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# Safety Assessment of Void Increase in Reactor Coolant System Induced by LOP/SLB

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## 1. Introduction

The natural disaster (that is, an unusual change in the weather such as climate warming, an earthquake driven by massive geological event, or a tidal wave driven by an earthquake) worldwide has been on the rise. Furthermore, the frequency in which these natural disasters are taking places is clearly on the rise. Many experts have expressed their concerns with regard to considering these phenomena in reactor safety design. Recently Fukushima nuclear accident has been issued in safety aspects of nuclear power plant.

The purpose of this research is to investigate the fuel integrity in primary heat transport system of heavy water reactor when flow instability with void occurs due to overcooling and depressurization of the primary heat transport(PHT) system, which are the possible results from loss of power(LOP) or steam line break(SLB) outside containment driven by natural disaster.

## 2. Methods and Results

In this section the flow regime map of an used analysis code and two accidents induced by natural disasters are described. Their results also are summarized at the end of the section.

### *2.1 Flow Regime Map*

Analysis code used is a one-dimensional, two-fluid thermal-hydraulic system code. This code is generally applicable to transient, two-phase flow in piping networks. It uses two general categories of flow regime: separated and mixed. This categorization provides a simple means of ensuring that no discontinuities in constitutive relations results from flow regime transitions[1].

A pipe component is deemed to be horizontal if its angle of inclination from the horizontal is less than 0.6 degrees. Two general categories of flow regimes, separated and mixed, are recognized in horizontal pipes. The mixed flow regime includes the disperse-bubble, intermittent and disperse-droplet flow regimes. To remove the potential of discontinuities in the constitutive relations between the separated and mixed flow regime categories, a weighted averaging procedure is employed.

The mixed flow regime includes the disperse-bubbly, slug and disperse-droplet flow regimes. The mixed flow regime modeling of interface shear is divided into these three regimes and are described by parameters appropriate to the individual regimes. The mixed flow regime map showing the three regimes is shown in dispersed bubble, slug, transition regions and dispersed droplet.

To avoid discontinuities, the interface shear and interface heat transfer coefficients are calculated for the mixed flow regime as a weighted average of the terms determined for each of the three regimes. The weighting factor relationship is given by,

$$f_{ki} = E_b f_{ki,b} + E_s f_{ki,s} + E_d f_{ki,d}$$

where $E_b$, $E_s$ and $E_d$ are the weighting factors for the disperse-bubble, slug and disperse-droplet interface terms $f_{ki,b}$, $f_{ki,s}$ and $f_{ki,d}$, respectively.

The weighting factors for the flow regimes in the mixed flow category are determined to match the flow regime boundaries.

### *2.2 Stream Line Breaks Outside Containment*

This section describes the sequence of events which would be expected to occur following a break in one of the steam mains outside containment which connect a steam generator to the steam balance header.

The exact event sequence depends on the size and location of the break. The break size determines the depressurization rate and therefore the timing of alarms, trips and automatic actions. Once the turbine governor valves have closed, depressurization continues at the rate which is completely determined by the break size. The lower secondary side pressure and temperature would result in lower primary side pressure and temperature. All PHT pumps run down, in which case the fuel is cooled by natural convection caused by the energy balance between decay heat and steam generators. If emergency core coolant injection doesn't work due to loss of power or absence of conditioning signal, the void in the PHT system is gradually increased. The reason why the void increases is the coolant shrinkage and inventory loss by liquid relief valve[2-3].

Fig. 1(up) shows the core flow of one pass and Fig. 1(down) shows the integrated void in the two primary heat transport loops. The flows initially increase because of the decrease in input power by reactor trip. The overcooling effect of the break reduces void in the primary heat transport system with lowering the flow resistance. However after about 300s the flow in loops shows unstable phenomena driven by two-phase fluid.

The void increases over 10 percent. Fig. 2 shows fuel and sheath temperature transients for all of four passes. The sheath temperature is strongly fluctuating in the period of low flow. Despite this transient flow without ECC injection, sheath temperature is sufficient to cool the fuel throughout the transients for the headers in pass 1, 2, 3 and 4. Note that there is higher increase of its temperature during short period of lower flow.

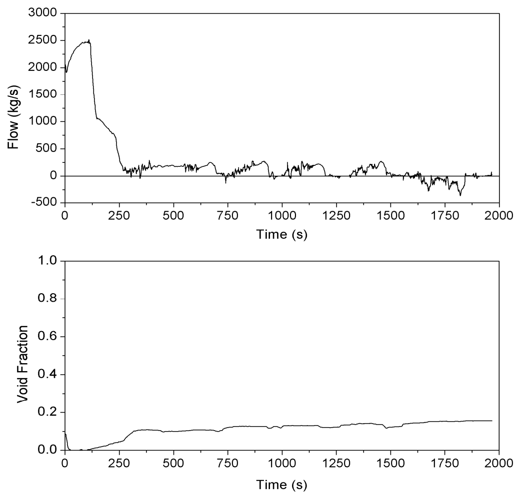


Fig. 1. 100% Steam Line Break Outside Containment for 10-20% Void Fraction: Primary Heat Transport Loop Flows(up) ; Integrated Void Fraction(down).

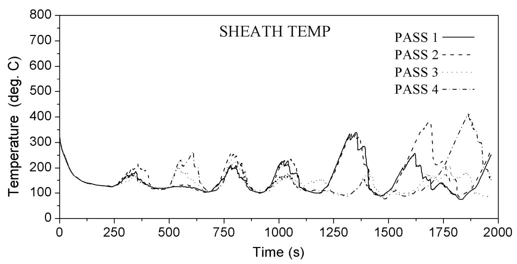


Fig. 2. 100% Steam Line Break Outside Containment for 10-20% Void Fraction: Sheath Temperatures for Each Pass.

### *2.3 Loss of Power*

The expected event sequence following a complete loss of power (that is, loss of class III, IV and emergency diesel generator) is slightly different from loss of class IV power[4]. The event should start from loss of full power, and then shutdown rods are free to drop when the clutch is de-energized. The sequence of this accident is as in the following. All PHT pumps run down, in which case the fuel is cooled by natural convection. The primary coolant flow decreases due to the rundown of the pumps. The flow power mismatch raises the primary coolant temperature and pressure, which initiates the opening of the PHT liquid relief valves. The steam generator feedwater pumps run down. The condenser circulating water pumps and the steam condenser become unavailable, which prevents the condenser steam discharge valves from opening. The MSSVs can open to control pressure. The pressurizer heaters and $D_2O$ feed to the PHT system become unavailable. PHT pressure and inventory control mode is switched automatically to "solid" mode.

Table I: Flow and Fuel Temperature for Void Fraction

| Void Fraction(%) | Average-Flow/Intensity After Trip (kg/s) | Sheath/Fuel-Center Temperatures after Trip(℃) |
|---|---|---|
| 10~20 | 50.0/91.6 | 162.8/173.5 |
| 20 | 51.8/59.9 | 136.0/146.3 |
| 30 | 52.4/67.0 | 168.8/184.4 |
| 40 | 36.0/38.6 | 179.2/190.9 |
| 50 | 17.5/43.5 | 186.8/198.6 |

### *2.4 Fuel Integrity with Void Fraction*

The void in loops is increased by the coolant shrinkage and inventory loss through LRV. The increasing amount of the void by both loss of power and steam line break outside containment is below 20 percent. In order to confirm the flow instability for a higher void, liquid relief valve is opened until void fraction reaches the desired values that are artificially set to 20%, 30%, 40%, 50%, respectively. Void increase is stopped by the action of the liquid relief valve. For each void value Table I shows the analysis results of average flow and fuel temperature for 1000~2000 seconds after reactor trip. When the system integrated void fraction is 10-20%, its average flow and intensity of main flow are 50.0 kg/s and 91.6 kg/s respectively. Otherwise the average flow with the 40% void is shown with a relatively low flow. Furthermore, its intensity shows largely a decrease of 58% against that of 10-20% void fraction. The reason is due to the additional effect of the flow resistance for void increase. The results show that fuel/sheath temperatures increase at higher voids.

## 3. Conclusions

The two-phase flow that has a characteristic of voiding due to overcooling and depressurization of the primary heat transport system has been disturbed in both primary coolant loops. Despite this transient flow without ECC injection, the periodic and unstable flow is sufficient to cool the fuel as shown in results. Even for higher voids the fuel/sheath integrity is sufficiently met with lower fuel and sheath temperature.

## REFERENCES

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