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Ex-vessel LOCA to Port interspace for the PD-2 phase design of HCCR TBS

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) Nuclear Fusion Technology Development Division has been involved in design of HCCR (Helium Cooled Ceramic Breeder) TBS (Tritium Blanket System) for the ITER project [1]. Conceptual design of the system was successfully reviewed and upcoming preliminary design readiness workshop in year 2020 is the next key milestone of the TBM program. In terms of design progress, HCCR TBS is PD-2 phase this year and sensitivity study on the key design parameters such as isolation valve closing time and crack size. In this paper, compilation results for the ex-vessel LOCA to port interspace have been discussed and important characteristics of safety functions have been pointed out in the summary.

2. The accident and nodalization

Ex-vessel LOCA is initiated by the rupture on an HCS loop in port interspace (PI), causing helium coolant leakage. Schematic diagram of the accident and nodalization are given in the Figure 1.

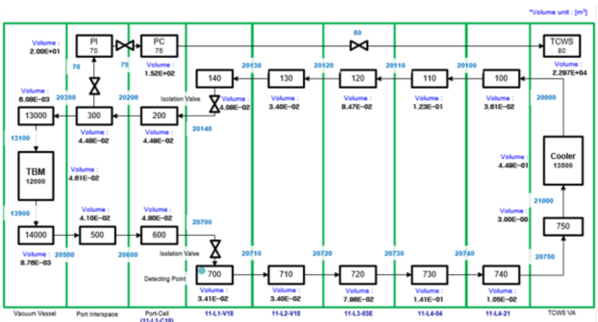


Figure. 1 Nodalization of the Ex-vessel LOCA

Double ended break of the coolant pipe is assumed and the damage size is established to be 0.00852m^2 (very large). Moreover, to assume extra circumstances such like smaller crack cases, 10 times smaller than break size of very large will be established as large case, 100 times smaller as small case, 1000 times smaller as very small case. In this accident analysis, when pressure of inter loop is detected below 4MPa, isolation valve activates and cases will be assorted by time taken to completely close valve. Initial closing time is established as 1 second while further analysis will be done by 3,5,and 10 seconds. All test cases are given in the Table 1.

Isolation valve is located between Port Cell (FB200 : cold side of HCS, FB600 : hot side of HCS) and 11-L1-C18 (FB140 : cold side, FB700 : hot side), inside the loop. Relief valve is located between Port Cell (FB75) and TCWS-VA (FB80), outside the loop.

HCS coolant pressure of loop is 8MPa while PI, PC, and TCWS-VA, which locates outside the loop, pressure is 0.101MPa (atmospheric pressure).

Coolant temperature of HCS loop are 300℃ at the left side of TBM and cooler while 450℃ at the bottom side. Since exact measure of inter TBM and cooler temperature are difficult, average of 350℃ are estimated and analyzed in this research. 25℃ is applied to room temperature of loop.

Test Index.	Room connection	Crack size	detection	Isolation time (second)
PIvs0401	PI	very small	4 MPa	1
PIvs0403	PI	very small	4 MPa	3
PIvs0405	PI	very small	4 MPa	5
PIvs0410	PI	very small	4 MPa	10
PIsm0401	PI	small	4 MPa	1
PIsm0403	PI	small	4 MPa	3
PIsm0405	PI	small	4 MPa	5
PIsm0410	PI	small	4 MPa	10
PIlg0401	PI	large	4 MPa	1
PIlg0403	PI	large	4 MPa	3
PIlg0405	PI	large	4 MPa	5
PIlg0410	PI	large	4 MPa	10
PIvl0401	PI	very large	4 MPa	1
PIvl0403	PI	very large	4 MPa	3
PIvl0405	PI	very large	4 MPa	5
PIvl0410	PI	very large	4 MPa	10

Table. 1 Validation Cases

3. Results

First case to cover in PI is PIvl0401~PIvl0410, which condition is as follows. External room connection to PI, crack size very large (0.00852m²), detecting pressure 4MPa, and isolation closing time 1, 3, 5 and 10 seconds.

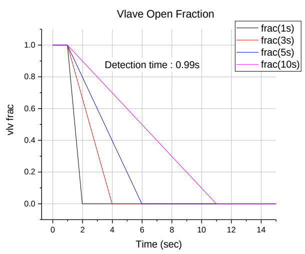


Figure. 2 Validation Cases

Figure 3 shows time per helium flow rate to external PI from inside the loop and pressure trend of PI where rupture happens. In Figure 3 (left), the point at which flow rate converges to 0 after 3 seconds is similar. Figure 3 (right) shows almost no change in pressure after 3 seconds, which can be inferred that large amounts of helium have already been released and saturated to outside after 3 seconds when the valve was not completely isolated. As well as equilibrium timing of external PI's pressure and non-isolated zone's pressure in internal loop can be found.

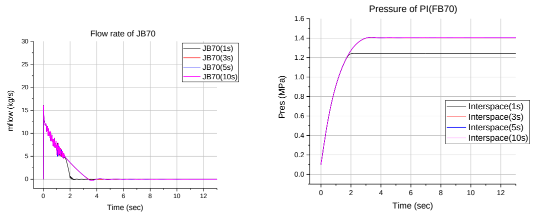


Figure. 3 Mass flow of leak path (JB70) and Pressure of Port Interspace (FB70)

Figure 4 show time per change of mass flow rate at JB20140, JB20700 where isolation valve is located. Figure 4-17 shows time per pressure change in FB600 and FB700 at right (isolated zone) and left (non-isolated zone) side of the isolation valve.

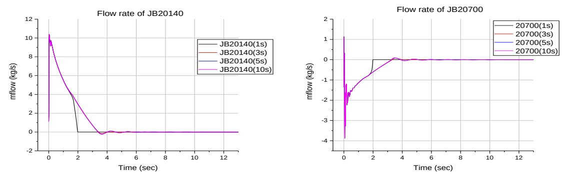


Figure. 4 Pressure of PI and FB700

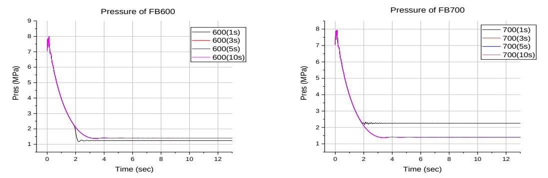


Figure. 5 Pressure of PI and FB700

According to Figure 5, 3s, 5s and 10s cases have slight oscillation at 3 seconds. This is considered to be due to a slight counter flow of helium leakage since pressure equilibrium has been already achieved through incomplete isolated isolation valve situations. However, when the isolation valve completely isolates, mass flow rate converges to 0 and no more flow happens. Additional difference between 3s, 5s and 10s can't be found in Figure 5 which means internal and external pressure accomplished pressure equilibrium before complete close of isolation valve.

In Figure 5, pressure convergent value of Port Interspace and FB700 by increasing closing time is shown. Pressure of PI surges as closing time gets longer while FB700 shows pressure decreasing tendency. Pressure convergent point of other closing time cases, such as 12 or 15 seconds, can be definitely estimated since above both graphs show linearity.

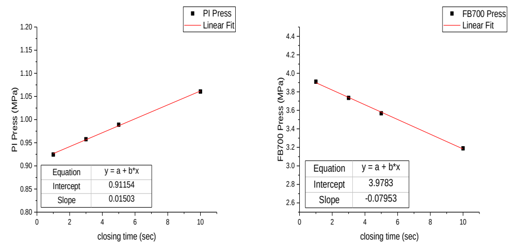


Figure. 6 Pressure of PI and FB700

In Figure 5, pressure convergent value is shown by the increase of crack size. Even though pressure increasing or decreasing as crack size surges is known, some pressure of specific crack size seems to be rather hard to estimate.

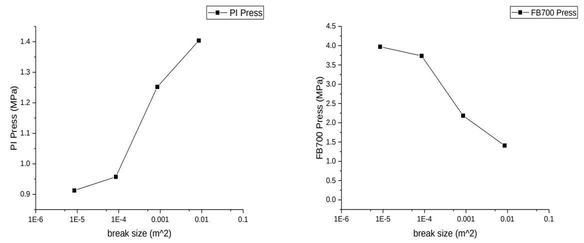
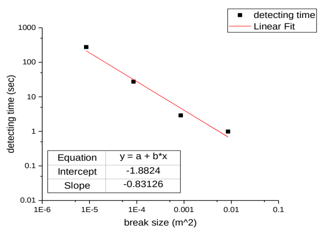


Figure. 7 Pressure of PI and FB700 by increasing crack size



Crack size(m²)	Detecting time(s)
0.00852	0.99
0.000852	2.90
0.0000852	27.61
0.00000852	275.61

Figure. 8 Detecting time by increasing crack size

The change of detecting time by increase in crack size is shown in Figure8. Except very large crack size case, detecting time nearly decrease 10 times as crack size increase 10 times, while linear fit alike above picture is shown when it is changed to log scale.

4. Further Works

Ex-vessel LOCA to Port interspace for the PD-2 phase design of HCCR TBS has been performed and results are reasonably acceptable. Based on the results, isolation valve, which takes longer than 3 seconds, has no meaning for this accident.

5. Acknowledgement

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6. References

[1] D.W. Lee, et. al., "Current Status and R&D Plan on ITER TBMs of Korea," Journal of Korean Physical Society, 49 S340-S344 (2006).