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Comment On: NRC-2021-0166-0001
Acceptability of ASME Code Section XI, Division 2, Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants, for Non-Light Water Reactors

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General Comment

I am providing two files to offer the following arguments relative to NRC's development of inspection and testing programs for non-light water reactors:

1. The Nuclear Energy Innovation and Modernization Act (NEIMA) incorporates the term "risk-informed and performance-based" (RIPB) in several places. NEIMA does not offer a definition for RIPB. The staff should use the Commission developed definitions in SRM-SECY-98-0144 and use the work that has been done over the past 20 years employing these definitions. Although risk-informed (RI) and performance-based (PB) have progressed on separate tracks for most of this time the rulemaking for Part 53 should be taken as an opportunity to establish RIPB practices within an integrated framework. Using NUREG/BR-0303 and other supporting work to ensure that there is consistent application for RI, PB and RIPB will go a long way toward making progress on NEIMA in a consistent and coherent manner.

2. As currently expressed by DG-1383 and other guidance mentioned in the comments provided, the approach that the staff has chosen for inspection and testing requirements falls short of delivering on the expectations of NEIMA. The staff should adopt a systems-based approach to establishing requirements in 10 CFR Part 53. From the perspective of such an approach the stated functional objective of guidance related to In-Service Inspection (ISI) and In-Service Testing (IST) would be seen as means to validate and verify on a continuing basis the fitness for service and operational readiness of some of the key design features and programmatic controls (Part 53 language) that provide the technical justification for the safety evaluation of a design. This logic should extend to relevant phases where pre-service inspection and testing as well as post-construction inspection and testing are considered.

3. NUREG/BR-0303 incorporates a consideration that the ACRS recommended in September 2000 when reviewing work related to PB guidance. This consideration relates to the concept that performance levels and reliability parameters should be set at the highest practical level. It is important for the staff to bear in mind that the purpose of ISI/IST is to validate and verify design provisions using a PB approach starting at the functional level and flowing down to systems and components. It is only at the component level that the prescriptive aspects of the ASME code become significant.

N. Prasad Kadambi Ph.D. P.E.
Retired NRC Staff

Attachments

NPK Comments for NRC-2021-0166_DG-1383

FRAMEWORK FOR RIPB IMPLEMENTATION OF ISI AND IST IN ADVANCED REACTORS

Comments on DG-1383 Pursuant to NRC-2021-0166

By

N. Prasad Kadambi Ph.D. P.E.

Retired NRC Staff

I offer comments on this subject to draw attention to the disconnect between the aspirations of the Nuclear Energy Innovation and Modernization Act (NEIMA) and the direction that the NRC staff has taken relative to crafting guidance in support of the rulemaking on 10 CFR Part 53. As currently expressed by DG-1383, the approach that the staff has chosen falls short of delivering on the expectations of NEIMA.

In public interaction, the staff has spoken of a systems approach to establishing requirements in 10 CFR Part 53. From the perspective of such an approach the stated functional objective of guidance related to In-Service Inspection (ISI) and In-Service Testing (IST) would be seen as means to validate and verify on a continuing basis the fitness for service and operational readiness of some of the key design features and programmatic controls (Part 53 language) that provide the technical justification for the safety evaluation of a design. This logic should extend to relevant phases where pre-service inspection and testing as well as post-construction inspection and testing are considered.

The fundamental functional objective of Part 53 is stated to be limiting release of radioactive material. The risk-informed (RI) criteria for this objective are given in the Commission’s Safety Goal Policy Statement. These criteria would be accomplished through establishing other performance requirements (with corresponding criteria) using appropriate means and methods. NEIMA speaks of a ‘‘technology-inclusive regulatory framework’’ as a framework developed using methods of evaluation that are flexible and practicable for application to a variety of reactor technologies, including, where appropriate, the use of risk-informed and performance-based techniques and other tools and methods. In this context, a framework should be seen as the architecture for performance objectives. The staff needs to recognize that this requires employing a performance-based (PB) approach from the highest level. The elucidation for how to meet this statutory provision should be viewed from the perspective of terminology clearly defined by the Commission in the SRM-SECY-98-0144, “White Paper on Risk-Informed and Performance-Based Regulation”.

Having laid down the fundamental safety objective in risk terms, the staff needs to establish the PB elements as defined in NUREG/BR-0303, “Guidance for Performance-Based Regulation” starting at that level. Additional functional objectives (which can be seen as means objectives) such as controlling heat generation, heat removal and chemical interactions are mentioned in the draft rule language as needing to be defined and have criteria associated with them. Fundamental functional objectives have a flow-down structure in which “Safety Objectives” are identified and these objectives are met by identifying “Safety Criteria”. A fully formed and formal “objectives’ hierarchy” should provide the architecture for design requirements from the application of rules in Part 53 that will deliver functional success at every level of the above-mentioned flow-down process for any given technology and design. On the other hand, the guidance that is being developed in the area of ISI and IST (of which DG-1383 is a part) takes a compartmentalized approach that forces applicants and licensees to employ a needlessly prescriptive approach that will quite clearly limit flexibility that should be available to the developers of a novel design concept.

NUREG/BR-0303 incorporates a consideration that the ACRS recommended in September 2000 when reviewing work related to PB guidance. This consideration relates to the concept that performance levels and reliability parameters should be set at the highest practical level. In the context of specifying performance for supporting rulemaking, it may be necessary to consider two separate objectives' hierarchies (OH). The first OH has its focus on the regulatory framework in which performance objectives at the statutory level are expressed as rules in the next level down, which is the Code of Federal Regulations (CFR). There onwards, the levels involve regulatory guides, inspection procedures and so on. In this vein the guidance architecture for ISI and IST processes should be PB in the provisions of DG-1383 and not just RI as it is stated to be. The guidance should begin with the generality of the regulation so as to accommodate the level of detail that would correspond to the phases of a design process without the designer having to shoe-horn validation and verification into an excessively prescriptive structure.

This idea of making a connection between the level of generality in regulations and the level of specificity in implementation of the regulation within a design process needs to be addressed by the Part 53 rulemaking. NUREG/BR-0303 does not explicitly address two related OH, which is what the above implies. The OH representing the regulatory framework should be logically consistent and coherent with the OH for design requirements. In a systems-based framework design requirements for ISI and IST would be PB to provide the maximum flexibility for the designer consistent with the safety objectives conforming to regulatory objectives. At this level, the focus is on validation and verification of design requirements as opposed to the details prescribed in Section C of DG-1383. Such details occur elsewhere as well, for example in the Interim Staff Guidance (ISG) in ADAMS Accession Number ML21216A051 related to "Risk-Informed ISI/IST Programs" in the Advanced Reactor Content of Application Project.

The discussion provided above was the subject of an exchange of communication between myself and the staff in relation to a comment I provided relative to the ISG in a public meeting on August 26, 2021. The bottom-line of this communication was a question posed to me by Joseph Sebrosky of the NRC staff as follows on August 30, 2021:

> "What performance based alternative approach for the risk informed ISI/IST ISG draft white paper ISG are you proposing? Can you provide an example of a performance-based ISI/IST approach that illustrates what you have in mind."

On September 19, 2021, I responded by providing a document that I have included with this comment as an attachment. In the transmitting message I had the following statement:

"The main point that I would like the staff to take note of is that the performance-based approach as defined by the Commission in SRM-SECY-98-0144 has certain unique features that have not been considered anywhere other than in NUREG/BR-0303. These features are extremely important to verify in any proposal from an applicant that purports to be performance-based because without these features the desire for flexibility could not be made accountable to accomplishment of performance objectives in a formal way. The framework that I have submitted takes this into account along with other research documented during my service at the NRC 20 years ago.”

The attachment is entitled, “Framework for RIPB Implementation of ISI and IST Programs in Advanced Reactors’ Applications”. It is focused on non-LWRs because the ISG does not accommodate a PB approach for LWRs. Having the focus of the various ISI and IST guidance take an integrated view on non-LWRs would not be inconsistent with the provisions of NEIMA. However, it is important to bear in mind that the purpose of ISI/IST is to validate and verify design provisions using a PB approach starting at the functional level and flowing down to systems and components. It is only at the component level that the prescriptive aspects of the ASME code become significant.

The staff should recognize that the ASME code is prescriptive because it needs to provide detailed rules, requirements, and criteria for the manufacture of specific components. The integrated framework for Part 53 should incorporate such requirements at the component level (which is generally at the lowest levels of the OH for a design) and employ the NUREG/BR-0303 methodology for all other levels.

In this vein, the staff has prepared DG-1380 to support high temperature application of components covered by ASME Section III, Division 5. I have provided comments on DG-1380 consistent with the approach taken in this submittal as part of Public Comment for NRC-2021-0117, which includes technical review of NUREG-2245 (ADAMS Accession No. ML21286A738). I request that my Public Comment for NRC-2021-0117 be incorporated by reference into this submittal.

In summary, NEIMA incorporates the term “risk-informed and performance-based” (RIPB) in several places. NEIMA does not offer a definition for RIPB. The staff should use the Commission developed definitions in SRM-SECY-98-0144 and use the work that has been done over the past 20 years employing these definitions. Although RI and PB have progressed on separate tracks for most of this time the rulemaking for Part 53 should be taken as an opportunity to establish RIPB practices within an integrated framework. Using NUREG/BR-0303 and other supporting work to ensure that there is consistent application for RI, PB and RIPB will go a long way toward making progress on NEIMA in a consistent and coherent manner.

FRAMEWORK FOR RIPB IMPLEMENTATION OF ISI AND IST PROGRAMS IN ADVANCED REACTORS' APPLICATIONS

An Informal Proposal Prepared by

N. Prasad Kadambi, Retired NRC Staff

PURPOSE:

The purpose of ISI and IST programs is to validate and verify on a continuing basis the fitness for service and operational readiness of some of the design features and programmatic controls (Part 53 language) that provided the technical justification for the safety evaluation of a design. Implementation of these programs with RIPB methods enables accomplishment of the Commission's transformative objectives as reflected in SRM-SECY-98-0144, "White Paper on Risk-Informed and Performance-Based Regulation". When the Commission offered its vision of modern regulatory practices in 1999 there was only sparce documentation of methods that could be invoked to pursue the outcome attributes that were described in the White Paper. In the ensuing two decades much research and experience provide ample basis for incorporating all aspects of the Commission's vision into advanced reactor ISI and IST programs. These programs can now be designed to obtain the effectiveness and efficiencies envisaged for licensees and NRC staff.

In 1998, the NRC issued NUREG/CR-5392 which discusses an approach to performance-based (PB) oversight for, among other things, covered results-oriented methods that would support the capability to detect and act upon emerging performance problems before they lead to adverse consequences. The research reported in this report is relevant to the implementation of ISI and IST programs in advanced reactors.

In addition, NRC issued NUREG/BR-0303 was issued in 2002 to offer feasible PB alternatives to objectives that previously only considered deterministic or risk-informed (RI) options. Guidance in NUREG/BR-0303 is unique because it offers a methodology and framework for safety decision-making that can formally incorporate flexibility, positive incentives for improved outcomes and margins whereby licensees and regulators can work together in a transparent way with accountability toward specific performance objectives.

The description in this document of specific elements of a risk-informed and performance-based (RIPB) framework draws on the staff's ISG for RI ISI and IST programs (ML21216A051) for the performance objectives for non-LWRs. As the staff has stated that LWRs will be subject to 10 CFR Part 50.55a, application of this framework for LWRs may require exemptions from certain regulations.

OBJECTIVES:

The Commission has stated in the White Paper the following:

"There have been significant advances in and experience with risk assessment methodology since 1975. Thus, the Commission is advocating certain changes to the development and implementation of its regulations through the use of risk-informed, and ultimately performance-based, approaches."

It appears that the Commission was thinking about the way PB approaches were defined as not being immediately amenable to implementation while the benefits of RI approaches could be realized right away.

The Commission identified the outcome attributes for the RI approach as:

1. Explicit consideration of a broader set of challenges;
2. Prioritizing challenges logically;
3. Consideration of a broader set of resources to defend against challenges;
4. Identifying and quantifying uncertainty;
5. Better decision-making with sensitivity tests.

The staff's ISG for RI ISI and IST programs (ML21216A051, referred to as ISG here onwards) appears to have all these attributes. However, before applying risk models to regulatory decision-making a closely related but distinct issue should be considered. This is related to NRC findings in past inspection reports about deficiencies that can arise in programmatic areas of performance. Programmatic weaknesses can behave analogously to common cause failure mechanisms. This makes them important for two reasons: they are potentially important causes of failure, and their capacity to affect multiple trains creates the possibility that when they do manifest themselves, they do so in events having high conditional probability of adverse consequences.

The Commission identified the outcome attributes for a PB approach as:

1. Parameters for monitoring;
2. Assess performance with objective criteria;
3. Flexibility to meet criteria to incentivize and reward improved outcomes;
4. Framework with physical and temporal margins.

Enabling realization of flexibility in the context of physical and temporal margins is a central feature of NUREG/BR-0303. Some advanced reactor developers may find a PB alternative to deterministic and prescriptive safety to be useful especially if a PRA is not available. Some micro-reactor designs may fall into this category. In the deterministic approach, the margins are specified as part of the responses to design basis accidents. As such, consideration of uncertainties is not a factor either in the probabilities or the outcome of decision- making. Although formal definition of a deterministic approach would recognize that uncertainty in a PRA sense do not apply, it is a fact that decision-making must consider uncertainty and ambiguity. Research documented in NUREG/CR-6833 offers a methodology to do this.

The Commission identified the outcome attributes of an integrated RIPB decision-making approach as:

1. Focus attention on the most important activities;
2. Objective criteria for evaluating performance;
3. Parameters for monitoring system and licensee performance;
4. Flexibility to incentivize and reward improved outcomes;
5. Decision-making focused on results.

The emphasis on outcomes and results suggests that RIPB stands in contrast to mandated prescriptive processes as the main approach to safety. The ISG, which is based on 10 CFR Part 50.55a and the ASME code, appears to be an exemplar of prescriptive processes. It would appear difficult to meet demands for flexibility in regulation unless PB options (based on NUREG/BR-0303) are included within the construct of the ISI and IST programs.

In addition to the prescriptiveness in 10 CFR 50.55a and the ASME code, lack of flexibility arises from the structure of requirements in the ASME standards being tied to individual components. Consideration of DID, margins, uncertainty, and monitoring strategies can be difficult and inefficient at the component level. A PB approach using NUREG/BR-0303 expands the application of requirements beyond components to systems, functions and design features within a structured set of performance objectives called an objectives' hierarchy.

The ISG refers to ARDCs from RG 1.232, “Guidance for Developing Principal Design Criteria for Non-Light Water Reactors,” for technology-inclusive systems requiring ISI programs. The systems cover the functional performance of the reactor coolant boundary, emergency cooling systems, containment heat removal, atmosphere cleanup systems, cooling of structures and equipment, and containment testing and inspection. The ISI program should include all piping, pressure retaining components and component supports that perform safety significant functions as well as piping whose failure could prevent SSCs from performing their safety function. The performance objectives of the safety functions can be expressed as heat transfer capability, chemical cleanup capability, or competent operator actions under emergent conditions. The guidance in NUREG/BR-0303 can be executed discretely to consider the challenges to be considered at the component, system or function level to obtain the necessary and sufficient performance margins to achieve success in accomplishing each of the specific objectives involved. The ISI program can selectively implement monitoring strategies to minimize unnecessary inspection requirements.

Advanced reactors may contain passive components that perform active safety functions (such as heat pipes). The monitoring strategies could include condition monitoring, surveillance, and inspection activities for these safety significant passive components. However, the performance objectives should include the basis for the inspection activities, including inspection intervals, and ensure that they are part of the ISI program.

A key part of the ISI program includes the decision-making related to discovery of adverse inspection results. Most often, this is caused by occurrence of actual degradation. The performance objectives for the ISI program need to include tracking degradation over time and, if necessary, taking actions such as expanding the inspections to other similar components or locations, reducing the time interval to the next inspection or taking corrective action. These objectives can be pursued at component, system, or function levels in a way that confidence in the safety significant functions is enhanced while avoiding unnecessary requirements.

The ISG refers to ASME issued BPV Code, Section XI, “Rules for Inservice Inspection of Nuclear Power Plant Components”, Division 2, “Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Power Plants.” Section XI, Division 2 as a potentially acceptable basis for a non-LWR ISI program. This ASME standard allows the applicant to propose a program specific to the technology of the non-LWR using expert panels and considering the degradation mechanisms applicable to the materials and the operating conditions of the design. Such an approach is amenable to implementing a RIPB ISI program. As Section XI, Division 2, contains acceptance criteria for the inspections only applicable in a limited temperature range, the RIPB approach may be more suitable for the temperature range covered by ASME Section III, Division 5.

The performance objectives for the ISI program also needs to examine under what plant conditions the inspections are best performed (e.g., full power, shutdown, etc.). The goal is to conduct the inspections during the plant conditions that, combined with the inspection technique itself and its related constraints, provide the necessary performance information while minimizing risk to worker safety and the public in general.

The ISG refers to ARDCs related to IST as those activities related to the following:

- ARDC # 1 “Quality Standards and Records”
- ARDC # 4 “Environmental and Dynamic Effects Design Bases”
- ARDC # 30 “Quality of Reactor Coolant Boundary”
- ARDC # 37 “Testing of Emergency Core Cooling System”
- ARDC # 40 “Testing of Containment Heat Removal System”
- ARDC # 43 “Testing of Containment Atmosphere Cleanup System”
- ARDC # 46 “Testing of Structural and Equipment Cooling Systems”
- ARDC # 46 “Testing of Structural and Equipment Cooling Systems”
- ARDC # 53 “Provisions for Containment Testing and Inspection”

The ISG associates these activities with motor operated valves, air operated valves, hydraulic operated valves, solenoid operated valves, check valves, manually operated valves, explosively actuated valves, rupture disks, safety and relief valves, pumps (motor and turbine operated), and dynamic restraints (snubbers). The programmatic requirements of the ARDCs may include various activities such as valve actuation (opening and closing times), relief valve actuation (opening and closing pressure), pump operation (flow rate, pressure), check valve (opening and closing, and leakage) and dynamic restraint operation. The test conditions may be as realistic as practical (e.g., pressure and temperature) so as to simulate actual operating conditions. Alternate testing techniques (e.g., bench testing of relief valves) may be defined where in place or at power testing is not feasible.

ARDCs correspond to the basic safety functions. Performance objectives of ARDCs cover the fundamental requirements related, for example, to control of heat removal and release of radioactive material. The IST frequency and/or IST techniques need to be based on maintaining system and functional reliability and performance consistent with the assumptions in the safety analysis.

The formulation of the non-LWR IST program performance objectives in the above manner appears to be focused on programmatic controls and may be unnecessarily prescriptive. A RIPB alternative may offer a better approach. Factors such as decision-making upon discovery of adverse results and identification of conditions under which testing should be done would likely be able to accomplish less prescriptively within a RIPB framework.

For an advanced reactor design with passive components that perform active safety functions, the IST program needs to include activities capable of assessing the operational readiness of components to perform their active safety functions. In a RIPB framework, the licensee could be given the option of establishing fitness for service by testing at the system or function levels also. In general, passive safety features will either be in standby or in operation depending on the design. When in standby, the IST program should verify that the conditions (e.g., pressure, fluid level, and temperature) necessary to activate the feature and ensure it performs its safety function are present. When in operation, the IST program should verify that the performance (e.g., heat transfer and reactivity insertion) of the feature aligns with predicted performance. This may involve measuring inlet and outlet temperatures, flow rates, changes in power level or other appropriate parameters, and using analysis to determine overall performance. For passive valves (i.e., valves that maintain their obturator position and do not need to change their state to accomplish their safety function), the IST program should verify that seat leakage and position indication (remote and local) are consistent with the assumptions in the plant safety analysis. The decision-making should also cover the process to be followed when the IST program identifies degradation or that misalignment has occurred. This should include tracking degradation over time and, if necessary, taking actions such as expanding the IST activities to other similar components, reducing the time interval between IST activities or taking corrective action to improve the component's performance. NUREG/BR-0303 provides guidance on developing the technical basis for maintaining margins (physical and temporal) to guide such decisions. The process should ensure that appropriate criteria are used to decide what additional actions to take to allow continued operation consistent with the licensing basis.

In evaluating whether or not DID is maintained, the main concern is degradation in the reliability and integrity of the barriers that (a) prevent the release of radioactive material, (b) maintain the integrity of systems relied upon for cooling from all sources of decay heat and (c) if failed, could prevent SSCs from performing their safety function. Such degradation can lead to not having the lines of defense assumed as part of DID. In a RIPB framework, failure could be defined by the magnitude and the confidence in relevant physical and temporal margins. Such an approach would identify performance objectives that include equipment capability as well as operator actions. These objectives would be derivatives of the top-level objectives of design features and programmatic controls.

PERFORMANCE FACTORS:

A plant's ISI and IST programs constitute essential parts of a reactor's justification for continued safe operation. Functionally, these programs can be viewed as part of a reactor's monitoring and oversight system. Such a system is equally important for the licensee as well as the regulator. For the licensee, objective evidence that they are meeting their responsibility for public health and safety supports public acceptance. It offers the regulator means to independently obtain assurance of validation and verification of compliance with the licensing basis. Considering performance factors starting at the top level with design features and programmatic controls makes performance amenable to logical decomposition in a way that provides better confidence in completeness of the factors which go into the safety decision-making along the lines of NURG/BR-0303.

According to NUREG/BR-0303, the ISI and IST programs can be designed and set up to be RI, PB, or RIPB. The differences lie in the decision-making structure. It would seem logical for water-cooled reactors in the US to use the staff's ISG because 10 CFR Part 50.55a would apply unless that regulation is exempted. This approach can be viewed to have two disadvantages:

- It is highly prescriptive and likely to include unnecessary requirements
- Compliance targets the component level, which can be quite inefficient because gathering data for reliability of components during operation can be problematic. A partial solution may be to monitor unavailability, which can raise other issues.

A key factor regarding which approach to employ for the ISI and IST programs may be the decision-making structure preferred by the licensee. The guidance in NUREG/BR-0303 enables alternatives, from a focus on reliability of components to one that focuses on margins toward fulfilling functional needs. For complex reactor related issues, the guidance recommends use of structured performance objectives in an objectives' hierarchy. It points out that the ACRS recommended that the decision-making should be aimed at as high a level in a hierarchical structure as feasible. This leads to the possibility of finding parameters that characterize successful performance at the system, function or design feature levels. The PB aspects of the alternatives would enable specification of margins at any of the levels identified in the structure as performance objectives in such a way that the monitoring and oversight functions would validate and verify the criteria associated with successful accomplishment of those objectives.

An example of how an alternative based on NUREG/BR-0303 could work in relation to the guidance in the ISG may consider the following question regarding the IST for non-LWRs:

"Are acceptance criteria established and justified for each component IST activity and are they consistent with the assumptions in the PRA on component reliability and performance? In general, the acceptance criteria should be based upon the uncertainties in component performance assumed in the PRA, such that any degradation in component performance is within the performance uncertainties assumed in the PRA."

This applies to the RI approach applied generically to all design features in the non-LWR. For some features of advanced reactors this question may pose problems. If this question is applied to a heat pipe in a non-LWR design, it may not be obvious where to apply the question. Many different types of heat pipes are being considered among the advanced reactor developers. The aspects related to reliability (a statistical quantity) and its uncertainty may be considered burdensome by the licensee for a design that would likely treat a heat pipe deterministically. A PB alternative would likely consider the possibilities of treating the heat pipe as a system or a function for which a suitable performance parameter should be defined and observed as part of the monitoring function. The heat pipe as a design feature would be amenable to direct observation and assessment of margins available during normal or emergent conditions. Questions regarding reliability and uncertainty would not be relevant when direct or calculable parameters are available for observation and decision-making. A suitable parameter for a heat pipe may be something analogous to the heat flux parameter associated with fuel pins in a reactor. The heat flux rating is often expressed as KW/ft and can be calculated by observation of flow and temperatures. It would also be relatively easy to specify minimum acceptable values for such parameters and observe changes over time due to factors such as fouling of heat transfer surfaces. The modeling associated with such analyses would be quite different from a PRA model.

FRAMEWORK STRUCTURE:

The proposed RIPB framework for ISI and IST programs is based on the programs being part of a safety case which shows what challenges to plant safety are being considered, and what plant capability is provided in the design for responding to those challenges. The safety case leads to allocation of performance goals over its elements and construction of an objectives' hierarchy. As described in NUREG/BR-0303, the result is an integrated, hierarchical presentation of hardware, human, and institutional performance areas that indicates how institutional performance supports the safety case.

In NUREG/CR-5392, a recommendation is made for any monitoring program to have observation of leading indicators of performance degradation rather than just flagging deterioration after it has occurred. This approach has benefits for NRC as well as the licensee. Incentives for licensees to avoid performance problems could result in getting to a basis for regulatory decision-making in which current prescriptive requirements that need monitoring of compliance to be supplanted by observation of outcomes as evidence that desired safety objectives are being accomplished.

A question may arise whether the observation of success in performance is incorrect because of flaws in the criteria used in decision-making. Another piece of NRC research documented in NUREG/CR-6833 (issued in 2003) offers a methodology for assessing the likelihood of such false positive conclusions.

An RIPB ISI and IST program based on NUREG/BR-0303 would take into account all the important performance factors to construct a decision-making framework that defines the desired outcome for the activities including going back to first principles such as Principles of Good Regulation. The approach starts with a desired outcome, identifies performance goals to achieve the outcome, and then identifies specific objectives and information needs to meet each performance goal. The regulatory oversight framework developed using this approach is represented in Figure A-2 of NUREG/BR-0303.

NURG/BR-0303 uses a structure that identifies those aspects of a licensee's performance that are important to the mission and therefore merit regulatory oversight. A plant's ISI and IST program falls into this category. The most important elements in each of these performance areas which form the foundation for meeting the overall agency mission were identified from a risk-informed perspective. These elements were identified as the cornerstones in the third level of the regulatory oversight framework structure. These cornerstones serve as the fundamental building blocks for the regulatory oversight process, and acceptable licensee performance in these cornerstones should provide the needed confidence in programs such as those for ISI and IST.

The Reactor Oversight Program (ROP), offered as an example of an objectives' hierarchy in NUREG/BR-0303, sought to identify performance indicators wherever possible as a means of measuring the performance of key attributes in each of the cornerstone areas. Where such a performance indicator could not be identified, the ROP proposed a "complementary" inspection activity. Where a performance indicator was identified, but was not sufficiently comprehensive, the ROP proposed "supplementary" inspection activities. The ROP also identified the need for "verification" type inspections to verify the accuracy and completeness of the reported performance indicator data. The ROP also identified aspects of licensee performance (such as human performance, the establishment of a safety conscious work environment, common cause failure, and the effectiveness of licensee problem identification and corrective action programs) that are not identified as specific cornerstones but are important to meeting the safety mission. It was concluded that these items generally manifest themselves as the root causes of performance problems. Hence, the construct and structure of the ROP appeared to take account of the recommendations of NUREG/CR-5392 but there was no attribution provided.

Other examples of constructs analogous to objectives' hierarchies have been offered in other activities but none has proposed a formal process of logical decomposition to assure completeness in the manner of ROP. A good example is the structure offered in SECY-18-0096 on functional containment.

PROCESS ELEMENTS:

The framework for ISI and IST programs is a logical construct of performance objectives associated with relevant design features and programmatic controls in which accomplishment of each of the objectives will entail activities organized into a process so as to be systematic, repeatable, and predictable relative to outcomes. The following are proposed as process elements that would be important in defining a suitably performance-based alternative to existing prescriptive provisions.

Functional Analysis:

A functional analysis identifies a complete set of functions that accomplish specific objectives each of which contributes tangibly to the desired outcomes. In a risk-informed approach, the functions would be derived from a PRA. In an integrated risk-informed and performance-based approach, the functions would be defined based on an objectives' hierarchy or a safety case that incorporated defense-in-depth considerations.

DID considerations may involve taking account of single-failure analysis (if ARDCs are used) or a "layers of defense" formulation. The functional analysis may be quite different for each of these approaches.

The functional performance areas that contribute to layers of defense would be presented in a safety case described in narrative form the functions that accomplish performance objectives. A safety case could be prepared from the modelling within a PRA supported by the structure of an objectives' hierarchy. The functional analysis should produce a hierarchy of functional specifications as a result of decomposition or disaggregation of functions associated with principal design criteria. In most cases, the functions would rely on systems and sub-systems performing to their requirements. It may not be necessary for the decomposition to go to the component levels, but if needed, prescriptive requirements for components would be specified.

The functional performance areas can be examined more closely with respect to employing a performance-based approach by posing three questions:

1. What are the factors for which credit is taken for the defense-in-depth elements of the safety case?
2. How much credit is allocated for these factors to fulfill their expectations?
3. How is confidence obtained that assigned level of credit to these defense-in-depth elements will be available during the stages of design, during construction and confirmed during operation?

Functional Categorization:

Functional categorization is part of a systematic and reproducible process in which desired goals and objectives can be represented within structures that provide relationships and dependencies among appropriate performance objectives. For example, the ISI and IST programs would functionally fall under licensing and inspection procedures or regulatory enforcement.

The functional categorization may also take account of the structure used for the objectives' hierarchy. In the ROP, "Reactor Safety" is decomposed into four cornerstones, "Initiating

Events", "Barrier Integrity", "Mitigating Systems" and "Emergency Preparedness". In more recent work on functional containment (SECY-18-0096), the structure employs top level objectives as "Reactivity Control", "Decay Heat Removal", and "Radioisotope Retention". The performance objectives would recognize the roles of systems and components within the functional relationships and dependencies including energy production functions, maintenance functions, auxiliary functions, and safety functions and an identification of hazards associated with these SSCs.

The integrated decision-making process of a performance-based approach includes consideration of where in the hierarchy criteria are to be specified. According to NUREG/BR-0303, an ACRS recommendation was that performance levels and reliability parameters should be set at the highest level possible. Functional categorization enables use of a formal systematic and reproducible approach for performance-based criteria at the highest levels while resorting to prescriptive approaches at lower levels.

Another ACRS recommendation was that guidance should be given on the extent to which multiple performance parameters that provide redundant information could be used to satisfy the defense-in-depth philosophy. The activities of functional analysis and functional categorization should enable consideration of specific elements of defense-in-depth that would be addressed in a way that provides for redundancy, independence and diversity which are important to defense-in-depth.

Another type of functional categorization could be based on the expected frequency of demand for specific functions. The categorization of licensing basis events produces event categories with a variety of functional scenarios to be considered for performance objectives. For advanced reactors, the considerations may take account of AOOs, LBEs, and BDBEs differently.

The results of the functional characterization may be used to check for completeness. Some analyses have characterized adequate safety as composed of adequate safety margins and adequate defense-in-depth. The adequacy of each would be gaged by how a structured decomposition covers the entire safety landscape.

Identification of Safety Margins

NUREG/BR-0303 interprets the Commission's definition of the PB approach to imply the necessity of a margin between performance criteria and acceptance criteria. This interpretation is consistent with standard engineering design practice in which normal and challenged operating conditions are considered in relation to a system state that represents an acceptance or limit state. This type of margin could occur at every level of decision-making within a hierarchical structure. Identifying the nature and attributes of the margins requires a deliberative process that considers in a formal way whether there is sufficient confidence in the existence of margins at the various levels. The evaluation at the outcome level is likely to involve quantitative as well as qualitative factors using expert judgement.

The functional analysis and functional categorization lead to the need to identify and define safety margins more specifically relative to functional objectives. Conventional design practice incorporates a safety margin between system capacity and the expected challenges against which the system is designed. There is an element of confidence associated with the estimates of the margin depending upon whether the estimates apply to design basis considerations or those beyond the design basis. The consideration of the margin and the level of confidence involved are consistent with supporting the regulatory function to monitor potential erosion of margin, as well as licensee responsibility for prompt corrective actions. It is in this context that advanced reactor applicants can propose RIPB based ISI and IST programs with confidence that staff will approve formal application of the Commission's outcome objectives for the programs.

A formal definition of safety margin may be beneficial for some performance elements. An example of such a definition in a system state perspective is as follows:

"***Safety Margin*****:** Safety margin is represented as the difference, expressed in consistent terms, between a capacity function (a representation of a system state) and a challenge function within the context of a particular scenario. The capacity function is associated with a system to represent its time-dependent capability to perform a safety function successfully in a conservatively or a realistically evaluated analysis. The capacity function could be expressed probabilistically as likelihood of successful performance when challenged as specified. The challenge function is defined within the context of a design basis or licensing basis scenario as the limiting or time-dependent set of conditions imposed on a system (or a function) due to challenging events. The challenge function could incorporate time-dependent physical parameters expressed in natural or calculated measures (see NUREG/BR-0303) or qualitatively with constructed or proxy measures. A probabilistic representation of the challenge function could be employed provided a suitable basis for comparison with the capacity function is defined in context and in consistent terms."

Selection of Performance Parameters and Decision Criteria

The reason to apply the performance criteria at as high a level in the hierarchical structure as practicable is to allow more flexibility in obtaining fitness-for-purpose and fitness-for-service. However, the need to assure opportunity to take appropriate corrective action requires that criteria be set in context appropriately for the issue, in a way that depends on available margin. In general, this tradeoff between flexibility and the need for prompt corrective action will require an iterative approach.

For example, the ISG offers as examples of systems subject to ISI those that would fall under ARDC #42 ("Inspection of Containment Atmosphere Cleanup System") and ARDC #45 ("Inspection of Structural and Equipment Cooling Systems"). The scope of the ISI program should include all piping, pressure retaining components and component supports that perform safety significant functions as well as piping whose failure could prevent SSCs from performing their safety function. Atmosphere cleanup systems may include sizeable mechanical, chemical, and electrical systems. Because such systems are likely to be on standby status, inspecting components of such systems and identifying criteria for them would likely be much less efficient than inspecting functional performance that incorporates systems interactions. Integrated performance parameters and decision criteria for inspections performed under carefully controlled conditions to assess margins would likely be more effective. Similar considerations may apply for structural and equipment cooling systems. For MSRs the functional criteria may not only involve heat removal by heat addition to assure fluid states in all or parts of the systems involved.

It appears reasonable to expect that similar considerations would apply for the IST program as well. Additional complications could occur with conditions associated with ASME Section III, Division 5 applications, especially for graphite components. It seems clear that only RIPB methods would be economically feasible for non-metallic components covered by Section III, Division 5.

Experience with the operating fleet can inform the understanding of strong linkages that can exist between observable characteristics chosen as the performance parameters to be used in a performance-based approach and the assessment of margin based on criteria applied to these parameters. For example, the quality of emergency backup power provided by a diesel generator would not necessarily be well-reflected by prescriptive criteria that are applied to each component part of the diesel generator. Hence, a prescriptive approach at the component level can become unnecessarily onerous. This is because even if very strict quality criteria are applied to each of the component parts, the overall diesel generator performance may not meet regulatory standards. On the other hand, a diesel generator taken as a whole system may adequately meet performance standards even if the component parts are of only commercial grade quality.

Formulating Suitably RIPB Options:

While the ISG is intentionally based on a PRA, an applicant may benefit from being able to compare “risk-informed”, “performance-based” and “risk-informed and performance-based” approaches to develop their ISI and IST programs. The guidance in NEI 18-04 considers categories of “plant functional capability” and “plant physical capability”. Performance attributes such as “reserve capacity to perform in severe events” and “robustness” of SSCs are considered important. Protective strategies are identified so that reasonable assurance is provided that the predicted performance of SSCs incorporate special treatment while designing, manufacturing, constructing, operating, maintaining, testing, and inspecting the plant and the associated processes.

The structure of the guidance offered in this framework document should lead an applicant through a step-by-step process that produces an outcome that is (1) consistent with the outcomes defined by the Commission’s White Paper; and (2) formally meets performance objectives that have been structured as elements within hierarchies. Suitable performance parameters and criteria are likely to be prescriptive at the lowest levels of the hierarchy, with other options becoming available at higher levels. The steps are not formulaic and involve deliberations that are referenced in NUREG-2150 to consider all aspects of desired outcomes. For example, the ACRS recommended that defense-in-depth could be addressed by having multiple performance parameters provide redundant information to satisfy the defense-in-depth philosophy. The guidance in NEI 18-04 implements this principle by avoiding reliance on any single design or operational feature.

SUMMARY:

In this document, a framework is proposed that would implement the structure and processes to realize the aspirations of the Commission as articulated in SRM-SECY-98-0144, “White Paper on Risk-Informed and Performance-Based Regulation”. Soon after the Commission provided the direction in the White Paper, the staff invested in much effort to incorporate risk-informed concepts into regulatory practice but there was considerably less investment in the complementary performance-based concepts. NUREG/BR-0303, “Guidance for Performance-Based Regulation” was published in 2002 but found little use in staff’s activities. NUREG/BR-0303 is structured to offer users of the guidance choices emphasizing RI, PB, or RIPB options while achieving the outcome objectives of the White Paper. More detail is offered with regard to formulating a PB alternative to any regulatory issue within the scope of NRC’s responsibility because the White Paper includes concepts within PB approaches that are not described anywhere else.

As part of ARCAP, the staff has issued an ISG (ML21216A051) to offer RI guidance to staff and applicants to develop ISI and IST programs. The framework described in this document can broaden the choices made available by staff's guidance under ARCAP. It is a fact that applicants can use NUREG/BR-0303 whether or not ARCAP includes it. However, because no developer of advanced reactors has included the Commissions vision in their formulation of a PB approach, it is appropriate for the staff to highlight the White Paper separately in ARCAP.

To the extent that ARCAP is expected to support Part 53 rulemaking, it is important that any guidance to applicants point to the White Paper because Part 53 will not be as effective and efficient as it can be unless the high-level goals of the Commission are realized. Many of the comments on Part 53 indicate that many stakeholders seem to think that the new regulation is inconsistent with Commission objectives. Hence, there is a need to make more explicit why and how Part 53 is RIPB. Such an explicit connection would recognize what makes the Commission's formulation of the PB approach different from all other formulations offered so far. All stakeholders want flexibility. However, there does not seem to be a recognition of the inherent tension between flexibility and accountability to meeting safety objectives. This connection provides the imperative for the ARCAP to recognize the value proposition of NUREG/BR-0303 and to make sure that it is part of the guidance to staff and applicants.

The framework description in this document is focused on non-LWR advanced reactors that have chosen to apply for design certification followed by a combined license. The role of the ISI and IST programs at the operations stage is to validate and verify on a continuing basis the fitness for service and operational readiness of some of the design features and programmatic controls (Part 53 language) that provided the technical justification for the safety evaluation of a design. Implementation of these programs with RIPB methods enables accomplishment of the Commission's transformative objectives as reflected in SRM-SECY-98-0144.

Some advanced reactor developers, such as those for micro-reactors, may find a PB alternative to deterministic and prescriptive safety to be useful especially if a PRA is not available. In the deterministic approach, the margins are specified as part of the responses to design basis accidents. Even if a PRA is not used, decision-making must consider uncertainty and ambiguity. Research documented in NUREG/CR-6833 offers a methodology to do this.

For complex reactor related issues, the guidance in NUREG/BR-0303 recommends use of structured performance objectives in an objectives' hierarchy. It points out that the ACRS recommended that the decision-making should be aimed at as high a level in a hierarchical structure as feasible. This leads to the possibility of finding parameters that characterize successful performance at the system, function or design feature levels. The PB aspects of the alternatives would enable specification of margins at any of the levels identified in the structure as performance objectives in such a way that the monitoring and oversight functions would validate and verify the criteria associated with successful accomplishment of those objectives.

Using the RIPB approach for programs such as ISI and IST strengthen safety in multiple ways by addressing DID in a way that does not appear to occur explicitly in the ISG. The first is based on an ACRS recommendation that guidance should be given on the extent to which multiple performance parameters that provide redundant information could be used to satisfy the defense-in-depth philosophy. The activities of functional analysis and functional categorization should enable consideration of specific elements of defense-in-depth that would be addressed in a way that provides for redundancy, independence and diversity which are important to defense-in-depth. The second way is by taking into consideration NUREG/CR-5392 findings that programmatic weaknesses can behave analogously to common cause failure mechanisms. This makes them important for two reasons: they are potentially important causes of failure, and their capacity to affect multiple trains creates the possibility that when they do manifest themselves, they do so in events having high conditional probability of adverse consequences.

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