Evaluation of Integrated System Dynamic Responses during a SWR Event in KALIMER-600

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1. Introduction

A sodium-water reaction (SWR) has been considered as one of the most important issues to be resolved for designing the steam generator and the related systems of a sodium-cooled fast reactor (SFR). Since the system dynamic responses during the SWR event obviously show different characteristics between the initial stage of the acoustic wave propagations and the long-term period of a bulk motion, its analysis should also be performed for both major events in general. In this study, the whole stage of a SWR event in KALIMER-600 including the very initial propagation and the long-term mass and energy transfer were evaluated with considerations of the fundamental features of the SWR phenomena and the guidelines for the pressure relief system design against a SWR event are also proposed.

2. SWR Analysis for KALIMER-600

2.1 Overview of KALIMER-600

The NSSS of KALIMER-600[1] consists of three major heat transport systems of PHTS (Primary Heat Transport System), IHTS (Intermediate Heat Transport System) and SGS (Steam Generator System). The skeleton of the overall heat transport system is configured in Figure 1.

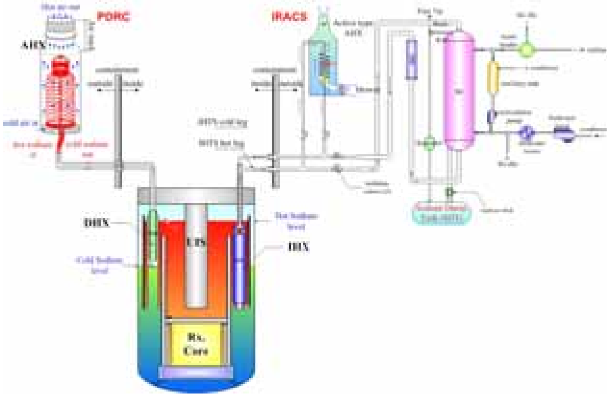

Figure 1. System Configuration of KALIMER-600

Among the heat transport systems described in Figure 1, the IHTS consists of two identical loops and each loop has its own steam generator and related SWR mitigating systems. A pressure relief system is used to relief the buildup pressure caused by a SWR and emphasis has also been given to prevent and mitigate possible SWR events in the design of the IHTS piping routing and SG design.

2.2 SWR analysis codes

For a reasonable prediction of the system dynamic responses during the SWR event in KALIMER-600, the SPIKE [2] and the SELPSTA [3] code were developed by using various simplifications and assumptions. The SPIKE code is based on the numerical scheme of the MOC (Method of Characterization) [2] for solving wave equations with a branch-junction concept. However, since the scheme is only used to solve the acoustic wave propagation phenomena, it does not have a proper method to consider the mass and energy transfer phenomena in a quasi-steady pressure transient. To this end, the SELPSTA code was developed by implementing the long-term mass and energy transfer (LMET) model [3], and it is based on the hypothesis that the system transient can be described by the pressure and temperature transient of the cover gas region. In order to evaluate the feasibility of the codes, experimental verifications were carried out [2][3] and it was demonstrated that the numerical simulation methods implemented in these codes adequately replicate the reaction phenomena with any reasonable understandings.

2.3 Evaluation of the SWR event in KALIMER-600

To evaluate SWR events in KALIMER-600, a proper source term of a pressure transient is postulated with the design basis tube leak (DBL). The DBL is based on the assumptions that the single double-ended guillotine break (DEGB) occurred at 1 msec just after the reaction occurrence and it is enlarged to 3-DEGB at 1 sec after the leak initiation. The tube leak rate maintains up to the ending time of the reaction, and the termination of the reaction is accomplished by either a tube-side steam isolation or shell-side sodium clearing. Figure 2 shows the pressure variance for the postulated DBL at each location of the IHTS. Since the initial pressure variations strongly depend on the characteristics of the wave propagation, they have different trends at each location. A sharp peak pressure and its oscillations can be shown at the rupture disk (RD) line mounted on the bottom of SG just after the reaction occurrence (~ several hundreds of milliseconds), but few pressure peaks and their oscillations are observed at the IHX heat transfer tubes. This is due to (i) the positional differences from the reaction zone and (ii) the IHTS configurations [1] to essentially mitigate a SWR.

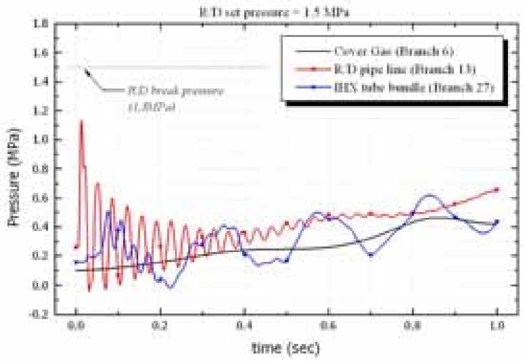

Figure 2. Initial pressure variations in each location

On the other hand, the pressure variation of the cover gas region shows the trend of a very smooth pressure increase and it is rarely affected by wave propagations since the contributions of the mass and energy transfer are very small during this initial stage of the reaction. Even though the trends of a pressure variation at each location are very different, the maximum pressure values, which we have concerns about, are much lower than the RD break pressure. It means that the integrity of the system components and IHTS piping can be safely maintained during the postulated SWR event.

Figure 3 shows the system pressure variations up to 1,000 seconds. For the parametric investigations of the CG volume changes, the nominal design value of 25.76 m^3 [1] and its ± 30% changed values were considered. The RD break time is about 6.4 sec for the nominal case but those for the ± 30% changes are 7.9 sec and 3.3 sec, respectively. It was found that the RD break time strongly depends on the system design parameters like the CG volume, and it means that a large volume can easily accommodate the long-term pressure transient. Before the RD break, the sodium drain tank (SDT) pressure remains at a constant value of the initial SDT pressure, and it slowly increases just after the RD break corresponding to the system pressure decrease. Since the SDT free volume is sufficiently large enough to hold the total IHTS loop sodium, the SDT pressure increase is relatively small compared to the system depressurization. The SDT pressure also increases as the reaction proceeds and it reaches the break pressure of the lower-pressure rupture disk (LPRD) (0.25 MPa [1]). When the LPRD breaks, the SDT pressure rapidly decreases to the environmental pressure and the system pressure also decreases with some pressure oscillations corresponding to the SDT pressure decrease.

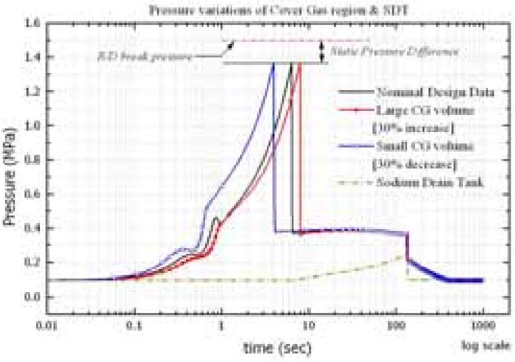

Figure 3. Pressure variations by different CG volumes

Based on the evaluation results, it was concluded that the rupture disk break pressure of 1.5 MPa is very feasible to maintain the integrity of the system components and the CG volume change of up to 30% increase or decrease is also acceptable to accommodate the pressure transient during the whole period of the SWR event.

3. Conclusions

For the evaluation of the SWR event in KALIMER-600, the SWR analysis computer codes were developed and the parametric analyses for the system design characteristics were performed by using the developed codes. The analyses results showed that the RD break pressure and the cover gas volume of KALIMER-600 is very feasible for maintaining the integrity of the system components. Based on the foundations, the guidelines for an appropriate pressure relief system design are proposed with sufficient considerations of the system design features. It is expected that the results of this study will contribute to the design improvement or optimization of the SWR mitigation system in KALIMER-600.

ACKNOWLEDGEMENT

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