A New Initiating Event Frequency Unit for Multi-Unit PSAs

Jae Won Lim [a], Jung Kuk Song [a], Beom Soek Kim [b], Dae In Choi [b], Bub Lin Kim [b], Seong Kyu Park [b*]
[a]*KEPCO E&C, 269, Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660, Korea*
[b]*Nuclear Engineering Services & Solutions, 1305, U-Tower, Dongchendong, Yongin-shi, Kyeonggi-do, 16827, Korea*
[*]*Corresponding author: sparkpsa@ness.re.kr*

1. Introduction

So far, a few of multi-unit probabilistic safety assessments (MUPSAs) [1, 2] have been performed in Korea. In most cases, MUPSAs have been focused on multi-unit initiators or common cause initiators such as seismic event and multi-unit loss of off-site power (MULOOP). However, among PSA practitioners, there has been some confusion for the initiating event frequency unit applicable for MUPSAs. In this paper, a new initiating event frequency unit is suggested and its applications are described. Also, the conversion of MUPSA initiating event frequency into SUPSA initiating event frequency is described in a consistent manner.

2. A New Initiating Event Frequency Unit Suggestion for MUPSAs

During performing MUPSAs in Korea, site-year has been mentioned as an initiating event frequency unit for MUPSAs. However, there have been some difficulties to keep consistency for initiating event frequency unit with single unit PSAs (SUPSAs).

To resolve this issue, as a new initiating event frequency unit for MUPSAs, "n-unit-ry" is suggested in this paper where n means total number of unit in the site. This unit just means reactor-year that n units are exposed to initiators simultaneously in the site. This new unit is derived, based on the idea that the site year doesn't have the same meaning if the number of units in the site is different.

With the concept of the new initiating event frequency unit for MUPSA, the following equation can be derived.

$$\text{m-unit-ry} = (m/n)*f \ \text{n-unit-ry} \qquad \text{(Eq. 1)}$$

where, n is the total number of units in the site

m is the number of units impacted by a specific initiator

f is the ratio of total exposure time of individual units for MUPSA initiator frequency calculation to total actual exposure time for all the units in the site

For the SUPSAs application, the equation below can be used.

$$\text{n-unit-ry} = (n/m)*g \ \text{1-unit-ry} = (n/m)*g \ \text{ry} \qquad \text{(Eq. 2)}$$

where, g is the total number of SUPSAs divided by n

3. Applications

To confirm applicability of the new initiating event frequency unit for MUPSAs and to show the consistency with SUPSAs, a virtual nuclear site is assumed. The site has 6 units at the present time. Two units (U1, U2) started commercial operation 30 years ago, another two units (U3, U4) started commercial operation 20 years ago, and the other two units (U5, U6) started commercial operation 10 years ago. The site operation information is illustrated in the Fig. 1 below.

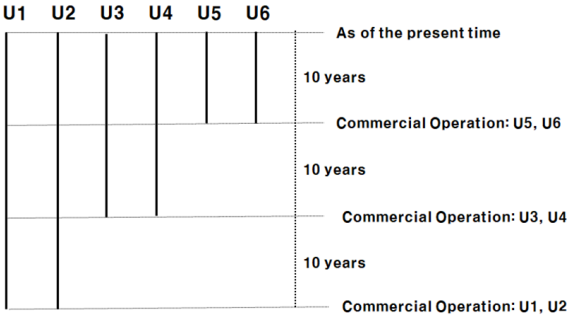

Fig. 1. A virtual nuclear site with operation experience

Four cases below are examined for confirming the applicability of the new initiating event frequency unit for MUPSAs and for showing the consistency with SUPSAs.

Case 1:
- 1 single-unit-LOOP during the first decade
- 1 single-unit-LOOP during the second decade
- 3 single-unit-LOOPs during the third decade

Case 2:
- 1 six-unit-LOOP during the third decade

Case 3:
- 1 two-unit-LOOP during the third decade

Case 4:
- 1 four-unit-LOOP during the third decade

For case 1, because single-unit-LOOP can occur in any units, the total exposure time for single-unit-LOOP for MUPSAs is as follows.

Total exposure time for single-unit-LOOP for MUPSAs
= 30 1-unit-ry (for Unit 1)
+ 30 1-unit-ry (for Unit 2)
+ 20 1-unit-ry (for Unit 3)
+ 20 1-unit-ry (for Unit 4)
+ 10 1-unit-ry (for Unit 5)
+ 10 1-unit-ry (for Unit 6)
= 120 1-unit-ry

Therefore, the frequency of single-unit-LOOP for case 1 in the aspect of 1-unit-ry is as follows.

5 single-unit-LOOP / 120 1-unit-ry
= 4.17E-2 single-unit-LOOP / 1-unit-ry

Because total exposure time for MUPSA initiator frequency calculation and the total actual exposure time are the same, f is 1.0. Therefore, the frequency of single-unit-LOOP for case 1 in the aspect of 6-unit-ry is as follows.

4.17E-2 single-unit-LOOP / (1/6)*1 6-unit-ry
= 2.50E-1 single-unit-LOOP / 6-unit-ry

In an MUPSA, single-unit-LOOP can be modeled in some selected units for modeling convenience. If it is modeled in all the six units, the frequency for each unit is a sixth of the calculated frequency because the frequency should be allocated to 6 units (i.e. 4.17E-2 / 6-unit-ry). If it is modeled in the selected two units, the frequency for each unit is an half of the calculated frequency because the frequency should be allocated to two units (i.e. 1.25E-1 / 6-unit-ry).

For SUPSAs application, the frequency for an individual unit is as follows by (Eq. 2).

2.50E-1 single-unit-LOOP / 6-unit-ry
= 2.50E-1 single-unit-LOOP / (6/1)*(6/6) ry
= 4.17E-2 single-unit-LOOP / ry

This frequency is the same as the one for MUPSAs which models single-unit LOOP in all the units in the site.

For case 2, the total exposure time for six-unit-LOOP for MUPSAs is 10 6-unit-ry (during the third decade).

Therefore, the frequency of six-unit-LOOP for case 2 in the aspect of 6-unit-ry is as follows.

1 six-unit-LOOP / 10 6-unit-ry
= 1.00E-1 six-unit-LOOP / 6-unit-ry

In MUPSAs, six-unit-LOOP should be modeled for all the units in the site, so the calculated frequency should be directly applied to each unit.

For SUPSAs application, the frequency for an individual unit is as follows by (Eq. 2).

1.00E-1 six-unit-LOOP / 6-unit-ry
= 1.00E-1 six-unit-LOOP / (6/6)*(6/6) ry
= 1.00E-1 six-unit-LOOP / ry

This frequency is the same as the one for MUPSAs which models six-unit LOOP in all the units in the site.

Because there have been no LOOPs during the first two decades, 30 6-unit-ry can be used as the total exposure time for six-unit-LOOP in the engineering aspect.

For case 3, if the two-unit-LOOP can occur only with the unit combination of (U1, U2), (U3, U4), and (U5, U6), the total exposure time for two-unit-LOOP for MUPSAs is as follows.

Total exposure time for two-unit-LOOP for MUPSAs
= 30 2-unit-ry (for Unit 1 and 2)
+ 20 2-unit-ry (for Unit 3 and 4)
+ 10 2-unit-ry (for Unit 5 and 6)
= 60 2-unit-ry

Therefore, the frequency of two-unit-LOOP for case 3 in the aspect of 2-unit-ry is as follows.

1 two-unit-LOOP / 60 2-unit-ry
= 1.67E-2 two-unit-LOOP / 2-unit-ry

Because total exposure time for MUPSA initiator frequency calculation and the total actual exposure time are the same, f is 1.0. Therefore, the frequency of two-unit-LOOP for case 3 in the aspect of 6-unit-ry is as follows.

1.67E-2 two-unit-LOOP / (2/6)*1 6-unit-ry
= 5.00E-2 two-unit-LOOP / 6-unit-ry

In an MUPSA, two-unit-LOOP can be modeled in some selected combination of units for modeling convenience. If it is modeled in the U1 and U2 combination only, the frequency for each unit is the same as the calculated frequency for MUPSA because the frequency should be allocated to only one unit combination of U1 and U2 (5.00E-2 / 6-unit-ry). If it is modeled in all the three unit combinations, the frequency for each unit is a third of the calculated frequency for MUPSAs because the frequency should be allocated to three combinations (1.67E-2 / 6-unit-ry).

For SUPSAs application, the frequency for an individual unit is as follows by (Eq. 2).

5.00E-2 two-unit-LOOP / 6-unit-ry
= 5.00E-2 two-unit-LOOP / (6/2)*(6/6) ry
= 1.67E-2 two-unit-LOOP / ry

This frequency is the same as the one for MUPSAs which models two-unit LOOP in three unit combinations in the site.

For SUPSAs application for only two units, the frequency for an individual unit is as follows by (Eq. 2).

5.00E-2 two-unit-LOOP / 6-unit-ry
= 5.00E-2 two-unit-LOOP / (6/2)*(2/6) ry
= 5.00E-2 two-unit-LOOP / ry

This frequency is the same as the one for MUPSAs which models two-unit LOOP in only one unit combination in the site.

For case 4, if the four-unit-LOOP can occur only with the unit combinations of (U1, U2, U3, U4), (U1, U2, U5, U6), and (U3, U4, U5, U6), the total exposure time for four-unit-LOOP for MUPSAs is as follows.

Total exposure time for MUPSAs
= 20 4-unit-ry (for Unit 1,2,3, and 4)
+ 10 4-unit-ry (for Unit 1,2,5, and 6)
+ 10 4-unit-ry (for Unit 3,4,5, and 6)
= 40 4-unit-ry

Therefore, the frequency of four-unit-LOOP for case 4 in the aspect of 4-unit-ry is as follows.

1 four-unit-LOOP / 40 4-unit-ry
= 2.50E-2 four-unit-LOOP / 4-unit-ry

The total exposure time for MUPSA initiator frequency calculation is 160 yr as shown below;

Unit 1 30 year (10 x 2 + 10)
Unit 2 30 year (10 x 2 + 10)
Unit 3 30 year (10 x 2 + 10)
Unit 4 30 year (10 x 2 + 10)
Unit 5 20 year (10 + 10)
Unit 6 20 year (10 + 10)

The relevant actual total exposure time is 100 yr as shown below;

Unit 1 20 year
Unit 2 20 year
Unit 3 20 year
Unit 4 20 year
Unit 5 10 year
Unit 6 10 year

Hence, f is 100 yr / 160 yr = 0.625

Therefore, the frequency of four-unit-LOOP for case 4 in the aspect of 6-unit-ry is as follows.

2.50E-2 four-unit-LOOP / (4/6)*(0.625) 6-unit-ry
= 6.00E-2 four-unit-LOOP / 6-unit-ry

In an MUPSA, four-unit-LOOP can be modeled in some selected unit combinations for modeling convenience. If it is modeled in the unit combination of (U1, U2, U3, U4) only, the frequency for each unit is the same as the calculated frequency for MUPSAs because the frequency should be allocated only to one unit combination. If it is modeled in the unit combinations of (U1, U2, U3, U4), (U1, U2, U5, U6), and (U3, U4, U5, U6), the frequency for each unit is a third of the calculated frequency for MUPSAs because the frequency should be allocated to the three unit combinations.

For SUPSAs application, the frequency for an individual unit is as follows by (Eq. 2).

6.00E-2 four-unit-LOOP / 6-unit-ry
= 6.00E-2 four-unit-LOOP / (6/4)*(6/6) ry
= 4.00E-2 four-unit-LOOP / ry

This frequency is easily confirmed by the 4 LOOP events during 100 ry (20yr + 20yr + 20 yr + 20 yr + 10 yr + 10 yr) which was used for MUPSAs initiator frequency calculation.

6. Conclusions

In this paper, as a new initiating event frequency unit for MUPSAs, "n-unit-ry" is suggested. With the underlying concept of the new unit, the following equation was derived.

$$\text{m-unit-ry} = (m/n)*f \ \text{n-unit-ry}$$

For the SUPSAs application, the equation below can be used.

$$\text{n-unit-ry} = (n/m)*g \ \text{ry}$$

Some practical applications were evaluated by applying the newly suggested initiating event frequency unit for MUPSAs. It was confirmed that it can be consistently applicable to MUPSAs and easily converted to initiating event frequency for SUPSAs. It is suggested that from now on, the new initiating event frequency unit for MUPSAs be applied to MUPSAs in the future for maintaining consistency in the initiator frequency unit for MUPSAs and SUPSAs.

REFERENCES

[1] KHNP, Multi-unit PSA for Kori-Saeul Site, 2022.

[2] KAERI, Development of Site Risk Assessment & Management Technology including Extreme External Events, 2017.