CONTAINMENT PROTECTION DURING SEVERE ACCIDENTS

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INTRODUCTION

It is imperative during any accident condition to minimize the release of fission products to the environment. The Containment serves as this last barrier to guard against a release. It is important then to understand how the containment will respond to an accident and to implement where possible features that will assist the structure in serving its design function as a barrier to the release of any fission products. The design of the Swedish Nuclear Facilities have adapted a number of protective measures that will assist in ensuring that the containment will serve its function. Much of the decision as to the types of systems that were to be employed was made under the Reactor Accident Mitigation Analysis research project (RAMA, 1984). The systems implemented included a large vent system with a rupture disc and two normally open isolation valves. This vent was designed to a Large LOCA event with a condensation pool bypass. Such an event would lead to containment failure and loss of piping systems penetrating the containment wall. The result would be a core melt due to lost injection sources. Following containment isolation signal and a time delay the vent system isolation valves would close. This would prevent the vent from operating late in an accident sequence, providing a direct path from containment to the environment. A second vent system was also added to address over pressure beyond the expected time of a pool bypass event. This vent, smaller in size also included a rupture disc and a parallel manual valve. The output from the vent is directed through a sparger and into a water pool where fission products are scrubbed from the gas stream. This vent is intended to preclude over pressure failure given that a core melt had occurred. The systems generated from the RAMA study included an independent spray system whose source of water is taken external to the plant and its operation is independent of plant power. As a result after manually initiating the system, spray water can be directed to containment to help control pressure and scrub fission products. Depending upon the containment design, a lower drywell flood system was implemented. The intent of this system is to ensure a deep water pool under the reactor vessel in the unlikely event the vessel fails and debris is discharged. Also included in the design were special shields for the penetrations that passed through the lower drywell floor. The implementation of these systems was as a result of rulemaking from the Swedish regulatory body (SKI). This paper will focus on the influence that the lower drywell water pool has on the accident and the contribution that the independent sprays and the filtered vent have on reducing the risk of an unfiltered release. The design and implementation of these systems varies depending upon the plant. Each unit has unique features and as a result the description used in this paper is not reflective of any one of the three units at Oskarshamn. These differences will be noted in the paper.

Accident Progression

The response of the containment during a severe accident is dependent upon the type of accident and selected plant features, which can influence the containment response. To facilitate the application of containment protective features, it is necessary to first understand the progression of a severe accident and its influence on the containment.

The decay heat generated during any reactor scram is transported to the condensation pool from the primary system through the (314) safety relief valves and from containment via the downcomers. As water is added to the reactor vessel the steaming that occurs initially continues to be transported to the pool. The condensation pool eventually begins to rise in temperature and it then becomes necessary to remove heat from the pool. The failure to provide this heat removal will eventually lead to pool saturation and a gradual rise in containment pressure. Failure to recover the pool cooling function will result in pressure values reaching the containment ultimate failure pressure. Figure 1 typifies a containment response to a lack of condensation pool cooling.

The Figure shows a gradual rise in pressure due to the steaming from the condensation pool. The rise in pressure is at a rate of about 3Pa/ sec. This sequence certainly provides adequate time to implement recovery actions and re-establish condensation pool cooling.

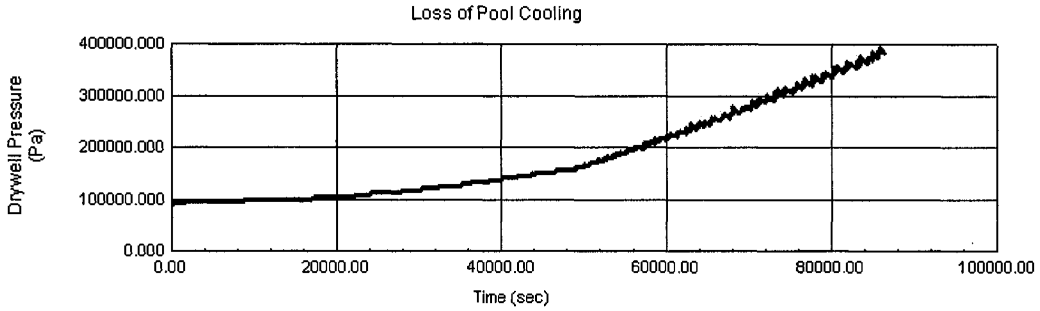

Figure 1 Containment Response No Pool Cooling

In this sequence a transient was the initiator and injection is being provided by the Auxiliary Feedwater System (327). The auxiliary feed water system uses as its suction source the condensation pool or a supply tank external to the drywell depending upon the unit design. If the pump takes suction from the condensation pool then its time of operation is limited to either NPSH limitations or high pool temperatures causing seal problems. If the water supply is an external tank then the pump is not subjected to the adverse conditions occurring as a result of the condensation pool reaching saturation conditions. The reactor core is being cooled and decay heat is transferred to the condensation pool. Without pool cooling, eventually saturation and steaming occur which is shown as the gradual growth in pressure. In this case the containment will eventually reach failure conditions and should a core melt occur with the containment already failed a direct path for release of fission products would be provided, this typically can result in large unfiltered releases.

As stated in the introduction, one measure employed in these designs is to flood the lower drywell with a deep water pool (i.e. 7 meters) to cool any debris which may be released from the failed vessel. Some stations have a lower drywell floor over the condensation pool. Thus instead of flooding, a mechanistic means is provided to allow debris to enter the condensation pool from the lower drywell floor effectively creating the same situation as flooding of the lower drywell. For designs where the debris enters directly a deep-water pool following vessel failure, the failure pressure can have an influence on the interaction of the debris with the water pool. The failure pressure will determine the velocity with which the debris enters the water pool, and the hydrodynamic forces that will act on the debris jet. The net result will be a particle size determined by these conditions. As the debris particles are quenched in the pool, they oxidize as part of this cooling process. The higher the velocity, the more break up and the higher the oxidation rates. The result is that a significant amount of non-constable gases can be formed which will create a more dynamic rise in drywell pressure. This was simulated assuming such an occurrence for a plant design where the debris enters a water pool; this is depicted in Figure 2.

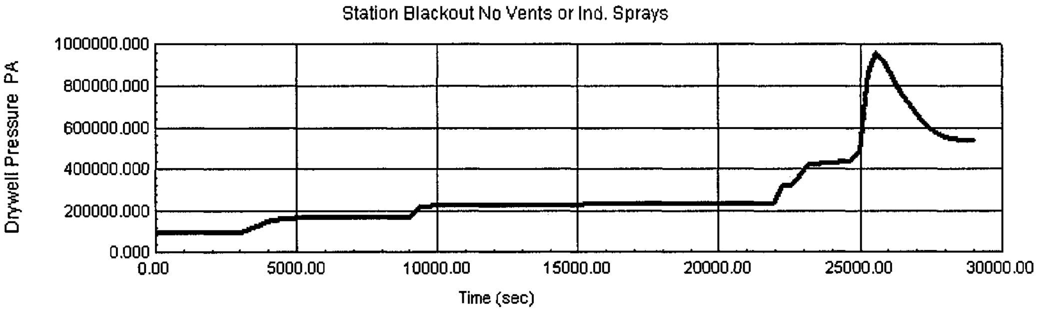

Figure 2 Drywell Pressure

In this sequence, the pressure rises in two small steps prior to 10,000 seconds. The first step occurs at the time the core uncovers and there is a release of hydrogen into the drywell gas space. The second step is the oxidation of debris particles as the debris enters the water pool in the lower vessel plenum. The drywell pressure remains at a fairly constant value until the first vessel failure at about 22,000 seconds and then the failure of the vessel lower head at about 25,000 seconds. In both of these failures, debris is entering the water pool in the lower drywell and oxidation of this debris is resulting in the production of hydrogen. The Figure shows a rapid rise in pressure reaching containment failure conditions. It is evident from these two sequences that the variability of the drywell response could have far ranging effects.

As the containment pressurizes it is expected that initially it will form many cracks and begin to leak. This leakage will allow the flow of steam and aerosols that may be present in the gas space to escape, but will not be sufficient to depressurize the containment. As the pressure rises further cracking will occur until the point is reached where the openings created are sufficient to relieve the drywell pressure. At this point the constituents within the gas space will be swept out with the blow down. The source term implications can be far reaching when an opening to the environment is created during accidents of this magnitude. It is important to understand how the fission products behave during these events so that appropriate actions can be taken. At the onset of core damage the volatile fission products as well as the noble gases are released form the fuel assemblies. The volatile fission product vapors will condense and form aerosols. These aerosols then deposit within the primary system and later revaporize. Those that do not settle within the primary system are transported to the containment depending upon the type of accident. For transient cases where the primary system remains in tact, the aerosols are transported to the condensation pool via the safety relief valve system (314) and to a high degree of efficiency filtered out of the gas stream and remain trapped in the condensation pool. If the initiator was a LOCA then the aerosols that initially escape the primary system enter the drywell gas space where they remain airborne until they settle in containment. Once the vessel fails then the aerosols plated out in the primary system have a release path when they revaporize and they then enter the drywell. It can be seen that there numerous release scenarios that could result in volatile airborne aerosols and if containment failure occurs while these products are airborne then they have a release path to the environment. Figure 3 depict for a station blackout sequence the mass of airborne fission products in containment.

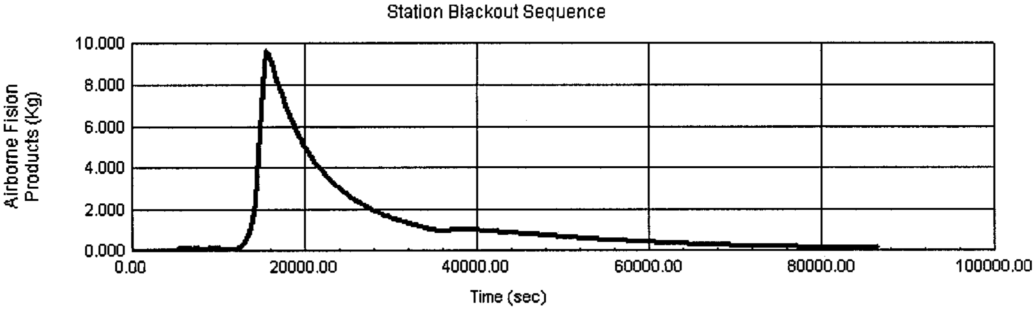

Figure 3 CsI in Containment

In this particular sequence, the vessel failed at around 12,500 seconds. The volatile aerosols became airborne within containment and then began to settle on structures and components. At anytime during their presence in the gas space should containment failure occur, these fission products would be swept out into the environment. It is important to recognize the timing of events and how they can play a role in effecting releases. If the containment failure precedes possible vessel failure as shown in Figure 1 then a direct release path is provided for the fission products depicted in Figure 3. On the other hand, if containment failure occurs within a time period close to that of vessel failure then the same effect could occur. This latter case may be the result of the sequence described by Figure 2.

Containment Protective Features

The containment protective features discussed in the introduction are depicted in Figure 4 with nominal values for their operation; the Figure reflects the Oskarshamn Unit 3 design.

If the event is a LOCA combined with a condensation pool bypass, then the 361 vent rupture disc would operate. After a time delay the vent is isolated. The 358 system would respond based on vessel level and isolation to flood the lower drywell . If this system should fail then any molten debris would attack the penetrations. The independent sprays 322 and the filtered vent would also be employed to protect from an unfiltered release.

To assess the level of protection that these systems afford a plant design, a PSA model has been developed which employs nominal probability Figures for these systems. An initiating event frequency of 1.0 has been used so that the outcome probabilities would be representative of a per unit or per cent contribution to the overall outcome and derivation of absolute Figures would not be required. The event tree and its probabilities are representative of Swedish facilities, not any one unit. The event tree and its probabilities are shown in Figure 5.

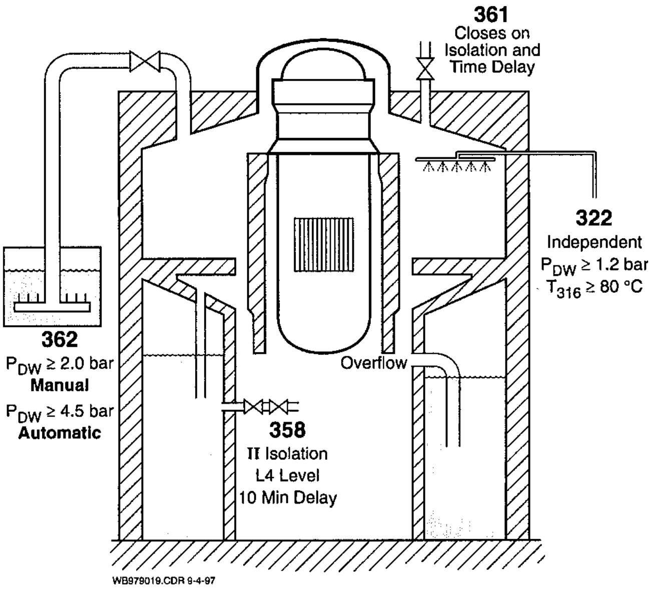

Figure 4 Containment Protective Features

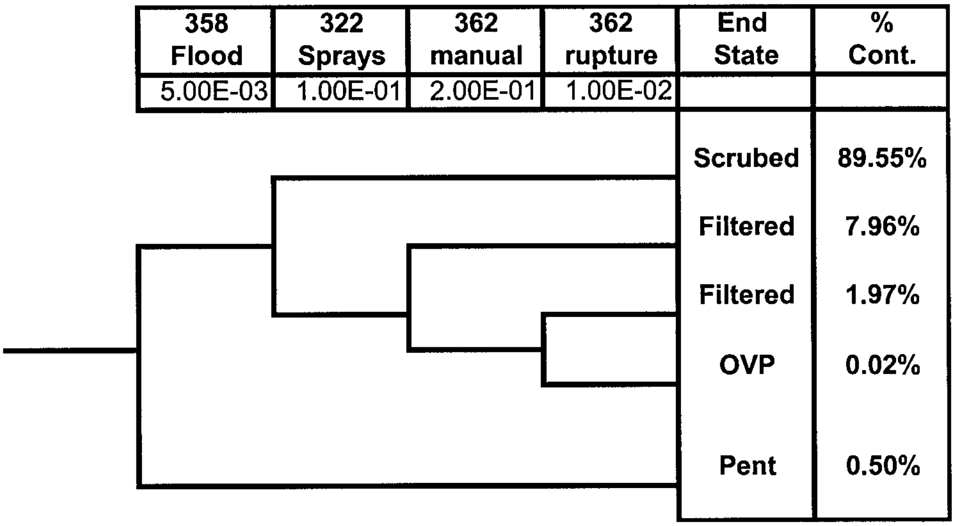

Figure 5 Containment Event Tree

The initiating event to this tree would be the composite core damage frequency from the level 1 analysis. The outcomes to the event tree are revered to as end states and depict the various states where the containment may end. These end states include scrubbed, filtered, OVP and Pent. Scrubbed refers to spray operation and implies that any airborne fission products will be removed form the containment gas space. This mechanism of spraying also reduces the containment pressure. Filtered is the end state associated with the vent system operating to reduce pressure. The end state designated as OVP refers to a state of containment over pressure. Finally the end state designated as Pent represents penetration failure.

Following the initiating event, the tree first checks to see if the lower drywell flooding system worked and if it has not then as stated before a breach of containment through the penetration will occur. Failure of this node results in a Pent. end state. After success of the flooding a check is made to see if the sprays have functioned. The outcome of this action will be a scrubbed release through the leakage paths in containment. If the sprays fail then the operator acts to manually open the filtered vent and should the manual system fail the rupture disc would be the next action to reduce pressure. The sprays are employed at first to reduce pressure thus eliminating the need to vent, which would be the preferred method of pressure reduction. If a rapid pressure rise had occurred due to formation of non-condensable gases from the debris water pool interactions then the tree would have to be revised inorder to show that the rupture disc would have been required. The rupture disc would have been the only mechanism to respond to the rapid rise in pressure.

It should be emphasized that the event tree of Figure 5 does not address the nominal containment spray system used to control pressure. It is assumed that it has failed, as the tree is entered. Should it have functioned then the release would have been limited to that of leakage paths. The key feature identified by this tree is that only a very small fraction of the sequences would result in some type of unfiltered or unscrubbed release. This is depicted clearer in Figure 6, which shows the release breakdowns.

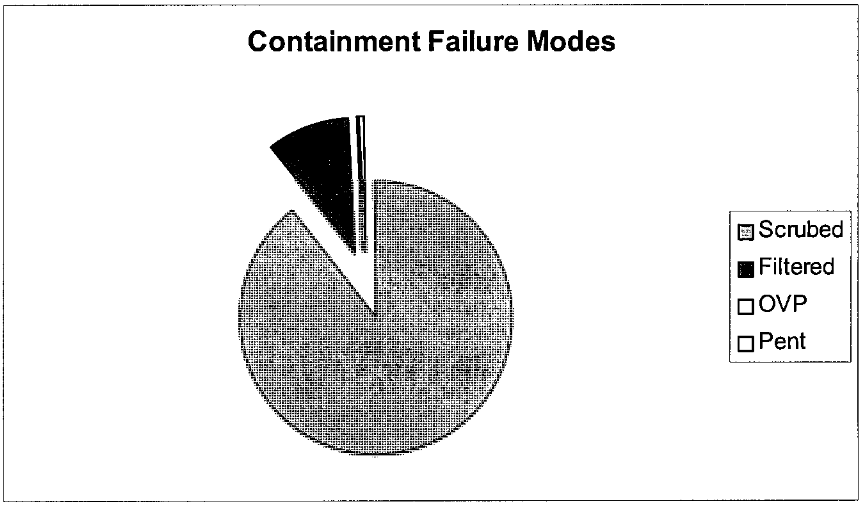

Figure 6 Consequence Break Down

Clearly the scrubbed and then the filtered release dominate the results. The scrubbed release exceeds the filtered release because procedurally it is preferred to first reduce pressure without having to create any containment openings. Less then 1% of all challenges to the containment result in a unfiltered or unscrubbed release.

Conclusions

The primary function of the containment is to serve as the final barrier to the release of fission products. The progression of an accident can result in unique challenges that may result in a breach of this final barrier. The accident can be of such a nature that the pressure rises quickly to levels challenging containment and not allowing for adequate operator intervention. Accordingly, the progression can be where the rise in pressure is at a slow rate providing time for mitigating actions. The simplified analyses outlined in this paper shows that the typical design considerations in the Swedish plant result in about 0.7% of all challenges resulting in a unfiltered or unscrubbed release. Over 99% of the challenges will be scrubbed, thus minimizing public risk. To gain a better perspective, assume a nominal core damage frequency of E-05. This would necessitate an unfiltered release frequency of about 7.0E-08. Regulatory Guide 1.174 lists as the minimum LERF for which changes in the LERF need to be assessed as 1E-05. Thus, these features offer a significant reduction in the LERF figure for the plant.