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Development of Quantitative Framework for Event Significance Evaluation

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1. Introduction

There is an increasing trend in quantitative evaluation of the safety significance of operational events using Probabilistic Safety Assessment (PSA) technique [1]. An integrated framework for evaluation of event significance has been developed by Korea Institute of Nuclear Safety (KINS), which consists of an assessment hierarchy and a number of matrices [2]. The safety significance of various events, e.g., internal or external initiating events that occurred during at-power or shutdown conditions, can be quantitatively analyzed using this framework, and then, the events rated according to their significance. This paper briefly describes the basic concept of the integrated quantitative framework for evaluation of event significance, focusing on the assessment hierarchy.

2. Integrated Evaluation of Event Significance

An integrated framework for event significance is shown in Fig. 1 in terms of a hierarchical structure. This framework is based on the use of internal-events, at-power Level-1 PSA model, and therefore, the event significance will be quantitatively evaluated if the event is covered by the PSA model. In fact a majority of operational events are caused by internal initiating events during power operation and they affect only the likelihood of core damage without any impact on containment function. Therefore, this PSA model can be usefully used for quantitative evaluation of most operational events.

The integrated framework also includes a number of matrices in tabular form, and the event assessment is actually performed using the matrices although not shown here due to lack of space. These matrices consist of specific evaluation factors and evaluation criteria with the tentative level of event response (ER) and the tentative event significance (ES) given the satisfaction of the assessment criteria included therein [2].

The ER level here means the differentiated regulatory response based on the severity of the event, such as the three levels of event response presently employed by the U.S. NRC, i.e., the Incident Investigation Team (IIT), Augmented Inspection Team (AIT), and Special Inspection Team (SIT) [3].

Each of the six steps in the assessment hierarchy of Fig. 1 is discussed below with the associated blocks.

(1) Radiological Impact − If the event involved certain radiological consequences (on-site or off-site; exposure or release), then the tentative ER level and ES are deterministically assessed using the matrix for radiological impact analysis that was developed using expert opinion of the cognizant KINS staff with relevant information from the open literature, e.g., documentation on International Nuclear Event Scale (INES) of the IAEA [4] and Significance Determination Process (SDP) of the NRC [5].

(2) Internal Initiating Event − Should an internal initiating event (i.e., originating in the plant systems such as a general transient or a small-break loss of coolant accident) occur during power operation, its significance can be quantitatively analyzed using the aforementioned PSA model. In the Phase 3 SDP or Accident Sequence Precursor (ASP) program of the NRC, a plant-specific regulatory PSA model called SPAR model is directly used to analyze the event significance in detail [6].

However, the integrated framework developed in this study is intended to be used in the early stage of event response by KINS and as a result the event significance should be estimated as soon as possible. For the early estimation of ES, a simplified formula was developed in this study to quantify the Conditional Core Damage Probability (CCDP) for the event. This formula has been validated by applying it to several events and then comparing the results with the ones obtained from the ASP approach. As shown in Fig. 1, this step also involves examination of whether the event involved a condition associated with Unplanned Scram with Complications (USwC) [7]. This USwC is a performance indicator recently developed by the NRC, but is applied here to differentiate operational events based on the operational complexity.

(3) Condition Event − The condition of structures, systems, or components (SSCs) often degrades severely reducing defense-in-depth (DID) capability of a nuclear power plant (NPP). Examples include a serious degradation of the reactor pressure vessel head in Davis-Besse NPP several years ago and the unavailability of an emergency diesel generator at another NPP much beyond the allowed outage time in the plant Technical Specifications (i.e., about 28 days). A simplified formula also was developed to evaluate the event CCDP for such condition events by use of the baseline Core Damage Frequency (CDF), duration of the condition, and the Risk Achievement Worth (RAW) [8] for the degraded SSC. This formula also has been validated similarly as for the one for initiating event analysis.

(4) External Event or Shutdown Event − Provided that an external event such as fire, internal flooding, or earthquake has occurred, the significance can be deterministically analyzed using the matrix based on the loss of operational control or safety function with

potential safety issue, etc. The events occurring at the plant condition below the entry point to the operation of residual heat removal (RHR) system are evaluated in consideration of the safety functions during shutdown conditions, violation of the Limiting Conditions for Operation (LCO), etc.

(5) Human Error, Emergency Preparedness, or CCF – Human errors (e.g., individual mistakes, organizational factors, or safety culture deficiencies) are analyzed by a matrix based on the K-HFACS human factors analysis and categorization methodology [9]. If the event involved some deficiencies in the emergency preparedness, the significance is assessed in consideration of the functional readiness of the emergency response facilities and organizations. The occurrence of a common-cause failure (CCF) breaks the redundancy or sometimes even diversity built into the SSC design posing a considerable threat to plant safety, and hence, is also given special consideration in determining the final ER level and ES as in the INES [4].

(6) Determination of the Final ER Level and ES – The final event-response level and event significance are determined by integrating the results from all the steps relevant to the event that occurred. How to integrate the specific results from the above steps was also devised in this study, and the usefulness of the overall methodology discussed herein has been demonstrated by applying to several actual events. [2].

3. Conclusions

The integrated quantitative framework discussed in this paper has the following characteristics [2]:

- Easy to use since the framework consists of a number of matrices in form of tables with specific criteria and these matrices can be examined following the assessment hierarchy;
- Allows determination of the integrated event significance and the appropriate level of event response within a short time following event occurrence;
- Helps differentiate the safety significance of events using the concept such as Unplanned Scrams with Complications (USwC); and
- Provides KNES (Korea Nuclear Event Scale) color coding (e.g., low white, medium yellow) that is harmonious with the IAEA's INES and the NRC's color-coding system.

In order to facilitate application of the integrated quantitative framework to actual event investigation by KINS, the evaluation process will be proceduralized in a user-friendly manner in the near future.

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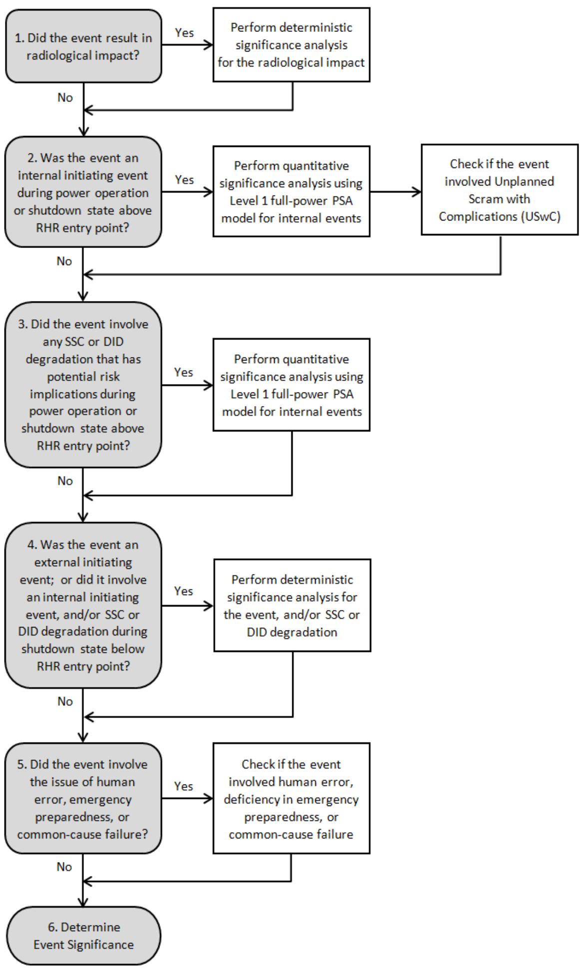

Fig. 1. Assessment hierarchy for event significance