Consideration on the Fire PSA Maturity and Realism

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1. Introduction

A hazard from internal fire occurred in nuclear power plants (NPPs) has been received a great attention. For this reason, since early 2000s, a lot of fire PSAs have been performed for enhancing the safety of domestic NPPs. But, due to lack of information and/or expertise, a number of early industry-sponsored fire PSAs have been characterized as being less mature and less realistic than internal events.

N. Siu, who engages in USNRC, addressed up-to-date maturity and realism in U. S. fire PSA, and suggested a number of questions whose answers will likely be useful in planning future activities [1]. In this paper, similarly, we'd like to touch upon the degree of maturity and the insight about realism primarily through identification of quantitative results of current Korean fire PSAs. Furthermore, rather than attempting to solve the problems on the maturity and realism of current fire PSA, this paper examines the licensee' implementations underway to resolve the technical issues.

2. On the Maturity of Fire PSA

In a dictionary, maturity means the state of having reached a stage of full or advanced development. A maturity model is a widely used technique that is proved to be valuable to assess certain phenomena or processes.

For example, maturity is, in a nuclear field, a question of how appropriately to use something related well in various regulatory decision making. It also expresses the analyst's, as well as public, confidence. Judging the maturity of a technical field is a subjective matter, being dependent on the judgment of the assessor.

For each area, a set of analysis activities are established, whose level of refinement depends on the aimed maturity level. Specifically, we should identify what level of analysis is possible, what is happening in the field, and what is needed to fill the technical gaps. We should also tie the notion of maturity to the number of experienced practitioners performing fire PSAs.

If we apply three practical indicators for judging technical maturity, i.e. practitioners, research agenda, and applications, as categorized in Ref. [1], to our experience in developing and applying fire PSA methods, models, and guidance, it appears to us that fire PSA of NPPs is: a) in an intermediate stage of development (except the indicator for practitioners), and b) less developed than internal event PSA.

Most of fire PSA in Korea have been performed utilizing EPRI Fire PRA Implementation Guide [2]. Regarding the quantification of core damage frequency (CDF), when we compare this methodology with new one, such as NUREG/CR-6850 [3], it seems that there are some gaps in terms of maturity and/or realism. In terms of maturity, we can identify some deficiencies of current fire PSA in the following areas:

- Circuit failure mode and likelihood analysis
- Post-fire human reliability analysis
- Severity factor determination in fire modeling, etc.

3. On the Realism of Fire PSA

Fire PSA, as with other PSAs in general, is aimed at identifying risk-significant scenarios and quantifying their likelihoods and consequences. In principle, it can address fire scenarios with a wide range of consequences (e.g., various stage of plant damage). Potentially important fire scenarios are identified primarily through conservative evaluation, and passed on to more detailed analysis stage if they meet certain screening criteria.

Realism addresses, in a nuclear field, degree to which an analysis represents the current state of knowledge relevant to a decision problem. It is, for example in a PSA context, a question of how well various actual incident scenarios can be evaluated. Even though we have some freedom on how to model certain phenomena or processes in PSA, the choice of a specific assumption or a particular approximation may influence its result. Also, it is questionable that the overall results of the analysis be sufficiently realistic for the purposes of the study. Therefore, to address the assumptions in view of sensitivity analysis and make judgments as to their appropriateness could enhance the realism of any PSA studies.

Quantitative problem related to the realism depends on whether plant walkdown, operators' interview, adoption of best-estimate analysis, and reflection of operating events are well done, or not.

In this section, we look at the topic from a number of angles: the summary and detailed outputs of past and recent fire PSAs, and up-to-date changes in terms of methods, models, and data for fire PSA.

3.1 Fire CDF estimates

Table I gives overall CDF estimates from recent fire PSAs, which was almost performed for the legal requirement on accident management program (AMP) of all domestic NPPs [4]. Sometimes, it was partly

revised since 2019. The total CDF here is the sum of internal CDF and external events' CDF at full power operation for each NPP. External events include seismic, internal fires, and internal flooding. It is noted that, if seismic PSA of Kori 2 unit and Hanul 1&2 units were provided to current AMP results, the average fire contribution to total CDF, as given in Table I, would be slightly decreased.

Table I: CDF estimates from recent fire PSAs

Sample size (in Korea)	26 units
Submittal dates	2019-2021
Avg. reported fire CDF (1/yr)	1.11E-06
Min. reported fire CDF (1/yr)	1.69E-08
Max. reported fire CDF (1/yr)	5.26E-06
Avg. fire contribution to total CDF	17.6 %
Min. fire contribution to total CDF	1.4 %
Max. fire contribution to total CDF	57.2 %

Also, Fig. 1 shows how recent estimates for fire CDF compare against estimates derived from previous analyses. It is based on both results from: a) recently submission for AMP PSA, which represents a value along the X-axis, and b) previously performed PSA mainly for operating license permission, which also shows a value along the Y-axis. The graph indicates that most (almost all) of the fire CDFs have decreased, some by a substantial amount. When we compare the results of past and recent fire PSAs, it seems that current average CDF of all 26 units have been decreased up to 10 times. However, controversy remains over how to judge the degree of the relative values and how to consider reduced uncertainty, and so on.

Even though the AMP analysis are being revised in order to reflect some regulatory perspectives, based on a review of current AMP submittals, it appears that these changes can be attributed to modelling changes, a breakthrough in conservative assumptions, and the incorporation of actual improvements in plant design and operation, including the adoption of mobile provision, i.e. MACST (Multi-barrier Accident Coping Strategy) facilities.

3.2 Important Fire Scenarios

Past studies, taken as a whole, have consistently found that fires resulting from ignition sources of electrical cables and/or cabinets in key plant fire areas, such as main control room (MCR) and emergency switchgear rooms, are significant. Also, some plant studies have shown that turbine building fire and fire inducing MCR abandonment could be important.

However, as mentioned before, quantitative ranking of important fire scenarios will depend on whether as-is plant layout confirmed by plant walkdown, operators' interview, adoption of best-estimate analysis, and reflection of operating events were done, or not.

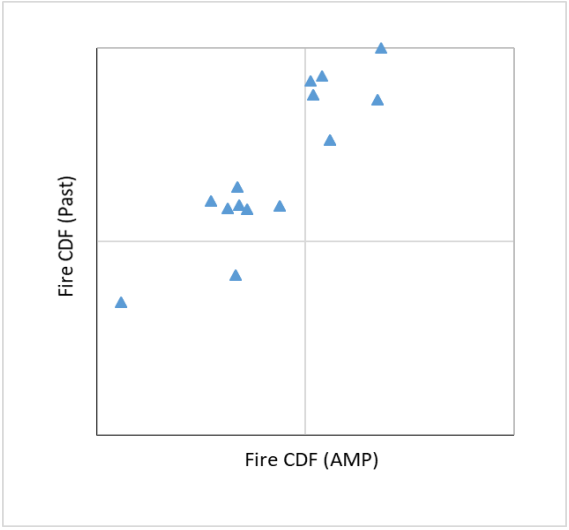

Fig. 1. Comparison of recent and past fire CDFs

4. Issues in Current Fire PSA

In this session, we address some issues arisen mostly from the implementation of AMP PSAs, including its revision, to resolve the regulatory perspectives.

4.1 Quantitative Screening (QNS) Analysis

The ASME/ANS PRA standard [5] states that, if QNS is performed, the fire PSA shall establish adequate QNS criteria [6] to ensure that the estimated cumulative impact of screened-out fire compartments on CDF is small. The standard also requires, as a minimum, to verify the QNS process does not screen the highest risk fire areas.

The licensee would like to meet the minimum requirement of the standard, i.e. Capability Category I of HLR-QNS-C1, and so AMP results are being revised for reflecting this content.

4.2 Estimation of Fire Ignition Frequency

The fire ignition frequency of each fire compartment can be determined according to aspects which can influence the degree of likelihood, e.g., distribution of combustible material, ignition sources, etc.

In performing the AMP PSA, the data of fire ignition frequency adopted from NUREG-2169 study [7], which incorporates fire event experiences in U.S. through the

year 2009. However, because a relative ranking scheme for identifying transient combustibles or activities is very difficult, the licensee has not adopted exact NUREG-2169 data for 3 ignition sources, i.e. transients, cable fires caused by welding & cutting, and transient fires caused by welding & cutting in a specific building. Up to now, the licensee has a plan to recalculate by dividing those ignition sources into all plant-wide areas by specific fire areas.

4.3 Shutdown Fire Risk of Reactor Building

In some NPPs, fire CDF of reactor building during shutdown operation was dominated. But, in another NPPs, fire CDF of that building during shutdown operation was screened-out just reflecting the result of QNS process. This leaves various questions as to whether current quantitative screening criteria are appropriate, analysis assumptions are consistent, or analysis methodologies are standardized.

The licensee would like to provide practical fire CDF values of the reactor building during shutdown operation for the unanalyzed NPP cases.

4.4 Multiple Spurious Operation (MSO) Analysis

The analysis of each fire area identifies all the affected components, either because they failed when performing their active function or they may suffer a spurious operation. Combinations of spurious operation, so called MSOs, in different systems that could affect one or more safety functions, should have been taken into account.

Since 2015, in terms of fire hazard analysis (FHA) in traditional fire protection program, Korean NPPs have been legally driven to identify any potential MSO scenarios.

Typical MSO scenarios' analysis should be done in fire PSA for new NPPs. Meanwhile, for operating NPPs, the licensee has assessed its impact on the representative one with a simplified way, that shows the risk of MSOs lies within the uncertainty boundaries.

5. Concluding Remarks

It seems that our consideration on fire PSA maturity may be heavily influenced by experts' views on the characteristics of a mature technical field. Also, we believe that, in order to promote the maturity, it is necessary to build technical infrastructure in the nuclear field and improve awareness of fire risks.

It is noted that another consideration on fire PSA realism relies heavily on: (1) information provided in recent AMP submittals, (2) detailed information from a set of international and/or domestic studies, (3) risk-informed approach for reducing potential conservatism.

For the endless development and prosperity of fire PSA in Korea, major deficiencies should be found and supplemented from the perspective of maturity and realism, and technical exchanges and cooperation between related experts should be strengthened.

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