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Reliability assessment of passive containment isolation system using APSRA methodology

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ABSTRACT

In this paper, a methodology known as APSRA (Assessment of Passive System ReliAbility) has been employed for evaluation of the reliability of passive systems. The methodology has been applied to the passive containment isolation system (PCIS) of the Indian advanced heavy water reactor (AHWR). In the APSRA methodology, the passive system reliability evaluation is based on the failure probability of the system to carryout the desired function. The methodology first determines the operational characteristics of the system and the failure conditions by assigning a predetermined failure criterion. The failure surface is predicted using a best estimate code considering deviations of the operating parameters from their nominal states, which affect the PCIS performance. APSRA proposes to compare the code predictions with the test data to generate the uncertainties on the failure parameter prediction, which is later considered in the code for accurate prediction of failure surface of the system. Once the failure surface of the system is predicted, the cause of failure is examined through root diagnosis, which occurs mainly due to failure of mechanical components. The failure probability of these components is evaluated through a classical PSA treatment using the generic data. The reliability of the PCIS is evaluated from the probability of availability of the components for the success of the passive containment isolation system.

1. Introduction

Advanced nuclear reactor designs incorporate several passive systems in addition to active ones, not only to enhance the operational safety of the reactors but also to eliminate the possibility of hypothetical severe accidents and their consequences. Unlike the active systems, the passive systems do not need external stimuli such as energy to operate; besides, despite of redundancy, active systems are vulnerable to failure. On these premises, a passive scheme for containment isolation was conceived and investigated (Ghosh et al., 1993). Passive systems are simpler in design and avoid human intervention in their operation, which enhances their reliability as compared to the active ones. However, their actuation and performance is always closely correlated with the system geometry and the operating parameters. Normally, the driving head of passive systems is small, which can be easily influenced even with a small change in operating condition. This is particularly true for the passive systems classified as "Type B" by IAEA (1991), i.e. those with moving working fluid; for example a passive containment isolation system (PCIS). PCIS is a passive system employed to isolate the containment from external atmosphere under accident conditions. The passive isolation system isolates containment by establishing a liquid seal in the ventilation duct following a loss of coolant accident (LOCA). The system derives its driving head from the differential pressure of the high-enthalpy and low-enthalpy zones of primary containment. The passive containment isolation system may fail to meet its design objective under certain degraded process conditions.

In the absence of plant data or sufficient experimental data from simulated facilities, the designers have to depend on existing 'best estimate codes' such as RELAP5 or TRACE or CATHARE, etc. for analyzing the performance of these systems. However, it is difficult to model accurately the characteristics of these passive systems using the above codes. In view of the above, assessment of reliability of passive safety systems is a crucial issue to be resolved for their extensive use in future nuclear power plants. Several physical parameters affect the performance of a passive safety system, and their values at the time of operation are a priori unknown. The functions of many passive systems are based on thermal-hydraulic principles, which have been until recently considered as not subject to any kind of failure. Hence, significant efforts are required to quantify the reliability of such systems.

In late 1990s, a methodology known as REPAS has been developed cooperatively by ENEA (D'Auria and Galassi, 2000), the University of Pisa, the Polytechnic of Milan and the University of

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Rome, that was later incorporated in the EU RMPS project. This methodology is based on the evaluation of a failure probability of a system to carry out the desired function from the epistemic uncertainties of those physical and geometric parameters which can cause a failure of the system. The RMPS approach considers a probability density function (pdf) to treat variations of the critical parameters considered in the predictions of codes. To apply the methodology, one needs to have the pdf values of these parameters. However, there are no guidelines on the pdf treatment of these parameters, which ultimately define the functional failure. Moreover, these parameters are not really independent ones to have deviation on their own. Rather, deviations of them from their nominal conditions occur due to failure/malfunctioning of other components. Hence, assigning arbitrary probability distributions for their deviations appear illogical. The REPAS method recognizes the model uncertainties of the codes. The uncertainties in code predictions are evaluated by calculations of sensitivities to input parameters and by code-to-code comparisons. The methodology has been applied to an experimental natural circulation test loop by Jafari et al. (2003). Zio et al. (2003) applied this methodology for reliability evaluation of an Isolation Condenser System. Marques et al. (2005) proposed the integration of reliability of passive system obtained by REPAS in accident analysis. A similar approach is followed by Pagani et al. (2005) to evaluate the failure probability of the gas cooled fast reactor (GFR) natural circulation system. However, they used simpler conservative codes to evaluate the failure of a system. In addition to this, the above methodologies are yet to be applied to real systems of innovative reactors and the true reliability number for each of the passive system needs to be worked out. On the otherhand, preliminary calculations at MIT have suggested that the reliability of passive natural circulation systems can prove to be lower as compared to an active system.

In this paper, a different methodology known as APSRA (Assessment of Passive System ReliAbility) (Nayak et al., 2008) is applied for evaluation of reliability of passive containment isolation system (PCIS). In this approach, the failure surface is generated by considering the deviation of all those critical parameters, which influence the system performance. Then, the causes of deviation of these parameters are found through root diagnosis. The deviation of such physical parameters is attributed to the failure of mechanical components such as valves, control systems, etc. Then, the probability of failure of a system is evaluated from the failure probability of these mechanical components through classical PSA (probabilistic safety analysis) treatment. Moreover, to reduce the uncertainty in code predictions, it is intended to use in-house experimental data from integral facilities as well as separate effect tests. The methodology has been applied to the PCIS of the Indian AHWR (Sinha and Kakodkar, 2006).

1.1. System description: AHWR containment system

AHWR employs a double containment system that consists of a primary containment enveloped by secondary containment as shown in Fig. 1. Primary containment comprises of a high-enthalpy zone (V1 – enveloping mainly the reactor core and main heat transport system) and a low enthalpy zone (V2 – enveloping rest of the systems including suppression pool). Under normal operating conditions, V2 region is in communication with the external atmosphere through the ventilation system that consists of ventilation duct, suction blower and filters whereas V1 region remains isolated from the V2 region through the suppression pool (connected by partially submerged vent shaft) and blowout panels. The V1 region is maintained at negative pressure with respect to V2 zone by continuous purging. Under accident conditions like small LOCA, involving release of high-enthalpy fluid, pressure in the V1 region rises. As the pressure raises enough to overcome the hydrostatic head in the partially submerged vent pipes, vent clearing takes place resulting in the release of air–steam mixture into the suppression pool .i.e. Gravity Driven water Pool (GDWP). Steam gets condensed in the pool water and non-condensable accumulates in the V2 region resulting in pressure rise with little delay. However, during accidents like large break LOCA, the pressure differential of V1 and V2 rises very fast such that blowout panel opens and the direct communication between V1 and V2 gets established. The schematic of the flow path between V1 and V2 is shown in Fig. 2. During the events leading to pressurization of V2 region, the containment needs to be isolated from external atmosphere by curtailing the flow from V2 to the atmosphere.

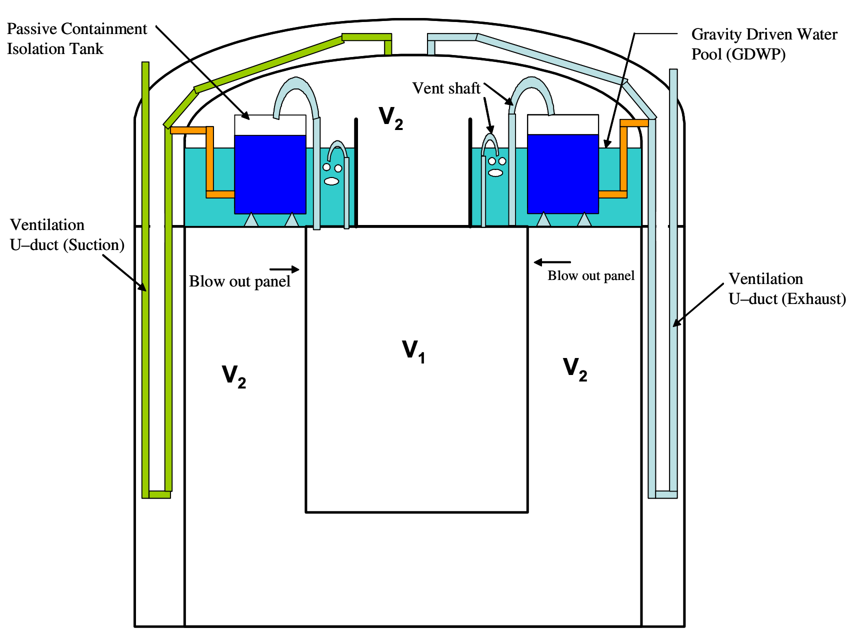

Fig. 1. Schematic of passive containment isolation system (PCIS) of AHWR.

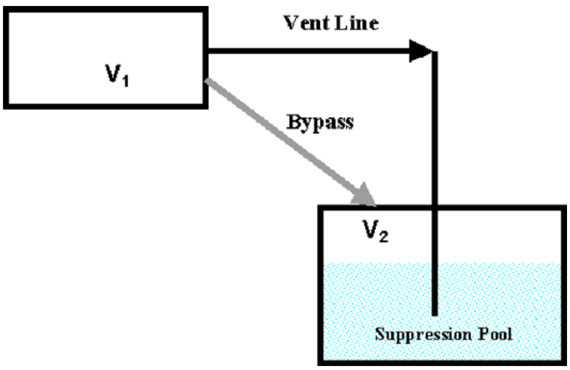

Fig. 2. Schematic of flow path between V1 and V2 zone.

1.2. System description: passive containment isolation system (PCIS)

A passive system is designed to isolate the containment by establishing a liquid (water) seal in the U-shaped ventilation duct, for Indian advanced heavy water reactor (Satish Kumar et al., 2003). The passive containment isolation system of AHWR as shown in Fig. 1 consists of tanks located in GDWP with an exit pipe connected to ventilation duct which is in communication to V2 region. The vent shaft from V1 region is connected to the top of the tank. Thus water in the tank would experience the V1 pressure and in the exit pipe V2 pressure. Under accident conditions the V1 pressure would rise more and faster than V2 and thus water from the tank would be displaced to spill into the U-shape ventilation duct and hence establishing a liquid seal that isolates the containment from external atmosphere. A separate system each for suction and exhaust duct is considered.

2. The APSRA methodology

In the APSRA methodology, the passive system reliability is evaluated from the evaluation of the failure probability of the system to carryout the desired function. In principle, in a PCIS, the operational mechanism of differential pressure should never fail as long as there is a high pressure region and a low pressure region along with the availability of water. However, even though the driving force is available and system geometry is intact, it may not be able to spill the required inventory in the ventilation duct to establish a liquid seal, if there is any fluctuation or deviation in the operating parameters. Since the applicability of the best estimate codes to passive systems is not well established, hence, APSRA methodology proposes to compare the code predictions with the test data to generate the uncertainties on the failure parameter prediction, which is later considered in the code for the prediction of failure conditions of the system. A detailed discussion of the APSRA methodology is given in the following section.

2.1. The methodology and its application to PCIS

Fig. 3 shows the structure of the methodology for the calculation of the reliability of passive system.

To understand the figure, let us move step-by-step.

Step I: Passive system for which reliability assessment is considered.

In Step I, the passive system for which reliability will be evaluated is considered. Here, the system considered is the PCIS of AHWR.

Step II: Identification of its operational mechanism and failure criteria.

In Step II, the APSRA methodology requires the designer to have a clear understanding of the operational mechanism of the passive system and its failure, i.e. characteristics of the passive system. To judge its failure, the designer has to define its failure criteria. The characteristics of the system can be simulated even with simpler codes which can generate the passive system performance data qualitatively in a relatively short period. In this step, the purpose is just to understand the system operational behavior but not to predict the system behavior accurately. For this the designer has to use the parameters identified in Step II, which can have influence on the performance of the system. Out of them, some must be critical in the sense that a disturbance in these parameters can lead to a significant change in the performance of the system, while others do not. Only a thermal-hydraulic expert can judge this behavior through parametric calculations, and these parameters must be considered for the reliability analysis of the system.

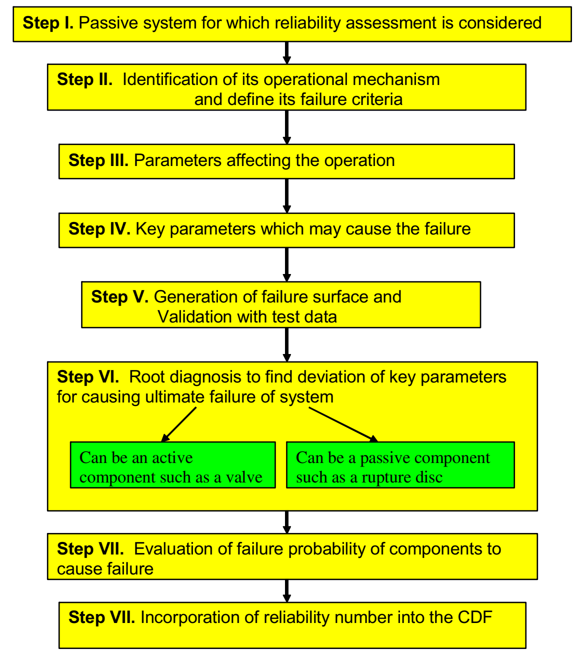

Fig. 3. The APSRA methodology.

For example, a PCIS operates due to differential pressure difference between V1 and V2 regions. A sustained liquid seal is required during the containment pressure transient following a postulated LOCA to prevent any leakage of radioactivity to the external atmosphere. The passive containment isolation is considered to fail if a sustained liquid seal does not form in the ventilation duct. As noted earlier, even though differential pressure is available between V1 and V2, the system may not fulfill the desired objective of the system, that is, a sustained seal formation in the U-shape ventilation duct during LOCA. The system designer may consider the system to fail if this criterion is not met.

Step III: Identification of parameters affecting the operation.

The performance characteristic of the passive system is greatly influenced by some critical parameters. Some of the critical parameters which influence the PCIS are

- Break size in a LOCA;
- Water level in the isolation tank located in GDWP;

Some examples on the influence of the above parameters on the PCIS behavior are given in the next section.

Step IV: Key parameters which may cause the failure.

The studies in Steps III and IV are complimentary to each other, in the sense that while the results of Step III help in understanding the performance characteristics of the system due to variation of the critical parameters, Steps IV generates the results for those values of the critical parameters at which the system may fail to meet any of the criteria given in Step III. For example, the most important factor that could deteriorate the performance of the isolation system is the initial water inventory (or tank water level) in the containment isolation tanks located in GDWP. The effect of the above parameters on the failure of PCIS is discussed below.

- Effect of break size:

In case of LOCA, the high-enthalpy fluid contained in the main heat transport system enters the containment (V1 zone), leading to pressure and temperature rise in the V1 zone. If pressure rise exceeds the submerged head of the vent shaft, steam–air mixtures enters the suppression pool (GDWP), where the steam gets condensed and non-condensables get released, and that leads to pressurization of V2 zone at a relatively slower rate than that of V1 zone. However, if the V1–V2 pressure differential exceeds a certain limit, the blowout panels open to provide a direct communication path between V1 and V2, in turn tending to equalize the V1 and V2 pressures during the course of time. The V1–V2 pressure differential is in fact the driving head for the actuation of the passive containment isolation system. The nature of the pressure transient following a LOCA is a function of the break size. The double ended break of largest pipe (header) in the Main Heat Transport System (MHTS) is referred to as 200%, whereas other double ended breaks are referred to as

$$\text{Break size} = 2 * \frac{\text{Cross sectional area of break pipe}}{\text{Cross sectional area of header}} \quad (1)$$

For higher break sizes both the V1 and V2 pressures rise relatively faster, resulting in the quick spill of water from tank to ventilation duct that enables isolation, however, the quantity of water to be spilled for establishing a liquid seal is higher because of high V2 pressure associated with LOCA of higher break size. This necessitates the assessment of the passive system following LOCAs for a wide range of break sizes.

- Effect of water level:

Another important parameter affecting the performance of PCIS is the amount of water inventory (or water level) in the tank meant for spilling water into the ventilation duct, since the initial amount of water contained in the tank and that spilled should be reasonably more than that required for establishing the liquid seal to ensure the isolation from the atmosphere.

Step V: Generation of failure surface and validation with test data.

Once the key parameters are identified in Step III (deviation of which can cause the failure of the system), the value of these parameters at which the system will fail, are calculated using a best estimate code. Hence there is another requirement for Step V, i.e. the results should be generated using a best estimate code such as RELAP5 in order to reduce the uncertainty in the prediction of the failure conditions. The results of Step IV generated using a simpler code is only useful in directing the inputs for Step V in order to derive the failure conditions rather quickly. As it may be noted that, the applicability of the best estimate codes to passive systems is not well understood. To reduce the uncertainty in the predictions, it is planned to carryout several experiments for the generation of failure data for the passive system under consideration. For simulation of failure parameters for PCIS, an experimental facility ‘passive containment isolation facility’ (PCIF) is being setup. The programme for benchmarking of the failure surface prediction is shown in Fig. 4. This is done in several steps.

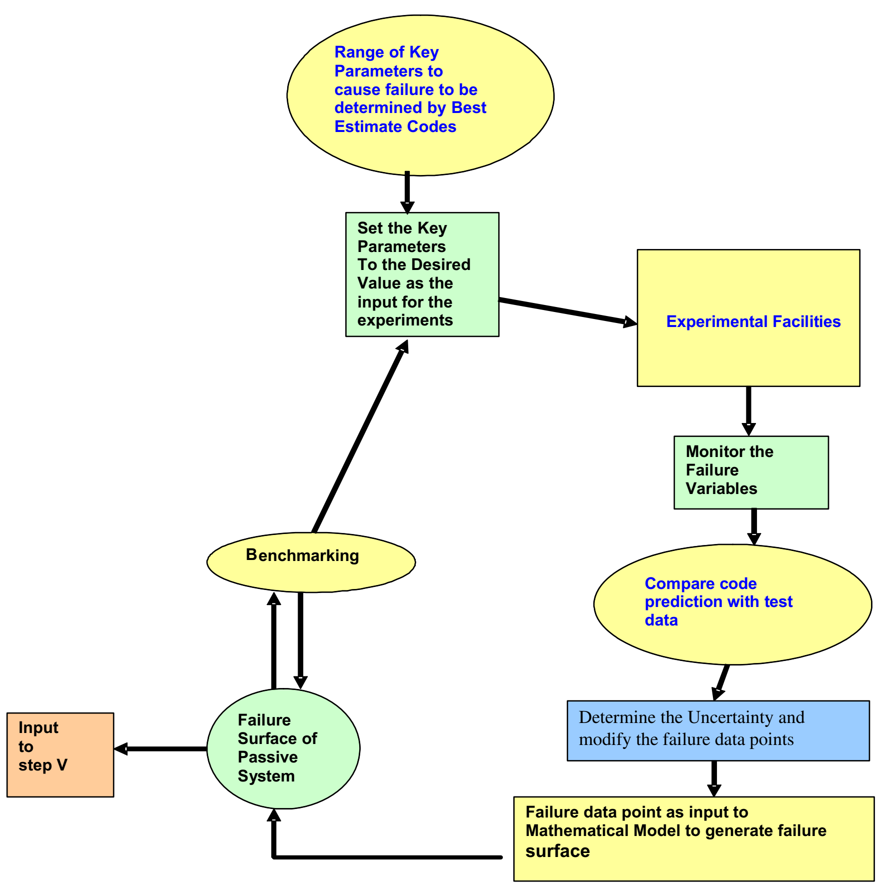

Fig. 4. The programme for benchmarking the failure surface.

(a) In the first step, the range of all key parameters to cause failure is determined by the best estimate code.
(b) Some of these parameters have to be chosen as an input for the experiments for determination of uncertainty in the code prediction for failure points.
(c) Experimental data will be generated in PCIF.
(d) The next step involves comparison of code prediction with test data for the failure points.
(e) Next, the uncertainty will be evaluated from the error distribution between the code prediction and test data.
(f) The failure data points will be recalculated considering the uncertainty in step (e) and the failure surface will be modified accordingly.
(g) The failure surface so generated will serve as input for Step VI in APSRA.
(h) However, for further reduction of uncertainty in the failure surface prediction, some of the failure points will be benchmarked again by experimental simulation.

Here, the performance of PCIS was assessed using RELAP5/Mod 3.2 (Fletcher and Schultz, 1995), however, this prediction would be benchmarked against the experimental data in future, to ascertain the uncertainty in the best estimate prediction. The nodalisation scheme is described in Fig. 5. The following assumptions are made to simulate the system behavior:

- Containment pressure transients are known a priori based on LOCA analysis.
- Containment pressure transient is based on the assumption of active isolation system availability. This leads to a conservative estimate as the V1–V2 pressure differential would be high if the active isolation of containment fails to occur.
- Only air is considered for pressurizing the tank and exit pipe as during the initial part of the LOCA the containment atmosphere would be predominantly air.

2.1.1. Performance under design basis accident conditions

Figs. 6a–f show a typical system performance for the large break LOCA (200% break size .i.e. the largest double ended rupture) with design water level in the tank. Fig. 6a shows the containment pressure transient following 200% break. It can be seen that for large break LOCA, high differential pressure is obtained immediately following LOCA, however, due to opening of blowout panels, the V1 and V2 pressure tend to equalize. It is important to note that, the failure of blowout panels to open fully is not considered for reliability assessment of PCIS. This is due to the fact that partially or fully closed blowout panels would suppress the pressure equalization and rather provide the higher differential pressure between V1 and V2, and hence a larger driving force for containment isolation. Fig 6b shows the water level in the tank and exit pipe following the pressure transient, where the tank level continuously decrease and the exit pipe level rises to the point of spill. Water level obtained in the duct following the pressure transient is shown in the Fig. 6c. It can be seen that there is a formation of differential column that acts as a seal against V2 pressure acting on the containment side leg of the U-duct. Fig. 6d shows the stack exit flow and its contents with regard to gas and liquid. It is found that during the process of spilling and seal formation some mass flows out of stack and most of it is liquid. This is due to high pressure in the V2 region prior to formation of seal and it justifies some excess water inventory and excess spill in the duct to account for the water loss that does not contribute to seal formation. It can be seen from Fig. 6e that once the seal is established there is no leakage from stack exit to atmosphere. Fig. 6f shows the formation of completely liquid seal at the bottom over a period of time. It may be observed that for this case, a substantial fraction of water from the tank is spilled in as early as 10 s following the LOCA (Fig. 6b), which is in fact more than adequate to establish the required seal. Of course, the stable seal formation time as predicted by the code is longer, but the effectiveness of seal formation occurs much earlier (i.e. around 10 s). As depicted in Fig. 6d, prior to stable seal formation, there are a few spikes predicted in the stack exit mass flow rate, however, they correspond mostly to high volumetric liquid fractions. This reveals that the mass of gas associated with stack release is very small. Fig. 6e shows that air leakage forms a very small part of the total leakage which is predominantly water. It also shows that most of the air leak occurs in the first 10 s and in fact it is nearly equal to the mass of air in the ventilation duct that has been swept out by water.

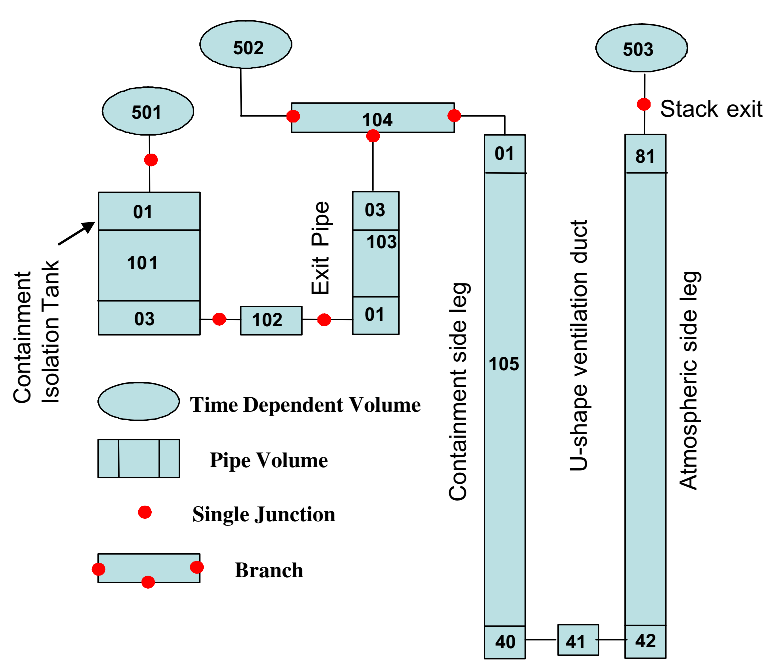

Fig. 5. Nodalisation of PCIS for RELAP5/Mod 3.2.

For a typical small break LOCA (10% break size) the system behavior under normal process conditions is as shown in Figs. 7a–f

For a small break LOCA the nature of pressure transient is significantly different, as shown in Fig. 7a. In this case, the pressure differential obtained is not high as compared to the case of large break LOCA, moreover, pressures do not equalize as blowout panels remain closed due to low pressure differential. Due to low pressure differential, a relatively smaller amount of water is spilled as

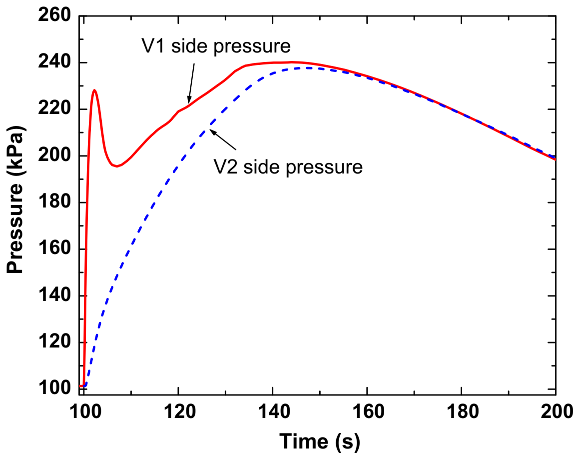

Fig. 6a. Containment pressure transient following 200% break LOCA.

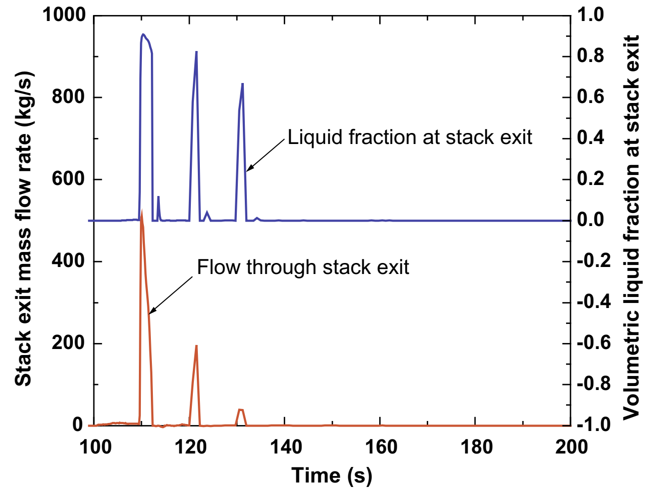

Fig. 6d. Discharge and liquid fraction at the stack exit following 200% break LOCA.

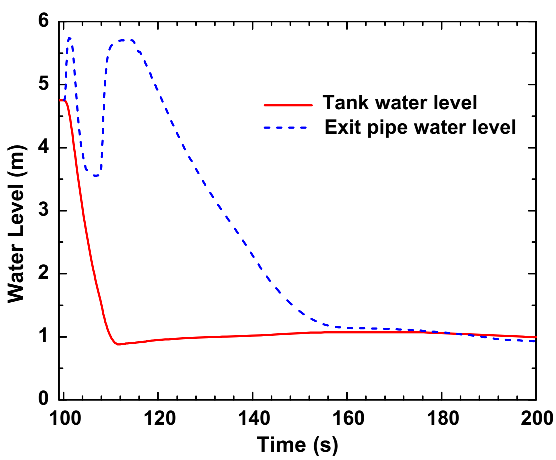

Fig. 6b. Water level in tank and exit pipe following 200% break LOCA.

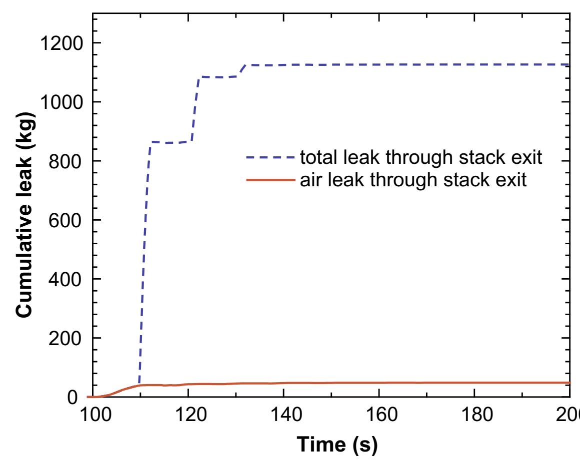

Fig. 6e. Cumulative leakage through stack following 200% break LOCA.

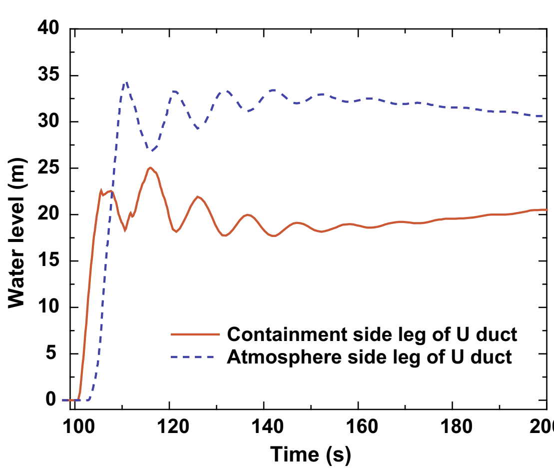

Fig. 6c. Collapsed water level in legs of U-duct following 200% break LOCA.

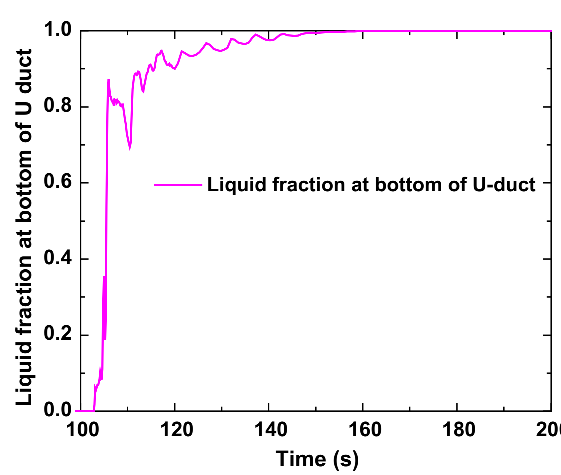

Fig. 6f. Liquid fraction at the bottom of seal following 200% break LOCA.

shown in Fig. 7b. However, it may be noted that due to lower pressure in V2 region, the amount of water required for seal formation is also smaller and a sustained seal gets established as depicted in Figs. 7c and 7e. Fig. 7d shows that during this transient, only some amount of gas leaves the stack which could be mainly attributed to the volume of gas in the U-duct displaced by liquid. The formation of voidless (purely liquid) node in the U-duct is shown in Fig. 7f.

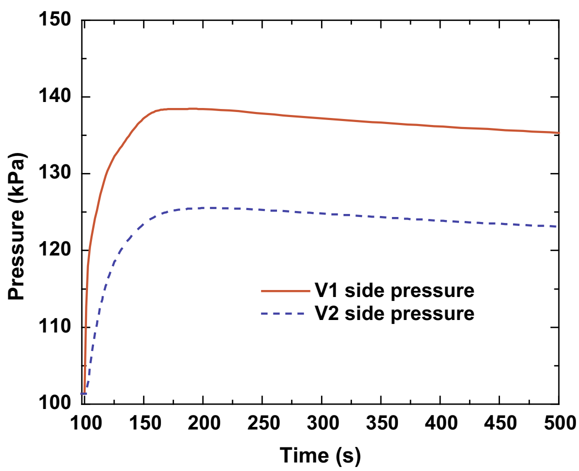

Fig. 7a. Containment pressure transient following 10% break LOCA.

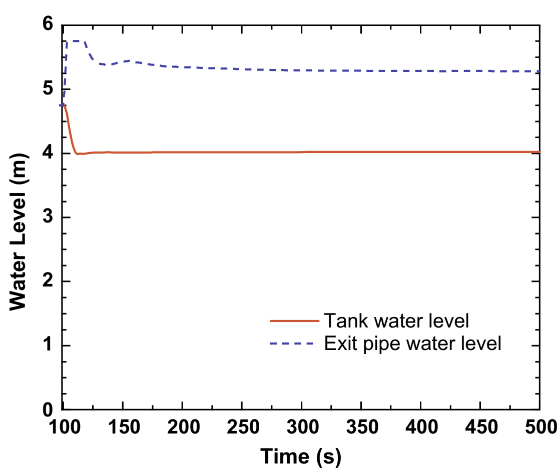

Fig. 7b. Water level in tank and exit pipe following 10% break LOCA.

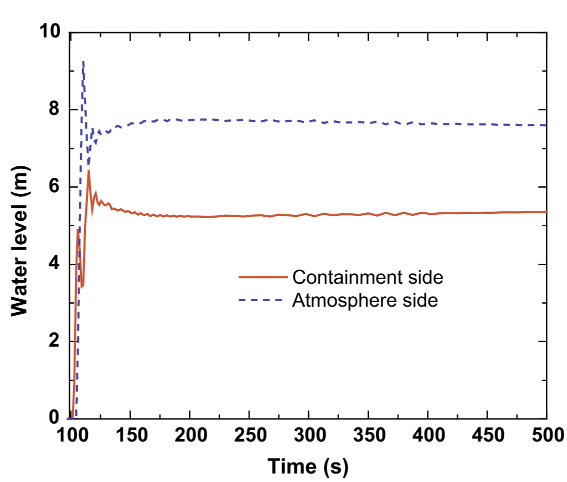

Fig. 7c. Collapsed water level in legs of U-duct following 10% break LOCA.

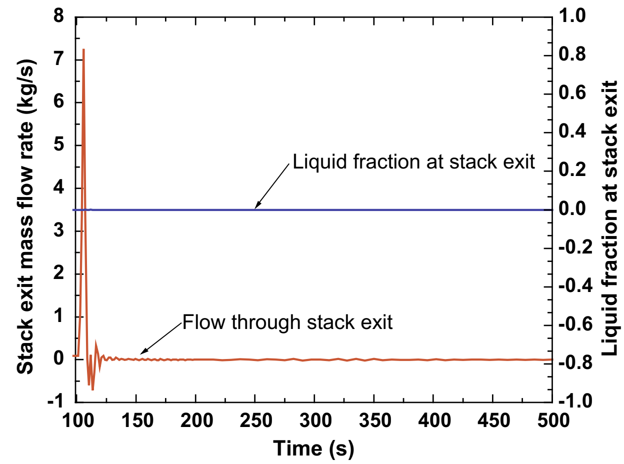

Fig. 7d. Discharge and liquid fraction at the stack exit following 10% break LOCA.

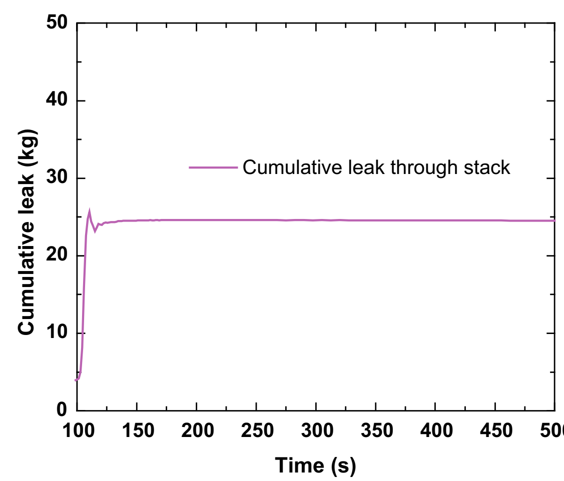

Fig. 7e. Cumulative leakage through stack following 10% break LOCA.

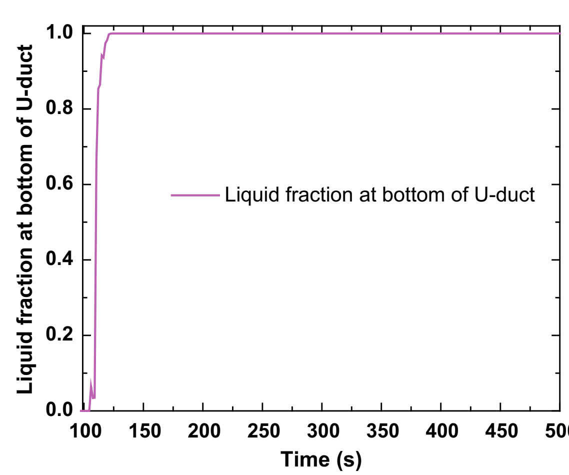

Fig. 7f. Liquid fraction at the bottom of seal following 10% break LOCA.

2.1.2. Performance under degraded conditions

The PCIS is analyzed for degraded condition of process by considering reduced inventory in the tank in steps of 5% till the failure point is obtained. A typical performance under large break LOCA (200% break size) at reduced water level of 30% in the water tank is as shown in Figs. 8a–c. Similarly a typical performance under small break LOCA (10% break size) at reduced water level of 85% in the tank is as shown in Figs. 9a–c. It is observed that under de-

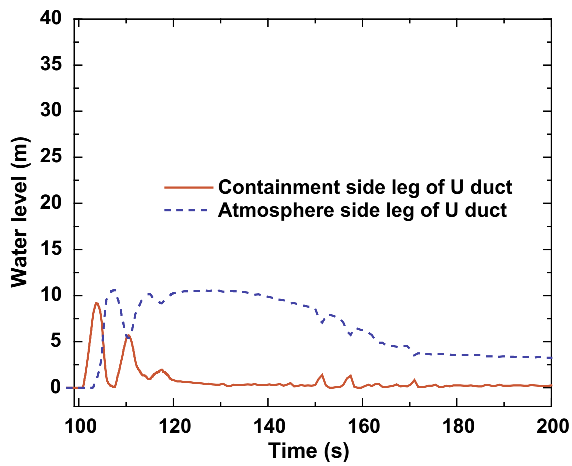

Fig. 8a. Performance of PCIS at 30% water level & 200% break LOCA.

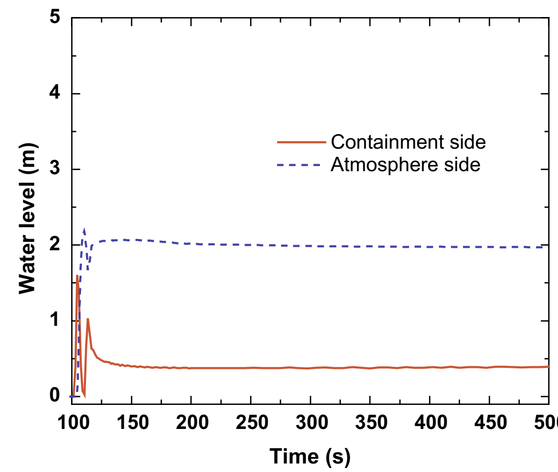

Fig. 9a. Performance of PCIS at 85% water level & 10% break LOCA.

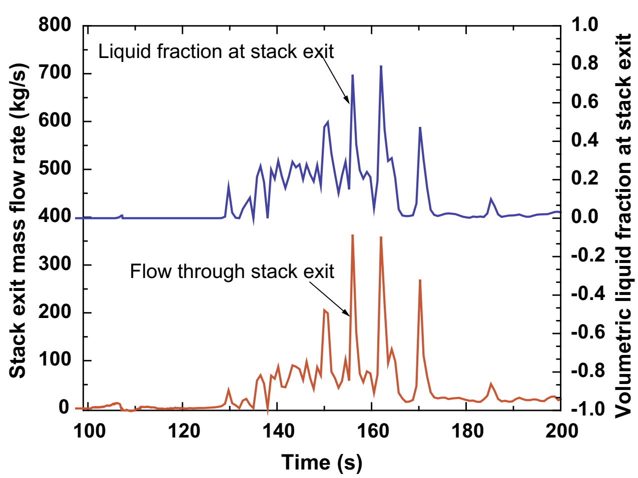

Fig. 8b. Discharge and liquid fraction at stack exit with 30% water level and 200% break LOCA.

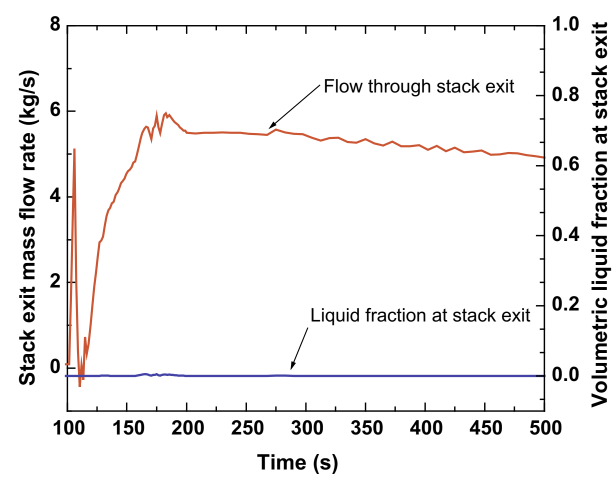

Fig. 9b. Discharge and liquid fraction at stack exit with 85% water level and 10% break LOCA.

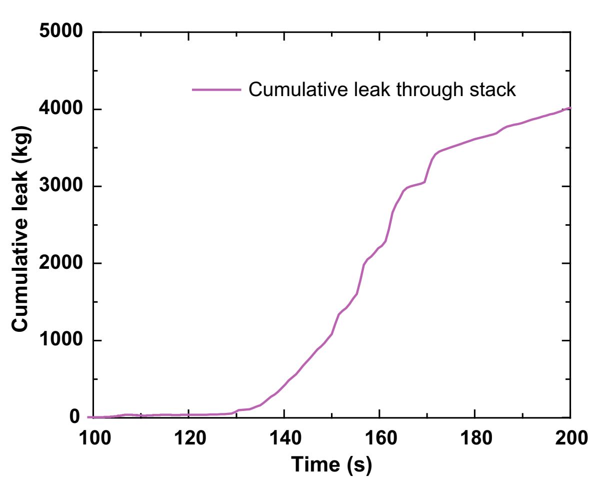

Fig. 8c. Cumulative leakage through stack at 30% water level and 200% break LOCA.

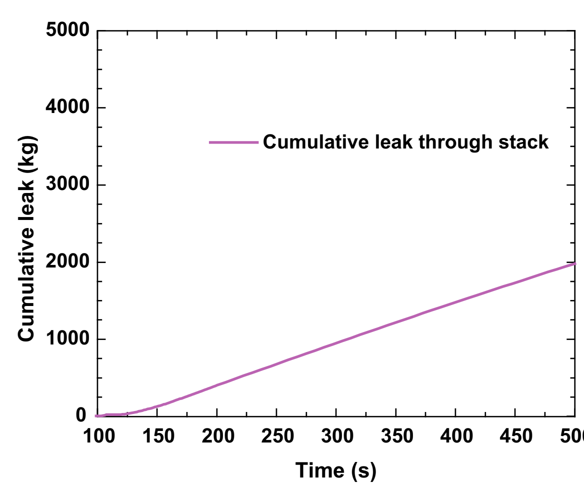

Fig. 9c. Cumulative leakage through stack at 85% water level and 10% break LOCA.

graded conditions corresponding to 30% water inventory in the water tank for 200% break size and 85% water inventory for 10% break size the liquid seal fails to form and there is continuous discharge of gas from containment to the external atmosphere.

2.1.3. Failure region

A failure region with respect to reduced water inventory in the tank is obtained as shown in Fig. 10. It is found that for large break LOCA, the system fails to isolate if the tank water level falls significantly, whereas for small break LOCA, isolation fails to occur even with little reduction in water level. Failures of PCIS for small and large break LOCA under degraded condition of reduced initial water level in the tank may be attributed to the two different modes having their genesis in the nature of containment pressure transients. At large break LOCA conditions, the V1–V2 pressure differential is very high so that water spills into duct even at reduced level whereas under small break LOCA, the V1–V2 pressure differential is not enough to raise the water level in exit pipe and spill into duct. This makes the system more vulnerable to failure during small break LOCA as compared to large break LOCA.

Step VI: Root diagnosis to find deviation of key parameters for causing ultimate failure of system.

After establishing the domain of failure, the next task is to find out the cause of deviation of key parameters which eventually result in the failure of the system. This is done through a root diagnosis method. For example, a reduction in the initial water level in the containment isolation tank can be due to:

- malfunction of make-up system;
- malfunctioning of isolation tank drain valves,

Besides this, a sustained liquid seal may fail to form due to the malfunction of ventilation U-duct drain valves.

A passive system fails to carry out its function not due to the failure of its mechanism, but definitely due to deviation of some of the parameters on which its performance depends. These so called "key parameters" deviate from their nominal values due to failure of either some active components such as a control valve, or an external pump, or electric signal, etc.; or due to failure of some passive components such a passive valve, or a relief valve, etc. For the evaluation of the reliability of the system at normal operational transients, the failure of components such as a pipe leading to LOCA should not be considered, unless one considers the corresponding failure criteria for the LOCA condition.

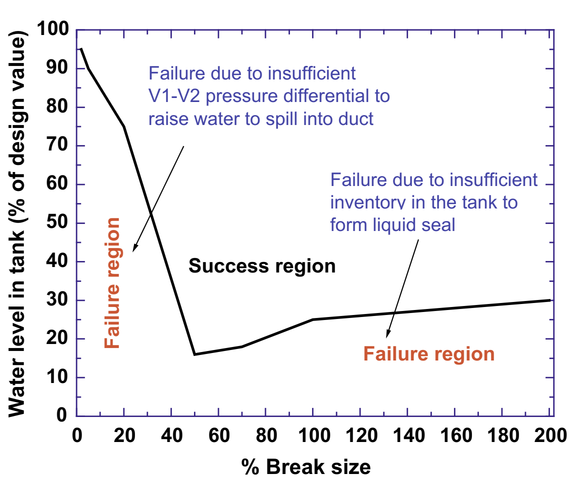

Fig. 10. Failure region for passive containment isolation system of AHWR with water level in tank as the degrading factor.

Table 1
The loss of coolant accident (LOCA) frequencies and the failure data of different components in the analysis

S. no.	Parameter	Frequency
1.	Small break LOCA	3.542e−2/yr
2.	Large break LOCA	6.296e−4/yr
3.	Leakage of Valves	4.00e−5
4.	Valve fail to remain in position	3.20e−5
5.	Control valve failure rate	7.2e−6/hr
6.	Control valve failure probability (considering mission time 8 h)	5.76.0e−5
7.	Drift in level indicator	3.96e−4
8.	Malfunction of level indicator	5.00e−4

Step VII: Evaluation of failure probability of components causing the failure.

This is the most critical step in evaluation of reliability of the system. Once the causes of failure of key parameters (due to failure of mechanical components) are known, as explained in Step VI, the next step is to evaluate the failure probabilities of the components. The failure probabilities of the components have been obtained from the generic data sources and are shown in the Table 1.

Step VIII: Evaluation of containment isolation reliability.

In this step, by using the component failure probabilities obtained from Step VII, system reliability analysis will be performed for obtaining the system failure probability by fault tree analysis. Since the functioning of PCIS depends on the occurrence of the LOCA initiating event, the failure frequencies of PCIS have been calculated by considering the occurrence of small break LOCA and large break LOCA. An example fault tree of PCIS failure (component failures leading to system failure) is shown in Fig. 11. The fault tree is shown for suction side seal failure for small LOCA. Similar fault trees are generated for exhaust side seal failure and large LOCA condition. The failure frequencies so obtained are given as follows:

Failure frequency of PCIS during small LOCA: 3.142e−5/yr;
Failure frequency of PCIS during large LOCA: 7.017e−7/yr.

These results will be useful in level-2 PSA analyses in obtaining the large early release frequency (LERF).

3. Summary and conclusions

Evaluation of passive system reliability is a challenging task. It involves a clear understanding of the operation and failure mechanism of the system which the designer must do before prediction of its reliability. Besides, the applicability of the 'best estimate codes' to assess the reliability of passive systems is not well established due to the lack of sufficient plant/experimental data. That also creates another problem in assessing the uncertainties of the best estimate codes when applied to passive system safety analysis.

In this paper, a methodology known as APSRA is proposed to analyze and evaluate the reliability of passive systems. The methodology first determines the operational characteristics of the system and the failure conditions by assigning predetermined failure criteria. The failure surface is predicted using a best estimate code considering deviations of the operating parameters from their nominal states, which affect the natural circulation performance. Once the failure surface of the system is predicted, the causes of failure which occurs mainly due to the failure of mechanical components, is examined through root diagnosis. The failure probability of these components is evaluated through a classical PSA treatment using the generic data. At present, the model has been applied to PCIS of the Indian AHWR concept. The failure probabilities of PCIS are found to be ~3.142e−5/yr and ~7.017e−7/yr for small break LOCA and large break LOCA, respectively. However,

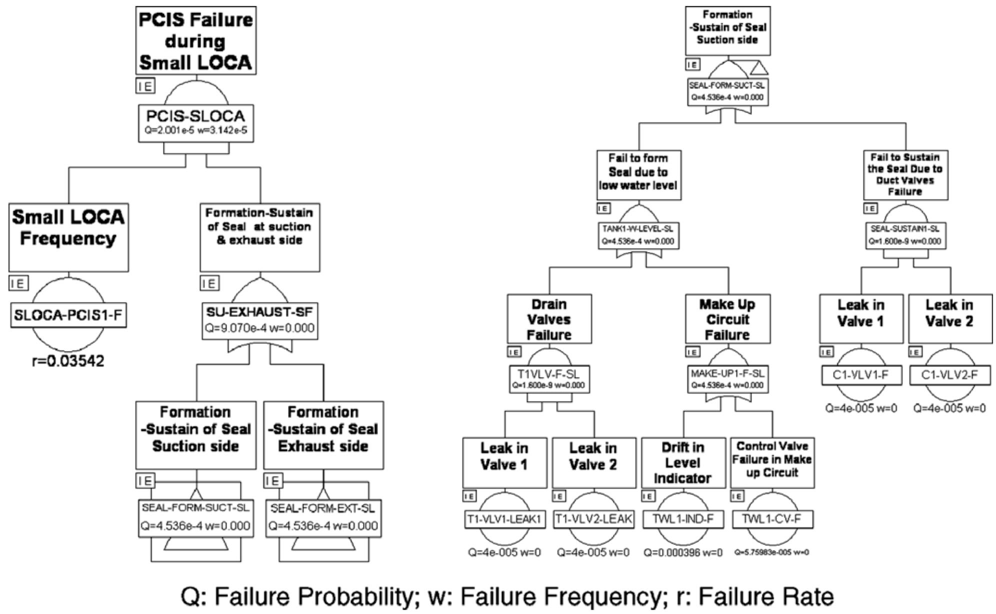

Fig. 11. Typical fault tree for the failure of PCIS.

to reduce the uncertainty in the failure surface prediction, the code predictions will be compared with the test data for certain conditions in near future. For this purpose, experiments are being carried out in an in-house facility to evaluate the data relating to failure of PCIS.

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