THE PSA BASED DEFENSE IN DEPTH EVALUATION OF INNOVATIVE SMR FOR THE DESIGN IMPROVEMENT

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EXTENDED ABSTRACT

The concept of defense in depth (DID) is the basic philosophy of a nuclear power plant (NPP) design and also plays the most important role in confirming safety when various issues or changes in design occur. Basically, the evaluation of DID for a NPP was performed qualitatively such as checklist.

Since it is difficult to exclude the subjectivity of the evaluator in such a qualitative evaluation, uncertainty or errors in the evaluation results are likely to occur. Recently, a DID evaluation method has been developed that combines the abstract DID concept of IAEA INSAG-10 [1] with PSA.

This paper applies this DID evaluation methodology to improve the design of a newly developed innovative small and medium-sized reactor (iSMR) [2]. The iSMR is designed to have an integrated pressurized water reactor-based core and steam generator, and is installed on site in a modular manner to produce sufficient electrical power.

The purpose of this study is to identify the weakness in the early design of iSMR and suggest alternatives for the design improvement by applying the developed quantitative DID evaluation method. The analysis results showed that the iSMR design has a well-balanced defense-in-depth structure but also it has weaknesses in the early design, which need improvement in response to some initiating events as shown in the Table 1 and Figure 1.

The reliability of each DID level of iSMR as shown in Table 1 can be obtained according to the DID reliability evaluation method of the referenced literature [2]. DID level 1 and 2 are related with initiating event of level 1 PSA. In general, DID level 1 can be interpreted as the root cause of an initiating event and DID level 2 as the prevention/mitigation of the root cause. Since the iSMR is in the conceptual design stage and also there is little available data, DID level 1 and 2 was evaluated using the geometric mean for the initial event. DID level 3 represent the prevention/mitigation of the initiating event occurred. In most of the NPP designs, they have redundant and independent safety system to prevent the initiating event. So, it needs to make detailed analysis for each safety system for the DID level 3. DID3.1 and DID3.2 in the table and the figure represent the detailed safety systems for the DID level 3, which represent emergency core cooling system and passive auxiliary feedwater system respectively. DID3.1 and DID3.2 were calculated using the accident sequence analysis results in terms of event tree and related system fault tree of the PSA model.

TABLE I. Reliability of DID level for early design of iSMR

No.	Initiating Event Name	IE freq.	DID1	DID2	CDF3.1	DID3.1	CDF3.2	DID3.2
1	%GTRN	5.55E-01	0.745117	0.745117	4.17E-05	7.51E-05	2.99E-08	7.17E-04
2	%ISLOCA	5.29E-09	7.27E-05	7.27E-05	5.29E-09	1.00E+00	7.80E-11	1.47E-02
3	%LOCA-CHGINCV	4.10E-04	0.020248	0.020248	4.10E-04	1.00E+00	1.08E-07	2.63E-04
4	%LOCA-CHGOUCV	1.75E-05	0.004183	0.004183	2.53E-09	1.44E-04	2.16E-11	8.55E-03
5	%LOCA-EDV	6.48E-04	0.025456	0.025456	6.48E-04	1.00E+00	9.46E-10	1.46E-06
6	%LOCA-ERV	7.20E-05	0.008485	0.008485	7.20E-05	1.00E+00	1.89E-08	2.63E-04
7	%LOCA-LDINCV	4.10E-04	0.020248	0.020248	4.10E-04	1.00E+00	1.08E-07	2.64E-04

8	%LOCA-LDOUCV	2.50E-06	0.001581	0.001581	3.61E-10	1.44E-04	1.87E-13	5.18E-04
9	%LODC-LOCA	8.28E-04	0.028775	0.028775	8.28E-04	1.00E+00	1.21E-09	1.46E-06
10	%LOOP	2.52E-02	0.158745	0.158745	4.41E-06	1.75E-04	3.00E-09	6.80E-04
11	%LSSB-INCV	2.85E-04	0.016882	0.016882	2.33E-06	8.16E-03	1.23E-09	5.29E-04
12	%LSSB-MSIVDOWN	5.44E-03	0.073756	0.073756	3.72E-07	6.84E-05	3.73E-10	1.00E-03
13	%LSSB-OUCV	1.16E-03	0.034059	0.034059	9.47E-06	8.16E-03	2.51E-09	2.65E-04
14	%RCSLOCA	8.90E-04	0.029833	0.029833	8.90E-04	1.00E+00	2.36E-07	2.65E-04
15	%SGTR	1.78E-03	0.04219	0.04219	1.35E-07	7.56E-05	1.71E-10	1.27E-03
16	%SUPP	1.64E-02	0.128062	0.128062	1.23E-06	7.51E-05	1.14E-09	9.28E-04

Using the DID measures developed in the reference [2], one can make a figure which shows overall DID structure of an NPP as shown in the Figure 1. X axis represents the DID strength for each DID level and Y axis represents initiating event considered in the PSA. Also, each color means different DID level by which one can find whole failed DID level and its strength. Through the quantitative DID evaluation of the early design of iSMR, it can be intuitively understood that the strength of DID3.1 in some initiating events should be improved to strengthen the overall DID strength, and also since most of initiating events have a high frequency due to the use of generic data, a method to lower this frequency should be considered when applying it to iSMR design.

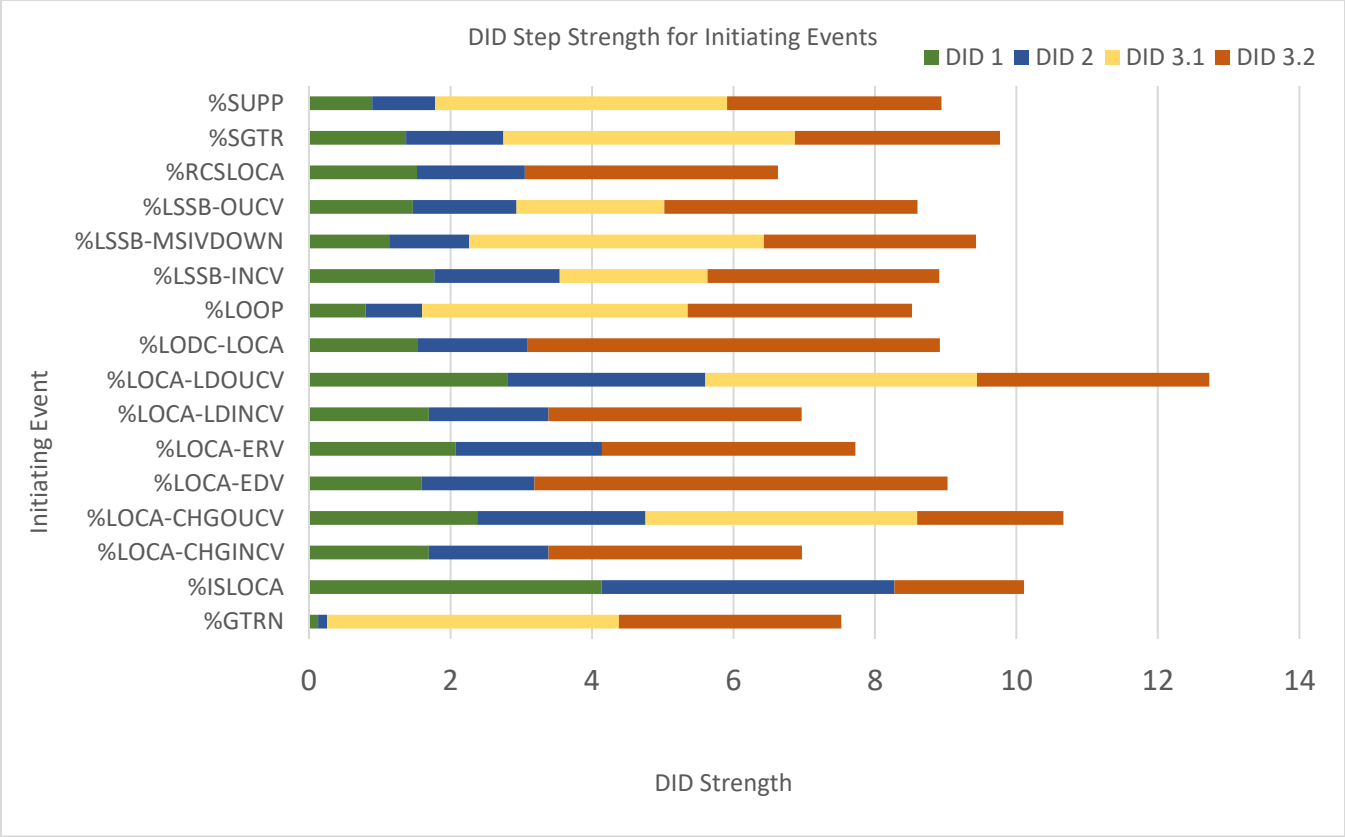

FIGURE 1. DID strength and failure number

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REFERENCES

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