Planning for future probabilistic risk assessment research and development

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Abstract

The US Nuclear Regulatory Commission's (NRC) Office of Nuclear Regulatory Research has started to develop a formal plan for future probabilistic risk assessment research and development topic areas. The plan is currently intended to provide a basis for high-level, resource allocation decisions in Fiscal Years 2007-2012, and will address broad probabilistic risk assessment topic areas. To help ensure the plan development activities address foreseeable regulatory and licensing needs, NRC will employ a number of mechanisms to identify and prioritize potential topic areas. These are expected to include: a technical gap analysis, case studies analyses, a review of similar planning activities performed by other US and international organizations, input from review committees and other stakeholders, and, possibly, the formation of a Technical Advisory Group involving senior technical staff within the agency. The plan will present the selected topic areas using a number of different conceptual frameworks. It will also identify technical objectives and general work activities for each topic area needed to ensure that associated research and development activities appropriately address key deployment and application issues faced by regulatory users.

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1 INTRODUCTION

As directed by its Probabilistic Risk Assessment (PRA) Policy Statement issued in 1995, the US Nuclear Regulatory Commission (NRC) has been increasing its use of risk information in its regulatory activities "to the extent supported by the state-of-the-art in PRA methods and data" (NRC 1995, Diaz 2005). This policy statement recognizes both the benefits and current limitations of PRA as a decision support tool.

As part of its continuing efforts to address these limitations, the Office of Nuclear Regulatory Research has started to develop a formal plan for future PRA research and development (R&D) topic areas. The intended uses of this plan are to (a) support high-level, resource allocation decisions for Fiscal Years 2007-2012 and (b) provide a starting point for the planning of detailed activities addressing the topic areas identified by the plan. It is expected that the resources required to develop and maintain a formal plan will be balanced by a number of benefits. These benefits include the increased assurance that future PRA R&D topic areas are tightly coupled to the regulatory needs of the agency, and the availability of documentation enabling internal and external stakeholders to determine where and why NRC is focusing its PRA R&D resources. The documentation will also facilitate updates to the R&D program as the agency's knowledge base and needs change.

This paper describes the current status of the plan development activity and future directions.

2 TERMINOLOGY AND SCOPE OF PLAN

Recognizing that the terms "PRA" and "R&D" establish limits on the general scope of the plan, it is useful to explain what these terms mean in the context of the plan development process.

"PRA," also called Probabilistic Safety Assessment (PSA), is, using the triplet definition of risk provided by Kaplan & Garrick (1981), an assessment of scenarios, consequences, and probabilities. Note that the triplet definition has been adopted by such consensus standards organizations as the American Society of Mechanical Engineers (ASME 2002), the American Nuclear Society (ANS 2003), and the National Fire Protection Association (NFPA 2006).

It is important to recognize that the above definition of PRA supports but does not restrict PRA to the classical event tree/fault tree methodology and its application. The definition only requires the probabilistic treatment of scenarios, however defined, and their consequences. Thus, for example, it is broad enough to accommodate the range of analytical methods being developed for the detailed treatment of the risk associated with complex, dynamic systems (Siu 1994).

Regarding the term "R&D," the NRC's Office of Nuclear Regulatory Research performs a broad range of activities, ranging from applied research through the performance of technical analyses to address regulatory issues. This broad range includes activities to develop methods and tools, and activities (e.g., the development of guidance documents) to support field deployments of these methods and tools. The PRA R&D plan is intended to address anticipated, future agency PRA technology needs not addressed by current programs and activities.

These needs are not necessarily limited to the development of new analysis techniques. For example, much of the PRA technical literature has focused on the development of improved analytical techniques for assessing risk, and on the application of these techniques in specific analyses, generally from the viewpoint of the organization performing the analysis. Less attention has been paid to issues arising from the needs of such organizations as NRC that may be reviewing analyses and making decisions based on evaluations of these analyses. These issues include risk model validation, review support, and uncertainty communication. Broad approaches for dealing with these issues have been developed for the current generation of event tree/fault tree-based risk models (ASME 2002). However, these issues have not been addressed, nor perhaps widely recognized by developers of new approaches.

As a particular example, direct simulation-based approaches to PRA may have considerable appeal because these approaches can incorporate complex phenomenology into an assessment. These approaches can reduce the need for some levels of modeling (e.g., through the elimination of the need to define intermediate success criteria) and can also provide a natural framework for empirically testing key model hypotheses. However, their use can provide new challenges to the reviewer of a PRA, who will need to have a good understanding of the specific model used in the assessment (and not just the general method).

A variety of tools to support the development of this understanding can be envisioned. These can include, for example, hierarchical representations of the causal relationships in the model, sensitivity analysis tools for testing the strength of these relationships, trace-back tools to understand the analytical path linking inputs and outputs, model uncertainty assessment tools (e.g., to identify key extrapolations and to address associated uncertainties), and tools to aggregate the detailed results of the simulation thereby supporting an overall understanding and communication of the results.

It appears that the development of tools to address PRA user needs can be addressed within a technical framework. We currently expect that activities to develop and test such tools will be identified and prioritized as part of the PRA R&D plan development process.

3 APPROACH

From a technical standpoint, the approach for developing the plan is expected to be relatively straightforward. After defining the specific objectives and scope of the plan, NRC will perform a variety of activities to identify potential R&D topic areas. These activities are expected to include: a technical gap analysis, case studies analyses, a review of similar planning activities performed by other US and international organizations (Kaufer 2005), input from review committees and other stakeholders, and, possibly, the formation of a Technical Advisory Group involving senior NRC technical staff. The topic area identification will be done with explicit recognition of relevant ongoing NRC R&D activities, including those involving human reliability analysis, digital instrumentation and control systems reliability analysis, fire risk analysis, advanced reactor risk analysis, standardized plant analysis risk model development, and PRA standards development.

The technical gap analysis is expected to involve a broad review of PRA methods, tools, and data in the context of NRC's regulatory needs. As discussed later in this paper, a key, initial challenge is the development of an appropriate conceptual framework for characterizing PRA R&D activities and potential gaps (i.e., areas where there may be insufficient activity to meet agency needs). To support communications with multiple stakeholders, a number of frameworks will be developed.

The case studies will examine selected recent issues and events faced by NRC from the perspective of if and how risk information was used to support agency decision making. The purpose of the examination is to identify potential needs for PRA R&D products. Potential case study candidates include the Davis-Besse reactor pressure vessel head corrosion issue and the August 14, 2003 loss-of-grid event.

Following the identification of potential topic areas, NRC will assess the potential benefits, costs, and outcomes of R&D activities in these areas and will prioritize the topic areas. For the initial version of the PRA R&D plan, the authors expect that these assessment and prioritization activities will be performed on an informal basis, perhaps using the "priority" versus "importance" representation used by Kaufer (2005). Updates to the plan may incorporate more formal processes for eliciting stakeholder opinions and for performing trade-offs across R&D alternatives. The resources required to implement such formal processes will be balanced against benefits. The latter could include increased staff exposure to and proficiency with the variety of tools and techniques available to collect and process subjective decision-support data.

4 SOME THOUGHTS AFFECTING POTENTIAL TOPIC AREAS

Although it is too early in the planning process to indicate specific topic areas to be included in the PRA R&D plan, the authors' experiences from past PRA-related planning efforts and analyses provide some potentially useful ideas relevant to the identification of topic areas and supporting R&D activities. Note that although most of the examples raised in the following discussion stem from applications involving nuclear power plants, many of the broader points can also be extended to non-reactor PRA applications.

4.1 *On the Current PRA Application Context*

The nuclear power industry and NRC have spent considerable resources developing methods, computational tools, plant-specific models, databases, guidance documents, and standards, as well as on the training of management and staff, in order to support the increased use of risk information in decision making. Nearly all of this work has been built on the technology of classical event tree/fault tree analysis, first developed and used in the landmark Reactor Safety Study (NRC 1975). Clearly, and consistent with the PRA Policy Statement, it is important that the PRA R&D plan appropriately support current applications based on this technology.

This means, for example, that in situations where alternatives to the event tree/fault tree method are discussed, the discussion may also need to address how these alternatives should be exercised in decision support applications. In some situations, it may be appropriate to use alternative modeling methods (e.g., direct simulation) to supplement specific portions of a classical analysis (e.g., to provide additional, independent insights). In other cases, it may be appropriate to replace specific results of the classical assessment with those of the alternative method. In such cases, work may be needed to ensure that the results of the alternative analyses are appropriately integrated into the overall risk assessment (which is likely, at least in the near term, to use the classical framework). Work may also be needed to develop and implement an appropriate and efficient deployment strategy for alternative methods.

4.2 *On New Systems and PRA Needs*

Because a PRA is a systems analysis, the introduction of new system designs and technologies can provide new challenges to PRA modeling methods, tools, and databases that have been developed for and applied to existing systems. For example, in the case of new nuclear power plant designs, the switch to digital instrumentation and control systems and the increased reliance on passive safety systems provide technical challenges that have been widely recognized but not yet resolved.

Some of these challenges arise from the need to understand and model, in probabilistic terms, the potential behaviors of these new systems under a variety of postulated abnormal conditions. Other challenges are likely to arise from the effects that these new systems have on other parts of the facility/process being analyzed. In the cases of both digital and passive systems, for example, the new system designs are expected to change the role, responsibilities, and required actions of plant operators, as well as the time windows for these actions. These changes will likely affect the human reliability analysis (HRA) portion of the PRA. It is not yet clear, from a regulatory perspective, whether these changes will require significant changes in available HRA methods and tools.

The NRC's assessment of PRA needs relevant to the review of advanced reactor license submittals is documented in Attachment 2 to SECY-03-0059 (NRC 2003). A number of development tasks are identified in that assessment, dealing with such topics as data, modeling methods (e.g., for the treatment of passive and digital systems, human actions, and such environmental hazards as internal floods, internal fires, and earthquakes), and the treatment of uncertainties. NRC is also undertaking a number of PRA development activities intended to support the certification and licensing of more near-term reactor designs. The NRC's plans for both new and advanced reactors will provide important input to the PRA R&D plan discussed in this paper.

4.3 *On Scope Limitations of Current PRAs*

The needs for PRA R&D are not limited to those associated with new system designs. NRC has a number of active programs (e.g., in HRA, fire risk analysis, and the development of Standardized Plant Analysis Risk models) that are aimed at addressing technical challenges in the risk-informed regulation of current systems and facilities. In addition, NRC has faced a number of issues over the years for which the assessment of risk implications has required the relaxation of common scoping limitations of the then-current PRA models. These issues have covered a diverse range of topics, including low-power and shutdown operations, pressurized thermal shock, and terrorism-related events.

It can be postulated that the agency might, in the future, be faced with other situations requiring assessments that go beyond the spatial, temporal, and organizational boundaries generally imposed for standard PRA models. (Some respective examples of such situations could be events involving multiple sites within a geographic region, a series of related events at a site occurring over time, and events involving interactions between on-site and off-site emergency response organizations.) It would appear useful therefore, during the initial development of the PRA R&D plan and during periodic updates of the plan, to question whether the assessments of currently recognized issues appear to require the relaxation of normal modeling constraints, and whether additional R&D activities are needed to enable such assessments.

4.4 *On Classical and Alternative PRA Methods*

As indicated earlier in this paper, the classical event tree/fault tree method used in nuclear power plant PRAs is not the only risk assessment method available. The PRA literature provides numerous examples of alternative methods in varying stages of development. A common theme underlying the development of many of these alternative methods is the desire to better and more explicitly address key system phenomenology and behavior within the PRA model.

In event tree/fault tree analysis, the system's physical behavior (e.g., in response to an initiating event) is addressed through qualitative modeling (e.g., when constructing event trees), the definition of success criteria, and the estimation of certain event probabilities. In many instances, detailed phenomenological models are used to support these activities. (For example, in the case of event probability estimation, phenomenological models can be used to predict the timing of events; the times for different events are then compared within a competing risks analytical framework.)

The significant, practical benefits of the classical approach include the development of logic models that can be solved extremely quickly (even for very complex systems), the direct and transparent use of system integral performance data (without requiring detailed modeling of the underlying phenomena), and the expression of results in high level, scenario-oriented terms that are readily understood by non-PRA specialists. The PRA R&D activities investigating alternatives to the classical approach are aimed at situations where (a) the available information may be in a different form than required by the classical approach (e.g., when there is good information on detailed physical mechanisms but not on integral performance under field conditions); (b) the assumptions underlying classical analysis may be problematic (e.g., when it is necessary to deal with strongly dynamic systems); or (c) alternative approaches can provide additional, valuable insights (e.g., when modeling the system in a more literal, one-to-one fashion provides insights regarding key behaviors underlying risk dominant scenarios).

Recognizing the importance of supporting current PRA applications (as discussed in Section 4.1) and of supporting NRC's broad set of needs (as discussed in Section 2), it is also important that NRC's PRA R&D planning process take advantage of ongoing, external R&D activities, when possible. Note that some of these activities may involve non-PRA related work. (For example, significant advances are being made in the modeling of military teams and organizations; some of the models developed for this work could prove useful, with appropriate modifications, in PRA applications.) The technical gap analysis mentioned in Section 3, will be a key tool for identifying potentially useful activities.

5 CONCLUDING REMARKS

As indicated at the beginning of this paper, the PRA R&D plan is currently in an early stage of development. A key technical issue being addressed is the development of one or more frameworks to support the performance of a technical gap analysis and communication with stakeholders. A number of alternatives to characterize the relevant space of PRA topic areas are being explored. These alternatives, currently focused on the needs associated with the regulation of commercial nuclear power plants, include a breakdown based on: classical PRA structure (i.e., in terms of Level 1, 2, and 3 analyses); products (e.g., methods, tools, data, knowledge); organizations (i.e., by offices and lower level organizations in NRC); and reactor classes (i.e., current, new, and advanced).

Two organizational questions currently being addressed involve (a) the makeup, role, and responsibility of the Technical Advisory

Group, and (b) the near-term approach for acquiring additional stakeholder feedback.

It is expected that the initial plan will be finalized by September 2006, in order to support decisions regarding potential changes in NRC's resource planning for Fiscal Years 2007 and beyond.

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