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Sensitivity Analysis in Fire PSA on PGSFR

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1. Introduction

A Prototype Generation IV Sodium Fast Reactor (PGSFR) is under design with defense in depth concept with active, passive, and inherent safety features. A fire PSA on PGSFR is done in 2017. The characteristics of the fire PSA on PGSFR are described with a sensitivity study in this paper.

2. Methods

The final result of fire PSA on PGSFR was mainly affected by the following three issues; 1) How to consider the sodium existence in the ignition frequency calculation, 2) Is the ignition frequency developed from the large commercial Nuclear Power Plants(NPPs) suitable for the small PGSFR?, and 3) What is the operator error probability during the Main Control Room (MCR) abandonment ?

2.1 Sodium Existence Factor in Ignition Frequency

Conservatively, the possible sodium fire due to sodium leak was reflected in the fire ignition frequency. Currently, the sodium fire frequency in the PGSFR fire PSA was based on the history data of BN-600. In BN-600, it is known that sodium fire occurred 6 times when sodium leaked 13 times from intermediate cooling pipe during 30 years(1980~2010) [1]. Thus, about 0.2/yr is used for the sodium fire ignition frequency due to sodium leak. Thus, the ignition frequency due to the sodium leak in each fire area, can be derived by checking the length of the sodium piping passing the fire area. For example, the sodium piping line of IHX, ADHRS, and PDHRS are passing the fire area F-C304. And the total length of the sodium piping lines passing the F-C304, is 155.7 m, which is 23 % of the total sodium piping lines of PGSFR. Thus, the sodium fire frequency at fire area F-C304 is 0.046/yr which is 23% of 0.2/yr.

However, we can think the other approach for the sodium fire ignition frequency. That is, we can use the sodium piping leakage rate (3.0E-9/ft/h)[2], to estimate the sodium fire ignition frequency for each compartment. Actually, this method was used for estimating the initiating event frequency of 'Loss of a PDRC train. Anyway, this approach is 3.4 times more optimistic than the previous history data approach.

As the result of the first sensitivity analysis, if we are using the optimistic ignition frequency of sodium leak, the Core Damage Frequency (CDF) can be reduced by 51%.

2.2 Small Reactor Factor in Ignition Frequency

The generic ignition frequencies of the fire areas are calculated by the methodology and data of NUREG-2169[3]. The generic fire ignition frequencies mentioned in Ref. [3] are based on the large commercial NPPs. Since the number of components of PGSFR is much fewer than those of commercial NPPs, it was assumed that the generic fire ignition frequency of PGSFR is proportionally smaller than the large commercial NPPs. The equipment number of PGSFR vs commercial NPPs is 592 vs 1177. Thus, it was assumed that the ignition frequency of PGSFR is smaller by the (592/1177) factor.

However, in the 2nd sensitivity analysis, we checked the effect by using the generic ignition frequency of Ref. [3] without considering the small reactor factor. As the result, the CDF can be increased by 27%.

2.3 Human Error Probability during MCR Fire

MCR fire modeling, MCR abandonment logic, and operator action during MCR fire have a lot of uncertainty.

Actually, PGSFR control room was not in detail designed. Thus, in this study, it is assumed that only two electric cabinets are used as MCR; 1) one cabinet is for DHRS(Decay Heat Removal System), 2) another one is for EPS(Electric Power System)

For MCR fire modeling, FDS[4] is used and the result of the FDS analysis shows that MCR abandonment occurs after 18.7 min. due to the optical density of the smoke is less than 0.3 m^{-1}.

As a similar method suggested in Ref. [5], an evaluation logic for MCR panel fires was set up as shown in Fig. 1.

Ignition: As assumed before, since the console of PGSFR have two electric cabinets, and there are 187 electric cabinets in PGSFR, if the generic ignition frequency (= 3E-2/yr) is used for the electric cabinets, the fire ignition frequency for the console is;

(2/187)*(3E-2) = 3.21E-4/yr

If we are using the small reactor factor,

(592/1177)*(3.21E-4/yr) = 1.61E-4/yr

In Fig, 1, since sequence 3 is the only MCR abandonment case;

$CDF_{(abandon)}$ = (Ignition Freq. in Console)(Prob of Path 3)(Operator's Failure to Use Remote Shutdown Panel)(Failure of Manually Open of PDRC Damper)
= (1.61E-4/yr)*(2.1E-3)(0.1)(0.1)

In Fig, 1, since Sequence 4, 5 are the MCR non-abandonment case;

$CDF_{(No\ abandon)}$ = (Ignition Freq. in Console)(1/2)* (Sequence 5 Freq.) * [CCDP(DHRS) + CCDP(EPS)] + (Ignition Freq. in Console)* (Sequence 4 Freq.)*[CCDP(EPS + DHRS)]

When the probabilities that Operator's Failure to use 'Remote Shutdown Panel' and 'Failure of Manually Open of PDRC Damper' are increased to double, respectively, the CDF increases by 13%.

3. Results and Conclusions

It is unusual that the sodium leak could be one of the ignition sources in the NPPs, and it is very unique factor in PGSFR. Thus, we handled the sodium fire very conservatively. In the sensitivity analysis, even though sodium fire ignition frequency is reduced by 3.4 times, CDF decreases only 51% since the sodium piping line passes through specific fire areas.

Also, if we do not consider the small reactor factor even though PGSFR is a very small reactor, the CDF can be increased by 27%.

The increase of two operator errors during MCR abandonment by double, shows 13% increase of CDF.

Acknowledgement

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REFERENCES

[1] JY Ryu, "Accident cases and accident management plan in SFR", Workshop of KNS spring conference 'Inherent safety of PGSFR' May 2014

[2] Idaho National Engineering Laboratory, Generic Component Failure Data Base for Light Water and Liquid Sodium Reactor PRAs, Informal Report, EGG-SSRE-8875, 1990.

[3] NRC, NUREG-2169, Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database, Jan. 2015

[4] McGrattan, K. et al., "Fire Dynamics Simulator (Version 6.5.2), User's Guide," NIST, 2016.

[5] F. Joglar, G. Ragan, "Modeling Main Control Room Fires", ANS PSA 2013, Sept. 2013, Columbia, SC. USA

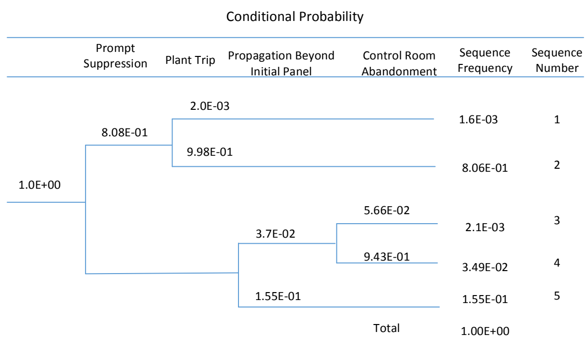

Fig.1 Evaluation Logic for MCR Panel Fires