PSA Research and Development at the U.S. Nuclear Regulatory Commission

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Abstract: Spurred by the anticipated need to license and regulate new systems (e.g., advanced reactors and fuel cycle facilities) and the recognition of advances in PSA technology (enabled in part by improvements in computing hardware), the NRC has initiated a number of PSA-related R&D activities. The activities address numerical methods (e.g., Binary Decision Diagrams, sensitivity analysis), modeling methods (e.g., simulation-based methods, probabilistic networks), and specific topic areas (e.g., Level 2/3 PSA). These activities are in their initial phases and are generally being conducted on a limited scale. It is anticipated that the initial results of these activities will support agency decision making regarding areas where NRC should conduct in-depth research aimed at improving the agency's ability to more accurately and/or efficiently address current problems or anticipated problems.

Keywords: PSA, research and development, advanced methods.

1. INTRODUCTION

Since the landmark Reactor Safety Study in 1975, the U.S. Nuclear Regulatory Commission (NRC) has spent considerable effort on the development and use of risk information to support decision making. In the last several years, the NRC has focused much of its attention on approaches intended to make best use of existing PRA methods. In this time frame, the bulk of NRC's probabilistic safety assessment (PSA) detailed research and development (R&D) work has been aimed at three areas where uncertainties are significant and can affect the agency's understanding of risk: human reliability analysis, fire risk analysis, and digital instrumentation and control systems reliability analysis.

In 2006, spurred by the anticipated need to license and regulate new systems (e.g., advanced reactors and fuel cycle facilities) and the recognition of advances in PSA technology (enabled in part by improvements in computing hardware), the NRC initiated the development of a plan for PSA R&D. As described in [1], the purpose of the plan was "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." Shortly after the initiation of this planning effort, the NRC undertook a number of broader planning activities. These broader activities involved:

- Agency-Level Strategic Planning – the agency updated its Strategic Plan to address Fiscal Years (FY) 2008-2013 [2]. This plan provides the agency's overall mission, values, strategic goals, strategic outcomes, strategies, and means to support the strategies. Regarding strategies, the plan refers to the use (where appropriate) of risk-informed approaches for both safety and security applications, to the conduct of safety-focused research to anticipate and resolve safety issues, and to the use of state-of-the-art methods.

- Planning to Implement Risk-Informed and Performance-Based Regulation – the agency created the Risk-Informed and Performance Based Regulation Plan (RPP). This web-based plan (see http://www.nrc.gov/about-nrc/regulatory/risk-informed/rpp.html) supports the integration of risk

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information and performance measures into the NRC's regulations, regulatory guidance, and oversight processes. The plan is organized along major arenas (reactor safety, materials safety, and waste management) and subarenas (e.g., operating reactors, advanced non-light water reactors, research and test reactors, new light-water reactors). For each subarena, the plan provides the objective, basis, goals, and risk-informed and performance-based activities.

- Long-Term Research Planning – the agency created a report to document future technical issues and associated long-term regulatory research activities that are not identified in other agency planning documents [3]. The report identifies a specific PSA activity (advanced modeling techniques for Level 2/3 PSA – an activity aimed at exploring the direct use of integrated accident progression and source term codes in PSA) and two broad topic areas where PSA methods, tools, data, and criteria may need to be developed: NRC activities associated with the U.S. Department of Energy's Global Nuclear Energy Partnership (GNEP) program, and reactor license renewal beyond 60 years.

- Advanced Reactor Research Planning – the agency drafted a set of reports to support regulatory decision making regarding High Temperature Gas Cooled Reactors (HTGRs) [4-6]. These reports provide a detailed assessment of the technical infrastructure development and safety research that would be needed to support NRC's reviews, and the proposed safety R&D needed in order to establish NRC's independent technical review capabilities. Regarding PSA, the reports identify the need to develop regulatory guidance and standard review plan, as well as PSA tools (including Standardized Plant Analysis Risk – SPAR – models and data) and insights. It is expected that the final versions of these reports will be completed shortly.

Since these broader activities naturally affected the direction, scope, and use of the PSA R&D plan, development of the latter was delayed until the former were completed. With the finalization (or near-finalization) of the updated Strategic Plan, Risk-Informed and Performance-Based Implementation Plan, Long-Term Research Plan, and Advanced Reactor Research Plan, efforts to develop a PSA R&D plan have been resumed.

This paper identifies ongoing NRC PSA-related regulatory research activities and discusses planned future R&D activities.

2. CURRENT PSA-RELATED REGULATORY-RESEARCH ACTIVITIES

The NRC's Office of Nuclear Regulatory Research (RES) has principal responsibility for the development of PSA methods, models, data, tools, information (including insights as well as analysis results), and guidance intended to support NRC's regulatory activities, especially with respect to reactors. As such, in the current fiscal year, RES is working on a variety of PSA activities covering a large number of topic areas. Table 1 provides a listing of representative activities, organized using a list of PSA topic areas.

All of the activities shown in Table 1 are aimed at providing near-term (i.e., within the next 1-2 years) products for ongoing regulatory concerns. A few activities, shown in boldfaced, italicized text in the table, also have developmental elements expected to provide useful products in a longer time frame. This emphasis on near-term products reflects the imperative for RES, as a technical support organization, to address the current, articulated needs of NRC's line organizations. The longer-term activities are intended to provide: a) the basis for addressing recognized, important sources of uncertainty requiring extended effort for resolution (e.g., human reliability analysis), b) PSA technology (e.g., dynamic PSA methods) that is expected to be useful in the anticipation and resolution of emerging issues, or c) PSA technology (e.g., improved numerical methods) that will enable the more accurate and/or efficient solution of existing problems.

Table 1: Representative RES PSA Activities

Area	Topic	Representative Activities (FY-2008)*
Reactors	Level 1 internal events at power	Development and maintenance: standardized event tree/fault tree models for all U.S. plants**
	Level 2	Development: Standardized Level 2 models**
	Level 3	Development: Improved consequence analysis code
	Low power and shutdown (LPSD)	Development: Standardized LPSD models**
	Operational data	Analysis: industry trends
	Event analysis	Analysis: accident precursor significance
	Generic safety issues (GSI)	Analysis: issue significance
	Performance indicators and thresholds	Support: implementation of new performance index
	New reactors (evolutionary)	Analysis: HRA needs for new reactors
	Advanced reactors	Analysis: HRA needs for advanced reactors
	Research and test reactors	
Non-Reactor Facilities and Activities	Geologic repositories	
	High-level waste	Analysis: Qualitative HRA for high-level waste
	Low-level waste/decommissioning	Development: performance assessment models and tools
	Fuel cycle facilities	Analysis: mixed oxide fuel fabrication facility
	Transportation	
	Sources	Development and implementation: HRA-informed training
Special Topics	Human reliability analysis	***Analysis: performance of HRA methods against simulator data***; Development: human events database
	Ageing	
	Passive components	
	Passive systems	
	Digital systems	***Analysis: PSA methods for digital systems***
	Common-cause failure	Support: international common-cause failure database
	Design and construction	
	Fire	Support: risk-informed fire protection support; Development: HRA for fire PSA
	Seismic	Development: Standardized external events models**
	Other external events	Support: international review of current status
	Security-related events	Support: rulemaking for new reactors
	Emergency preparedness and response	
General Systems Analysis Methods and Tools	PSA tools	Maintenance: PSA software (SAPHIRE)
	Uncertainty and sensitivity analysis	Development: guidance for treatment of uncertainties
	Advanced computational methods	
	Advanced modeling methods	***Review: dynamic PSA methods***
	Elicitation methods	
Implementation and Application	PSA quality (e.g., guidance, standards)	Development: PSA standards
	Risk-informed regulation infrastructure	Development: risk-informed and performance-based technology-neutral framework for new reactors
	Risk-informed regulation applications	Support: steam generator tube rupture resolution
	Risk perception and communication	

*Boldfaced, italicized activities include longer-term, developmental elements
**Activity is part of the NRC's Standardized Plant Analysis Risk (SPAR) program

3. PLANNED FUTURE PSA R&D ACTIVITIES

Table 1 shows a number of PSA topic areas where RES has either limited or no ongoing regulatory research activity. It is expected that some of these gaps will be addressed as part of RES' efforts to address specific current or anticipated regulatory needs. Thus, for example, the passive systems topic area is covered in the NRC's Advanced Reactor Research Program [4]. Other gaps will be considered in the course of RES' planning efforts.

With respect to PSA R&D, RES is currently planning to initiate new activities in the areas of advanced computational methods and advanced modeling methods. This planning is consistent with the NRC's Strategic Plan [1], as well as with specific input from senior advisory committees (e.g., see [7]) and our understanding of the PSA state-of-the-art.

Some of the specifics on these planned activities are discussed below. It is worth noting that the initial activities are of limited scope and generally exploratory in nature. This is based on the recognition that: a) both the NRC and licensees have made considerable investments in current PSA technology, and b) there are sizeable benefits yet to be gained from the full application of current PSA technology to existing problems and processes.

3.1. Advanced Computational Methods

With continuing developments in mathematical algorithms, as well as increasing computer speed and storage, there is increased capability to address such computationally demanding problems as the exact quantification of a realistic PSA model and the assessment of multivariate sensitivities. On the other hand, for NRC applications, it is not yet clear whether such improved capabilities will significantly affect regulatory decision making, or if their added value will offset their development, implementation, and maintenance costs. Work on the following two topics would help inform decision making regarding potential extended efforts in this area.

- Binary Decision Diagrams (BDDs) – As discussed in [8], BDDs provide a means for quantifying PSA models without the numerical approximations (e.g., the rare event approximation, the min-cut upper bound approximation) used in standard PSA codes. For most PSA models of interest in NRC applications, it would appear that the numerical improvement would probably be masked by the significant uncertainties in the PSA model parameters, as well as by uncertainties in the model itself. However, this assertion has not been tested. Moreover, as discussed in [8], the use of an exact solution could change the values of certain risk importance measures that are used in some regulatory applications. The planned assessment (likely employing a set of benchmark problems) will address the potential value of BDDs for NRC applications and the nature of situations where current BDD algorithms may not provide a solution.

- Advanced sensitivity analysis methods – Because there are significant uncertainties in PSA models and results, sensitivity analysis is an important tool in risk-informed applications [9]. At the basic event level, PSA models are mathematically quite simple (being largely multilinear), and so simple "one at a time" methods (including standard risk importance measures) are quite informative. However, in situations where non-linear phenomenological sub-models underlie multiple basic events, such as in the case of current external events and Level 2 analyses, improved approaches capable of dealing with multivariate problems could be valuable. The value of such approaches is likely to be even greater for PSA models that take an integrated, simulation-based approach to the treatment of key phenomena. The NRC is currently planning to identify and assess advanced sensitivity analysis methods potentially useful for NRC PSA applications, in order to provide a basis for further developments in this area (if needed).

3.2. Advanced Modeling Methods

Ongoing improvements in computer speed and storage are also increasing the feasibility of advanced PSA modeling methods that integrate the modeling of key phenomena directly in the PSA. (The field of "dynamic PSA" [10] addresses one subset of these methods.) Such methods not only avoid such intermediate modeling concepts as success criteria, they also provide a natural framework for empirical validation of the PSA sub-models (if not necessarily the integrated model) and for the efficient use of expert judgment in places where empirical data are not available. On the other hand, the implementation of these methods can be quite complex and computationally demanding. Additional issues include: the validity of the sub-models, the efficiency of sampling schemes and the validity of selected samples (for simulation-based approaches), the reviewability of the integrated model, and the effectiveness of the aggregation/display of the integrated model results (including uncertainty). It is expected that each of the following three projects will address these issues.

- Advanced Modeling Techniques for Level 2/3 PSA. As discussed in the NRC's Long-Term Research Plan [3], the NRC is planning to initiate an exploration of a simulation-based approach to Level 2 and Level 3 PSA. The initial work will involve a scoping study to evaluate both methodological and implementation-oriented issues, as discussed above, and will address uncertainties in scenario characteristics (e.g., the timing of key events) as well as phenomenological uncertainties. It is expected that later work will develop a fast-running Level 2 tool (based on MELCOR, NRC's severe accident code) and assess whether improvements are needed in the agency's current Level 3 tools.

- Simulation-Based Methods. The preceding Level 2/3 project addresses one particular application of simulation-based methods for PSA. Other potential applications include human reliability analysis, external events analysis, passive systems analysis, and new component analysis (i.e., the analysis of components for which field performance data are not yet available). Recognizing that simulation-based methods are widely used in other fields for analyses of complex, stochastic systems, NRC is currently planning to assess the state-of-the-art with respect to the needs of risk-informed decision making (which must address rare events) and determine potentially fruitful avenues for further development (if needed).

- Probabilistic Network Modeling. Network models (including Bayesian Belief Nets and dynamic flowgraphs) provide an alternative to simulation-based models as a means to represent causal influences in a stochastic system. In a PSA context, network models have been used to treat such diverse applications as chemical process systems, software-based control systems, and organizations. As with the case of simulation-based methods, NRC is currently planning to assess the state-of-the-art with respect to the needs of risk-informed decision making and determine potentially fruitful avenues for further development (if needed).

3.3. PSA R&D Planning

In parallel with the planning and initiation of the above projects, the NRC will develop a PSA R&D plan, in accord with the intentions described in [1]. The objectives of the plan are expected to remain as described in Section 1 of this paper. In addition to identifying planned activities and the basis for these activities, the plan will explicitly address its relationship with higher level planning documents (e.g., the NRC Strategic Plan, which identifies challenges for the agency) as well as lower-level documents (e.g., plans for specific topic areas such as digital instrumentation and control systems research). In order to ensure that the expected research products will support regulatory applications, the plan development process will involve internal stakeholders from the NRC's line organizations. In order to ensure that the planned activities take appropriate advantage of recent PSA developments (non-nuclear as well as nuclear, international as well as U.S.), the plan development process will also involve input from external PSA experts.

4. CONCLUSION

The NRC is currently performing a broad range of PSA regulatory research activities to support the agency's risk-informed regulation needs. In order to determine whether significant PSA R&D efforts should be undertaken to address anticipated needs, the NRC has initiated a number of limited scope evaluations regarding advanced PSA computational and modeling methods, and is working to develop a plan for PSA R&D. The results of these efforts are expected to provide a first step in preparing the agency for future challenges posed by new technologies, new facilities, and new demands on PSA technology to support decision making.

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