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Application of Core Exit Temperature for Effective Safety Injection Strategy of Severe Accident Management Guidance

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1. Introduction

Accident management is classified into preventive and mitigative regimes, whose details are given in Fig. 1. The preventive regime is dealt with Emergency Operating Procedures (EOPs) to achieve the relevant objective in terms of preventing core damages. On the other hand, the mitigative regime corresponds to Severe Accident Management Guidance (SAMG) under the specified conditions. Due to limited time for operator's action under the postulated severe accident, immediate and short term actions are needed and relevant strategies are constructed in the SAMG. Therefore, the SAMG includes a variety of information to assist the proper operator actions. Among these, pre-calculated graphs and formulas facilitate understanding of plant status and operator's action needed for accident mitigation. These are essential for ease of application and regarded as Computational Aids (CA). The representative example is the estimation of injection flow rates for removing decay heat and oxidation heat of core, and hydrogen generation rate, to mention a few [2]. Most of all, calculation of the necessary injection flow rate is important in order to mitigate and/or terminate core damages. In estimating the flow rate for accident mitigation, Core Exit Temperature (CET) is utilized as a key variable. CET is considered most effective and reliable means for diagnosing core state. As such, CET has been adopted as a criterion transitioning from EOPs to SAMG. In this study, the necessary flow rate is calculated utilizing simple model with CET for RCS injection in mitigation strategy of SAMG. MELCOR simulation results are introduced for the calculation.

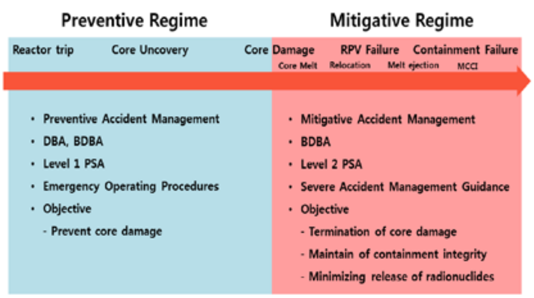

Fig. 1. Preventive and mitigative regime of accident management

2. Simple model using CET

The increasing trend of CET signifies the core heat up and insufficient core cooling. Also CET reflects a similar trend of cladding temperature, i.e., increasing CET rate is similar to the rate of increasing cladding temperature. It is considered as the effective and important variable to monitor for accident management [3, 4].

2.1 Simple model for injection flow rate calculation

Decay heat and oxidation heat is the main target to remove during the accident phases. Therefore, total heat generation in the core is considered as a following equation.

$$q_{\mathrm{Tot}} = q_{\mathrm{de}} + q_{\mathrm{ox}} - q_{st} \quad (1)$$

where, q_{de} is decay heat, q_{ox} is oxidation heat in and q_{st} is removal heat by superheated steam. Decay heat is function of time since the reactor trip. It is assumed that increasing rate of CET contributes to oxidation heat generation. Thus, oxidation heat can be formulated as the following equation.

$$q_{\mathrm{ox}} = \frac{E_{\mathrm{ox}}}{T_{\mathrm{R}}} \times \dot{T}_{\mathrm{CET}} \quad (2)$$

where, E_{ox} is total oxidation energy in [J] during accident sequence. T_R in [K] is the range of CET from oxidation reaction start to maximum detectable range. $\dot{T}_{CET}$ is increasing rate of CET in [K/sec]. Then the required flow rate to remove core heat is obtained as Eq. (3).

$$Q_{\mathrm{Inj}} = \frac{q_{\mathrm{Tot}}}{(h_{\mathrm{g}} - h_{\mathrm{Inj}})} + \frac{\mathrm{V_{core}}}{\mathrm{t_{fill}}}\rho \quad (3)$$

where, h_g is specific enthalpy of saturated steam and h_{inj} is specific enthalpy of injected coolant both in [J/kg]. It is assumed that injected coolant reaches saturation state. V_{core} is volume of core in [m^3] and t_{fill} is recovery time of core inventory in [sec].

3. MELCOR calculation results for CET application

In order for utilization of simple model, CET data are obtained from MELCOR simulation for a hypothesized event of SBLOCA without ECCS such as HPSI and LPSI. A base case without any operator action and a mitigated case using the secondary feed and bleed at 5 min since the SAMG entrance are considered for OPR1000. Detailed nodalization and relevant information can be found in Lee et al.'s work [5].

Figure 2 shows MELCOR simulation results for CET. Increasing tendency of CET for base case is higher than in the mitigated case. In the latter case, substantial heat is removed through steam generator by secondary feed and bleed. From the calculation results, oxidation starts at CET=900 K. Total oxidation energy of base case and mitigated case is calculated 5.74×10^{10} J and 7.74×10^{10} J, respectively. The difference is attributed to the fact that steam is continuously provided for zircaloy-oxidation reaction by SITs supply in the mitigated case.

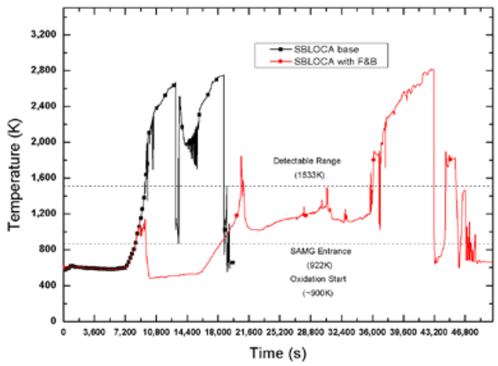

Fig. 2. MELCOR simulation results for CET

4. Application of CET for flow rate calculation

Using Eq. (3), the flow rate required for core heat removal is calculated using MELCOR simulation results. Some assumptions are introduced for calculation. Decay heat is assumed as 30MW at 2 hours following the reactor trip. RCS pressure is assumed as 2 MPa. However, the effect by RCS pressure is negligible for the calculation of flow rate. The injection flow is assumed subcooled at 333 K. The recovery time is also assumed 45 min. The increasing rate of CET is obtained in the range of 900 K to 1,533 K because start point of oxidation heat generation is CET of about 900 K and the maximum detectable CET is 1,533 K in OPR1000. The increasing rate of CET is considered from the base case. The oxidation energy is considered from the mitigated case. In Eq. (2), the oxidation heat calculated (E_{ox}) is considerably conservative because oxidation reaction is considered only within assumed CET range whereas E_{ox} is the value covering all accident periods. Figure 3 shows a resulting flow rate for core heat removal depending on the CET increasing rates. The shaded area indicates the additional flow rate which should be supplied to recover the core state coolable. The suggested methodology is expected to be meaningful for the mitigation strategies in a simple and intuitive way.

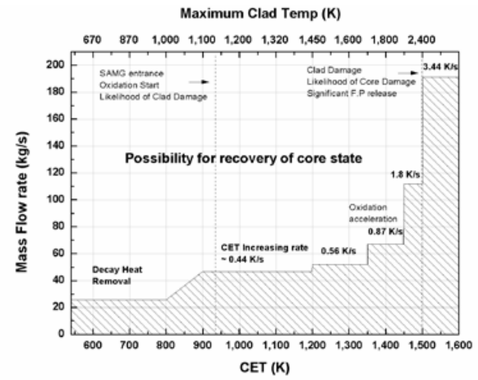

Fig. 3. Necessary flow rate for removal of core heat using CET

5. Conclusions

A simple model of flow rate necessary for core heat removal is developed using CET data obtained from MELCOR simulations of OPR1000. The suggested model is expected to contribute on judging the core state in its coolability and required flow injection due to ease of application. More detailed analyses are needed to normalize by including additional accident scenarios.

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