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Realistic LOCA Containment Analysis Using A Merged Version of RELAP5/CONTEMPT4

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Abstract

Realistic containment analyses for large LOCA using a merged version of RELAP5/CONTEMPT4 are conducted. Analyzed are Generic LOCA with respect to the mass and energy releases from the RCS and containment pressure and temperature behaviors. The break locations considered are the double-ended guillotine breaks at the RCP discharge and hot legs for UCN 3&4 plants. For discharge leg break, the predicted containment pressure and temperature reach a peak during blowdown phase, thereafter the pressure and temperature decrease gradually without the second reflood peak. For the hot leg break it is found that the bypass break flow through the broken steam generator during post-blowdown is negligibly small so that the containment atmosphere is not pressurized after the end of blowdown.

1. Introduction

The containment receives mass and energy releases following a postulated rupture of the reactor coolant system (RCS). Since the pressure in the RCS is high during the blowdown phase, the break flow from the RCS to the containment is critical flow. Therefore, the containment backpressure does not influence the mass and energy release rates from the RCS. During the blowdown period, most of the initial primary coolant is rapidly released to the containment. The blowdown phase ends when the RCS pressure is reduced near the containment pressure.

During the reflood phase, the different break locations have different characteristics. For a cold leg pipe break, a significant amount of the ECC water entering the core is carried out of the core by the steaming action of the core to coolant heat transfer process. This fluid leaving the core must pass through a steam generator (SG), where it is heated from the SG secondary coolant before it reaches the containment. However, compared to the results from the breaks at other locations, the core flooding rate is low because the break flow path includes the reactor coolant pump. For a hot leg pipe break the flow path resistance is relatively low, which results in a high core flooding rate, but the majority of the fluid leaving the core vents directly to the containment without passing through the SG. There is no physical mechanism for rapidly releasing the SG energy to the containment after the end of blowdown (EOB). Therefore, a post-blowdown analysis for the hot leg break LOCA has not been conducted in the system 80 type plant.

In this paper, for the discharge leg and hot leg breaks the thermal hydraulic phenomena in the RCS and containment system are investigated to understand the realistic behavior of the systems with respect to the containment mass and energy release analysis.

2. Analysis Method

2.1 Computer Code Used

KAERI has developed the RELAP5/CONTEMPT4 code [1], a merged version of RELAP5/MOD3.1 [2] and CONTEMPT4/MOD5 [3], to produce the system analysis code which can consider the realistic containment back pressure. The merged version has been used in KAERI for the development of realistic evaluation methodology for ECCS performances during large break LOCA. The well-known system analysis code of RELAP5/MOD3 is adopted to simulate the reactor coolant system behavior, while the CONTEMPT4/MOD5 code is adopted to simulate the containment response. The two codes are explicitly coupled by using the concept of process control so that the code modifications are minimized and the inherent features of each code are not degraded. The merged version has the capability of considering the feedback effects of thermal hydraulics in the RCS and the containment system.

The RELAP5/MOD3.1 code uses a two-fluid model for flow of a two-phase steam-water mixture containing a noncondensible component in the steam phase and a nonvolatile component in the liquid phase. The two-fluid equations consists of continuity, momentum, and energy equation for each phase. Constitutive relations are also incorporated for closure of the governing equations. The numerical solution scheme used in RELAP5/MOD3 is a semi-implicit scheme using staggered grid and donor cell concept.

The CONTEMPT4/MOD5 is a multi-compartment and multi-junction containment system analysis code. A compartment is divided into vapor region and liquid pool region. The vapor region is considered to be a homogeneous mixture of non-condensable gases and water in both the liquid and vapor state, while the liquid pool region is filled with pure water in liquid phase. Mass and energy in a compartment vapor region are interchanged by interactions with the pool region, heat transfer through structures, safeguard systems such as fans and sprays. The numerical solution scheme is basically explicit. Since the numerical solution procedures of the RELAP5 and CONTEMPT4 codes are different each other, explicit coupling is made to merge the two codes instead of implicit coupling.

As mentioned previously the thermal hydraulic transient in the RCS is not affected by the containment response during blowdown phase. However, during post blowdown phase, the mass and energy discharges from the RCS influence the thermal hydraulic behavior in the containment, while the containment pressure provide a back pressure for the calculation of break flow. The thermal hydraulic behaviors in both systems provide boundary conditions for each other at every calculation time. Since it is essential for the realistic evaluation of containment performance to simulate the feedback effects of the RCS and containment system during post-blowdown phase, the merged version is very beneficial in analyzing the large break LOCA including blowdown, refill, reflood and post-reflood phases.

2.2 Nodalization and Major assumptions

The data utilized for the representation of the RCS and the containment system are taken from the UCN 3&4 design data at PSAR stage. Almost plant parameters and initial conditions are nominal values except core power. Full stretched core power level by 102% and 1973 ANS decay heat table are used for the analysis. ECC flow including SIT and SIP is maximized to increase the containment mass and energy releases. Active core is modeled by the average and hot channels, in which each channel has 20 subvolumes. Radial connections between core average and hot channels are modeled using cross-flow junctions. Vessel downcomer is axially splitted by two spaces which are connected to the intact loop and broken loop respectively, and 6 cross-flow junctions are used to radially connect two splitted downcomers.

The combination of Tagami and Uchida correlations embedded in the CONTEMPT4/MOD5 is selected for the condensation heat transfer during the entire LOCA transient. These correlations are used in the conservative containment analysis for the licensing purpose. The passive heat structures and active heat removal systems such as spray are modeled in the conservative manner to make consistency with the licensing calculation.

3. Analysis Results

Double ended guillotine break is assumed to take place at zero seconds. Fig.1 shows the pressure transients in the RCS and pressurizer during blowdown phase for discharge leg (DEDLG : double-ended discharge leg guillotine) and hot leg break (DEHLG : double-ended hot leg guillotine), respectively, Fig.2 shows the two-phase mixture flow rates from the break during blowdown phase for both breaks. The difference of initial flow rates is due to the break area. Fig.3 shows the ECC flow rates including the SIT and SIP. The injected ECC water for DEHLG easily penetrates into the lower plenum since the pressure difference between the RCS and containment is small. While in DEDLG, most of the injected ECC water bypasses the downcomer and spills out the containment.

For DEDLG the break flows from the reactor vessel (RV) side and reactor coolant pump (RCP) side are shown in Fig.4 and Fig.5, respectively, in which depending on the containment condition the break flows are divided as steam and liquid phase, respectively. The flow rates from the SG side are much lower than those from the RV side because of the high hydraulic resistance of the reactor coolant pump and SG. As shown in Fig.5 the two-phase flow leaving the core is not fully vaporized in the present analysis. However in licensing analysis the mixture flow leaving the core is assumed to be all vaporized by the reverse heat transfer in SG. The total steam flow rates predicted by different methods are presented in Fig.6. The realistic steam release rates are very different from those of UCN PSAR. The steam release rates predicted realistically during post-blowdown phase are so low that the containment atmosphere is not pressurized after the EOB. For DEHLG, the break flows from the RV side and the SG side are shown in Fig.7 and Fig.8, respectively. The steam flow from the RV side flow after the EOB is so small that the containment is not be pressurized. Flow through the broken SG path is not established essentially even though there are some spikes in the flow rates.

The SG secondary coolant is the major energy source of the break flow to be released to the containment. The transient SG secondary temperature are presented in Fig.9 and Fig.10. As shown in the figure the temperatures in the secondary SG nodes for discharge break decrease, while for hot leg break only economizer temperature decreases and evaporator temperature remains constant. Fig.11 shows the collapsed water level in the active core. The water level decreased once during the early blowdown period and increased rapidly when the SITs water are injected into the system. Since the flooding rate varies approximately in proportion to the square root of the loop resistance, the reflooding period for the hot leg break is very short compared to that of the cold leg break as shown in figure. Fig.12 and Fig.13 show the total energy released to the containment for discharge and hot leg break, respectively.

Fig.14 shows the containment transient pressure analyzed by the COTEMPT4. As the coolant exits the break, a portion of it flashes into steam due to the pressure and temperature differences between the RCS and containment. Temperature flashing model was selected for both methods. As shown in Fig.14 the containment pressure predicted realistically reaches peak before the EOB and decreased consequently both for discharge leg and hot leg breaks. The second peak is not predicted in the present analysis, while it always appears in the conservative analysis. The significant difference is due to the over-conservative assumptions and models embedded in the licensing model. Based on the present result, it can be concluded that the highest containment peak pressure occurs for the hot leg break at near EOB condition.

4. Conclusion

The postulated double-ended breaks at the discharge leg and hot legs for the UCN 3&4 plants are analyzed using a merged version of RELAP5/CONTEMPT4 with realistic assumptions. The containment peak pressure predicted is much lower than that of the conservative analysis. For the discharge leg break, the predicted containment pressure and temperature reach a peak during blowdown phase, thereafter they decrease gradually without the second reflood peak. For the hot leg break it is found that the bypass break flow through the broken steam generator during post-blowdown is negligibly small so that the containment atmosphere is not pressurized after the EOB.

References

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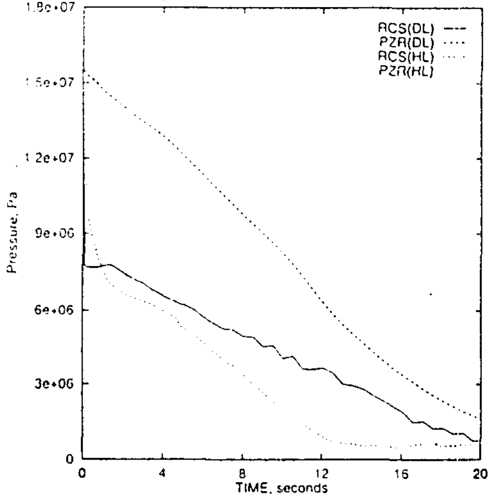

Fig.1 Pressures in the RCS and pressurizer

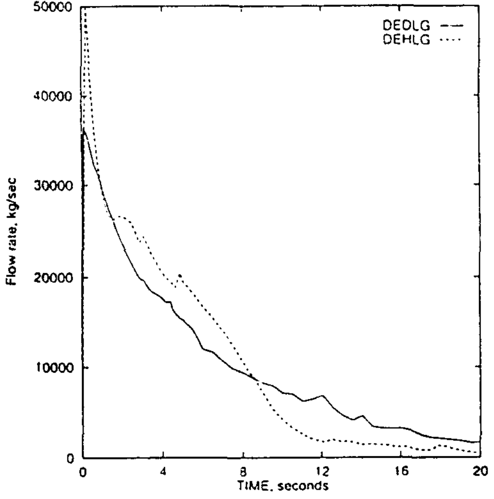

Fig.2 Two phase mixture flow rates from break

Fig.3 ECC flow rates

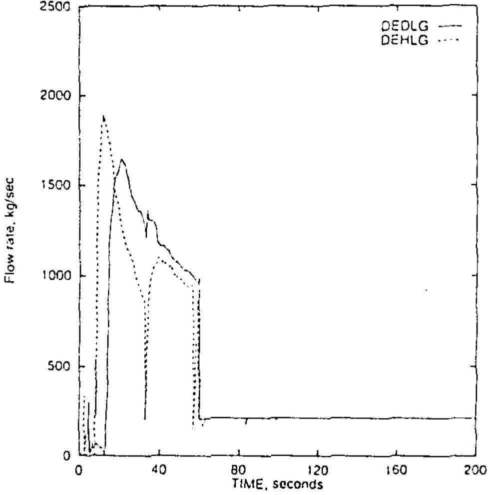

Fig.4 Mass release rates form RV side for DEDLG

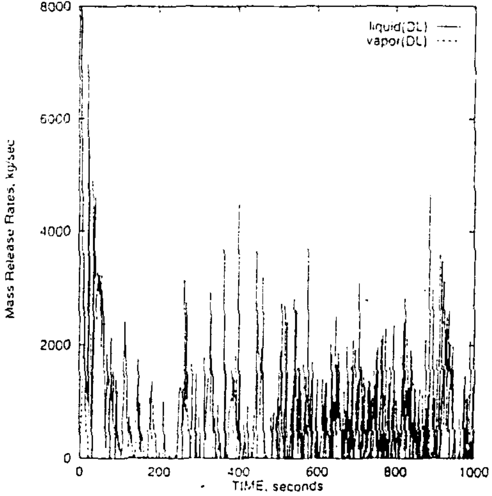

Fig.5 Mass release rates form RCP side for DEDLG

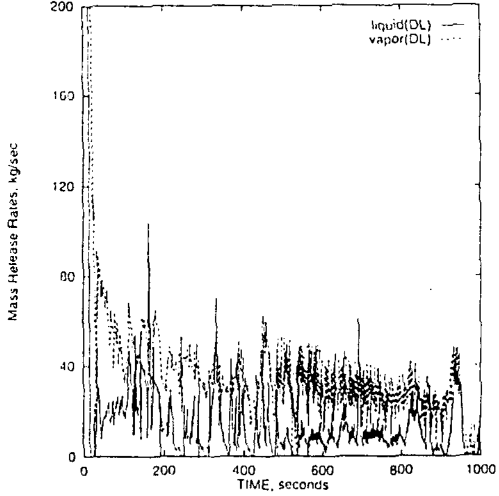

Fig 6 Total steam release rates for DEDLG

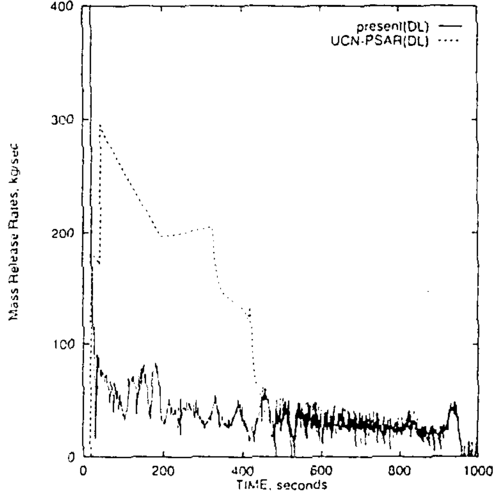

Fig.7 Mass release rates form RV side for DEHLG

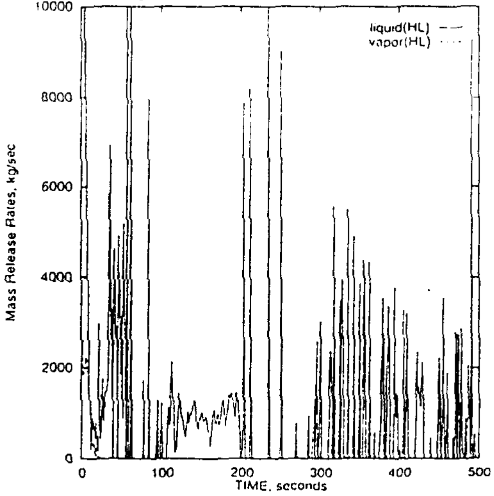

Fig 8 Mass release rates form SG side for DEHLG

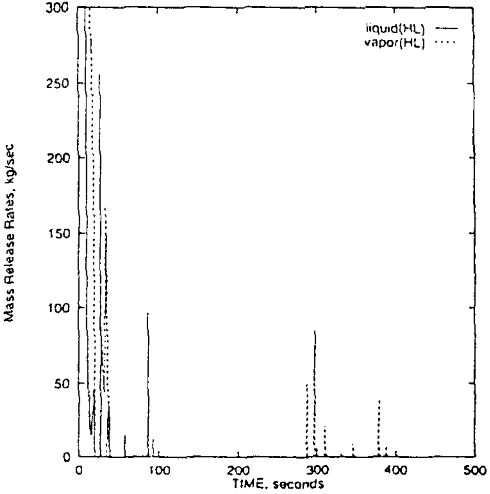

Fig.9 SG secondary temperature for DEDLG

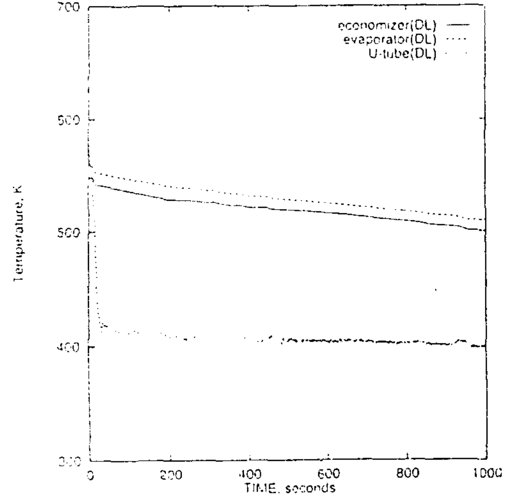

Fig.10 SG secondary temperature for DEHLG

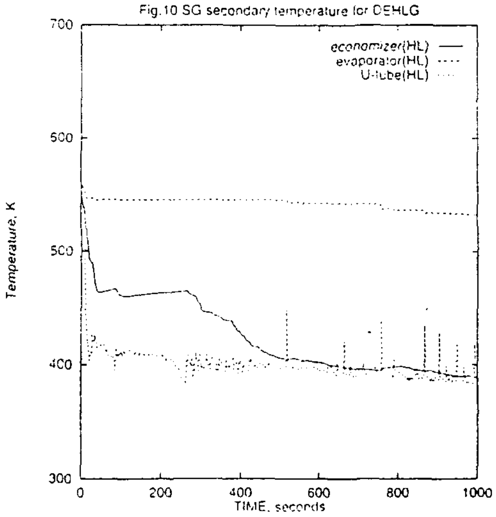

Fig.11 Collapsed level in core and downcomer

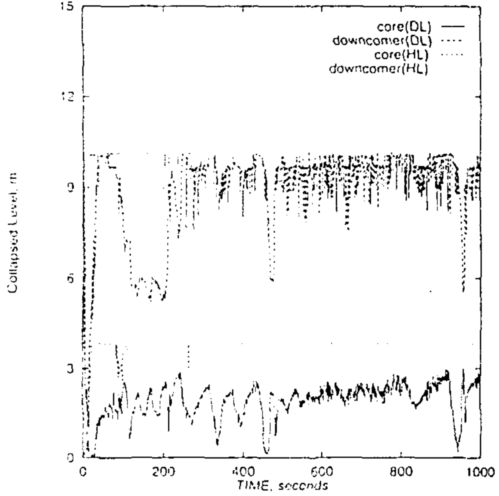

Fig.12 Integrated Energy Release for DEDLG

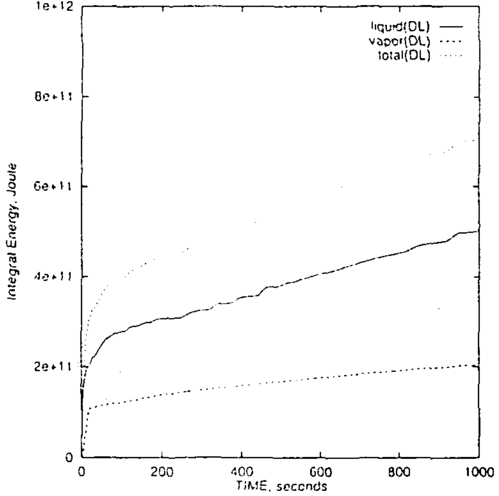

Fig.13 Integrated Energy Release for DEHLG

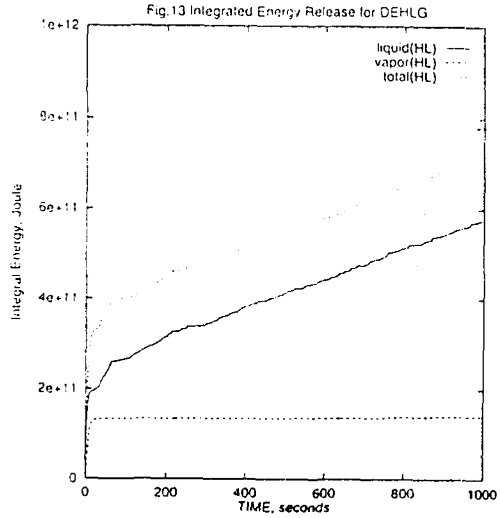

Fig.14 Containment pressure