New Insights on Risk-Informed Performance-Based Approaches to Technology-Neutral Regulatory Framework for Generation IV Reactors

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1. INTRODUCTION

The current regulations for nuclear power plants focus on light water reactors (LWRs), and as such they may not be properly applied to non-LWR reactors such as Generation IV Reactors. For instance, there is no plant state comparable to core damage in pebble bed reactors [1]. As a result, the surrogate safety goal based on core-damage frequency (CDF), as being applied to LWRs in many countries directly or indirectly, needs to be somehow modified for such advanced plants.

Therefore, there are considerable interests worldwide in developing new licensing structure for advanced nuclear power plants.

In this paper, we briefly discuss the new licensing approaches developed by the NRC and suggested by PBMR, Pty. LTD focusing on the two topical areas mentioned above. Next, our insights are given with respect to these approaches along with our suggestions for future research.

2. TECHNOLOGY-NEUTRAL FRAMEWORK OF THE NRC

The risk acceptance criteria of the TNF recently developed by the U.S. NRC are represented by a so-called Frequency-Consequence (F-C) Curve which depicts acceptable limits in terms of the frequency of potential accidents or abnormal events, and their associated consequences [2]. The F-C Curve shown in Figure 1 has been derived from current regulatory requirements in 10 CFR Parts 20, 50 and 100. Part 20 limits the radiation doses from licensed operation to individual members of the public.

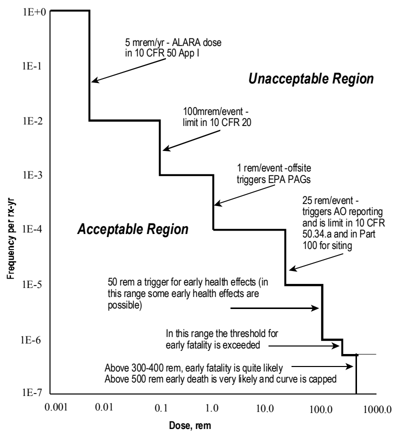

Figure 1: Frequency-Consequence Curve of the Technology-Neutral Framework

The F-C Curve may be used during design stage of an advanced nuclear plant to check whether each event sequence with a significant frequency of occurrence from a full-scope probabilistic risk assessment (PRA) for the subject plant satisfies the associated consequence limits. If not, the plant should be re-designed until every significant sequence meets the dose criteria. In addition, the LBEs to be determined as discussed below also should satisfy the risk acceptance criteria of the F-C Curve.

3. LICENSING APPROACH PROPOSED FOR PBMR

In the risk-informed approach proposed for PBMR licensing, the acceptability of plant risk is represented by a Frequency-Consequence (F-C) Chart [3]. This F-C Chart includes Top-Level Regulatory Criteria (TLRC) that establishes limits on the frequencies and consequences of LBEs based on the current regulations (Figure 2).

As indicated in Figure 2, if an event sequence falls within the areas left to the TLRC lines, it is regarded as acceptable; otherwise, unacceptable. Only those event sequences with frequencies larger than 5E-7 per plant-year are considered in the licensing process.

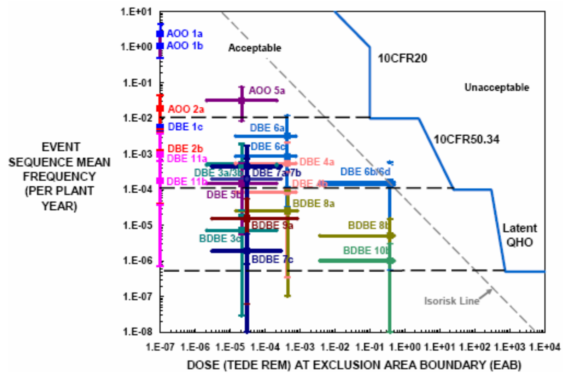

Figure 2: Frequency-Consequence Chart of the PBMR Licensing Approach

4. INSIGHTS INTO THE NRC AND PBMR APPROACHES

4.1. Insights on Risk Acceptance Criteria

Our review of the risk-informed and performance approaches developed in the NRC's TNF project and proposed for the PBMR licensing indicates:

• The frequency and consequence limits in both F-C Curve and F-C Chart are established on the basic philosophy that the higher the expected dose consequences, the lower should be the allowed event frequency. In view of the fact that a near-inverse variation between event frequency and consequence is generally considered acceptable as in Farmer Curve originally developed by F. R. Farmer [4], the use of this basic philosophy in constructing F-C Curve and F-C Chart appears adequate.

• There are significant differences in interpreting the current regulations between the NRC and the PBMR approaches, because the current regulations, such as 10 CFR 50 Appendix I, 10 CFR 20, and 10 CFR 50.34, define specific limits on dose consequences (e.g., 5 mrem per year, 100 mrem per year, and 25 rem per event) but does not clearly specify the associated frequencies.

• Both F-C Chart and F-C Curve are primarily intended to help assure that every single event sequence (or group of event sequences) meets the frequency-consequence criteria set forth in these diagrams. In other words, the cumulative risk from all event sequences considered in the design cannot be directly represented on them. As a result, these diagrams do not provide a means by which the acceptability of the cumulative risk can be readily verified. Apparently some design acceptance criterion based on the concept of a complementary cumulative distribution function (CCDF) needs to be developed as pointed out in an internal NRC review of the framework approach by the Subcommittee on Future Plant Designs [5].

4.2. Insights on Licensing Basis Events

The processes for selecting LBEs in the NRC's TNF [2] and the PBMR licensing approach [3] are rather complicated, requiring a detailed consideration of the uncertainty analysis results (e.g., 95th percentile confidence bounds for event sequence frequency and dose-consequence), grouping of similar event sequences, and so on. Furthermore, an iterative analysis is required to carry out the first step of the LBE selection process in the TNF, i.e., "Modify the PRA to only credit those mitigating functions that are to be considered safety significant." In connection with this step, the framework suggests an iterative approach where the impact on the selection of LBEs is evaluated with a proposed set of safety significant SSCs, then re-assessed with another set of safety significant SSCs, until the desired set of LBEs and other design objectives are achieved.

In addition to the complicated and iterative nature, the LBE selection process heavily depends on a full-scope PRA at "design stage." The NRC document on technology-neutral framework [2] points out that a high level of confidence is needed in the results of the risk assessment, since the risk assessment will be an integral part of the design process and licensing analysis. A high quality PRA is also required in the PBMR approach. However, especially in the case of advanced reactors these LBE selection processes needs reconsideration, because such a high level of confidence in the PRA results may not be achieved especially at the design and licensing stage due to several reasons.

Furthermore, it may be noted here that in the risk-oriented approach the primary focus was placed on what events or event sequences are selected as LBEs, however more important is the LBE analysis process itself because the reactor design can be improved by changing various options during the analysis process. In this regard, the deterministic approach holds considerable merit over the risk-oriented approach because emphasis in the former is on the process of analyzing the plant's transient behaviors through detailed thermal-hydraulic calculations with systematic documentation of specific data and assumptions employed, and also consideration of various consequences such as the reactor coolant pressure boundary (RCPB) pressure, core thermal-hydraulic margins, or containment pressure.

5. CONCLUSION

The risk-informed and performance-based licensing approaches discussed herein have great potential to facilitate decision making for safe reactor design by clearly indicating regulatory requirements in terms of frequency of occurrence and expected consequence for the whole spectrum of potential accident sequences and selecting accident scenarios to be used as design or licensing bases in a more rational way than was done in the past. However, they tend to depend too much on a PRA at design stage which has considerable uncertainties, without paying sufficient attention to the traditional safety analysis methodology that has played an important role in ensuring plant safety thus far. Therefore, an effective blend of deterministic and probabilistic approaches taking advantage of both traditional safety analysis methodology and risk insights apparently needs to be developed.

References

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