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NRC FORM 390 (12-2003)

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Risk Metrics for New Light-Water Reactor Risk-Informed Applications

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ABSTRACT

This paper discusses the evolution of risk metrics as the implementation of the Commission's 1986 Safety Goal Policy Statement evolved and as it was being applied to new reactors and subsequently to risk-informed applications for currently operating reactors. The lower risk estimates for new reactors raise several issues regarding how to apply acceptance guidelines for changes to the licensing basis and thresholds in the Reactor Oversight Process (ROP). The author describes in general terms possible options for addressing risk-informed changes to the licensing basis for new light-water reactors, including the major advantages and disadvantages of each option.

Key Words: new reactors, risk metrics

INTRODUCTION AND BACKGROUND

On February 12, 2009, the staff provided the Commission a memorandum and attached white paper [1] that identified potential issues posed by the lower risk estimates of new reactors when implementing the current framework for risk-informed applications, including risk-informed changes to the licensing basis and the Reactor Oversight Process (ROP). The potential issues discussed in the February 12, 2009, memorandum arise in part as a result of the evolution of risk metrics as the implementation of the Commission's 1986 Safety Goal Policy Statement [2] evolved and as it was being applied to new reactors and subsequently to risk-informed applications for currently operating reactors.

In general terms, reactor risk metrics refer to the quantitative measures of risk to the public from reactor operations up to and including severe core damage accidents. Following issuance of the Commission's Safety Goal Policy Statement, through a series of Commission papers and Staff Requirements Memoranda (SRMs), the Commission established quantitative goals for core damage frequency (CDF), large release frequency (LRF), and conditional containment failure probability (CCFP) for new light-water reactors (LWRs)[1] [3,4]. The goals and objectives for new LWRs are:

- CDF < 10^{-4} /yr
- LRF < 10^{-6} /yr
- CCFP less than approximately 0.1

At the time the Commission approved the use of an LRF goal of less than 10^{-6} /yr for new reactors, the Commission had not agreed upon a definition of a large release, but it was thought that this goal was within an order of magnitude of the Commission's quantitative health objectives. In a subsequent Commission paper (SECY-93-138) [5], the staff concluded that alternative definitions of a large release being considered would result in a large release guideline several orders of magnitude more conservative than the safety goal prompt fatality quantitative health objective and that the need for a precise definition had diminished in importance. As a result, the staff recommended and the Commission agreed that work on the development of a large release definition be terminated. However, the Commission and the staff continued to utilize an LRF goal of less than 10^{-6} /yr in its review of new reactors. Without an agreed upon definition of LRF, each applicant for a certified design proposed their own definition of an LRF, and as a result, the definitions of LRF in the design certification documents of the standard designs all differ to varying extents.

The Commission also provided guidance regarding its expectations on enhanced safety for new reactors in the past. From the 1985 Policy Statement on "Severe Reactor Accidents Regarding Future Designs and Existing Plants," the Commission stated that it "fully expects that vendors engaged in designing new standard (or custom) plants will achieve a higher standard of severe accident safety performance than their prior designs." [6] The 1986 and 1994 Policy Statements on the "Regulation of Advanced Nuclear Power Plants" further stated that "the Commission expects that advanced reactors will provide

[1] For the purpose of this paper, the term "new reactor" refers to evolutionary and advanced LWRs, including the plants using multi-train, mostly active engineered safeguards (Advanced Boiling Water Reactor (ABWR), System 80+, U.S. Advanced Pressurized-Water Reactor (US-APWR), U.S. Evolutionary Power Reactor (U.S. EPR)), as well as those plants with mainly passive safeguards systems (Advanced Passive 600 (AP600), Advanced Passive 1000 (AP1000), Economic Simplified Boiling-Water Reactor (ESBWR)).

enhanced margins of safety and/or utilize simplified, inherent, passive, or other innovative means to accomplish their safety functions." [7]

In SECY-93-087 and the associated SRM [8], the staff implemented the Commission's Policy through the specification of deterministic design features that provide severe accident prevention and mitigation capability. Implementation of these probabilistic and deterministic attributes addresses the Commission's expectations that new reactors have improved safety performance compared with the fleet of currently operating reactors, and has led to, for example [9]:

- High level of redundancy
- Physical separation of safety systems
- Very low contribution to risk from interfacing systems loss-of coolant accident (ISLOCA)
- Low contribution to CDF from anticipated transient without scram (ATWS)
- Rapid reactor coolant system depressurization capability
- Core melt mitigation capability
- Containment combustible gas control capability.

While the Commission has expressed its expectation that new reactors will have improved safety performance compared with the then currently operating reactors, the Commission did not approve adopting the industry's more stringent risk objectives. For example, in the SRM on SECY-89-102, "Implementation of Safety Goal Policy," the Commission has made it clear that it expects that "advanced designs will reflect the benefits of significant research and development work and experience gained in operating the many power and development reactors, and that vendors will achieve a higher standard of severe accident safety performance than their prior designs ...However, the NRC will not use industry's design objectives as the basis to establish new requirements." [3] Additionally, from the SRM on SECY-90-016, "Evolutionary Light Water Reactor Certification Issues and Their Relationship to Current Regulatory Requirements," the Commission stated that "although the Commission strongly supports the use of the information and experience gained from the current generation of reactors as a basis for improving the safety performance of new designs, the NRC should not adopt industry objectives as a basis for establishing new requirements." [4]

In the revised Advanced Reactor Policy Statement released in 2008, in response to a public comment on the draft policy, the Commission stated that the "policy statement does not state that advanced reactor designs must be safer than the current generation of reactors, but rather that they must provide the same degree of protection of the environment and public health and safety and the common defense and security that is required for current generation light-water reactors." [10]

In 1995, the NRC issued the Probabilistic Risk Assessment (PRA) Policy Statement that encouraged the use of PRA in all regulatory matters [11]. In 1998, the NRC issued Regulatory Guide (RG) 1.174, providing a risk-informed integrated decision-making framework [12]. In the development of RG 1.174, staff recommended the use of a CDF guideline of 10^{-4} per reactor year and a large early release frequency (LERF) guideline of 10^{-5} per reactor year. The values proposed as guidelines for CDF and LERF were selected to be consistent with the Safety Goal Quantitative Health Objectives (QHOs). In particular, as stated in SECY-97-077 [13], "the value of 10^{-5}/RY for the LERF guideline corresponds to that value, estimated from existing PRA results, necessary to ensure that the early fatality QHO would be met without undue conservatism. In effect, the guideline value for LERF is a surrogate for the Commission's QHO on early fatality risk."

Further, as discussed in SECY-97-077, the staff recognized that the Commission had also proposed in the Safety Goal Policy Statement a general performance guideline of 10^{-6} per reactor year for a large release of radioactive material to the environment. This guideline was proposed for staff evaluation and the results of the staff evaluation were reported in SECY-93-138 [5]. Although work on defining a large release to be used with a frequency of 10^{-6} per reactor year was stopped (as reported in SECY-93-138), increased NRC management attention will be given to proposed changes that cause LERF to increase by more than one percent of the guideline value of 10^{-5} per reactor year. This will help ensure that the intent of the Commission's general performance guideline is considered in the review of proposed risk-informed changes requiring NRC approval. Today, the risk-informed process, metrics, and guidelines defined in RG 1.174 have been incorporated into numerous licensee and regulatory programs for operating reactors including the Maintenance Rule, the ROP, risk-informed Technical Specifications, and other programs and processes. More recent studies have confirmed that CDF and LERF are surrogates for the QHOs [14].

In 1999, SECY-99-007 [15] further linked the risk metrics in RG 1.174 with the ROP by stating that "the risk implications and regulatory actions associated with each performance band and associated threshold should be consistent with other NRC risk applications, and based on existing criteria where possible (e.g., Regulatory Guide 1.174)..."

DISCUSSION

With the implementation of an enhanced level of severe accident prevention and mitigation design capability being confirmed through the review of applications for design certification for new LWRs, the staff is looking toward identifying potential issues that may arise with the transition to operations and the use of the existing risk-informed framework. In fact, the staff is currently reviewing one application for risk-informed technical specifications initiatives 4b and 5b (completion times and surveillance test intervals, respectively) as part of the US-APWR design certification. In addition, other industry representatives have expressed interest in pursuing risk-informed inservice inspection of piping for new reactors, and staff expects additional risk-informed applications for new reactors in the future.

During staff's consideration of these risk-informed initiatives, the issue has been raised whether the current numerical risk metric goals for CDF and LERF should be applicable to new light-water reactors, or whether alternate metrics (e.g., CDF and LRF) be developed consistent with the Commission's safety expectations and approved goals for new reactors. On February 12, 2009, the staff provided the Commission a memorandum and attached white paper [1] that identified potential issues posed by the lower risk estimates of new reactors when implementing the current framework for risk-informed applications, including the ROP and changes to the licensing basis.

Two factors that arise regarding the extension of the current risk-informed framework to new reactors are the use of LRF in design certifications and COL applications, and the relatively low risk profiles of many of the new reactor designs. For one, the continued use of LRF poses a dilemma going forward regarding the implementation of risk-informed changes to the licensing basis, and to a lesser extent, with the ROP.

The origination of LRF stems from the Safety Goal Policy Statement. The Commission proposed a General Performance Guideline for further staff evaluation:

> "Consistent with the traditional defense-in-depth approach and the accident mitigation philosophy requiring reliable performance of containment systems, the overall mean frequency of a large release of radioactive materials to the environment from a reactor accident should be less than 1 in 1,000,000 per year of reactor operation."

But as noted above, the Commission does not have an approved definition of LRF, and each of the major design centers has developed its own definition. If the staff implements a risk metric using LRF for new reactors, the lack of a uniform definition for LRF would need to be addressed.

A second factor is that CDF estimates for new reactors are observed to be typically 10 to 1,000 times lower than those for currently operating reactors when internally initiated events and those externally initiated events that have been quantified are included (see Figure 1 for internal events at power, for example) [9]. Correspondingly, LRF (or LERF) estimates are 10 to 10,000 times lower for new reactors, while CCFP estimates are typically 3 to 10 times lower. However, it is important to note that all design certifications to date have used seismic margins analysis methodology, which excludes site-specific hazard curves. As such, the seismic risk contribution for new reactors has not been fully quantified. It is likely that the factors noted above between new reactors and currently operating reactors will narrow once all risk contributors are accounted for, and that seismic risk could in the final analysis represent a *floor* on the estimated total baseline risk for new LWR designs.

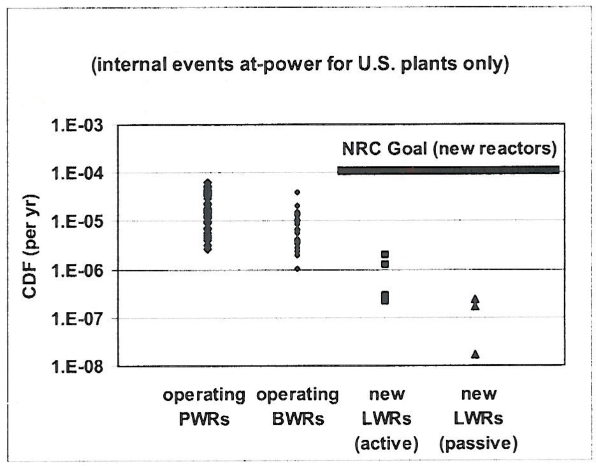

Figure 1. CDF by Plant Type

Regardless, the lower risk estimates for new reactors, combined with the Commission's expectation of enhanced safety, raise several issues regarding applying existing acceptance guidelines for changes to the licensing basis and thresholds in the ROP. Additionally, the question has been raised as to how can these expectations of enhanced safety performance be implemented in operational programs and the ROP without unduly penalizing new reactors that already have more robust designs (with regard to severe accident capability) than currently operating reactors? Is it reasonable that some new reactor designs with 3 or 4 redundant trains of safety systems should have more restrictive guidelines regarding the implementation of risk-managed technical specification completion times than current reactors with only 2 trains of redundancy?

Risk-Informed Changes to the Licensing Basis

RG 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk Informed Decisions on Plant Specific Changes to the Licensing Basis," provides an approach for using PRA in risk-informed decisions on plant-specific changes to the licensing basis for current reactors. This guide is the foundation on which many other risk-informed programs (e.g., risk-informed inservice testing, risk-informed inservice inspection of piping and risk-managed technical specifications) are based at the agency.

RG 1.174 describes five principles for making risk-informed decisions. Specifically, the proposed change:

- Meets current regulations (presumption of adequate protection), unless the change is explicitly related to a requested exemption or rule change
- Is consistent with the defense-in-depth philosophy
- Maintains sufficient safety margins
- Results in an increase in CDF or risk that is small and consistent with the intent of the Commission's Safety Goal Policy Statement
- Will be monitored using performance measurement strategies.

RG 1.174 provides acceptance guidelines as to what constitutes "small changes" in CDF (ΔCDF) and LERF (ΔLERF), respectively. These are reproduced here as Figures 2 and 3. For most new LWRs with baseline CDF estimates at or substantially below 10^{-6}/yr, a 10^{-6} ΔCDF, or even an order of magnitude lower 10^{-7} ΔCDF, would no longer constitute a "small change" *on a relative basis*. "Small increase" for current reactors may not have the same ramifications when applied to new reactors. Furthermore, RG 1.174 does not explicitly consider the impact of changes on the features included for enhanced safety during the design and certification of new reactors.

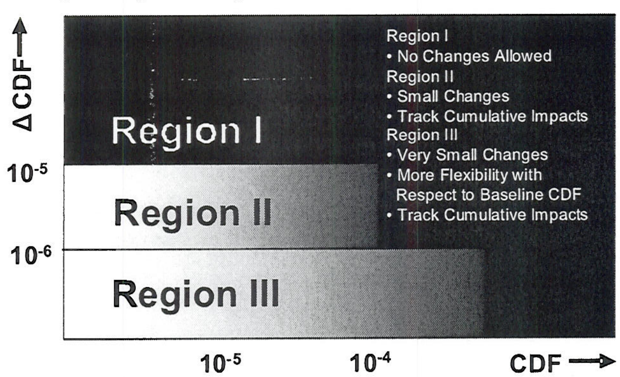

Figure 2. Acceptance Guidelines for CDF

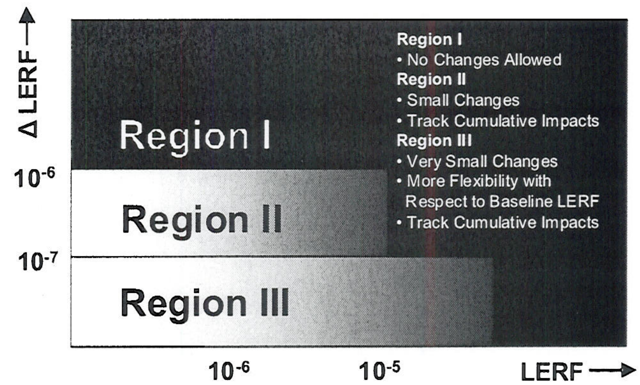

Figure 3. Acceptance Guidelines for LERF

Reactor Oversight Process

The regulatory framework for reactor oversight is a risk-informed, tiered approach to ensuring plant safety. There are three key strategic performance areas: reactor safety, radiation safety, and safeguards. Within each strategic performance area there are cornerstones that reflect the essential safety aspects of facility operation. Satisfactory licensee performance in the cornerstones provides reasonable assurance of safe facility operation and that the NRC's safety mission is being accomplished. Within this framework, the NRC's operating ROP provides a means of collecting information about licensee performance, assessing the information for its safety significance, taking appropriate NRC action, and ensuring that licensees take appropriate corrective actions. Because there are many aspects of facility operation and maintenance, the NRC inspects utility programs and processes on a risk-informed sampling basis to obtain representative information. A more detailed description of the ROP can be found in Management Directive (MD) 8.13 [16].

In the reactor safety arena, the three programs and processes that have the most direct tie to quantitative risk measures, including risk-related thresholds and/or guidelines, are

- The Mitigating Systems Performance Index (MSPI) [17]
- The Significance Determination Process (SDP) of inspection findings (IMC 0609) [18]
- NRC Incident Investigation Program, MD 8.3. [19]

With regard to setting numerical thresholds, SECY-99-007, "Recommendations for Reactor Oversight Process Improvements," [15] discusses a close link to RG 1.174. It states, in part:

"The concept for setting performance thresholds includes consideration of risk and regulatory response to different levels of licensee performance. The approach is intended to be consistent with other NRC risk-informed regulatory applications and policies as well as consistent with regulatory requirements and limits...(3) the risk implications and regulatory actions associated with each performance band and associated threshold should be consistent with other NRC risk applications, and based on existing criteria where possible (e.g., Regulatory Guide 1.174)..."

MD 8.13 describes the principles that form the basis of the ROP. Two principles, of note, are related to the risk-informed concept:

- "Risk-informed thresholds for licensee safety performance establish whether only routine NRC interaction is warranted or increased NRC interaction (including enforcement) is warranted."
- "A risk-informed baseline inspection program establishes the routine level of NRC interaction with all licensees, provides a sufficient indication of licensee performance, and indicates when additional inspection activity is warranted."

The "White Paper on Options for Risk Metrics for New Reactors" provided hypothetical but realistic examples where the lower risk profiles for some new reactor design could be viewed as problematic in that numerical thresholds of performance (e.g., 10^{-6} for green/white) would rarely be reached [1]. In one example, a 5-fold increase in the internal events CDF associated with a performance deficiency and condition would need to endure for about 6 months before resulting in the "white" performance band being reached. For the example cited, a 100-fold increase in the internal events CDF for about 2 months would be necessary to cross into the "Yellow" band, and a 1,000-fold increase in CDF for the same 2 months to reach "Red" significance.

If the ROP were strictly *risk-based,* relying entirely on quantification of ΔCDF and ΔLERF to establish performance, then one might argue that the fact that a new reactor has lower risk profile (than currently operating reactors) is a characteristic to its favor, allowing greater *relative* degradation in performance before reaching various bands of performance calling for increased NRC oversight.

On the other hand, an 8×10^{-7} /yr increase in core damage frequency for a degraded condition lasting one year for a new reactor with a baseline 10^{-7} to 10^{-6} /yr CDF provides a significantly different perspective and risk insights than the same increase for an operating plant with 10^{-5} /yr baseline. Certainly, in the former case, a major system or sub-system would have been rendered substantially degraded for an extended period of time, possibly calling into question the effectiveness of licensee programs.

Thus, another principle of the ROP, as stated in MD 8.13, is:

- "The performance indicators have objective, risk-informed thresholds that identify outliers from nominal industry performance so that deficiencies can be identified and corrected before they pose an undue risk to public health and safety...NRC will continue to assess the performance indicators and their thresholds to ensure they provide appropriate insights on performance attributes."

In the broadest sense, failure or unavailability of new reactor systems or sub-systems resulting in, for example, an 80% to 800% increase in baseline CDF for upwards of one year might not be viewed as "nominal" performance, and could be indicative of significant licensee performance issues requiring additional NRC oversight.

POSSIBLE OPTIONS

The staff developed an initial set of possible options for risk metrics for new reactors, and provided a preliminary set of advantages and disadvantages for each option [1]. This was followed by a series of public meetings and briefings before the Advisory Committee on Reactor Safeguards (ACRS). The staff has identified two distinct aspects to the issues discussed above that can be categorized as follows:

1. Risk-informed changes to the licensing basis that could be viewed as constituting voluntary changes to the design as well as operational programs and processes, including but not limited to such initiatives as risk-managed technical specifications and risk-informed in-service inspection of piping.

2. The setting of risk-informed thresholds for performance bands in the ROP for new reactors.

Only the options associated with risk-informed changes to the licensing basis are discussed in this paper, although the process and reasoning for the setting of thresholds for the performance bands in the ROP are consistent.

For changes to the licensing basis, the staff is currently considering options that can be characterized in broad terms as:

- **Option 1: No change to the existing risk-informed framework for changes to the licensing basis.**

Under this option, the staff would continue to use the existing risk-informed framework for licensing changes. This option would recognize that the acceptance numerical thresholds established in these processes are consistent with the Commission Safety Goal Policy Statement and would provide a consistent set of acceptance guidelines for both existing and new reactors. This option would also be consistent with previous Commission guidance that the NRC should not adopt industry objectives as a basis for new requirements.

- **Option 2: Modify the risk-informed framework for changes to the licensing basis to explicitly address the need to evaluate the impact on those features added for enhanced safety.**

Option 1 has the following advantages:

- Provides a consistent set of acceptance guidelines for both existing and new reactors.
- Is consistent with the bases for RG 1.174 acceptance guidelines that are derived from Commission's 1986 Safety Goals.
- Would not impose additional requirements on new reactors.
- Acknowledges and gives credit to new reactors for lower risk estimates.

Option 1 has the following disadvantages:

- May not be consistent with Commission's 1985, 1986, and 1994 Policy Statements on expectations that new reactor designs will achieve a higher standard of severe accident safety performance.
- Could result in less restrictive change process than the Commission established for the review of new reactors.
- Could allow large *relative* increases in CDF and risk compared to the baseline CDF and risk estimates for new reactor designs.

Option 2 has the following advantages:

- Remains consistent with Commission's Policy Statements on expectations that new reactor designs will achieve a higher standard of severe accident safety performance.
- Acknowledges that new reactor CDF and risk estimates are significantly lower than existing reactors and adjusts acceptance guidelines in RG 1.174 accordingly.
- Would substantially maintain the plant risk profile previously reviewed by the staff and documented in the SER.

Option 2 has the following disadvantages:

- May be inconsistent with the underlying technical basis for the current thresholds in RG 1.174 that are derived from the Commission's Safety Goals.
- May be viewed as penalizing new reactors for having lower risk. For example, a new reactor design that includes a high degree of redundancy of safety systems, or additional severe accident mitigation capability, may not be allowed the same degree of flexibility in future design changes or changes to operational program (e.g., risk-managed technical specifications) as a currently operating reactor with less severe accident capability.
- New reactors licensed under Part 52 already have a comprehensive change control process with respect to severe accident capabilities.

It should be noted that changes to the existing regulatory framework suggested by Option 2 may, in some instances, consist of changes in numerical guidelines, but could also be implemented using more qualitative considerations in RG 1.174, e.g., consideration of defense-in-depth. In effect, it may be possible to implement the Commission's expectation of enhanced safety without necessarily revising quantitative risk guidelines in all instances.

A Commission policy paper with one or more recommendations addressing both risk-informed changes to the licensing basis and thresholds in the ROP is anticipated in early 2010.

CONCLUSIONS

The Commission stated through a number of policy statements regarding severe reactor accidents that it expects new plants to achieve a higher standard of severe accident safety performance than their prior designs. Through a series of Commission papers and Staff Requirements Memoranda, the Commission also established quantitative goals for core damage frequency, large release frequency, and conditional containment failure probability for new LWRs, as well as specification of deterministic design features that provide severe accident prevention and mitigation capability. However, the Commission has also stated that while it strongly supports improvements in the safety performance of new designs, the NRC should not adopt industry objectives as a basis for establishing new requirements.

As a result, the estimates of CDF and risk for new LWRs are shown, on average, to be significantly lower than the fleet of currently operating reactors. The lower risk estimates for new reactors raise several issues regarding how to apply acceptance guidelines for changes to the licensing basis and thresholds in the ROP.

The NRC staff has developed an initial list of options for addressing risk-informed applications and the ROP for new LWRs, along with a description of some of the major advantages and disadvantages of each option. The staff has engaged stakeholders and the ACRS through papers and public meetings, and continues to refine the potential options. A Commission policy paper with one or more recommendations addressing both risk-informed changes to the licensing basis and thresholds in the ROP is anticipated in early 2010.

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