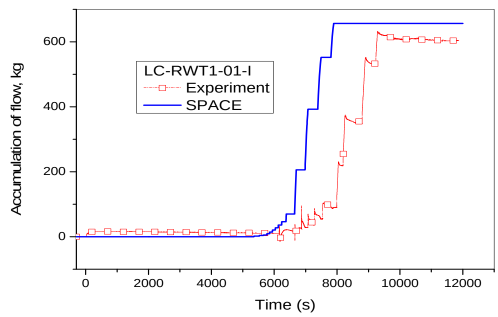


Figure 4. Accumulation of POSRV flow

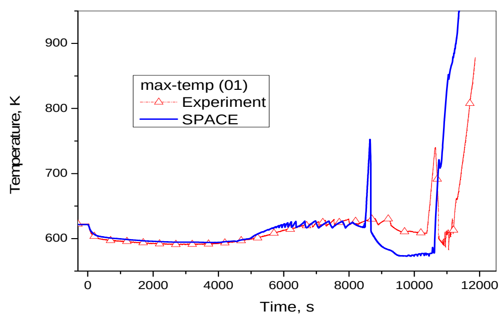


Figure 5. Maximum temperature of heater rod

*2.4 Sensitivity calculation*

In the base case calculation, it was grasped that the heat loss to atmosphere was under predicted by the

SPACE code. The heat loss is increased by the factor of 4.85 for the heat transfer coefficient of single phase vapor at the boundary heat structure. Fig. 6 shows the comparison of calculation results with test data for the SG levels. The decided difference between calculations is shown from about 2,000 seconds. The SG dry-out was more delayed in the sensitivity calculation than in the base case, however, the supply of auxiliary feed water was much more close to the test data.

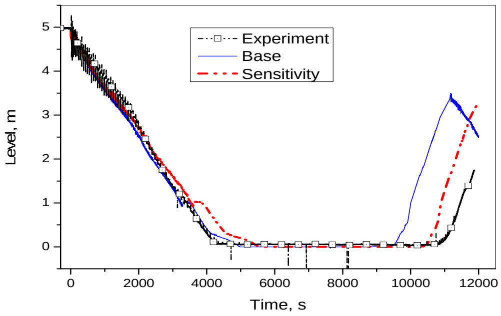


Figure 6. Comparison of SG Level

Table 2. The comparison of event sequence

| Test Sequence | Time, sec | | |
|---|---|---|---|
| | **Test** | Base | Sens. |
| SBO Occurrence | 0.0 | 0.0 | 0.0 |
| Trip signal for Rx. shutdown | 0.0 | 0.0 | 0.0 |
| RCP/MFIS/MSIS trip | 0.0 | 0.0 | 0.0 |
| Decay power start (8%) | 12.0 | 12.0 | 12.0 |
| MSSV first opening | 13.0 | 13.0 | 13.0 |
| SG dryout | 4685.0 | 4785 | 4940 |
| POSRV first opening | 6156.0 | 5530 | 5933 |
| SGTR on SG-1 | 9247.0 | 8172 | 9255 |
| Core heat-up start | 10379.0 | 8571 | 9885 |
| Supply of active AFW to SG-2 | 10886.0 | 8693 | 9997 |

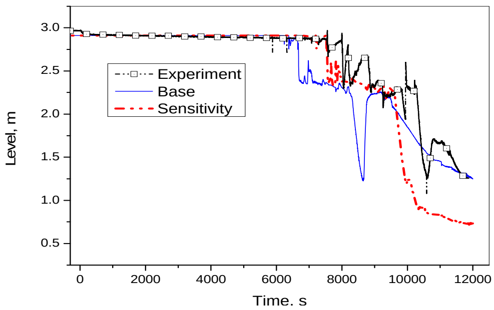


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Figure 7. Comparison of core Level

he prediction for core level was greatly improved in the sensitivity calculation and the start of temperature increase of heater rod was fast only 494 seconds while 1,800 seconds in the base calculation. The heater rod rapidly start to be heated by the release of primary coolant to the secondary riser due to the SGTR and the core level is shortly recovered after the supply of auxiliary feed water, however, again reduced because of the very large SGTR flow. The difference for the time of auxiliary feedwater supply is 889 seconds in the sensitivity calculation, 2193 seconds in the base case calculation. All results are greatly improved in the sensitivity calculation.

## 3. Conclusions

The ATLAS test 'Prolonged SBO with SGTR' was simulated for the evaluation of the SPACE code applicability to the DEC accidents. The base case calculation for the transient test represented the very fast event sequences compared with those in the test because of a smaller external heat loss. Thus sensitivity calculation was conducted using adjustment factor of 4.8 for the heat transfer coefficient of noncondensable gas phase which was one of the parameters of the external heat loss. The results show the good agreement with the test data. Conclusively it can be investigated how much the external heat loss, which can be a heat loss barometer when the other test was simulated. Also the result shows that there is no problem in the SPACE application for a plant station blackout.

## REFERENCES

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