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An Approach for Justifying Safety Margin in the Risk-Informed Integrated Decisionmaking

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1. Introduction

In risk-informed decision-making, licensing basis changes are expected to meet five principles as follows [1,2].

① The change meets the current regulations.
② The change is consistent with the defense-in-depth philosophy.
③ The change maintains sufficient safety margins.
④ The risk increases by the change are small and are consistent with the sefety goal policy.
⑤ The impact of the change should be monitored using performance measurement strategies.

According to the principles above, the appropriate engineering analyses should be conducted to justify the proposed licensing basis change, including traditional and probabilistic analyses. Each of these principles should be considered in the risk-informed integrated decision-making process, as illustrated in Fig 1 [1].

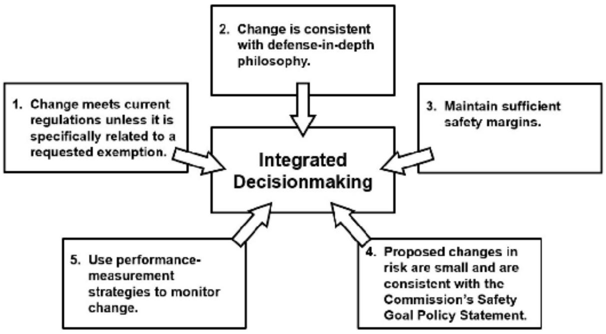

Fig. 1 Risk-informed integrated decision-making process [1]

This paper focuses on the engineering approach to justify the principle 3 (maintaining sufficient safety margin) in the risk-informed licensing basis changes. Note that the author does not take any position on the sufficient level of safety margin(SM) itself, but rather explore an practical engineering approach to justify whether the change maintains current SM given in terms of traditional analysis. It can help risk-informed decision makers evaluate impact on the current SM likely to result from the proposed licensing basis changes.

2. Current Domestic Regulatory Requirements for the Principle 3

The engineering evaluation should assess whether the impact of the proposed licensing basis change is consistent with the principle 3 (maintain sufficient SM). Similar to NRC regulatory guide[1], the domestic requirements for the principle 3 can be summarized as follows [2.3.4].

- ○ In determining the design performance characteristics of the system, the SM indicates the margin for uncertainty of the design performance. Therefore, the SM should be sufficiently maintained so as to reflect the degree of understanding of existing uncertainties and the potential impact of the proposed licensing basis changes. For this purpose, the followings shall be considered:
  - ✓ With sufficient SM, the change shall meets the existing engineering code/standard or the alternatives approved by the regulatory body.
  - ✓ The change shall meet the safety analysis acceptance criteria in the licensing basis or the proposed revisions shall provide sufficient margin for consideration of uncertainty in analysis and data.
- ○ The level of justification required to the SM depends on how many uncertainties are involved in the performance variables in question, availability of alternative means to compensate for degraded performance, and the consequences of failure of the affected components, etc. Thus, the results of uncertainty analysis associated with the risk assessment (in particular, uncertainties in the analyses and models affected by the proposed changes) provide useful information in regulatory decision-making process. Therefore, the results of uncertainty analysis should be considered when determining whether to allow reduction of the SM due to the proposed change.

3. An Engineering Approach for Justifying the Principle 3

SM can be defined by a variety of ways [5] and generally start with the concept of distance between design capacity and load estimates as shown in Fig. 2 [6].

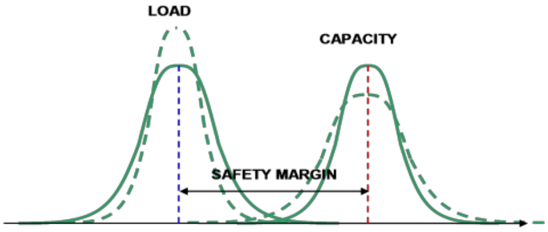

Fig. 2 General definition of safety margin

And, the SM refers to the probability that the load (L) exceeds the design capacity (C) and can be simply evaluated as follows [6].

$$P(L>C)=\int_{c=-\infty}^{c=+\infty}\int_{l=c}^{l=+\infty} f_C(c)f_L(l)dldc=\int_{c=-\infty}^{c=+\infty} f_C(c)[1-F_L(c)]dc$$

But, it is very difficult to quantify the dynamic effects of these SMs because the current PSA model structure is based on the static reliability concept. For example, given the dynamic characteristics of SM, the probability of core damage may exist in the success accident sequences of the event tree, and vice versa. In particular, this issue is more important in the passive system PSA model [7].

Consequently, principle 3 (maintaining sufficient SM) is an area that should be addressed by traditional approaches rather than by probabilistic ones. In the paper, a practical engineering procedure for principle 3 are proposed as shown in Fig. 3, with references like SM action plan (SMAP)[5], TEC-DOC-1332[8], and NUREG/CR-5249[9].

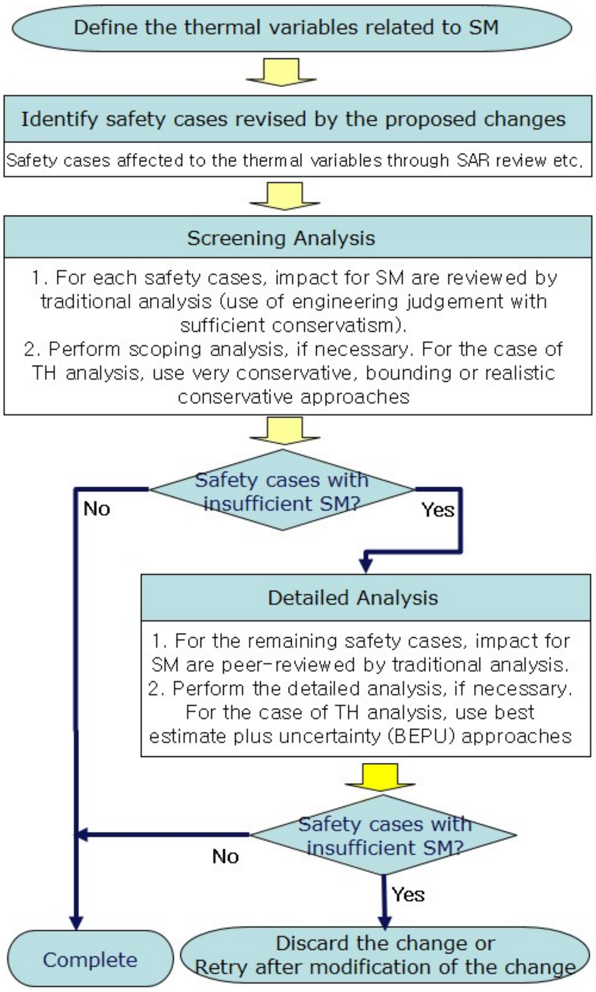

Fig. 3 The proposed approach for justifying safety margin in risk-informed decision-making

3.1 Definition of Safety Margin by Thermal Variables

In the paper, first of all, SM is defined with the terms of thermal variables and distances, which are used as design basis in design documents such as safety analysis report (SAR), etc. In the case of OPR-1000 reactor, the terms are shown in Fig.4 like SAFDL(Specific Acceptable Fuel Design Limit) [1], LSSS(Limiting Safety System Settings), POL(Power Operating Limit), LCO(Limiting Condition for Operation), ROPM(Required Over-Power Margin), AOPM(Available Over-Power Margin), and so on. Consequently, SM[2] is defined as follows.

SM(WR) = SM(NR) + Operation Margin(OM)
= SM(NR) + ROPM + SAM

,where SAM(safety analysis margin) is the distance from normal or specific operating condition to POL. And note that POL corresponds to the initial conditions for traditional safety analyses (TH analyses) for deign basis accidents.

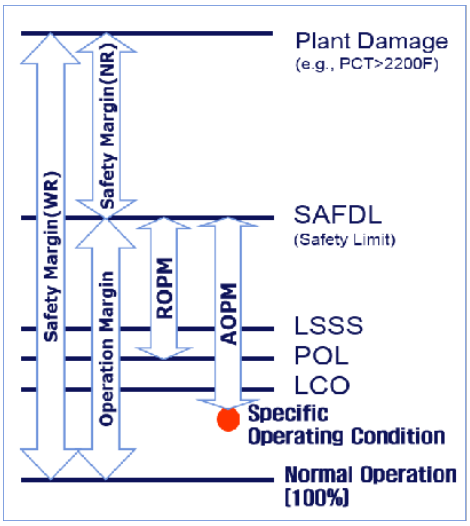

Fig. 3 Definition of safety margins in terms of thermal variables.

3.2 Identification of Safety Cases Revised by the Proposed Changes

The followings are carried out to complete a list of safety cases affected by the proposed changes. First, it is important to review the impact on the initial conditions of the design basis accident (DBA) analysis due to the proposed licensing basis changes in the viewpoint of SM. So, the impact on the POL (i.e., the initial conditions of the DBA analysis) due to the proposed changes should be investigated.

Second, it is necessary to review how the proposed changes affect engineering judgment or assumptions involved in PSA model or supporting works such as

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[1] DNBR (departure from nucleate boiling ratio) ≥ 1.3, LPD (local power density) ≤ 21kW/ft, RCS pressure ≤ 2750psig.

[2] In this paper, safety margin is meant by wide range(WR), not narrow range(NR)

thermal hydraulic (TH) analysis, etc. It is because the PSA models include DBA scenarios as well as beyond DBA ones, and many assumptions and engineering judgments are used when analyzing those accident scenarios.

3.3 Screening and Detailed Analysis

For all safety cases, first, screening analysis should be performed by traditional approaches with bounding and conservative assumptions. For screening analysis, three approaches shown in table 1 (VC, BEB, RC approaches) are recommended. Refer to SMAP[5] for more detailed information on approaches. If there are any safety cases that are not screened out, the detailed analysis can be applied to the remaining safety cases. For these cases, impact for SM of the proposed changes should be peer-reviewed by more realistic traditional approaches, including BEPU approach in table 1 (Refer to SMAP[5] for more detailed information)

Table 1 Methods of safety analyses for the proposed changes(*)[5]

	Application codes	**Input and BIC**	**Assumption**	**Analysis method**
VC	Conservative codes	Conservative input	Conservative assumptions	Deterministic
BEB	Best estimate (realistic) codes	Conservative input	Conservative assumptions	Deterministic
RC	Best estimate codes + Uncertainty	Realistic input + Uncertainty	Conservative assumptions	Deterministic
BEPU	Best estimate codes + Uncertainty	Realistic input + Uncertainty	PSA-based assumptions	Deterministic + probabilistic

* BIC (boundary and initial conditions), VC(very conservative), BEB(best estimate bounding), RC(realistic conservative), BEPU(best estimate plus uncertainty)

If any of safety cases is finally judged that SM is insufficiently maintained and unless an appropriate technical discussion is possible in consideration of the state-of-art technology, the proposed licensing basis changes should be revised or discarded to reflect the results of the investigation

4. Conclusions

This paper focuses on the engineering approach to justify the principle 3 (maintaining sufficient safety margin) in the risk-informed licensing basis changes. Principle 3 is an area that should be addressed by traditional approaches rather than by probabilistic ones. A practical engineering procedure for principle 3 are proposed in the paper. The proposed procedure was applied to licensing basis changes of the surveillance test intervals for safety-related I&C systems in OPR-1000 reactors [10]. It can help risk-informed decision makers evaluate impact on the current SM likely to result from the proposed licensing basis changes.

ACKNOWLEDGEMENTS

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