ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis
Columbia, SC, September 22-26, 2013, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2013)

KNOWLEDGE ENGINEERING TOOLS – AN OPPORTUNITY FOR RISK-INFORMED DECISION MAKING?

N. Siu, P. Appignani, and K. Coyne
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC USA
Nathan.Siu@nrc.gov, Peter.Appignani@nrc.gov, Kevin.Coyne@nrc.gov

ABSTRACT

Trends affecting the NRC's increased use of risk information include the increasing number of nuclear power plant risk-informed licensing applications, the broader (and more challenging) range of applications of risk assessment methods, the increasing demands on the risk models supporting these applications, and the changing demographics of NRC staff. A tremendous amount of relevant information is potentially available to the NRC staff (and more is being generated continuously), but analysts may not be aware of these information sources. The challenge is how to enable the staff to identify and efficiently access and use this information. Recognizing that significant advances have been made in the information technology community, the NRC is planning to initiate a scoping study investigating the current state of knowledge engineering tools and their potential value in NRC risk assessment and risk management applications. The study will focus on the state of content analytics technology, specifically how analytical methods can be used to search diverse sources of information (e.g., technical reports, databases, and correspondence) to identify and analyze information relevant to risk applications.

Key Words: knowledge engineering, content analytics, risk information

1 INTRODUCTION

In accordance with its Probabilistic Risk Assessment (PRA) Policy Statement issued in 1995 [1], and as recently discussed by the U.S. Nuclear Regulatory Commission's (NRC's) Risk Management Task Force (RMTF) in NUREG-2150 [2], the NRC strives to improve and expand its use of risk information[1] in all of its regulatory activities. Considering the breadth, depth, and diversity of the NRC's risk information needs, and the analogous demands on the information needed to develop risk models, the goal to improve and expand in an resource constrained environment represents a significant challenge to both the NRC's information infrastructure and to the staff themselves.

In recent years, a variety of advanced knowledge engineering (KE) tools and techniques potentially useful to NRC staff have emerged. These tools and techniques address such information technology challenges as the use of naturally-posed ("natural language") questions and answers to explore technical documents; the analysis of document content; and the encoding and application of expert knowledge in the creation and review of systems models. Some of these tools and techniques (e.g., those associated with natural language processing, as popularized by the IBM Watson project [5]) appear to be in a developmental stage. Others (e.g.,

[1] In this paper, following SECY-98-0144 [3], we define "risk" as the answer to the classic three questions posed by Kaplan and Garrick [4]: "What can go wrong?" "How likely is it?" and "What are the consequences?."

those associated with analyzing document content) appear to be already in use by government agencies facing information management problems similar to those faced by NRC.

Subject to the availability of adequate resources, the NRC is planning to initiate a scoping study that will explore the application of advanced KE tools and techniques to support PRA activities. The purpose of this study is to determine if these KE techniques are sufficiently mature to provide NRC staff with (1) ready access to a much larger information base than the PRA and hard-linked documents (i.e., the information base would likely include documents not identified by the PRA authors but relevant to the technical issues being reviewed), and (2) flexible, expert-informed tools to query this information base. This querying supports both the creation of the PRA model and efforts to use the model results and insights in support of risk-informed decision making. Thus, the study would support performance of the Analysis and Deliberation steps identified by the RMTF's characterization of the regulatory decisionmaking process (see Figure 1), and likely other steps in that process as well.

Figure 1. The Regulatory Decisionmaking Process (from NUREG-2150 [2])

Of course, the challenge of dealing with large amounts of information in the face of changing organizational demands and resources is not unique to risk-informed decision making. However, as discussed later in this paper, the characteristics of risk assessment and risk-informed decision making would appear to accentuate key issues. From the assessment perspective, these characteristics include the multidisciplinary nature of the analysis and the relative rarity of the events normally considered in a PRA. From the decision making perspective, these characteristics include the uncertainty in the risk assessment results (which should be a reflection of the uncertainty in the overall state of knowledge regarding the process or system of interest) and the need to provide a perspective on results.

The scoping study is planned to be undertaken as part of the agency's Long Term Research Program [6, 7], which is used to investigate topics expected to meet critical mission needs in 5 to 10 years. Depending on the results of the study, follow-on activities could develop practical tools to address the agency's ever-increasing use of risk information, coupled with the agency's ongoing and projected loss of risk experts.

This paper provides an overview of current trends in NRC's risk information needs; challenges in meeting these needs; potentially relevant KE tools, techniques and activities to meet these challenges; and the current state of planning for the NRC's scoping study, including the study's specific objectives, scope, and approach.

2 TRENDS IN NRC RISK INFORMATION NEEDS

As discussed in NUREG-2150, the NRC currently uses risk information in all areas of regulatory purview, including materials (e.g., medical sources), waste (both low level and high level), uranium recovery, fuel cycle facilities, interim spent fuel storage, and transportation, as well as reactors (both power and non-power). The extent and formality of usage varies across the program areas, and the area-specific recommendations provided by NUREG-2150 vary accordingly. These recommendations are provided in Appendix A of this paper. It can be seen that a number of the recommendations (e.g., regarding the use of PRA insights when defining design basis events) have KE implications. A typical example might be helping users identify fleet-wide insights relevant to a proposed design basis event, and in understanding the models and modeling assumptions underlying those insights.

It's also worth mentioning that risk information is being used to support all regulatory functions – see Figure 2 – and at all organizational levels. For example, risk-informed decision making arises in day-to-day staff decisions (e.g., the prioritization of onsite inspection items), in major Commission policy decisions (e.g., regarding the imposition of broad requirements for filtered, containment venting), and situations in-between (e.g., deciding whether to allow a plant to continue operation under degraded conditions).

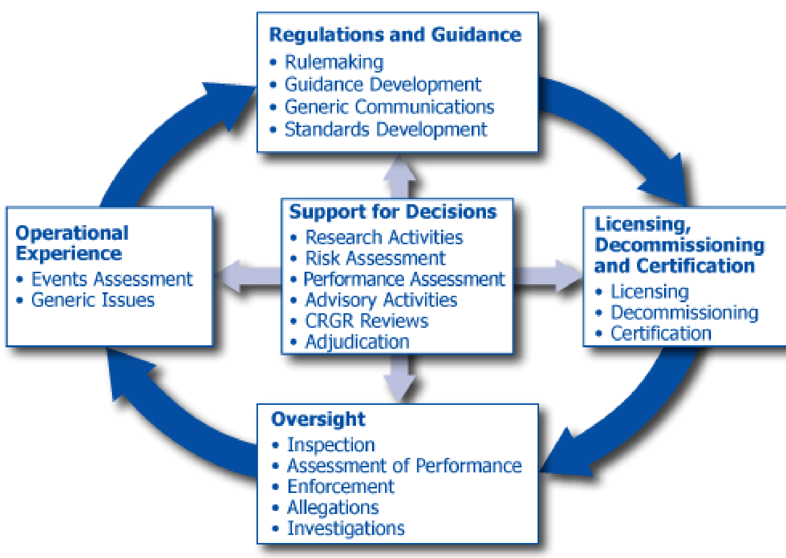

Figure 2. Regulatory Functions

Based on the authors' observations, it appears that a number of trends relevant to risk information needs were already well underway prior to the publication of NUREG-2150. These include:

- the increasing use of currently available PRA models in "routine" applications;
- an increasing number of applications requiring extensions of the PRA models (e.g., allowed levels of reactor pressure vessel embrittlement, understanding the safety significance of consequential steam generator tube ruptures), with an associated

burden on decision makers to understand model assumptions and limitations in these extended applications;

- the increasingly demanding use of the PRA results and insights (e.g., to support decisions where the absolute results play a significant role in the decision making process and/or where there are increasing demands on the explanatory power of the PRA in addressing system details);
- more complex risk decisions that require a thorough understanding of plant system behavior (e.g., success criteria), operator performance, subtle dependencies between human actions or component failures, and a fuller understanding of component functionality under degraded conditions.
- the increasing likelihood of NRC having to address a variety of design applications with new features (e.g., multiple reactor modules, new concepts of operation); and
- the changing demographics of NRC staff, which affects not only the average level of risk-related experience of the staff (many new staff members have not had the chance to develop hands-on experience with practical PRA modeling prior to joining NRC), but also the manner in which the staff interacts with information systems.

The March 11, 2011 Tohoku earthquake and subsequent tsunamis, core meltdowns at the Fukushima Dai-ichi plant, and strong safety challenges at other Japanese nuclear power plants have highlighted a number of issues. The resolution of these issues is expected to result in additional trends affecting the agency's risk information needs. These issues, some of which are discussed in further detail by Siu, et al. [8] include:

- the scope of current PRAs for operating U.S. plants (many of which, according to a recent U.S. Government Accountability Office report [9], have not updated their treatment of external events since the Individual Plant Examination of External Events – IPEEE – program in the 1990s [10]);
- the risk from events involving multiple units at a site and even multiple sites;
- the assessment and treatment of uncertainty for extreme natural events (and, more generally, low-probability high-consequence events); and
- the appropriate balancing of deterministic and probabilistic information in regulatory decision making.

Regarding the last point, we observe that following the Fukushima Dai-ichi accident, there have been calls to reduce the emphasis on, or even to entirely abandon the explicit use of risk information. Such calls include recommendations to perform "worst-case analyses" and to develop mitigation strategies that are independent of accident cause. Even within the PRA community, there have been proposals to increase the emphasis on "conditional analyses" and "resilience." These proposals would appear to weaken one of the greatest strengths of PRA analysis – namely placing accident scenarios on the level playing field of risk quantification in order to identify key insights in a consistent and unbiased manner. However, recognizing the importance of challenging assumptions, these proposals deserve a thorough and open debate that is beyond the scope of this paper. We note that the outcome of such a debate, some of which is expected to occur as the agency addresses the recommendations of NUREG-2150, could very well affect the agency's risk information needs.

3 CHALLENGES

3.1 General Challenge

A tremendous amount of information potentially useful to the development and use of risk models is currently being generated. For example, for the Fukushima Dai-ichi accident alone, there are over 20 official Japanese investigation reports and numerous official reports from other countries and international bodies, all of which provide relevant information for PRA analysts and agency decision makers. In addition to event reports, such varied sources as inspection reports, PRA model results (e.g., the output of the agency's Standardized Plant Analysis Risk – SPAR – models [11]), operational experience data, and research and development efforts (including activities outside as well as within the nuclear industry) are important. Further, as indicated in the previous section, the volume and variety of this information is likely to grow. The fundamental KE challenge is how to enable users to efficiently access and use this information.

This challenge is clearly not unique to the risk arena – significant development efforts are underway in the commercial information technology sector and a number of products are already available, as discussed later in this paper. It remains to be seen if these efforts and products are sufficiently mature to immediately accommodate the typical characteristics of risk problems, including:

- <u>A systems viewpoint</u>. A risk-informed decision generally needs to consider the performance of the system as a whole, and should not focus exclusively on one aspect of the problem. In some cases, analysts and decision makers may need to cope with situations where potentially important aspects are poorly understood.
- <u>Diverse and implicit sources of information</u>. The basis for a PRA model may reside in a wide range of sources (e.g., licensing basis information, operating experience, licensee submittals) that may or may not be explicitly referenced in the PRA model's documentation. Understanding of this basis can be key to appropriate use of the model's results and insights.
- <u>Involvement of multiple disciplines</u>. Dealing with the system as a whole typically requires input from a wide range of technical disciplines. These disciplines have, in addition to their unique bodies of knowledge, their own technical cultures which affect how they create and consume information.
- <u>Problem complexity</u>. A risk problem may require consideration of a large number of disparate scenarios. For example, both scenarios triggered by low-probability/high-consequence natural disasters that overwhelm facility defenses and scenarios involving chains of more likely but also more independent events could be important to a facility's risk profile.
- <u>Treatment of rare events</u>. Risk assessments and risk-informed decision making often deal with rare, beyond design basis events. In some situations, analysts and decision makers need to deal with novel designs and even design principles. In

situations where direct experiential data are sparse, modeling (including modeling assumptions) plays a fundamental role and it is critical that modeling details be adequately understood.

- Addressing details. Risk-significant scenarios can arise from unique, plant-specific design and operational features that lead to subtle dependencies between potential failure events. Changes in relatively small details (e.g., the routing of a particular set of electrical cables) can impact a risk study's results and insights.
- Involving a broad user base. Within the NRC, risk information is being used by decision makers with a broad range of technical backgrounds and exposure to risk concepts. With the ever-increasing breadth of risk-informed decision making, the breadth of this user base is also likely to grow.

These characteristics would seem to imply a KE approach that supports searching and the drawing of inferences by a wide range of users across a very wide, yet very technical set of information. Further, as a practical matter, since the implementation of such an approach would likely require substantial involvement by a wide range of subject matter experts (e.g., to provide word/phrase associations and search heuristics), an additional challenge involves the efficient use of such experts (to minimize the disruption to other high priority activities).

3.2 An Example

To illustrate one type of challenge that might be addressed by improved KE tools, consider the flooding of the Blayais nuclear power plant (a four-unit site) in December, 1999. As discussed by Vial, Rebour, and Perrin [12], that event involved a storm that caused a loss of offsite power to Units 2 and 4, followed by a flooding-induced loss of Unit 1 essential service water (Train A) and of the low-head safety injection and containment spray system pumps for Units 1 and 2, as well as flooding of a number of areas of Units 1 and 2. The beyond-design basis flooding involved the overtopping of a protective dyke from the combined effects of storm surge and wind-driven waves. According to Ref. 12, weaknesses in the site's flooding protection included:

- Lack of consideration of the extreme meteorological conditions experienced in the plant design;
- Loss of site accessibility due to area flooding (affecting arrival of additional equipment and staff);
- Lack of consideration of the simultaneous impact on multiple units;
- Problems in promptly detecting flooding of key plant rooms;
- Problems in managing the release of water from flooded plant areas.

We observe that these weaknesses are similar (and in some cases, identical) to those highlighted by the Fukushima Dai-ichi accident, some 11 years after the Blayais event.

The Blayais event is now generally acknowledged as an important indicator of the potential importance of external flooding. However, a review of the conference programs for the Probabilistic Safety Assessment and Management (PSAM) and Probabilistic Safety Assessment (PSA) conferences held after Blayais and prior to Fukushima shows considerable interest in the treatment of internal flooding (especially in the 2008-2011 time period), but little activity regarding external flooding. (Perhaps the lone exception is a 2011 paper by Ferrante, et al. on dam failure frequencies [13].) We also note that the currently endorsed version of the American Society of Mechanical Engineers/American Nuclear Society (ASME/ANS) PRA standard [14] includes a requirement that, following pre-Blayais NRC guidance on the treatment of external floods in the Individual Plant Examination of External Events program [15], allows the screening of a non-seismic external event if the design basis for that event meets deterministic criteria provided in the NRC's 1975 Standard Review Plan [16]. The ASME/ANS standard also provides the following text prior to its requirements for external flooding PRA: "These [external flooding PRA] approaches, based on a combination of using of the recurrence intervals for the design-basis floods and analyzing the effectiveness of mitigation measure to prevent core damage, have usually shown that the contribution to CDF [core damage frequency] is insignificant." The ASME/ANS standard is currently being revised to address the potential for premature screening of external events (including external floods). From the standpoint of this paper, the relevant KE challenge is how to better ensure that important lessons from key events (which may not be widely recognized as "key" at the time of their occurrence) find their way into risk assessment and risk management activities without requiring the occurrence of an accident or even a severe condition (e.g., the flooding of the Fort Calhoun site in 2011).

3.3 Another Example

As a completely different example of a situation where improved KE tools could be useful, we observe that NRC staff are often the reviewers and users (but not principal developers) of PRA models. Recognizing that logically equivalent (or nearly equivalent) models can take many different visual forms (consider the "large event tree/small fault tree" versus "small event tree/large fault tree" debate in the early days of PRA, later discussions on the merits of event sequence diagrams versus event trees, and current work on automated development of binary decision diagram models), one challenge to the reviewer/user is to be able to understand the essential aspects of the model despite these different forms.

PRA model results, including lists of dominant sequences and cut sets as well as various importance measures, provide useful diagnostic information identifying what the model indicates as being important. Documented modeling assumptions provide additional useful information (e.g., regarding what was left out, or how certain important aspects were treated). However, key judgments regarding, for example, the appropriateness of the model are dependent on the expertise of the reviewer. Recognizing the variability in such expertise (and this variability is accentuated by the previously mentioned demographic trend regarding NRC staff), it would appear that KE approaches and tools that increase the accessibility of reviewing benchmarks (e.g., the modeling of similar systems in other PRAs, relevant operational experience) could be helpful.

4 THE PROMISE OF NEW TECHNOLOGIES

The NRC, as with any organization that deals with large volumes of information, has a number of information technology systems and associated activities aimed at: (1) electronically capturing information important for the agency's decision making efforts, and (2) making the resulting information base accessible to the staff. In addition to the NRC's official recordkeeping system (Agencywide Documents Access and Management System – ADAMS), staff can access information through a variety of tools, including the agency's website and staff-created Sharepoint sites. Users can employ standard search tools and other aids (e.g., hyperlinks, file structures, citations and reference lists, document tables of content and indices) to find relevant files (e.g., text documents, spreadsheets, databases, images, computer codes and models) and specific pieces of information in these files.

Recently, the NRC has begun to explore the potential of using "content analytics" to enable the staff's improved use of potentially available information. Content analytics is the act of applying expert intelligence and specialized analytics practices to digital content.

An organization produces two types of content: structured and unstructured. Structured content typically resides in a database. Unstructured content can be found throughout the organization. It can be text-based, as in the case of emails, office documents and Web documents – or non-text-based, such as voice, images or video. Content analytics software uses natural language queries, trends analysis, contextual discovery and predictive analytics to identify patterns and trends across an organization's unstructured content. This software typically involves both text analytics (a set of linguistic, statistical, and machine learning techniques that allow text to be analyzed and key information extracted) plus features enabling users to visually identify and explore trends, patterns, and statistically relevant features found in various types of content spread across various content sources.

Both the private and public sectors have begun to use content analytics software to provide visibility into the amount of content that is being created, the nature of that content and how it is used. It appears that with the current state of development, such software may be ready for use in NRC's risk assessment and risk management applications.

A separate line of technology development that may be relevant to NRC's risk information needs concerns the use of so-called "formal methods." Formal methods, which are well-known in the computer science field, involve the development of mathematical specifications for hardware and software systems, and are intended to support the development and verification of such systems. In a PRA context, similar efforts have a rich history, dating back to efforts in the early 1970's to automatically generate fault trees from system diagrams [17]. A recent effort in this line involves the Open PSA initiative, discussed elsewhere in this conference [18]. From a model reviewer's perspective, the intriguing aspect of such efforts is that they are aimed at developing standardized representations of models. Such standardized representations could, for example, facilitate comparisons between models of similar systems.

5 NRC PLANS

Recognizing that ongoing KE development efforts outside the agency might be useful to the agency's risk assessment and management activities, the NRC is currently planning to initiate a small project that will explore the application of advanced KE tools and techniques. This project, when initiated, will be performed under the auspices of the NRC's Long-Term Research Program [6, 7]. Consistent with the scope of that program, the project will be conducted as a scoping study aimed at determining if additional agency effort to develop actual KE tools aimed at supporting risk applications is worthwhile. We note that, given the pace of developments in the information technology arena, it is possible that the scoping study will identify products that are ready (without further software development) for pilot use in actual NRC applications (e.g., in support of NRC's ongoing Level 3 PRA project [19]).

At this point, the focus of the effort is on exploring the state of content analytics technology. The project is currently aimed at assessing the risk information needs of prototypical agency users of that information, characterizing current methods employed by users to meet these needs, identifying areas for potential improvement, identifying and characterizing KE tools that may be able to address these areas, performing demonstration analyses using selected KE tools, evaluating the results and lessons from the demonstration analyses, and providing an overall assessment of potentially fruitful areas for further development that would result in improved tools for NRC staff use.

Regarding the use of formal methods, we have recently become aware of an intriguing project being conducted by Electricité de France regarding the use of the Open PSA approach to support knowledge management [19] and will follow that project with interest.

6 CONCLUSIONS

With its ever-increasing use of risk information in regulatory decisionmaking, the NRC could greatly benefit from KE approaches and tools that facilitate staff access to and use of the numerous and diverse documents that contain information potentially valuable to analysts and decision makers. The NRC is planning to initiate a scoping study investigating the current state of these KE approaches and tools, in order to determine whether additional effort is warranted. We recognize that the availability of improved KE tools will not, by itself, overcome systemic problems in information dissemination (e.g., a community mindset overstating or understating the risk significance of a class of events) but such tools could better support informed discussions on the issues.

7 REFERENCES

1. U.S. Nuclear Regulatory Commission, "Use of Probabilistic Risk Assessment Methods in Nuclear Activities: Final Policy Statement," *Federal Register, Vol. 60*, p. 42622 (60 FR 42622), August 16, 1995.
2. U.S. Nuclear Regulatory Commission, *A Proposed Risk Management Regulatory Framework*, NUREG-2150, ADAMS Accession Number ML12109A277, April, 2012.
3. U.S. Nuclear Regulatory Commission, "Staff Requirements Memorandum Regarding SECY-98-144, 'White Paper on Risk-Informed and Performance-Based Regulation,'" ADAMS Accession Number ML003753601, March 1, 1999.
4. S. Kaplan and B. J. Garrick, "On the Quantitative Definition of Risk," *Risk Analysis*, **1**, pp.11-37 (1981).
5. D. Ferrucci, E. Brown, J. Chu-Carroll, J. Fan, D. Gondek, A. A. Kalyanpur, A. Lally, J. W. Murdock, E. Nyberg, J. Prager, N. Schlaefer, and C. Welty, "Building Watson: An Overview of the DeepQA Project," *AI Magazine*, **31**, No. 3, pp.59-79 (2010).
6. U.S. Nuclear Regulatory Commission, *U.S. Nuclear Regulatory Commission Long-Term Research: Fiscal Year 2009 Activities*, Final Report, ADAMS Accession Number ML080150121, October, 2007.
7. U.S. Nuclear Regulatory Commission, *Research Activities FY 2010-FY-2011*, NUREG-1925 rev. 1, ADAMS Accession Number ML11031A000, December, 2010.

8. N. Siu, D. Marksberry, S. Cooper, K. Coyne, and M. Stutzke, "PSA Technology Challenges Revealed by the Great East Japan Earthquake," *Proceedings of PSAM Topical Conference in Light of the Fukushima Dai-Ichi Accident*, Tokyo, Japan, April 15-17, 2013. (Also available from NRC: ADAMS Accession Number ML13038A203.)

9. U.S. Government Accountability Office, *Nuclear Regulatory Commission: Natural Hazard Assessments Could Be More Risk-Informed*, GAO-12-465, April, 2012.

10. U.S. Nuclear Regulatory Commission, *Perspectives Gained from the Individual Plant Examination of External Events (IPEEE) Program*, NUREG-1742, April, 2002.

11. U.S. Nuclear Regulatory Commission, "Status of the Accident Sequence Precursor Program and the Standardized Plant Analysis Risk Models," SECY-12-0133, ADAMS Accession Number ML12220A604, October 4, 2012.

12. E. Vial, V. Rebour, and B. Perrin, "Severe Storm Resulting in Partial Plant Flooding in 'Le Blayais' Nuclear Power Plant," *Proceedings of International Workshop on External Flooding Hazards at Nuclear Power Plant Sites* (jointly organized by Atomic Energy Regulatory Board of India, Nuclear Power Corporation of India, Ltd., and International Atomic Energy Agency), Kalpakkam, Tamil Nadu, India, August 29 – September 2, 2005.

13. F. Ferrante, S. Sancaktar, J. Mitman, and J. Wood, "An Assessment of Large Dam Failure Frequencies Based on US Historical Data," *Proceedings of ANS PSA 2011 International Topical Meeting on Probabilistic Safety Assessment and Analysis*, Wilmington, NC, March 13-17, 2011, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2011).

14. "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," ASME/ANS RA-Sa-2009, Addendum A to RA-S-2008, ASME, New York, NY, American Nuclear Society, La Grange Park, Illinois, 2009

15. U.S. Nuclear Regulatory Commission, *Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities, Final Report*, NUREG-1407, 1991.

16. U.S. Nuclear Regulatory Commission, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*, NUREG-75/087, 1975.

17. S. A. Lapp, and G. J. Powers, "Computer-aided synthesis of fault-trees," IEEE Transactions on Reliability, **R-26**, pp. 2-13 (1977).

18. W. Epstein and A. Rauzy, "New Developments in Open PSA," *Proceedings of ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis*, Columbia, SC, September 22-26, 2013.

19. A. Kuritzky, N. Siu, K. Coyne, D. Hudson, and M. Stutzke, "L3PRA: Updating NRC's Level 3 PRA Insights and Capabilities," *Proceedings of IAEA Technical Meeting on Level 3 Probabilistic Safety Assessment*, Vienna, Austria, July 2-6, 2012.

20. M. Hibti, T. Friedlhuber, and A. Rauzy, "Automated Generation of Event Trees from Event Sequence Diagrams and Optimisation Issues," *Proceedings of PSAM Topical Conference in Tokyo in Light of the Fukushima Dai-ichi Accident*, Tokyo, Japan, April 14-18, 2013.

APPENDIX A – NUREG-2150 RECOMMENDATIONS

Risk Management Regulatory Framework

- The NRC should formally adopt the proposed Risk Management Regulatory Framework through a Commission Policy Statement.

Power Reactors

- The set of design-basis events and accidents should be reviewed and revised, as appropriate, to integrate insights from the power reactor operating history and more modern methods, such as probabilistic risk assessment (PRA).
- The NRC should establish through rulemaking a design-enhancement category of regulatory treatment for beyond-design-basis accidents. This category should use risk as a safety measure, be performance-based (including the provision for periodic updates), include consideration of costs, and be implemented on a site-specific basis.
- The NRC should reassess methods used to estimate the frequency and magnitude of external hazards and implement a consistent process that includes both deterministic and PRA methods. Consideration of the risks from beyond-design-basis external hazards should be included in the proposed design-enhancement category.
- The NRC should develop and implement guidance for use in its security regulatory activities that uses a common language with safety activities and harmonizes methods with risk assessment and the proposed risk-informed and performance-based defense-in-depth framework.

Nonpower Reactors (NPR)

- The proposed defense-in-depth framework should be applied to the NPR licensing process to ensure that the current amount of defense in depth is appropriate given the relatively small radioactive hazard. This application should include safety and security licensing matters.
- The NRC should evaluate the utility of performing a pilot risk assessment, including consideration of external hazards, using modern risk assessment methods at an NPR. This evaluation would assess the value of the risk insights gained from the risk assessment on the basis of possible safety enhancements and possible contributions to a more efficient and effective risk-informed and performance-based regulatory framework for NPRs.

Materials

- The NRC materials program should continue to apply risk insights and performance-based considerations, as appropriate, in rulemaking, guidance and policy development, and implementation in accordance with the proposed risk management framework. This consideration should include both safety and security licensing processes.
- The development and rollout of the recommended Risk Management Policy Statement should be closely coordinated with the leadership of the Agreement States.

Low-Level Waste (LLW)

- The NRC should adopt the concept of risk management to the LLW program, as well as any revisions proposed to 10 CFR Part 61 (including performance assessment requirements) and related guidance documents.
- The NRC should develop an explicit characterization of how defense in depth, within the proposed risk management framework, applies to the LLW program and build this into current and future staff guidance documents and into training and development activities for the staff.
- The NRC should include environmental reviews within the scope of its risk management framework.

High-Level Waste (HLW)

- Any future revisions to the regulatory framework for geologic disposal of HLW should be done in accordance with the proposed risk management framework to ensure that risk information continues to be appropriately considered in the development of requirements and appropriately reflect any future HLW disposal paradigm.

Uranium Recovery

- Notwithstanding the current uncertainty associated with the EPA rulemaking, the NRC should adopt the proposed risk management regulatory framework to the uranium recovery program to provide greater efficiency, effectiveness, and predictability in policy development and regulatory decisionmaking.
- The NRC should work closely with the Agreement States and the regulated community to guide implementation of risk management in the uranium recovery program.
- The NRC should include environmental reviews within the scope of its risk management framework.

Fuel Cycle

- The fuel cycle regulatory program should continue to evaluate the risk and the associated defense-in-depth protection by using insights gained from ISAs. ISAs should continue to evolve to support regulatory decisionmaking.

Spent Nuclear Fuel (SNF) Storage

- While elements of the proposed risk management approach have been used in the SNF storage regulatory approach to evaluate the acceptable level of risk and the sufficiency of defense in depth (physical barriers, controls or margins) more consistently, the NRC should develop the necessary risk information, the corresponding decision metrics, and numerical guidelines. This is important in guiding further changes to the existing SNF storage regulatory approach and the evaluation of strategies for extended SNF storage activities.
- As part of the implementation of the proposed risk management regulatory framework, the NRC should more consistently consider the concept of defense in depth explicitly and evaluate its proper use in the SNF storage regulatory program. The NRC should also improve appropriate parts of staff.

Transportation

- Considering the strong international regulatory basis for transportation and the need to conform U.S. standards to those of the IAEA and other member states, application of the proposed risk management framework should focus on implementation guidance.
- The risk management process should be used to influence the future outcome of IAEA deliberations on proposed changes in international transportation regulations.
- The NRC should explore the value of using risk insights to justify regulations different from the IAEA's for domestic use only, such as regulations dealing with domestic storage and transportation of high burnup fuel. Risk information could be used to develop a more flexible approach toward implementing and making gradual changes to current transportation regulations.