Estimation of Fire Frequencies in Low Power and Shutdown fire Probabilistic Risk Assessment

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Abstract: In this paper, the method for quantification of fire frequency at LPSD (Low power and shutdown) operation is presented. To reflect system alignment in fire frequency, LPSD period is classified by POS (Plant operating states : classified operation modes at LPSD operation) . Calculation method is divided into two cases depending on whether the unavailable equipment are considered or not. Each methods have opposite characteristics in terms of conservatism and convenience.

Keywords: Fire PRA, Fire frequency, LPSD, POS

1. INTRODUCTION

Fire frequency, in fire PRA (Probabilistic Risk Assessment), is a probability of the fire induced accidents per year in nuclear power plant. Fire frequency is important for performing fire PRA because it takes same role as initiating event frequency in internal event PRA. In spite of this importance, calculation methodology of fire frequency in LPSD (Low power and shutdown) is not clearly defined compared to at-power operation modes although generic data is introduced in EPRI TR-1003111[1]. In this reasons, based on KEPCO E&C's experience in assessing fire PRA and fire frequency, the research on calculating the fire frequency at LPSD about APR1400 is carried out in this paper.

2. METHODOLOGY

2.1. Plant specifics

APR1400 is an advanced pressurized water nuclear reactor with 1400 MW electricity designed by KEPCO E&C. The output of this reactor is 1400 MW. Auxiliary building of APR1400 is divided into four divisions A, B, C and D. Elevations are ranging from 55ft to 190ft with 8 floors. There is a turbine building with a main generator besides to the auxiliary building and compound building is connected to each auxiliary building of two units. Main transformers and other buildings are located in yard area. Offsite power is supplied from main transformer through two trains of auxiliary transformers. If power supply from auxiliary unit transformer is impossible, power is supplied through stand-by auxiliary transformer of the same train. At-power operation period of the APR 1400 is about 18 months and LPSD period is about 1 month. During LPSD, usually maintenance of A trains are conducted priory and B trains are conducted after A trains. During LPSD, online maintenance is not carried out.

2.2. Calculation of fire frequency

Fire frequency is calculated as below equation.[2]

$$\lambda_{IS,J} = \lambda_{IS}\, W_L\, W_{IS,J,L} \qquad (1)$$

$\lambda_{IS,J}$: $Fire\ frequency\ of\ ignition\ source\ IS\ in\ location\ J$
λ_{IS} : $Plant-level\ fire\ frequency\ associated\ with\ ignition\ source\ IS$
W_L : $Location\ weighting\ factor\ associated\ with\ the\ ignition\ source$
$W_{IS,J,L}$: $Ignition\ source\ weighting\ factor\ reflecting\ the\ quantity\ of\ the\ ignition$

λ_{IS} is a generic fire frequency of 'IS' type ignition source in location 'J' which is introduced in EPRI TR-100311. W_L is considered when two or more reactors share one area. W_L has the same value as the number of reactors sharing the area. For example, when calculating fire frequency for a compartment in compound building, W_L has value of 2 because compound building is shared by two reactors. $W_{IS,J,L}$ is calculated by division of number of ignition sources in compartment by number of ignition sources in all locations. If there are 3 batteries in compartment and 10 batteries in all locations, $W_{IS,J,L}$ is 0.3

LPSD operation is occurred during maintenance and refueling outage. In this paper, LPSD is defined as period for maintenance and refueling outrage. λ_{IS}, referred in above equation, is obtained by dividing the number of fire events occurred during the LPSD operation into duration of LPSD operation period. To convert this to the value for entire operation period, following equation has to be applied additionally.

$$\lambda_{IS,J,LPSD} = \lambda_{IS,J} \times T_{LPSD} \qquad (2)$$

T_{LPSD} : $Outrage\ fraction\ , = \frac{Reactor\ years\ for\ LPSD\ operation}{Reactor\ years\ for\ At-power\ and\ LPSD\ operation}$

$\lambda_{IS,J,LPSD}$: $Plant-level\ fire\ frequency\ associated\ with\ ignition\ source\ IS\ in\ LPSD$

Outrage fraction T_{LPSD} is the ratio of LPSD duration to total operation period. In this paper, outrage fraction is assumed to 0.05.

2.3. POS definition

LPSD is defined as for maintenance and refueling outage period. During outage, some equipment alignment of system configuration are changed depending on operation modes because of reactor core reload or test and maintenance. PRA quantification has to be performed per each system configurations because PRA result is changed depending on system configuration. In this reason, various operation modes are considered for LPSD PRA while only one operation mode is considered in at-power PRA. And these operation modes have to be classified in terms of system configuration and equipment alignment because shifted alignments. Based on these classification tasks, plant operation during LPSD is separated to 18 operation modes. These classified operation modes are defined as POS (Plant Operating States). In this paper, 6 POS are considered for analysis as shown in the table 1 below.

Table 1: POS Classification

POS NO.	Duration(hr)	Description
3B	37.6	Cooldown with Shutdown Cooling System to 140 ºF
4A	1.3	Reactor Coolant System drain-down (pressurizer manway closed)
4B	20.3	Reactor Coolant System drain-down (pressurizer manway open)
5	16.8	Reduced Inventory operation and nozzle dam installation
6	54.9	Fill for refuelling
10	85.7	Reactor Coolant System drain-down to Reduced Inventory after refuelling

POS 7, POS 8 and POS 9 are not considered in fire PRA because occurrence of core damage is impossible since fuel is off from the core. POS 12B, refill of the RCS after refueling with the pressurizer manway closed, is screened quantitatively from the average shutdown model based on a thermal-hydraulic analysis. The analysis assumes the time to core damage is greater than 24 hours after a loss of shutdown cooling. Other remaining POS (POS 1 to 3A and 11 to 15) are excluded since there are no maintenance which is most important factor in this analysis. At each POS in LPSD operation, alignment of systems and the equipment are changed. For example, a pump in stand-by state at POS 'A' may be out of service at POS 'B'. It may be assumed that the equipment which are in unavailable conditions are not likely to ignite because they are de-energized. This may affect to fire frequency of all fire compartments. In this reason, fire frequencies are calculated for each POS respectively.

The method for calculating fire frequencies for each POS is shown in the equation below.

$$\lambda_{POS-IS,J} = T_{POS} \times \lambda_{IS,J,LPSD} \quad (3)$$

$\lambda_{POS-IS,J}$: Plant-level fire frequency in specific POS

T_{POS} : POS duration fraction, $= \frac{Duration\ of\ POS}{Duration\ of\ overall\ LPSD\ operation}$

$\lambda_{IS,J,LPSD}$: Plant-level fire frequency associated with ignition source IS

$\lambda_{POS-IS,J}$ is the fire frequency of ignition source 'IS' in the location 'J' at the specific POS. T_{POS}, the POS fraction, is calculated by dividing duration of a particular POS into total LPSD operation period. If LPSD operation period is 100hr and duration of POS'A' is 10hr, T_{POS} is 0.1. $\lambda_{IS,J,LPSD}$ is the fire frequency of ignition source 'IS' at the location 'J' at the all LPSD operation period.

2.4. Applying unavailable equipment for fire frequency

In the LPSD operation, states of the equipment is changed according to POS because of de-energization for maintenance. In this paper, since they are more likely to temporary ignition sources than fixed ignition sources, it is assumed that they are not included in fixed ignition sources. In this case, the result of the fire frequency calculation is varied depending on whether these equipment are included in the calculation formula of the fire frequency or not. This is because $W_{IS,J,L}$, Ignition source weighting factor, is calculated in the following manner during the calculation of the fire frequency.

$$W_{IS,J,L} = \frac{N_J}{N_L} \quad (4)$$

N_J : Number of ignition source in compartment J

N_L : Number of ignition source in location

N_J is the number of ignition sources 'IS' in the fire compartment 'J'. N_L is the number of ignition sources 'IS' in the all location. Increased number of N_L reduces fire frequencies of fire compartments where 'IS' type ignition sources exist.

In this paper, fire frequency analysis was performed by dividing the calculation method into two cases depending on whether de-energized equipment are included in N_L or not.

First calculation method is to holding N_L as fixed-value. In the other hand, in second case, calculates the fire frequency excluding the equipment in maintenance. For example, if there are 100 pumps in all location and 10 of these pumps are in maintenance, N_L is 100 for case 1 and 90 for case 2.

3. ANALYSIS RESULT

3.1. Target fire compartment : Diesel Generator Area

Diesel Generator Areas were selected as target fire compartment where arrangement of diesel generator is changed depending on POS. There are four sources of diesel generators in the plant. 1E diesel generators A and B are located in Diesel Generator Area A and B at auxiliary building respectively. Except diesel generator, there are electric cabinets and air handling units as ignition source in Diesel Generator Area. Diesel generator A is in maintenance at POS 10, and diesel generator B is in maintenance at POS 3B to POS 6.

3.2. First method : fixed value of ignition sources

In this case, fire frequency at diesel generator area was calculated with fixed N_L as 4 per all POS. The results are shown in the table 2 below.

Table 2: Calculation Result of fixed value of ignition sources-method

Unit : per year

POS	DG Room				N_L	$N_{train\ A}$	$N_{train\ B}$
	Train A	Equipment State	Train B	Equipment State			
3B	2.68E-05	Standby	5.09E-06	Maintenance	4	1	0
4A	9.28E-07	Standby	1.76E-07	Maintenance	4	1	0
4B	1.45E-05	Standby	2.75E-06	Maintenance	4	1	0
5	1.20E-05	Standby	2.28E-06	Maintenance	4	1	0
6	3.92E-05	Standby	7.44E-06	Maintenance	4	1	0
10	1.16E-05	Maintenance	6.12E-05	Standby	4	0	1

Fire frequencies are same for Diesel generator area A and B at POS 3A, 11, 12A and 13 when Diesel generator A and B are all stand-by. At remaining POS in which one train of diesel generator is in maintenance, fire frequencies for each diesel generator areas are different.
With this fixed-value of ignition source method, fire frequency is low because N_L which is denominator at fire frequency equation, is slightly lower than actual number of ignition sources. However, since consistent value of N_L is used without POS classification, it is more convenient to calculate fire frequencies for each POS.

3.3. Second method : excluding equipment in maintenance

In this method, N_L is available depending on unavailable equipment. In POS 3B to 10, when one of diesel generator is in maintenance, N_L is 3 instead of 4. The results for diesel generator areas are shown in the table 3 below.

Table 3: Calculation Result of excluding equipment in maintenance-method

Unit : per year

POS	DG Room				N_L	$N_{train\ A}$	$N_{train\ B}$
	Train A	Equipment State	Train B	Equipment State			
3B	3.40E-05	Standby	5.09E-06	Maintenance	3	1	0
4A	1.18E-06	Standby	1.76E-07	Maintenance	3	1	0
4B	1.84E-05	Standby	2.75E-06	Maintenance	3	1	0
5	1.52E-05	Standby	2.28E-06	Maintenance	3	1	0
6	4.97E-05	Standby	7.44E-06	Maintenance	3	1	0
10	1.16E-05	Maintenance	7.76E-05	Standby	3	0	1

In this method, it can be confirmed that the fire frequencies of diesel generator areas are slightly increased since diesel generator in maintenance is not included in denominator N_L.

This method provides conservative fire frequencies. On the other hands, need more effort for calculation because N_L is varied per each POS.

4. Conclusion

In this paper, calculation of fire frequency for LPSD fire PRA is performed with introducing POS conception. When considering POS, there are unavailable equipment especially those under maintenance. The method of reflecting these equipment for the fire frequency calculation and not reflecting method were compared and their advantages and disadvantages were identified. As a result of comparison, it is found that accuracy of the fire frequency is somewhat reduced but analysis process becomes more convenient while reflecting unavailable equipment to fire frequency calculation. On the other hands, conservative result is deduced and analysis process becomes less convenient while excluding unavailable equipment from fire frequency calculation.

Among above calculation methods, fixed value of ignition sources-method looks more suitable for calculating fire frequency since applying same number of ignition sources as at-power analysis make it easy to analyze for all POS. However, if the number of unavailable equipment are more than the example in this analysis, the conservatism of another case, excluding equipment in maintenance-method, may be highlighted. So further consideration and study should be given to determine which of above two methods is more appropriate.

References

[1] *"Fire Events Database and Generic Ignition Frequency Model for U.S. Nuclear Power Plants"*, EPRI, Palo Alto, CA: 2001. 1003111.

[2] *"Fire-Induced Vulnerability Evaluation (FIVE)"*, EPRI, Palo Alto, CA: 1992. TR-100370