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Sensitivity Analysis of Core Damage by Loss of Auxiliary Feed Water during the Extended Loss of All AC Power

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1. Introduction

Fukushima accident was caused by long hours of Station Black Out (SBO) caused by natural disaster beyond Design Based Accident (DBA) criteria. It led to the reactor core damage.

After the accident, the regulatory authorities of each country (Japan, US, EU, IAEA, and etc.) recommended developing the necessary systems and strategies in order to cover up the Extended Loss of All AC Power (ELAP) such as one occurred in the Fukushima accident. And the need of procedure or guideline to cope with ELAP has been raised through the stress test for Wolsong Nuclear Power Plant unit 1[1].

Current Emergency Operating Procedures (EOP) used in domestic nuclear power plant are seemed to be insufficient to cope with ELAP. Therefore, it has been required to be improved.

In this study, the reactor core damage time for OPR1000 type Nuclear Power Plant (NPP) was analyzed to develop a strategy to handle ELAP and to apply to the EOP. The reactor core damage time in the ELAP condition was calculated according to the time of Auxiliary Feedwater (AFW) loss.

2. Modeling

Fig. 1 is the nodalization of OPR1000 NPP for the analysis with RELAP5/Mod3.3 code. This model used for the analysis of reactor core damage time based on the time of AFW loss in ELAP condition.

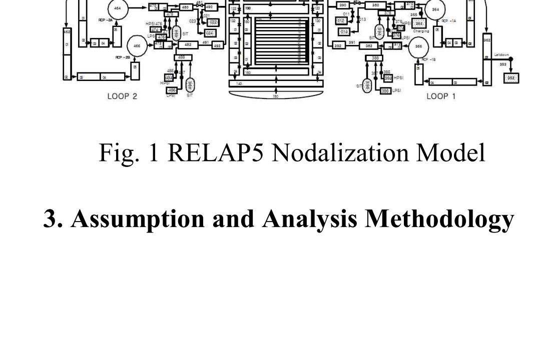

Fig. 1 RELAP5 Nodalization Model

3. Assumption and Analysis Methodology

The methodology of WCAP-17601-P[2] for Combustion Engineering NSSS Designs has been applied to OPR1000 nuclear power plant. ELAP coping time is determined base on the core uncovery with a maximum defined leak rate from the Reactor Coolant Pump (RCP) seals.

In the ELAP condition, the general assumptions for analysis are as follows:

○ Initiating event: Loss of onsite power and offsite power at the same time.
○ Provide auxiliary feed-water to all Steam Generator (SG) symmetrically.
○ Progress to depressurize and cooldown of the Reactor Coolant System (RCS) if the EOP is satisfied.
○ Following instrument power supplies (batteries) are available during the period of analysis.
- Pressurizer level and pressure
- Temperatures in the hot leg and the cold leg
- Steam generator level and pressure

○ Available to control SG Pilot-Operated Relief Valve (PORV) and Turbine-Driven AFW (TDAFW) pump flow (Instrument air injection or manual control).
○ Start cooling down with cooling rate of 75˚F/hr after 2 hours of SBO.
○ Available to use TDAFW pump.
○ In case of OPR1000 nuclear power plant, it has a Controlled Bleedoff System and the amount of seal leakage per RCP is limited to under 15 gpm(3.4 ㎥/hr) because of the operation of flux limit check valve. Based on this, the initial amount of the seal leakage per RCP is assumed to 1 gpm(0.23 ㎥/hr). If the degree of subcooling in the cold leg is lower than 27.8℃(50˚F), the initial seal leakage per RCP is assumed to be increased to 15 gpm(3.4 ㎥/hr).
○ The scenario includes total 6 cases classified by the time of loss of auxiliary feed water after the accident. The loss of auxiliary feed water right after the accident is Case 1, Case 2 is after a half an hour, Case 3 is after an hour, Case 4 is after 2 hours, Case 5 is after 4 hours, and Case 6 is after 8 hours.

4. Analysis Results

It is necessary to secure AFW flow for successful reactor core cooling. Thus, in the early stage of transient, the acceptable time of the feedwater flow interference is required to be quantified. The results of analysis about SG exhausted time, core uncovery time and reactor core damage time after AFW loss on OPR1000 nuclear power plant are shown in Table 1.

Core uncovery time can be defined with a collapsed water level and void fraction. Though the collapsed level go down below the top of fuel, the water could cover up the top as form of two phase flow. Therefore, It is appropriate to determine the core uncovery based on core void fraction.

Core damage time refers to the coping time against ELAP situation. In order to prevent from the core uncovery, it is required to feed water to RCS before the batteries are depleted.

Table 1. SG exhausted time and reactor core damage time in loss of feedwater-OPR1000 nuclear power plant

Case No.		1	2	3	4	5	6
AFW Loss [hr]		0	0.5	1	2	4	8
SG Exhausted [hr]		0.38	1.42	2.45	3.33	5.68	12.4
Core Uncovery	Based on collapse water level	1.10	2.44	3.71	4.95	8.91	16.8
	Based on core void fraction	1.03	2.34	3.60	4.82	8.75	16.7
Core Damage [hr]		1.62	3.05	4.37	5.70	9.78	17.9

Fig. 2 ~ 5 show the changes of steam generator wide range level, core collapsed water level, core void fraction, and fuel cladding temperature respectively.

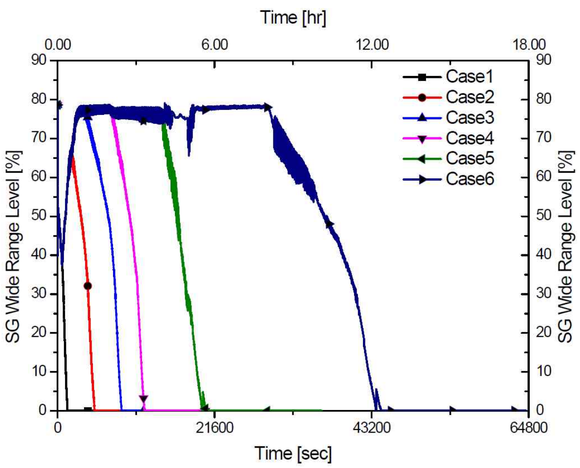

Fig. 2 SG Wide Range Level

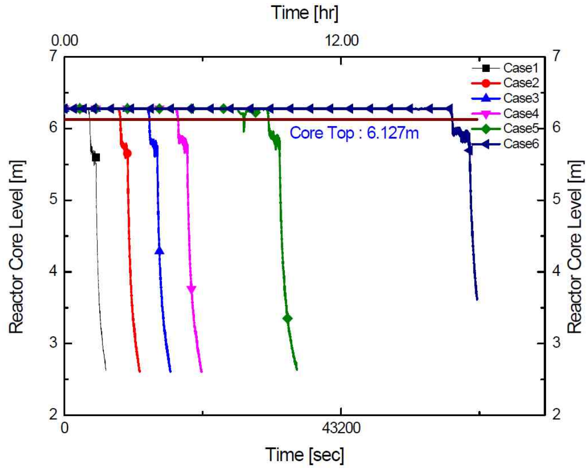

Fig. 3 Core Collapsed Water Level

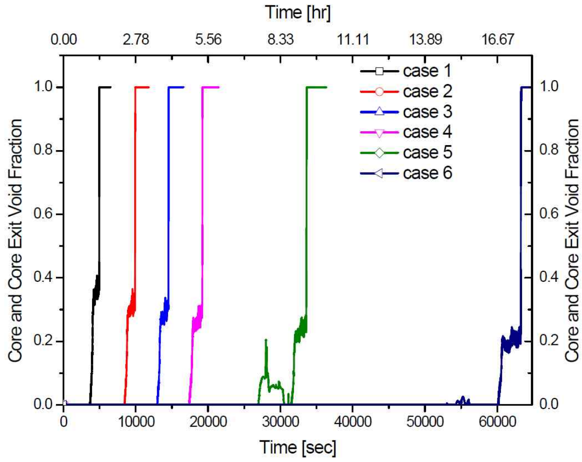

Fig. 4 Core Void Fraction

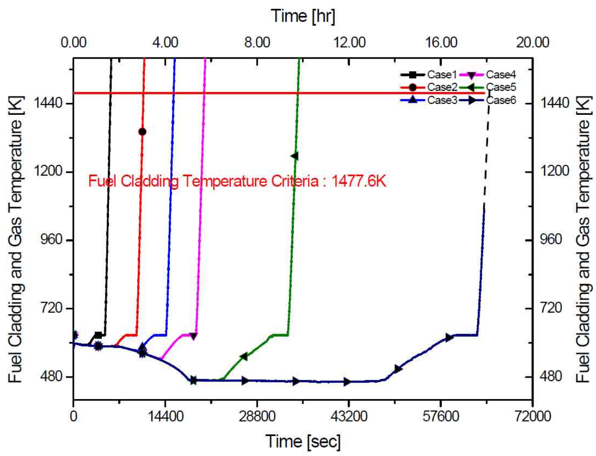

Fig. 5 Fuel Cladding temperature

5. Conclusion

As the result, the time of AFW loss in the ELAP condition influences greatly on core damage time. In other words, the heat removal by the secondary side can play an important role in ensuring the coping time preventing the core damage. It will be possible to use the results of this analysis in the development of coping strategies in the ELAP situation.

REFERENCES

[1] KHNP, Stress Test Report for Wolsong Unit 1, July 2013.
[2] Westinghouse, Reactor Coolant System Response to the Extended Loss of AC Power Event for Westinghouse, Combustion Engineering and Babcock & Wilcox NSSS Designs, WCAP-17601-P Revision 0, August 2012.