ASSESSMENT OF PASSIVE CONTAINMENT ISOLATION FEATURE OF ADVANCED NATURAL CIRCULATION REACTOR

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ABSTRACT

Recent inclination in nuclear industry is towards providing as many passive features as possible. These passive features enhance safety substantially. The Passive Containment Isolation System (PCIS) system is one of the important passive features in the conceptual design of advanced natural circulation reactor. This system isolates the primary containment from the atmosphere in the event of Loss of Coolant Accident (LOCA), thus reducing the possible escape of radioactivity outside containment. The pressure transient in the V1 and V2 zones of the primary containment following the postulated accident provides the driving force to the passive system and ensures the isolation of containment from atmosphere by establishing a liquid seal in the U-shaped ventilation duct. The time required to form the effective liquid seal as well as leakage to atmosphere are some important aspect during the postulated accident.

The PCIS performance can be challenged by its various system parameters i.e. water inventory in the passive containment isolation tank, filter resistance at end of ventilation duct and pressure transient in the containment following various sizes of inlet header break. The present work aim to look in these aspects and evaluate the performance of the system under various important parameters combination.

The paper elaborate modelling of PCIS in two different system code i.e. RELAP5 and CATHARE and results of intercode comparison for time required to form the effective liquid seal as well as leakage to atmosphere along with levels in the u-shape ventilation duct during large break LOCA. Then paper further addresses the PCIS behaviour under different system parameter combination during LOCA transient for sustained liquid seal formation.

INTRODUCTION

The existing reactors mostly use active safety systems. The reliability of the active systems cannot be increased above a threshold and further promptness of operator action, to prevent probable fuel failure and fission product release, is debatable. In view of this, advanced reactors are designed with adequate passive and inherent safety features to provide protection for any event that may lead to a serious accident [1]. The function of confinement of any radioactivity released in the containment is also made more reliable by adopting robust, redundant, and passive design features. The Passive Containment Isolation System (PCIS) is one of the important passive features to limit the escape of radioactivity release to atmosphere in advanced natural circulation reactor. This advance reactor employs a double containment system i.e. primary containment & secondary containment. The primary containment is further zoned as V1 (high enthalpy) and V2 (low enthalpy) regions. Under normal operating conditions, the V1 and V2 regions are connected only through vent shafts, with downstream ends of vent shafts submerged in GDWP that also acts as a suppression pool. Blow Out Panels (BOP) are also provided in the reactor building to limit the pressure on the containment building structure under accidental conditions by directly connecting V1 and V2 volumes. The PCIS consists of a water tank i.e. Passive Containment Isolation Tank (PCIT) with water level maintained at a preset value as shown in Fig.1. The space above the water level is kept in communication with volume V1 through a vent shaft. From the bottom of the tank, where an outlet is provided in the form a vertical pipe, the system is in communication with volume V2 via the connection with the ventilation duct at an appropriate elevation. It may be noted that the volume V2 is ventilated to atmosphere through a ‘U’ duct, from which a branched connection to PCIT is taken. So, under any operating conditions, the top space of the PCIT would experience the pressure of V1 volume while the pipe connected to the outlet of the tank would experience the pressure of V2 volume. Hence, at any instant, hydrostatic differential pressure head between the two volumes would govern the water level in the outlet pipe. In the event of volume V1 pressurizing to certain pressure beyond the V2 pressure, the water in pipe at the outlet of PCIT rises to spill into the ventilation duct.

Under postulated LOCA conditions, V1 and V2 regions undergo a pressure transient. The V1 pressure rises more rapidly than V2 pressure. This leads to spilling of water from the tank into ventilation duct. However after opening of BOPs, the pressures tend to equalize as V1 and V2 are brought in direct communication. The high-pressure condition in the V2 demands for the quick isolation of containment system from atmosphere to prevent any eventual release to the atmosphere. The isolation of containment is achieved by establishing a liquid U- seal in the ventilation duct [2].

In this paper, PCIS model is developed for system code RELAP5 [3] and further with CATHARE [4]. The transient analysis post 200% LOCA in the containment is analysed using both the model. The results obtained from these two codes are compared for time required to form the effective liquid seal as well as leakage to atmosphere along with levels in the u-shape ventilation duct during large break LOCA. Further as passive safety systems rely on natural forces, such as gravity or natural convection to perform their accident prevention and mitigation functions once actuated and started. Because the magnitude of the natural forces, which drive the operation of passive systems, is relatively small, counter-forces (e.g., friction) can be of comparable magnitude and cannot be ignored [5]. To address this issue, a parametric study with different system parameter combination during LOCA transient has been done to assess the PCIS behaviour for sustained liquid seal formation.

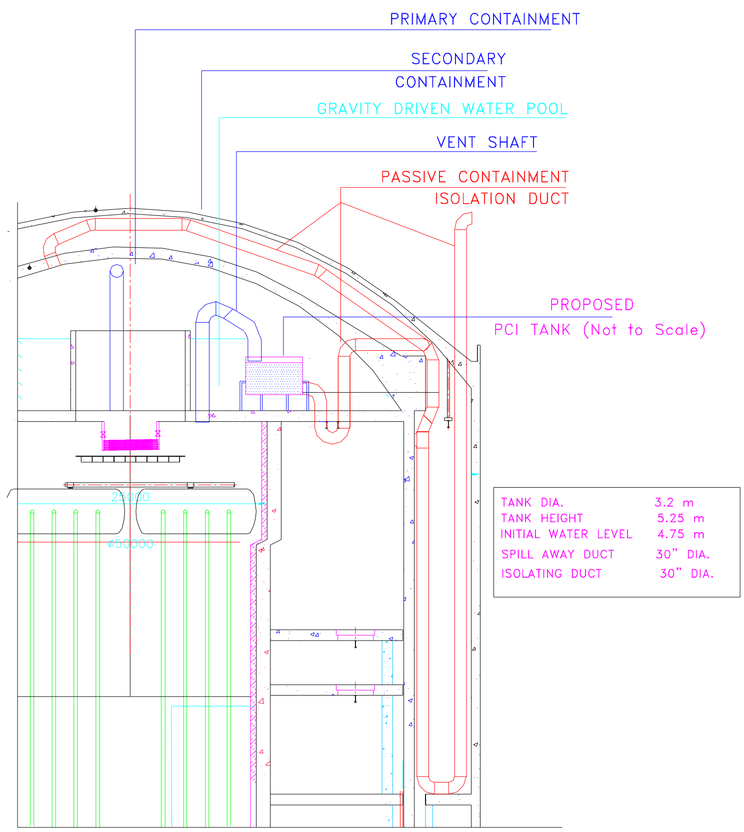

Fig.1: Layout of Passive Containment Isolation System

PASSIVE CONTAINMENT ISOLATION SYSTEM MODELLING

The PCIS system is modelled in best estimate code RELAP5 as well as CATHARE as shown in Fig 2 and Fig 3. The RELAP5 modelling is being described in detail in following paragraph. The CATHARE modelling is kept similar for comparative studies.

The PCIT is modelled with component 203 having 3 control volumes. The first volume i.e. 203-01 is initialized with air and bottom two volumes are initialized with water. The exit pipe is modelled with the help of component 204 having 3 control volumes in it. The ventilation duct is modelled with the component 206. There are first 40 control volumes simulating the vertical downward part of the duct, 206-41 control volume simulates the horizontal portion of the duct and 206-42 to 206-81 i.e. remaining 40 volumes simulates the upward portion of the ventilation duct. RELAP5 specific Time Dependant Volume (TDV) is used to represent the conditions in V1, V2 and atmosphere. The TDV 207, TDV 201 and TDV 205 simulate the atmosphere, V1 condition and V2 conditions respectively. The single volume 202 simulates the vent shaft connecting the V1 volume with the PCIT. The component 208 models the part of ventilation duct connecting the V2 volume. Appropriate junction connection are used to link the above described control volume at various places. The details of the various control volume and junctions are presented in the table 1.

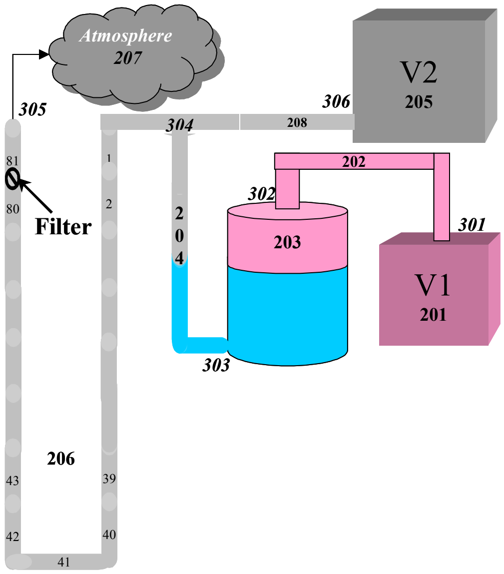

Fig. 2: PCIS model in RELAP5

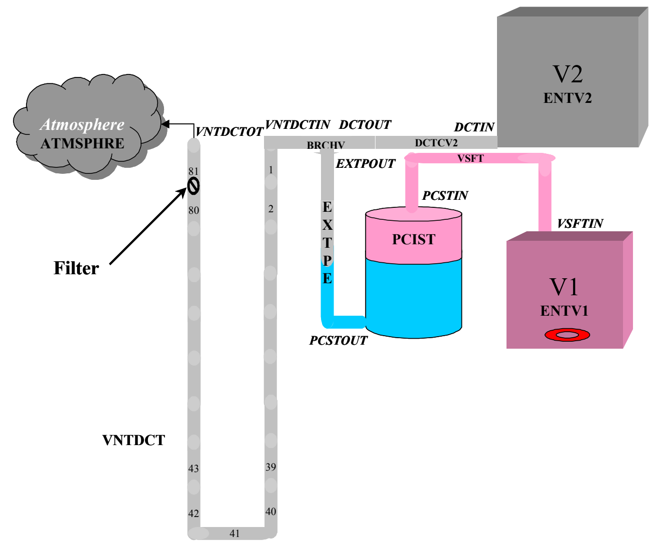

Fig. 3: PCIS model in CATHARE

Table 1: Description of the Hydrodynamic Components and Junctions

RELAP5	CATHARE	Description of the volume
Vol. No./Junction no.	Name of axial/Volume /junction	
201	ENTV1	Volume V1
202	VSFT	Vent shaft connection between V1 and PCIT
203-01, 203-02 and 203-03	PCIST	PCIT volumes
204-01, 204-02 and 204-03	EXTPE	Exit pipes
205	ENTV2	Volume V2
206-01 to 206-81	VNTDCT	Ventilation duct
207	ATMSPHRE	Atmosphere
208-01 and 208-02	DCTCV2	Duct connection from V2
301	VSFTIN	Connection between V1 and vent shaft
302	PCSTIN	Connection between vent shaft and PCIT
303	PCSTOUT	Connection between PCIT and exit pipe
304	BRCHV	Branch to connect exit pipe, V2 duct

		and ventilation duct
305	VNTDCTOT	Connection between duct and atmosphere
306	DCTIN	Connection between V2 duct and V2

The model is initialized with atmospheric conditions i.e. normal operating condition and run for the 100 s to get the stabilized conditions in the circuit.

Further from separate analysis [6], containment V1 and V2 pressure transients are obtained following 200% inlet header break. These pressure transients are applied to present PCIS model in V1 and V2 volumes as boundary condition to run the transient calculations for the PCIS in case of inlet header break. The objective is to observe the sustained liquid seal formation. This seal formation in the ventilation duct is challenged by several parameters i.e. water inventory in the PCIT, filter resistance at end of ventilation duct and pressure transient in the containment following various sizes of inlet header break. The first analysis has been performed with all the system at design conditions. In this case, the filter resistance has been simulated using restricted exit area.

TEST MATRIX

A intercode comparison is done for post 200% IH break LOCA with model developed in RELAP5 and CATHARE for water seal formation in the ventilation duct. Further, a sensitivity study is performed to cover the various initial tank inventories at the time of accident and various filter loss coefficient effect on effective seal formation. In the present analysis, 200% inlet header break pressure transient for V1 and V2 has been utilized to evaluate the performance of PCIS. The test matrix is given in table 2.

Table 2: Test matrix for parametric study

Case ID	IH Break size	Tank inventory	Filter resistance	
			Restricted area	Filter loss coefficient
1	200%	100%	Yes	-
2	200%	80%	Yes	-
3	200%	60%	Yes	-
4	200%	40%	Yes	-
5	200%	20%	Yes	-
6	200%	100%	-	K = 130
7	200%	100%	-	K = 65
8	200%	100%	-	K = 260
9	200%	20%	-	K = 130
10	200%	20%	-	K = 65
11	200%	20%	-	K = 260

RESULTS AND DISCUSSION

Intercode Comparison Results

The comparison results of PCIS performance for seal formation and other important parameters during 200% IH break have been presented using RELAP5 and CATHARE code. These results bring out the comparison of the integrated discharge from the tank (fig 4), leak to the atmosphere (fig 5) for both the codes.

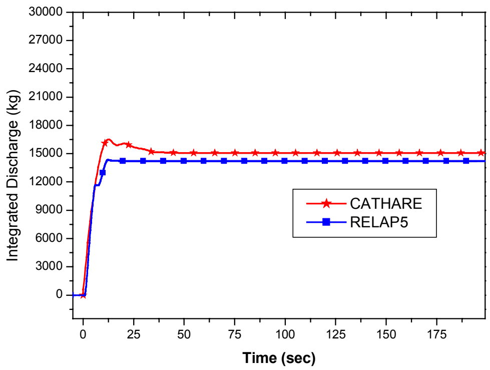

Fig. 4: Water Inventory Discharge from PCIT in to ventilation duct

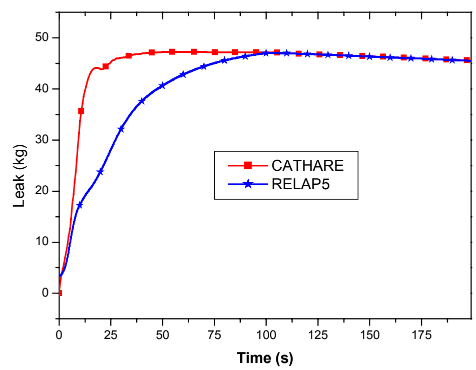

Fig. 5: Integrated leak from Ventilation duct to atmosphere

Fig 6 presents the water level variation in the both side of the U-duct with time against the containment V2 pressure transient for CATHARE and RELAP5. After spilling the water in containment side of u-duct, the water level rise in atmosphere side of U-duct is faster in CATHARE compare to RELAP5.

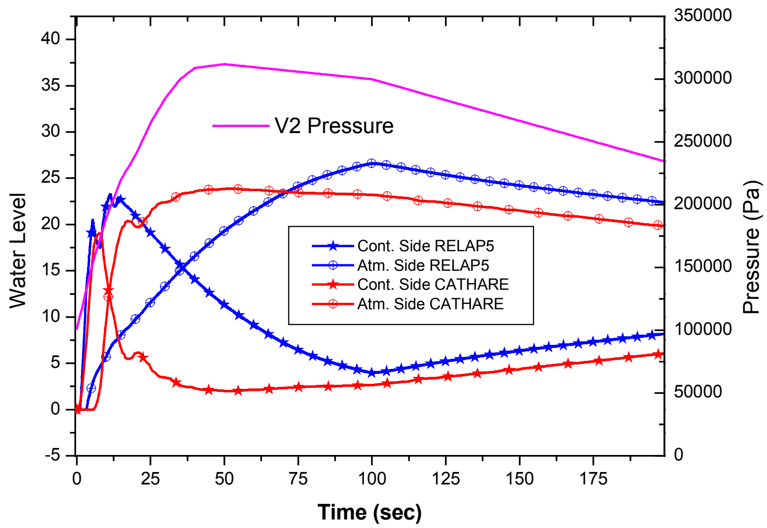

Fig. 6: Water level in ventilation duct & V2 volume pressure

Results of Sensitivity/parametric Studies

The tank water inventory has important role in the liquid seal formation in U tube ventilation duct. With higher pressure in the V1 area than V2 area during LOCA transient in the containment, this pressure difference cause the water in the tank to spill into ventilation duct leading to seal formation. It is clear from the Fig. 7 that till 40% tank inventory, the spilled water is sufficient to form the effective seal in the ventilation duct. The seal formation can be observed for the 100% water inventory case in Fig. 8. The sustained liquid level found in the both leg of U-tube is indicator of water seal formation. The variation in the level in both the legs of ventilation duct during course of the transient can be attributed to change in the V2 pressure over transient duration. The level behaviour during 80% to 40% cases is similar in nature.

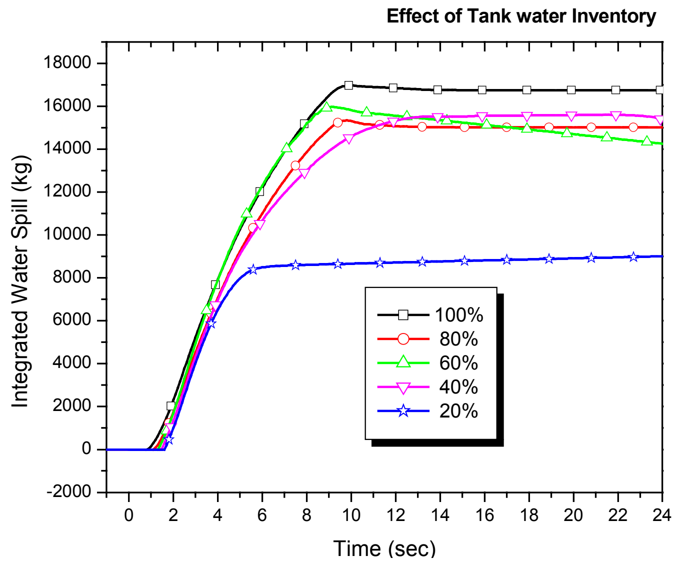

Fig. 7: Integrated water discharge from PCIT in to ventilation duct

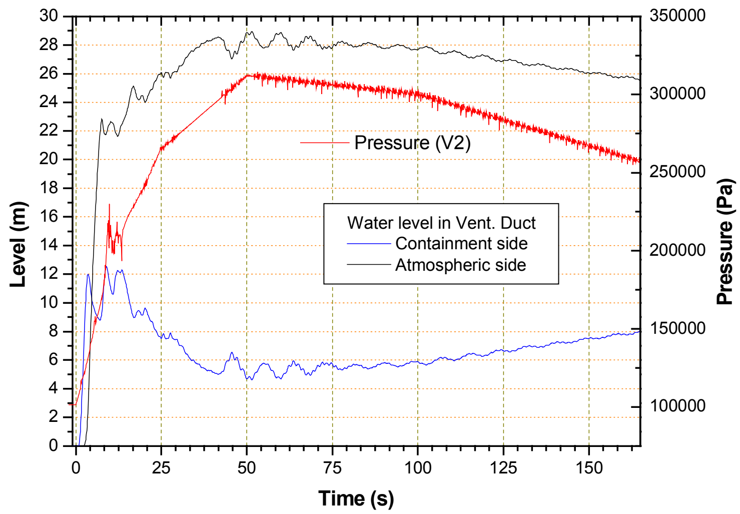

Fig. 8: Water level in ventilation duct & V2 volume pressure (100% inventory)

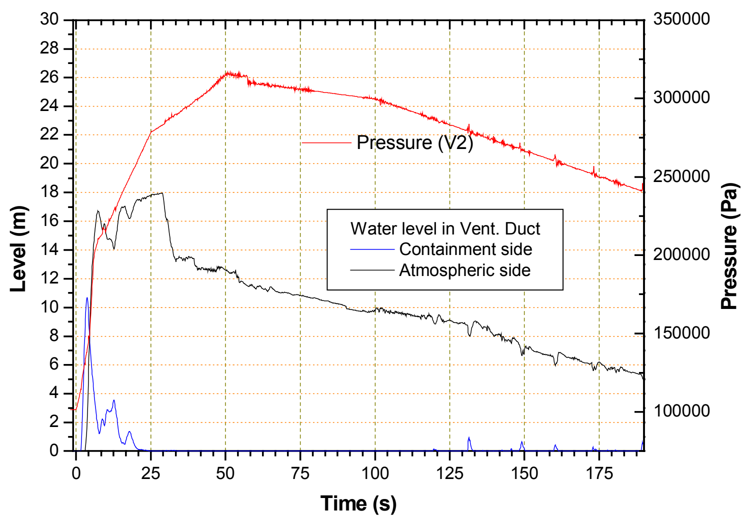

Fig. 9: Water level in ventilation duct & V2 volume pressure (20% inventory)

For the case of 20% tank inventory, the amount of water is not sufficient to hold the water in the duct for seal formation as shown in Fig. 9. The falling level in the atmospheric side leg of the ventilation duct is clearly indicating that water is getting flushed out of the duct over transient and no seal formation is observed.

The leak behaviour during the transient also shows that water seal formation for cases i.e. 105, 80%, 60% and 40% as shown in Fig. 10. It can be seen that leak took place during initial 20 s. The water spilled in the duct pushes the initial air column present in the duct. After the water column is established in both side of ventilation duct, there is no further leak once effective seal formation is observed. This behaviour is not present in the 20% tank inventory case. The case of 20% water inventory, the large amount of water is lost throughout the transient is clear indicator of no seal formation.

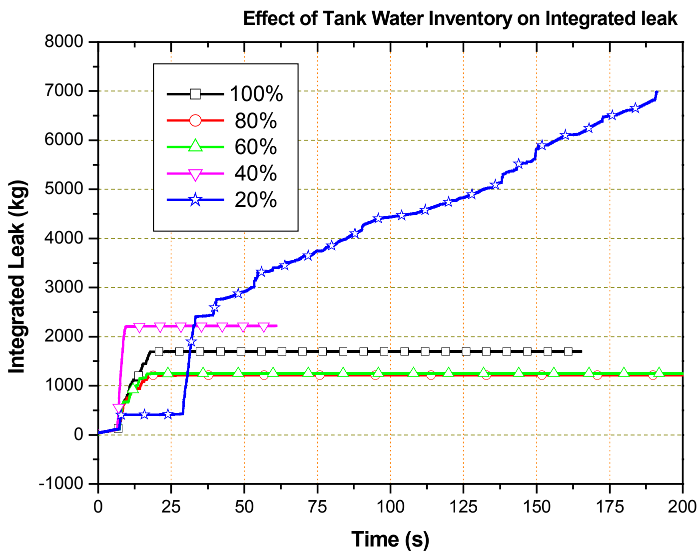

Fig. 10: Integrated leak from ventilation duct in to atmosphere

So, it can be established that except for water inventory less than 20%, the effective seal formation in ventilation duct in a passive manner is observed. The integrated leak is found to be large before seal formation in all the cases. Few more case studies have been performed for 100% tank inventory with varying filter loss coefficient. The results for integrated leak are shown in the Fig. 11. It can be seen that with appropriate loss coefficient, the leak to atmosphere has been reduced quite satisfactorily during the transient duration. This leak is very less compare to earlier cases as shown in Fig. 10.

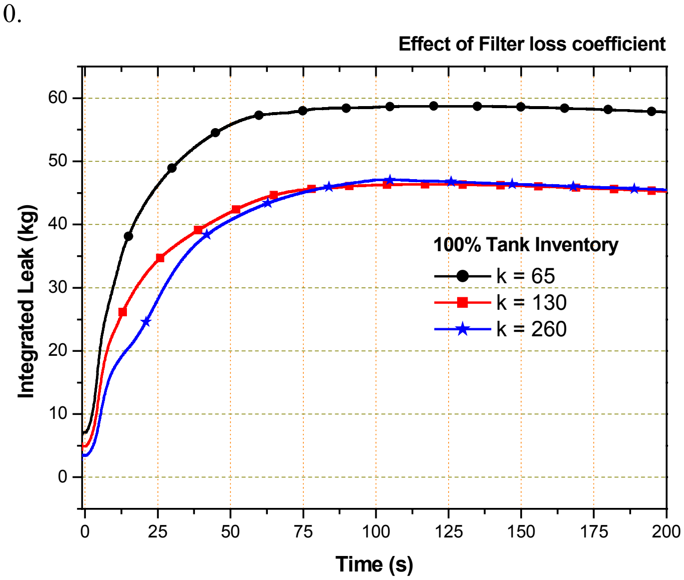

Fig. 11: Integrated leak from ventilation duct (with variation of Filter loss coefficient)

CONCLUSION

The performance of the PCIS is found to be satisfactory for different tank inventory except for 20% tank inventory case. The pressure drop in filter modelled by restricted area is giving higher integrated leak before seal formation. However, modelling with suitable loss coefficient, leak to atmosphere is reduced significantly. The sensitivity studies with different loss coefficient shows that loss coefficient above normal value has no advantage in reducing the leak further. Further, the PCIS has to be tested for the different lower break sizes with varying tank inventory to check the adequacy of design for water seal formation. A coupled calculation of MHT, containment and PCIS system and further reliability study is desired.

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