A Strong and Viable Technical Service Organization to Meet Current and Future Regulatory Challenges: The Nuclear Regulatory Commission's Vision and Perspectives ǂ

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Abstract. The Office of Nuclear Regulatory Research (RES) is one of the program offices of Nuclear Regulatory Commission (NRC). RES develops technical tools and analytical models, conducts experiments and maintains database of test results, and provides confirmatory analyses and technical guidance needed to support the NRC's regulatory decisions. RES is essentially the NRC's technical support organization (TSO) that provides technical expertise and capabilities to support NRC's regulatory program offices, namely the Office of Nuclear Reactor Regulation (NRR), the Office of New Reactors (NRO), the Office of Nuclear Material Safety and Safeguards (NMSS), and the Office of Nuclear Safety and Incident Response (NSIR) in licensing and regulatory decisions. RES develops the technical bases to confirm that the methods and data generated by the nuclear industry for design, construction, and operation, help ensure that adequate safety is established and maintained. The paper will provide an overview of the role and functions of RES in supporting NRC's licensing and regulatory activities. A brief discussion of the process used to conduct research and to ensure high quality research products will be provided. Some of the current technical projects and future technical challenges will also be highlighted.

1. Introduction

A technical service organization (TSO) is typically understood to be an organization that provides technical services and support to nuclear regulators or power plants to inform safety significant decisions. Thus, the TSOs are expected to provide specific research, analysis and testing, independent technical or scientific advice, and competent judgment to a regulatory authority or organization operating a nuclear power plant. The Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research (RES) is considered to be a TSO-like organization that provides the technical bases to the NRC's regulatory offices.

However, RES is different from a TSO as defined above, both in its role and functions. This paper will elaborate on RES's role in supporting the NRC's mission on U.S. civilian use of radioactive materials to protect public health and safety, promote the common defense and security, and protect the environment. Moreover, it will discuss how RES, a statutorily mandated office within the NRC, is an integral part of the NRC that maintains its independence, while providing the technical basis to support the NRC's decisions. In addition, this paper discusses RES's processes for conducting research and developing and maintaining technical capabilities to address the NRC's challenges in regulating the U.S. nuclear industry in the future. The term 'industry' is used in this paper to represent a licensee, nuclear power plant operator, or a consortium of licensees or operators.

ǂ The views expressed in this paper are those of the authors and do not constitute an official position of the NRC.

2. Establishment of the NRC and RES

The U.S. Congress, in the Energy Reorganization Act of 1974 [1], mandated the formation of the NRC. The same Act also established RES (Sec. 205) for "(1) developing recommendations for research deemed necessary for performance by the Commission of its licensing and related regulatory functions, and (2) engaging in or contracting for research which the Commission deems necessary for the performance of its licensing and related regulatory functions."

The role of RES is further promulgated in Title 10, "Energy," of the Code of Federal Regulations (10 CFR) Part 1, "Statement of Organization and General Information" [2], which states that RES:

(a) Plans, recommends, and implements programs of nuclear regulatory research, standards development, and resolution of generic safety issues for nuclear power plants and other facilities regulated by the NRC;

(b) Coordinates research activities within and outside the NRC including appointment of staff to committees and conferences; and

(c) Coordinates NRC participation in international standards related activities and national volunteer standards efforts, including appointment of staff to committees.

Therefore, the roles and responsibilities of RES were defined along with those of other NRC program offices by the law. In other words, the law mandated the capability to independently perform research to develop the technical basis for ensuring the safety of the U.S. public regarding any use of radioactive material.

3. The NRC's Regulatory Mission

The NRC licenses and regulates the U.S. civilian use of radioactive materials to protect public health and safety, promote the common defense and security, and protect the environment. Thus, the NRC is responsible for ensuring safety in the design, construction, and operation of commercial nuclear facilities and in the other domestic uses of nuclear materials, such as in medicine and industrial activities.

To fulfill its responsibility to protect public health and safety, the NRC performs the following five principal regulatory functions:

(1) Develops regulations and guidance for applicants, certificate holders, and licensees.

(2) Licenses or certifies applicants to use radioactive materials and operate or decommission nuclear facilities.

(3) Inspects and assesses certificate holders, licensee operations, and facilities to ensure compliance with NRC requirements; investigates allegations of wrongdoing; responds to events and accidents involving licensed facilities and materials; and takes appropriate enforcement actions when necessary.

(4) Evaluates domestic and international operational experience associated with licensed facilities and activities.

(5) Conducts research, holds hearings, and obtains independent reviews to support regulatory decisions.

Figure 1 shows the interrelationship between these regulatory functions and how RES support (function 5 above) is used in the other four functions of NRC's regulatory program.

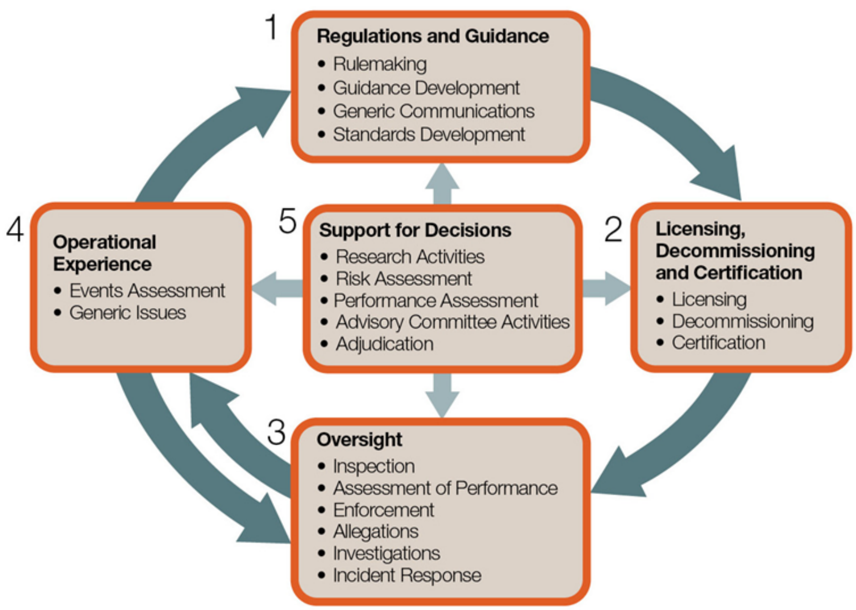

FIG. 1 The NRC's Regulatory Process. (Source: NRC's Strategic Plan [3])

4. The Role and Functions of RES

The NRC Principles of Good Regulation [4], issued in 1991, promote the principles of Independence, Openness, Efficiency, Clarity, and Reliability as fundamental guideposts in ensuring the quality, correctness, and consistency of NRC regulatory activities. Reliability is a key principle in defining the role of the RES. This principle states that regulations should be based on the best available knowledge from research and operational experience.

Unlike technical programs in some TSOs, the NRC research program is designed to improve the NRC's knowledge in areas where uncertainty exists, where safety margins are not well characterized, and where there are technical issues to be resolved to support regulatory decisions. RES provides technical advice, analytical tools, and information for the Commission and NRC staff to identify and resolve safety issues, make regulatory decisions, develop regulations and guidance, conduct independent analyses to support decisions, grant or or deny licensee proposed changes, renew plant operating licenses, evaluate operating experience, evaluate proposed designs and technologies, and enhance the efficiency and effectiveness of NRC programs and processes. RES conducts the NRC's internal research, as well as the cooperative research with the U.S. Department of Energy and other government agencies, the nuclear industry, universities, and NRC's international partners. To perform the internal research, RES relies on in-house expertise as well as the services provided by DOE laboratories and commercial contractors. The NRC's RES program is not available for commercial purposes.

It should be noted that the responsibility for the safety of nuclear power plants and for the safe use, storage, and disposal of radioactive material lie with the owners and operators. Accordingly, the industry and related organizations have the responsibility to develop and provide the necessary data and information to satisfy the NRC's regulations. The research that the industry conducts provides much of the information that the NRC needs to fulfill its regulatory responsibilities. However, in some instances, the industry's research may not fully cover the breadth and depth of the issue. In such cases, the NRC regulatory offices seek the services of RES to perform additional research to independently confirm the industry position. RES conducts this type of confirmatory research to resolve any uncertainties associated with the research results and to assess any impact on a broader regulatory issue.

An illustrative example of a broad issue, where industry actions required additional research by RES, involves the pressurized water reactor (PWR) sump clogging issue. Initially, RES conducted limited scoping studies to determine if chemical effects were a potential concern. Once these studies identified that a concern may exist, the nuclear industry and the NRC collaborated in a joint research effort to more clearly identify the concerns. After this joint research was completed and the concerns were evident, NRC embarked on a significant research effort to evaluate the broad implications associated with chemical effects on sump clogging. This research was used to identify other issues that the nuclear industry needed to address through their own research programs. The results also helped confirm the validity of this research and the application of the research results to the assessment of chemical effects on sump clogging. Thus, the primary objective of NRC research is to be able to confirm or refute positions or analyses put forward by the industry, on the basis of having clear and sufficient knowledge of the issues involved. This knowledge may prompt the NRC staff to require or specify additional research by the nuclear industry, as appropriate.

RES engages in three categories of research to support the NRC's regulatory activities, depending on the nature of, the anticipated duration of, and the regulatory need for the activity. Shorter duration research activities, requested by NRC's regulatory offices to satisfy a stated regulatory need, are termed "confirmatory" research. This is because such activities involve performing experiments or developing analytical tools to be used by staff to independently confirm an applicant's or licensee's analyses. These activities often result in delivering a well-defined product on a predetermined schedule. Some examples of this research include activities on sump clogging in emergency core cooling systems (ECCSs), neutron absorber degradation, primary water stress corrosion cracking, probabilistic risk assessment of reactor systems, risk associated with fire, neutronics analyses, criticality safety assessment, thermal hydraulic analyses of safety margins, and effects of radioactive release to environment.

RES also conducts "forward looking" and long term research. This is because NRC recognizes that the industry does not always conduct sufficient forward looking research to anticipate and address potential nuclear safety issues. This forward looking research contributes to fulfilling NRC's role, including the ability to be prepared to address safety issues and changes in technology that might arise in the future.

Forward looking research supports anticipated regulatory needs within the next few years. Long term research activities scope out potential future regulatory needs (i.e., approximately five years from the present and beyond) to determine the likelihood that a related regulatory decision will be needed and to identify the research required to support that decision. In particular, the forward looking and long term research activities address anticipated problems of potential safety significance that the industry might not be pursuing and a new and expanded knowledge to address the safety issue can help the NRC accomplish its mission. Increasing the NRC's knowledge and understanding of the underlying technologies or phenomena related to plant safety helps the NRC discover unforeseen situations. Hence, this research prepares the NRC with the knowledge to address potential future safety issues. Some examples of forward looking research include activities related to subsequent license renewal (SLR) (that is, license renewal beyond a facility's 60-year operating lifetime), long term plant operations, extended spent fuel storage and transportation, and some forward looking research activities related to the Fukushima Dai-ichi accident. Examples of long term research include scoping activities about smart grid impacts on nuclear power plants and assessing potential climate variability contributions to risk at nuclear facilities.

4.1 RES Organization and Functions

RES consists of three technical divisions and a division to oversee the program management and policy development and analysis (PMDA) (see Figure 2). The technical divisions, Division of Engineering (DE), Division of Systems Analysis (DSA), and Division of Risk Analysis (DRA) maintain and develop the technical capabilities needed to respond to the current and future research needs of the NRC. PMDA oversees budget planning and execution, manages information technology needs, and provides management and staffing controls in support of the needs of the technical staff in RES and the NRC.

DE coordinates research activities with the program offices, in such areas as material characteristics, aging, natural hazards, digital instrumentation and controls (digital I&C), homeland security, and other engineering aspects of NRC-regulated activities and facilities. DE develops advanced computational tools to evaluate pressure vessel and piping integrity and to assess seismic hazards and structural integrity. The division also serves as the NRC lead for coordinating NRC codes and standards activities.

DSA plans, develops, and manages research programs to develop and maintain broad technical expertise, experimental data, and tools for numerical simulation analyses in the areas areas of criticality safety, thermal hydraulic and severe accident phenomenology, accident source terms, and accident sequence analysis. DSA develops analytical capabilities for a wide spectrum of conditions, including normal operations and design basis and severe accident conditions for current, new, and advanced reactor designs. The division's research program also involves quantifying margins, reducing unnecessary regulatory burden, and reducing uncertainties for areas of potentially high risk or safety significance. In addition, the division develops the methods, data, standards, and modeling tools to assess dose and health effects and the effects (and their magnitude) of released radioactive material on the environment outside nuclear facilities.

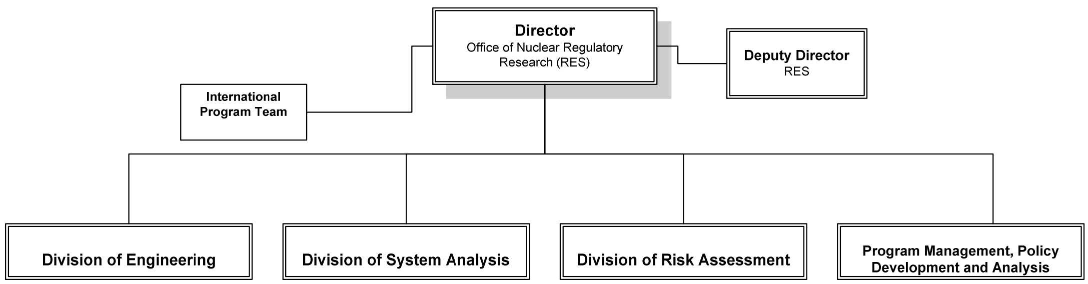

FIG. 2 RES organizational chart

DRA develops, recommends, plans, and manages research programs relating to probabilistic risk assessments (PRA), human factors and human reliability analysis, performance and reliability analysis, movement of radionuclides through environmental systems, operating experience, and fire safety (including fire modeling, fire PRA methods, and fire testing). The division develops and uses PRA based methodologies, models, and analysis techniques, such as the standardized plant risk models (SPAR), the Systems Analysis Programs for Hands on Integrated Reliability Evaluation (SAPHIRE) code, and other PRA codes. The division conducts research to provide safety perspectives on the impact of human performance on nuclear power plants and other NRC regulated activities. The division develops risk informed performance indicators and thresholds to provide support to the NRC Reactor Oversight Program (ROP). It also implements the Accident Sequence Precursor Program for operating nuclear power plants. The division manages and coordinates research on modeling and monitoring for environmental assessment, flood assessment, flood protection, materials performance, and groundwater issues. The division remains cognizant of nuclear power plant operational and reliability data systems in the industry and the NRC and serves as a focal point for coordination and evaluation of the NRC's safety data collection programs. More than 100 current RES projects and activities are summarized in NUREG-1925 [5]. A few representative examples of research activities are described in Appendix I.

5. The Process for Conducting Research

RES has developed a process for the regulatory and other program offices to request technical assistance or analysis to support the technical and regulatory needs of the NRC. Unlike some TSOs, RES does not independently embark upon research without the need and consent from the Commission or regulatory offices. The process ensures that the staff appropriately captures the scope, content, and schedule of requested technical products and services and communicates with the requesting offices on the extent of services and deliverables. This process also provides schedules for completion of milestones, identification of stakeholders, and documentation of agreements and approvals.

The process for engaging RES to perform research work for the regulatory and other program offices typically involves three different levels of requests based on the scope of work and resource requirements (staff time and funding). The requested products should be consistent with the role of RES to supply technical tools, analytical models, analyses, scientific information, experimental data, and guidance to support regulatory decisionmaking. The three levels of work requests are (1) Informal Assistance Request, (2) Research Assistance Request, and (3) User Need Request. For activities not addressed under these three mechanisms, RES engages the program offices in the development and endorsement of a research plan. A research plan may cover multiple existing work requests and include other work such as long term research or ongoing support for codes and models.

The above process ensures that RES uses the proper level of administration to develop a complete and mutually agreed on technical service agreement before the start of actual work. The technical service agreement ensures that the requested work has been adequately communicated to and approved by the appropriate levels of management, both in RES and in the requesting office. The engagement of management allows RES to respond better to user office requests with a high degree of confidence that resources are available to complete the work. In addition, this engagement ensures that the schedules for product and service deliverables are properly understood and achievable. All work requests are processed, tracked, and monitored to ensure that RES provides timely and high quality products to the regulatory offices.

Research products include NUREGs, technical reports and publications, and RES-generated regulatory guides. All research products undergo internal peer review within RES before being provided to the regulatory offices. These products are reviewed by staff from regulatory offices to ensure that the needs of those offices are adequately and satisfactorily met. The feedback and comments from the customer offices on the research products will be addressed to enhance the quality of the products. In addition, major research products are usually reviewed by the Advisory Committee for Reactor Safeguards (ACRS). The ACRS is an independent committee that reviews and advises the Commission with regard to the licensing and operation of production and utilization facilities and related safety issues, the adequacy of proposed reactor safety standards, the technical and policy issues related to the licensing of evolutionary and passive plant designs, and other matters referred to it by the Commission. RES staff facilitates the ACRS reviews through informal and formal briefings to the ACRS and its various subcommittees. RES also recognizes the importance of external peer review to ensure the quality of its research products. Harnessing the wide knowledge base of external peer reviewers enhances the quality of the research products. RES strives to make the results of peer reviews evident, whenever possible, through discussions in professional meetings. In addition, significant research products are made available for public comments before finalization. RES also recognizes the need for quality control of the internally developed computational confirmatory tools. In order to ensure the quality of advanced computational tools, extensive validation and verification with experimental data is performed. After the completion of a research project or program, RES conducts a quality survey to determine the quality and timeliness of its support to the regulatory offices. The results of the quality survey are used to continuously improve the research program.

6. Domestic and International Collaborations

Domestic and international collaborations are important activities undertaken by RES to fulfill its commitment to the NRC's mission. Accordingly, RES has developed positive and fruitful work relationships with many domestic and international entities. These collaborations provide timely and thoughtful peer input while giving the NRC the ability to leverage its expertise and resources on key topics of common interest.

As examples, RES partners with the U.S. Department of Energy (DOE) and the Electric Power Research Institute, Inc. ("EPRI") through a separate Memorandum of Understanding (MOU) with each organization. EPRI conducts research, development, and demonstration relating to the generation, delivery, and use of electricity. The above mentioned MOUs are used to facilitate cooperative research and information exchange pertaining to nuclear safety. This cooperation enables RES to enhance its capabilities, leverage its resources, and avoid duplication of efforts. Under an MOU, RES may cooperate with, share data and technical information with, and (in some cases) share costs with external organizations like DOE or EPRI whenever such cooperation and cost sharing is mutually beneficial. While the NRC can collaborate and share resources to run experiments or develop data, the NRC retains its independent responsibility for evaluating and interpreting the data and making regulatory determinations. In addition, RES partners with a number of other U. S. federal agencies, such as the National Aeronautics and Space Administration, National Institute of Standards and Technology, National Academy of Sciences, and National Science Foundation, in mutually beneficial research activities involving sharing of knowledge, data, analyses, test facilities, and test results.

One of the areas of NRC DOE cooperative research is related to the long term operation of light water reactors. DOE conducts research in this area under the Light Water Reactor Sustainability Research (LWRS) Program while the NRC's research explicitly supports the NRC's SLR program. The addendum to the MOU between the NRC and DOE in this area allows data to be shared and ensures that both the NRC and DOE remain cognizant of all related efforts. This collaboration has led to some jointly-funded efforts. These efforts include the expanded materials degradation assessment, which evaluates material degradation in passive system components during the SLR period.

Examples of areas of NRC EPRI cooperation include the development of advanced computational tools for assessing reactor component safety, aging and qualification of electrical cables, interface of digital instrumentation & controls and human factors, long term operations, seismic risk, fire risk, probabilistic research assessment, and non-destructive examination.

RES has also implemented approximately 100 bilateral or multilateral agreements with more than 30 countries and other international organizations, including the Organisation for Economic Cooperation and Development (OECD) and the International Atomic Energy NRC (IAEA). These agreements cover a wide range of activities and technical disciplines, including including severe accidents, thermal hydraulic code assessment and application, digital instrumentation and control, nuclear fuels analysis, seismic safety, fire protection, and human performance and reliability. Results of these activities contribute to the NRC's knowledge base and help inform the technical basis for NRC's regulatory decisionmaking. These efforts also provide access to laboratories and experimental facilities that are not available domestically, such as the Halden Test Facility in Sweden.

7. The NRC's Knowledge Base and Knowledge Management

The NRC recognizes the importance of its knowledge base, which relies on developing, maintaining, and strengthening its technical expertise and core capabilities. This vision is best captured by former Commissioner Kenneth C. Rogers in a proposal to the Commission that the NRC should take steps to enhance the maintenance, renewal, and extension of NRC's knowledge base [6]. He stated, "The quality of NRC's decision making is ultimately dependent on the NRC's ability to: identify relevant technical knowledge needed for its regulatory decision making; gain access to that knowledge; and, transfer that knowledge readily into its regulatory practice." This statement underscores the following main principles that are relevant and adhered to in RES.

- *The NRC knowledge base requires continuing maintenance and extension,*
- *Qualified staff are the key to maintaining the NRC knowledge base, and*
- *Transferring knowledge into regulatory practice is a desired outcome of research.*

To ensure high quality and maintain credibility, RES maintains strong technical expertise in many technical disciplines. The research staff stays technically up-to-date to conduct research, and to direct and oversee the research of others, to understand and interpret research results and analyses, and to advise other regulatory offices and senior managers in their regulatory decisionmaking. Appropriate resolution of complex technical issues requires the research staff to access the technical expertise in other organizations, to obtain different perspectives, and to assemble critical masses of skills and expertise.

Thus, knowledge management (KM) is an integral part of the RES mission. KM activities are focused on capturing, preserving, and transferring key knowledge among employees and stakeholders. The body of knowledge can be used when making regulatory and policy decisions and ensures that issues are viewed and analyzed within a historical context. The primary mechanism of KM involves the documentation of technical bases resulting from the research activities in the form of NUREG publications. Recently, RES has initiated the development of NUREG/KM series documents that capture historical events and highly significant technical and safety information with an aim to preserve this knowledge for future generations [7 - 11]. RES also fosters technical exchanges through multiple avenues, such as RES seminars, staff participation in international and domestic conferences and workshops, and dissemination of technical information to a variety of stakeholders. All of these activities form the core of the KM effort at RES. Mentoring of junior staff by senior staff and knowledge transfer between senior and junior staff are some of the other KM activities.

An important component of the RES KM program is the development of virtual Communities of Practice (CoPs) where RES staff members can share and collect information in their area of interest. Through such CoPs, staff can have access to existing sources of technical information

information to achieve goals and objectives of the NRC mission. The discussion and communication through the global CoPs have contributed to improved understanding of technical issues, development of more viable and practical solutions, and enhancement of analytical and computational tools. RES has several CoPs on topics such as human factors; high temperature gas cooled reactors; liquid metal cooled reactors; fire protection; health effects; and structural, geotechnical, and seismic engineering.

8. Future Challenges

In its strategic plan for fiscal years (FYs) 2014 through 2018 [3], the NRC has identified new challenges, as it continues to operate in a dynamic environment. Several of these challenges require research support, including the following:

- Continued implementation of enhancements to improve nuclear safety based on lessons learned from the 2011 nuclear accidents at the Fukushima Dai-ichi;
- Continual learning and adaptation of the regulatory framework to address knowledge of and response to the specific hazards, uncertainties, and risks associated with each nuclear site;
- Continued readiness to review applications involving new technologies such as small modular reactors, medical isotope production facilities, and rapidly evolving digital instrumentation and control systems; and
- Globalization of nuclear technology and the nuclear supply chain, which drives the need for increased international engagement on the safe and secure use of radioactive material.

RES has embarked upon several research efforts to address the future challenges to the NRC.

Several decades ago, the recovery of Three Mile Island Unit II (TMI 2) advanced the understanding of severe-accidents in PWRs. Similarly, the post-Fukushima forensic analyses offer an opportunity to better understand severe accident progression in BWRs. An international program to assist the Government of Japan in the cleanup efforts for the Fukushima reactors may include identifying and gathering information that will enhance NRC research activities in areas such as severe accident modeling. These activities will better inform severe accident management guidelines. RES is engaged with DOE, the OECD/Nuclear Energy Agency (NEA), the IAEA, and the Japanese regulatory and research organizations in discussing technical issues related to Fukushima cleanup efforts.

Several research projects are underway in the fire risk area. RES is planning additional testing and fire experiments and development of fire prediction models through collaborative efforts with U.S. industry and international organizations. RES is working with NIST to perform a comprehensive series of experiments on the heat release rate (HRR) from electrical enclosures. The summary report, to be published in the near future, is expected to advance the state of the art for modeling fires in electrical enclosures.

RES is addressing technical challenges related to digital I&C systems by shifting the research focus toward activities that address evolving regulatory needs. Past research has focused on analyzing digital system failure modes, an area in which significant progress has been made. Current research programs are focusing on digital I&C reliability modeling using PRA and on hazard analyses of digital I&C systems to support the current deterministic regulatory framework.

RES is actively engaged in collaborative programs with foreign regulators and TSOs, with an aim to augment the technical database and information on safety issues. Current and future programs include research on fuel performance, zirconium fire issues, non-destructive examination, irradiation damage of reactor materials, seismic testing and analysis of nuclear power plant systems, structures, and components, analysis of earthquake experience data, human factors, human reliability assessment, and ground-water monitoring.

9. Summary

RES is a TSO-like organization mandated by the U.S. Congress to support the NRC. RES is fully integrated within NRC, along with other regulatory offices, and operates like a TSO to the regulatory offices and the Commission. It carries out the NRC's research program providing independent information and expertise needed to support NRC's regulatory decisionmaking process, as well as identifying and characterizing technical questions in anticipation of potential future safety issues.

To accomplish its goals and objectives, RES has established appropriate mechanisms to initiate and drive research to fulfill the needs of regulatory offices. The primary mechanisms and the process to ensure the research products meet high quality standards are detailed in the paper. While a sound process is an enabler, the technical expertise and core capabilities are the necessary ingredients for the conduct of research to meet the expectations of the regulatory offices and the Commission. Accordingly, in addition to maintaining in-house expertise, RES relies on the services provided by DOE laboratories and commercial contractors to extend its capabilities. RES also leverages support from various domestic and international collaborations to fulfill its mission.

There are a number of future challenges that RES is striving to address through well-planned and well-established programs. RES has embarked upon several research efforts to address these challenges. Examples of these challenges are discussed in the paper.

10. Acknowledgements

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Appendix I. Selected Research Activities

A.1 Research Activities Related to the Fukushima Dai-ichi Accident [Activities Have Elements of Both Forward Looking and Confirmatory Research]

The NRC established the Near Term Task Force (NTTF) of senior NRC experts after the Fukushima accident. The NTTF issued a report entitled "Recommendations for Enhancing Reactor Safety in the 21st Century" on July 12, 2011[A.1]. In the report, the NTTF concluded that while continued operation and licensing activities pose no imminent risk, enhancements to to safety and emergency preparedness are necessary. It presented a dozen recommendations for the Commission's consideration. The NRC subsequently prioritized and expanded the NTTF recommendations (in SECY 11 0137, "Prioritization of Recommended Actions to Be Taken in Response to Fukushima Lessons Learned," dated October 3, 2011[A.2]). The recommendations were divided into three tiers based on the urgency of the issues, as described described in SECY 11 0137. On March 12, 2012, the NRC issued the first regulatory requirements for the nation's operating reactors based on the prioritized NTTF recommendations. The NRC also established the Japan Lessons Learned Project Directorate (JLD) to focus exclusively on implementing the lessons learned. RES has been supporting the NRC's lessons learned effort through participation in the JLD Steering Committee and several several JLD working groups and through followup research. Some of the related research activities are briefly described below.

A.1.1 Fukushima Dai-ichi Accident Study with MELCOR

The NRC and DOE jointly sponsored an accident reconstruction study as a means of assessing assessing the severe accident modeling capability of the MELCOR code. MELCOR is the state of the art system level severe accident analysis code. The objectives of the study were to (1) collect, verify, and document data on the accidents by developing an information portal system; (2) reconstruct the accident progressions using computer models and accident data; and (3) assess the MELCOR code and the Fukushima models and suggest potential future data data needs [A.3]. A follow-on study funded by DOE that is focused on MELCOR uncertainty analysis of the Fukushima Dai-ichi accident is expected to be completed by end of 2014.

The NRC and DOE are also participating in a benchmark study of the Fukushima Dai-ichi accident. The study, led by OECD/NEA, will include benchmarking workshops to share information and experience related to analyzing the severe accidents at Fukushima Dai-ichi. The objectives of this project are to (1) improve the understanding of severe accident

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phenomena, (2) compare and improve the methods and models of the best estimate computer codes, (3) assist in the development of guidance for decommissioning efforts in Japan by evaluating the accident progression and current status, and (4) promote international cooperation.

A.1.2 Hydrogen Control and Mitigation inside Containment and Other Buildings

In accordance with 10 CFR 50.44, "Combustible Gas Control for Nuclear Power Reactors," licensees are required to use various hydrogen control and mitigation schemes inside containment buildings, depending on their unique design characteristics. As a result of insights and continued post-accident analyses of the Fukushima events, the NRC will reassess the hydrogen control rule as it relates to the various containment designs, including the potential of hydrogen transport into surrounding buildings.

A study of the accident at Fukushima is underway through an international collaborative program. This study will examine hydrogen generation from all sources to benchmark the current hydrogen control and mitigation schemes. Moreover, the NRC will pursue the assessment of any potential or (if possible) identifiable leakage paths from the primary containments into the reactor buildings found through forensic studies of the Fukushima accident. As needed, the NRC will perform accident progression studies using the MELCOR code to examine the containment performance of different containment types.

A.1.3 Spent Fuel Pool Study and Expedited Transfer of Spent Fuel

The NRC recently completed the Consequence Study of a Beyond Design Basis Earthquake Affecting the Spent Fuel Pool (SFP) for a U.S. Mark I Boiling Water Reactor [A.4], commonly referred to as the Spent Fuel Pool Study (SFPS). This study was initiated to determine whether accelerated transfer of older, colder spent fuel from the SFP at a reference plant to dry cask storage significantly reduces risks to public health and safety. The SFPS considered ground motion associated with a seismic event that is beyond the SFP's current design basis and used analysis methods to determine the potential damage states of the SFP. The SFPS also used detailed modeling to assess the event progression of several scenarios to determine the consequences of any resulting fission product release. The results of the study indicated no no early fatalities for any of the scenarios studied and low individual latent cancer fatality risk for the scenarios studied because effective protective actions limit exposure. The NRC continues to believe, based on this study and previous studies, that SFPs provide adequate protection of public health and safety.

A.1.4 Flooding Research

The NRC regulatory offices have asked RES to develop an approach, technical basis, and regulatory guidance for performing probabilistic flood hazard assessments (PFHA). RES is currently developing a multiyear research program plan to address this request. Because

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[A.4] UNITED STATES NUCLEAR REGULATORY COMMISSION, "Consequence Study of a Beyond Design Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," NUREG-2161, September 2014, ADAMS Accession No. ML14255A365.

flooding is a complex phenomenon with multiple potential causes and site specific design and mitigation implications, many research activities will be associated with this effort. Some of the initial activities include the development of a PFHA framework, development of flood hazard information digests for operating NPP sites, quantitative reliability of passive and active flood protection features, understanding of issues related to human reliability analysis with respect to flood protection and/or mitigation procedures, understanding the uncertainties in dam breach modeling, and quantifying uncertainties in probabilistic storm surge models. RES is also providing specialized technical expertise to support the NRC's NTTF Recommendations on flood hazard reevaluations and walkdowns.

A.2 Seismic Research [Confirmatory Research]

The RES seismic research program in support of regulatory activities is being conducted under a research plan. The current emphasis of this research plan is to evaluate potential risks to U.S. nuclear plants posed by events such as severe earthquakes and tsunamis. To this end, the development of a new seismic source characterization (SSC) model for the Central and Eastern United States (CEUS) has been completed. The CEUS SSC model will be used in conjunction with modified Probabilistic Seismic Hazard Assessment (PSHA) software to perform seismic hazard calculations in order to confirm licensee submittals on the seismic hazard reevaluations. An ongoing project is examining the paleoliquefaction features to understand and quantify large pre-historic earthquakes. This understanding will help inform earthquake recurrence relationships used in seismic hazard analysis. To further understand the soil/structure interactions, RES staff is a conducting a two dimensional nonlinear soil response analysis. The development of a multidimensional soil constitutive model is being pursued.

In the geotechnical and seismic engineering area, RES is conducting an engineering evaluation of post liquefaction residual strength and an evaluation of the applicability of current structural, geotechnical, and seismic regulations to advanced design small modular reactors on individual foundations. Other projects currently underway include an evaluation of numerical tools for assessing soil/structure interaction (SSI) of deeply embedded nuclear power plant structures and a computational platform for addressing SSI under non-traditional seismic input loads.

A.3 Fuel Dispersal during a Loss of Coolant Accident [Confirmatory Research]

The NRC is engaged in various research activities to understand performance of nuclear fuel in accident conditions and to confirm that this performance is acceptable. One finding that has emerged from these research activities in recent years is the possibility that loss of coolant accident (LOCA) conditions may lead to fragmentation, relocation, and dispersal of high burnup fuel. RES developed a research plan to evaluate the conditions that could result in fuel dispersal and to predict the quantity of fuel that could be dispersed. The results to date indicate that a small number (sometimes none, depending on the scenario considered) of the most vulnerable high burnup rods are predicted to rupture. However, the estimates are very sensitive to assumptions regarding the fuel fragmentation, relocation, and dispersal phenomena. The estimates are also very sensitive to the characteristics and assumptions of the emergency core cooling system (ECCS) system. RES is performing additional research and calculations to understand these effects.

A.4 Primary Water Stress Corrosion Cracking (PWSCC) [Confirmatory Research]

PWSCC in primary pressure boundary components composed of nickel based alloys is a degradation mechanism that can affect the operational safety of PWRs. Nickel-based materials that were originally used in PWRs include Alloy 600 and its companion weld metals Alloy 182 and 82. These materials are known to be susceptible to PWSCC. Newer nickel-based materials have higher chromium content and include Alloy 690 and its weld metals Alloy 152 and Alloy 52. These materials are expected to be much less susceptible to PWSCC and are being used both in new reactor applications and to mitigate potential cracking in existing reactor applications. RES is conducting extensive research to evaluate the PWSCC susceptibility of these higher chromium alloys. The primary objective of this research is to determine the relationship between PWSCC susceptibility and metallurgical characteristics. Specific tasks are currently addressing the effects of dilution zones and existing weld defects on PWSCC susceptibility, and characterization of the susceptibility of heat-affected zones. Experiments will be performed to measure crack growth rates in nickel based alloys in simulated PWR environments. The microstructural and fracture surface characterization of test materials will be performed. Limited experiments are also being conducted to compare the crack initiation susceptibility of the lower chromium alloys (Alloys 600, 82, and 182) and the higher chromium alloys (Alloys 690, 52, and 152). The work will provide valuable information for assessing current and potential mitigation methods that use these higher chromium materials in existing reactors and for evaluating the acceptability of these materials in new reactors.

A.5 Concrete Degradation and Alkali/Silica Reaction Research [Confirmatory Research]

By the year 2015, more than 65 percent of the operating reactor containments in the United States will be more than 20 years old. Seventy percent of the containments are made of reinforced or prestressed concrete. As nuclear plants age and continue to operate, incidence of degradation of structures, systems, and components caused by aging has been and will continue to be identified. Examples of some incidents of concrete and steel degradation include containment delamination, leaching of concrete in tendon galleries, corrosion of steel liners attached to concrete containments, and alkali/silica reaction cracking in concrete, among others. Methods and acceptance criteria are needed to monitor and evaluate aging effects. The objective of the NRC's research is to determine whether current inspection and maintenance programs are sufficient in identifying and characterizing degradation in a timely manner.

A.6 Level 3 PRA [Forward Looking Research]

In light of the PRA and severe accident modeling advances over the last two decades, the Commission directed the NRC staff to perform a full scope comprehensive site Level 3 PRA. A Level 3 PRA includes accident sequences, which evaluate core damage (Level 1), severe accident progression, and the release of radioactive material to the environment (Level 2), and offsite radiological consequences (Level 3). This study will generally rely on state of practice methods and approaches to estimate radiological consequences from reactor accidents at power or during low power or shutdown modes of operation. However, the Level 3 project will also include evaluation of multi-unit risk, spent fuel radiological sources, and low power and shutdown operations. Vogtle Electric Generating Station Units 1 and 2 are participating in in this research by providing plant specific information that RES will use to develop the PRA models.

A.7 Smart Grid Impacts on Nuclear Power Plants [Long Term Research]

This project will assess efforts to develop the smart grid to (a) ensure that these efforts do not result in unsafe or unintended consequences and (b) determine whether new regulatory tools are necessary to deal with any problems identified. For instance, if smart grid technology creates offsite electrical-supply reliability problems for nuclear power plants, a suitable tool will be needed to evaluate that impact. The study will assess the status of the smart grid effort, summarize potential safety and regulatory issues relating to the development of smart grid technology, and identify issues that could affect any nuclear power plant event involving the loss or degradation of offsite power.