U.S. Nuclear Regulatory Commission Long-Term Research: FY 2009 Activities

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Prepared by:
The Office of Nuclear Regulatory Research, RES

In coordination with:
The Office of Federal and State Materials and Environmental Management Programs, FSME
The Office of New Reactors, NRO
The Office of Nuclear Material Safety and Safeguards, NMSS
The Office of Nuclear Reactor Regulation, NRR
The Office of Nuclear Security and Incident Response, NSIR

Enclosure
Executive Summary

This report provides the first step in the development of an integrated, long-term regulatory research plan. The U.S. Nuclear Regulatory Commission (NRC) currently identifies, as a matter of routine, research activities supporting current and anticipated near-term (within the next few years) regulatory needs. This report documents future technical issues and associated long-term regulatory research activities which are not currently identified within the agency’s planning documents. The report is intended to inform the ongoing Fiscal Year (FY) 2009 planning, budgeting and performance management (PBPM) process.

Background The NRC performs regulatory research to support the achievement of the goals identified in its Strategic Plan. These goals are to: ensure protection of public health and safety and the environment; ensure the secure use and management of radioactive materials; ensure openness in NRC’s regulatory processes; ensure that NRC actions are effective, efficient, realistic, and timely; and ensure excellence in agency management.

NRC’s research strategies are developed to be consistent with the NRC’s role as a regulator. For example, the nuclear industry often performs research to establish safety cases (e.g., for license amendments for existing facilities, licenses for new facilities, and new rulemakings). In these cases, NRC’s research enables the independent review of the industry research results and applications, as well as the treatment of potentially significant beyond-design basis issues. Furthermore, NRC’s performance of research helps ensure that the technical bases for regulatory decisionmaking are sound and publicly available to the extent allowable.

The NRC has plans for many of its research activities documented at a variety of programmatic levels. There are plans for specific technical topic areas (e.g., digital instrumentation and control), for programs (e.g., advanced reactor licensing), and for agency-wide initiatives (e.g., risk-informed and performance-based regulation). As they exist today, most of these plans focus on current and near-term regulatory issues, with secondary consideration of long-term research activities associated with potentially emerging technical and regulatory issues.

- **Regulatory research**: activities aimed at providing the NRC staff with new methods, tools, and information to support regulatory decisionmaking.

- **Long-term regulatory research**: forward-looking regulatory research performed to provide fundamental insights and technical information, or address potential technical issues or identified gaps to support anticipated future (> 5 years) NRC needs.

Research-related strategies supporting the NRC’s achievement of its goals:

- Ensure that NRC regulations and regulatory processes have sound technical bases;
- Prepare the agency for anticipated changes in the nuclear industry that could have safety, security, or environmental implications;
- Develop improved methods by which the agency can carry out its regulatory responsibilities; and
- Develop and maintain an infrastructure of expertise, facilities, analytical capabilities, and data to support regulatory decision-making.
To support the development of a forward-looking regulatory research program, the NRC is developing an integrated research plan. This plan will: identify long-term research activities; provide the basis for the assessed needs; identify research areas where NRC's resources can be leveraged through cooperation with other organizations; and indicate how, using existing mechanisms, feedback will be used to evaluate research program performance. The integrated plan will present this information at a level of detail suitable to support operational decisionmaking. It will rely upon topic-, program- and initiative-specific research plans (either existing or needing development) to provide detailed information on research issues and activities.

The long-term, integrated plan will be maintained as a living document. Periodic updates will be performed to reflect changes in the agency's knowledge base and priorities, and in the external environment. These updates will address, in addition to the startup of new research activities, the termination or redirection of ongoing activities to better meet the needs of the agency.

This report documents the first steps in the plan development process. It provides the purpose of the plan and identifies long-term research activities to be initiated in FY 2009.

**Purpose of Plan**

The primary purpose of the plan will be to identify and prioritize long-term research activities to support NRC PBPM process. The plan will also support the development of reports and other communication tools (e.g., brochures, information sheets) addressing specific issues (e.g., the NRC’s research plans for supporting the licensing and regulation of new facilities).

**Long-Term Research Activities**

Table E.1 lists long-term candidate research activities to be initiated in FY 2009. These activities support two anticipated programs: the Global Nuclear Energy Partnership (GNEP) and a program addressing reactor license renewal beyond 60 years. Other significant activities listed are for potential new test facilities and for cross-cutting work supporting multiple NRC programs.

The regulatory research associated with GNEP, a U.S. Department of Energy (DOE) initiative, involves the development of the regulatory infrastructure and the technical bases (e.g., methods, tools, data) needed to support rulemaking, design certification, and regulatory guidance. The types of activities undertaken will be heavily influenced by the technologies selected by DOE (e.g., aqueous separation and liquid-metal fast reactor).

The staff expects the regulatory process for evaluating applications for license renewal beyond 60 years to be similar to the current license renewal
process; however, current evaluations do not address the adequacy of the technical basis for plant life extension beyond 60 years. Therefore, a new technical basis will be required to support the evaluation of license extension applications and pre-application topical reports. Additional research will be needed in order to build on existing knowledge to develop this new technical basis; additional tasks will include modifying existing key technical reports to extend the technical basis to 80 years.

Test facilities are an important source for data needed to support both direct evaluations of proposed systems and design concepts and the validation of models supporting safety cases. The development, operation, and maintenance of such facilities can be costly, and the NRC participates in a number of cooperative programs to leverage its resources. In areas such as digital instrumentation and control and human factors research, the development of new test facilities or programs would improve the NRC’s ability to support regulatory decisionmaking. In FY 2009, the staff intends to evaluate the need for selected facilities and identify possible options, and if approved, initiate development of the facilities.

Cross-cutting regulatory research (i.e., research that addresses technical issues common to multiple regulatory programs and initiatives) is an important component of NRC’s research portfolio. The long-term cross-cutting research activities identified in this report address potential new safety technologies (e.g., applications of nanotechnology in sensor devices) and the potential for improved analytical tools (e.g., for performing multiphase computational fluid dynamics analysis) enabled by advances in computer hardware and software. In many cases, the candidate FY 2009 activities involve the performance of scoping studies to assess the current state-of-the-art, identify specific NRC needs, and develop recommendations for further work.

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Table E.1 Long-Term Research Areas and Activities
Work on the activities identified in this report is planned in FY 2009 to ensure that the agency has an independent technical basis to effectively address future safety and security issues that are anticipated to arise as the agency continues to strive for more realistic assessments and more efficient regulatory decisionmaking.

Table E.1 has been developed through a variety of means. These means include the solicitation of research ideas from the staff (principally staff in the Office of Nuclear Regulatory Research), the review of existing research plans from both NRC and external organizations, and the review of selected reports on NRC research activities (including the NUREG-1635 reports produced by the Advisory Committee on Reactor Safeguards (ACRS) and NUREG-1802, an expert panel report on the role and direction of NRC's nuclear regulatory research).

The output from all suggested research activities will be aligned with anticipated regulatory uses. In some cases, consideration has been given to the potential for staff development associated with the planned research. This consideration acknowledges that, in addition to developing/strengthening technical expertise needed to address specific problems (e.g., knowledge regarding the limitations of current methods and tools in particular applications), active participation in a research project can be helpful in developing broader problem-solving skills related to technical issues. These benefits are of increasing importance to the agency as it loses expertise due to staff retirements.
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1 Introduction

1.1 Background

The NRC performs regulatory research to support the achievement of the goals identified in its Strategic Plan. These goals are to: ensure protection of public health and safety and the environment; ensure the secure use and management of radioactive materials; ensure openness in NRC’s regulatory processes; ensure that NRC actions are effective, efficient, realistic, and timely; and ensure excellence in agency management.

*Regulatory research:* activities aimed at providing the NRC staff with new methods, tools, and information to support regulatory decisionmaking.

*Long-term regulatory research:* forward-looking regulatory research performed to provide fundamental insights and technical information, or address potential technical issues or identified gaps to support anticipated future (> 5 years) NRC needs.

NRC’s research strategies are developed to be consistent with the NRC’s role as a regulator. For example, the nuclear industry often performs research to establish safety cases (e.g., for license amendments for existing facilities, licenses for new facilities, and new rulemakings). In these cases, NRC’s research enables the independent review of the industry research results and applications, as well as the treatment of potentially significant beyond-design basis issues.

Furthermore, NRC’s performance of research helps ensure that the technical bases for regulatory decisionmaking are sound and publicly available to the extent allowable.

The NRC has plans for many of its research activities documented at a variety of programmatic levels. There are plans for specific technical topic areas (e.g., digital instrumentation and control), for programs (e.g., advanced reactor licensing), and for agency-wide initiatives (e.g., risk-informed and performance-based regulation). As they exist today, most of these plans focus on current and near-term regulatory issues, with secondary consideration of long-term research activities associated with potentially emerging technical and regulatory issues.

To support the development of a forward-looking regulatory research program, the NRC is developing a long-term, integrated research plan. This plan will: identify long-term research activities; provide the basis for the assessed needs; identify research areas where NRC’s...
resources can be leveraged through cooperation with other organizations; and indicate how, using existing mechanisms, feedback will be used to evaluate research program performance. The integrated plan will present this information at a level of detail suitable to support operational decisionmaking. It will rely upon topic-, program- and initiative-specific research plans (either existing or needing development) to provide detailed information on research issues and activities.

The long-term, integrated plan will be maintained as a living document. Periodic updates will be performed to reflect changes in the agency’s knowledge base and priorities, and in the external environment. These updates will address, in addition to the startup of new research activities, the termination or redirection of ongoing activities to better meet the needs of the agency.

This report documents the first step in the plan development process. It provides the purpose of the plan and identifies long-term research areas activities to be initiated in Fiscal Year (FY) 2009.

1.2 Objectives

The primary purpose of the plan will be to identify and prioritize long-term research activities to support NRC planning, budgeting and performance measurement process. The plan will also support the development of reports and other communication tools (e.g., brochures, information sheets) addressing specific issues (e.g., the NRC’s research plans for supporting the licensing and regulation of new facilities). The intent is that NRC’s plans for future research will be both more cohesive and transparent to both internal and external stakeholders as a result of this process.

The specific objectives of this report are to:

- Identify potential long-term research activities;
- Inform out-year budget planning activities, starting with the FY 2009 budget; and
- Identify long-term activities where NRC research can be leveraged by entering into (or extending) collaborative agreements with external entities.

1.3 Report Scope

The scope of this report is limited to research activities aimed strictly at anticipated future needs which are not currently identified within the agency's planning documents. Thus, for example, the report addresses activities associated with the emergence of new technologies (e.g., nanotechnology) that have not yet been applied in nuclear facilities but could be in coming years. Conversely, the report does not address currently planned research activities, some of which may be long-running, that are relevant to existing or anticipated regulatory concerns. These latter activities, which include research supporting current reactors, new reactors, advanced reactors, nuclear materials, waste, transportation, and security, are identified in the operating plans of the NRC offices performing the research.

Research activities specifically associated with high temperature gas cooled reactor (HTGR) designs are addressed in NRC’s Advanced Reactor Research Plan. A draft version of this plan is available in the Agencywide Documents Access and Management System - ADAMS (accession number ML070600065).
1.4 General Assumptions

There are several general assumptions pertaining to the agency’s role in future research, collaboration and coordination with external stakeholders, and the development of broad, internal capabilities that have been used to guide the selection of the research activities summarized in this report.

With respect to the agency’s fundamental research role, it is assumed that research will remain focused on contributing to the technical basis development necessary for supporting known or anticipated regulatory decisionmaking. Licensees and applicants will continue to perform the developmental research activities used to justify requested regulatory decisions while the agency-sponsored research activities will largely remain confirmatory in nature. This separation will allow the agency to independently evaluate the supplied technical justification.

However, coordination with industry owners and research groups; licensees; and applicants will still be necessary to ensure that principal technical issues are appropriately identified and addressed. Additionally, it is assumed that future NRC research will continue to rely on extensive collaboration and coordination with other external organizations. These organizations include universities; government and independent laboratories; other government agencies; and international organizations and governments. This interaction allows the NRC to leverage its resources by assimilating relevant lessons learned, operating experience, and research findings from other organizations to most efficiently reveal areas that may require research.

Finally, it is assumed that the agency will continue to support personnel and infrastructure development so that capabilities will remain in place to support agency-sponsored research. Specifically, it is assumed that the agency will develop, maintain, or enhance, as appropriate, the following capabilities:

- Broad expertise in critical technical areas to support multipurpose regulatory activities, maintenance of in-house expertise, and knowledge management;
- Knowledge management tools applicable to nuclear technology for both retaining and transferring knowledge;
- Smart tools and technology to decrease staff training requirements, and allow more efficient, focused regulatory decisionmaking; and
- Computing and information technology (IT) infrastructure to manage increased amounts of available information, provide smart/targeted access to needed information, increase information portability, and increase availability and use of sophisticated, networked simulation tools.

These capabilities will be necessary for the agency to most efficiently handle and process information, promote knowledge management, and effectively focus resources.

1.5 Process for Identification of Research Activities

The long-term research activities identified in this report were developed through a variety of means. These means include the solicitation of research ideas from the staff (primarily staff in the Office of Nuclear Regulatory Research, but also staff and management representatives from each of the program offices), the review of existing topic-specific and program-specific research plans from both NRC and external organizations, the review of selected reports on
NRC research activities (including the NUREG-1635 reports produced by the Advisory Committee on Reactor Safeguards (ACRS) and NUREG-1802, an expert panel report on the role and direction of NRC's nuclear regulatory research) and other relevant currently-existing planning tools (e.g., the Operating Plan).

Supporting information was developed in each of the following topic areas:

- Materials
- Structural and Component Integrity
- Non-Destructive Examination
- External Hazards
- Nuclear Fuels
- Thermal-Hydraulics
- Severe Accidents and Consequences
- Radiation Protection
- Environmental Assessment and Protection
- Reprocessing Spent Nuclear Fuel
- I&C and Electrical Systems
- Human Factors
- Fire Safety
- Risk Assessment
- Nuclear Material / Plant Security
- EP & Incident Response
- Decision Support

1.6 Report Organization

Chapter 2 provides a description of activities within several research areas. The Global Nuclear Energy Partnership (GNEP) and reactor license renewal beyond 60 years are identified as possible program initiatives that will require research to support resulting licensing decisions. Research activities related to the development of integral test facilities and cross-cutting capabilities are also discussed. It is envisioned that these activities will support a broad array of agency programs and initiatives.
2 Program Areas and Initiatives with Supporting Research Needs

2.1 GNEP / Reprocessing

2.1.1 Background and Assumptions

The Global Nuclear Energy Partnership (GNEP) is a U.S. Department of Energy (DOE) initiative that aims to:

- Expand the use of nuclear power,
- Minimize nuclear waste,
- Develop advanced proliferation resistant recycling and separation technologies,
- Develop advanced burner reactors for transmutation of long-lived fission products,
- Establish reliable fuel services,
- Demonstrate grid-appropriate, exportable reactors, and
- Enhance nuclear safeguards technology.

To accomplish these goals, DOE officials hope to partner with industry to build an industry-led, commercial-scale fuel reprocessing/fuel fabrication plant and a fast burner reactor.

The NRC has already engaged in technical exchanges with DOE to keep abreast of DOE's plans and evaluations of technologies to be used for GNEP, and to anticipate any changes to NRC's regulatory infrastructure that would be needed to license commercial GNEP facilities. The staff envisions these interactions with DOE will continue and become more frequent once DOE has completed its evaluations of industry capabilities to develop commercial facilities. The staff is evaluating regulatory options for licensing GNEP facilities, including rulemakings that may be necessary in multiple areas (e.g., safeguards, waste management, environmental protection) to address the unique aspects of GNEP technologies.

The role of NRC in licensing the possible GNEP facilities has not yet been determined. However, due to the recent shift of DOE's approach to GNEP from small-scale demonstration facilities to a large-scale industry approach, it is assumed for the purposes of this report that both the consolidated fuel treatment center\(^1\) (CFTC) and the advanced burner reactor\(^2\) (ABR) will be commercial-scale facilities, licensed by the NRC, and built on either a commercial site or at an existing DOE site.

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1. A commercial reprocessing plant is expected to include facilities for complex chemical separations of fission products and transuranic nuclides, interim storage of separated radionuclides, waste solidification, and fabrication of fuel containing transuranic nuclides.

2. The ABR (sometimes referred to as an advanced processing reactor – APR) will be a nuclear reactor that accepts recycled nuclear fuel and consumes more transuranic elements than it creates, while generating electricity. It is expected to be a liquid-metal cooled fast reactor. In the context of this type of reactor, the term “burn” means to transmute or convert transuranics into shorter-lived isotopes.
In addition, the specific technologies that will be developed under GNEP are still being considered by DOE. These include the technologies for the CFTC for reprocessing/fuel fabrication and for the ABR. It currently appears that DOE plans to pursue aqueous separation technologies, especially the uranium-extraction- (UREX+1a) based separation processes, and sodium-cooled fast reactors, as most of the GNEP literature in the public domain has focused on these technologies.

Figure 1 provides a sample GNEP schedule based on information provided by DOE. The Secretary of Energy’s Decision on the path forward for GNEP is expected by June 2008. Given the uncertainty in the GNEP schedule and technology selection, the staff does not expect to begin the majority of the work to develop the technical and licensing infrastructure for GNEP until FY 2009. At the same time, the staff is exploring options to accelerate this schedule consistent with any accelerated schedule proposed by DOE. Any research activities related to rulemaking prior to FY 2009 will be addressed through the agency’s typical budgeting processes or through a Memorandum of Understanding with DOE. Beginning in FY 2009, the regulatory safety research is expected to focus on the following design and technology arenas: accident analysis (including risk assessment), reactor systems analysis, fuels performance, materials performance analysis, structural analysis, consequence analysis, transportation, nuclear materials safety and safeguards, waste safety, occupational/public exposure, criticality safety, and potential environmental impacts.

![Figure 1 Sample GNEP Timeline](image-url)
2.1.2 Regulatory Uses

The technical issues and regulatory needs associated with GNEP technologies were originally communicated in SECY-06-0066 [ADAMS accession number ML060410386], which is publicly available. In Staff Requirements Memorandum SRM-SECY-06-0066 [ADAMS accession number ML061370017], the Commission approved the development of a conceptual licensing process for GNEP, but cautioned that the licensing process should proceed at a pace commensurate with DOE’s progress in identifying GNEP technologies.

Research will be needed to support regulatory infrastructure development. Technical bases are required to support the NRC’s safety evaluations for pre-application and design certification reviews as well as for rulemaking. This will require the generation of technical reports and analytical tools that can be used by the program offices to justify approval of the safety evaluation reviews, as well as to identify any needed updates to regulatory guidance.

Data and information are needed to assess public health, safety, and environmental impacts from potential routine and accidental releases of radionuclides. Important contributors to risk need to be identified. Specifically, tools and technical knowledge on the aqueous and non-aqueous chemical separation processes, waste solidification and packaging processes, and the fabrication and testing of irradiated and non-irradiated transmutation fuels need to be updated or developed.

In addition, risk-informed strategies are needed to assess reprocessing accidents and criticality scenarios. The staff needs to develop the technical expertise and tools to independently review and evaluate the acceptability of a spent fuel reprocessing plant application, including the safety and environmental impact analyses. Without these capabilities, the agency will not be in a position to support the development of regulatory criteria and independently confirm an applicant’s results, data, and computer codes.

For the aspects of GNEP related to the ABR, research will be performed to assess the ability to predict the behavior of the new plant design under normal and accident conditions. Results will be applied to enable the staff’s independent assessment of issues associated with the advanced reactor design. Further, research activities will result in developing the staff’s technical insights in these areas and applying those insights toward establishing independent analysis tools and capabilities. Activities include the assessment of validation issues and modeling approximations, validation of success criteria, input into probabilistic risk assessment (PRA) models, and understanding of safety margins.

2.1.3 Technical Areas and Activities

As stated above, it is assumed that research activities will focus on reprocessing and fuel fabrication technologies, as well as the use of reprocessed fuel in the ABR. Specific activities that may be initiated in FY 2009 (depending on further program developments) include:

- Summarizing the international knowledge base and operating experience,
- Developing the expertise, guidelines, and codes for assessing radionuclide separation processes, worker and public exposure, and plant operations,
- Developing risk assessment methods, tools, data, and criteria addressing the unique characteristics of the CFTC and ABR (including potential co-location issues),
The Super System Code (SSC) series comprising SSC-L for loop-type LMRs and SSC-P for pool-type LMRs was developed by Brookhaven National Laboratory for the NRC in the late 1970s.

- Developing fire models that address GNEP fire hazards and protection schemes,
- Developing risk-informed strategies to evaluate accident assessment capabilities, including criticality prevention strategies, for spent nuclear fuel reprocessing and fabrication facilities,
- Development of model updates to the Super System Code\(^3\) series for ABR systems analysis,
- Review for applicability of past experiments related to liquid-metal reactors, and
- Identification of any additional experiments that are needed to assess passive cooling system performance.

The specific long term research activities related to GNEP will be informed by DOE’s selection of specific technologies (currently scheduled for June 2008), and its ongoing activities related to research and development.

2.2 Reactor License Renewal Beyond 60 Years

2.2.1 Background and Assumptions

The original operating licenses for commercial nuclear power plants are valid for 40 years from the issuance date. Currently, 48 applications to renew this original license for an additional 20 years have been approved and 8 renewal applications are under review. Additionally, potential applicants have submitted letters of intent indicating that 30 additional reactors will apply for license renewal between 2007 – 2013.

Many plants have made significant plant modifications and upgrades. For example, many plants have replaced steam generators, to support continued operation, including the potential for long-term extended life to support license renewal. These modifications and upgrades, in many cases, are designed more robustly and perform more efficiently than the original plant equipment. It is expected that plants will attempt to maximize the return on these investments. Additionally, the revision of 10 CFR 50.61, the pressurized thermal shock (PTS) screening rule, may reduce or eliminate a potential life-limiting regulatory consideration for several plants. Given these considerations, and assuming that favorable economic and political conditions exist over the next several years, it is possible that some current licensees will apply for an additional 20 year plant life renewal beyond their current (or anticipated) 60-year license. While several industry representatives have informally

\(^3\) The Super System Code (SSC) series comprising SSC-L for loop-type LMRs and SSC-P for pool-type LMRs was developed by Brookhaven National Laboratory for the NRC in the late 1970s.
inquired about the possibility of license renewal beyond 60 years, no formal letter of intent to pursue such a renewal has been received.

The earliest that a plant can seek a license renewal request under 10 CFR 54 is 20 years prior to the termination of its existing license. The earliest expiring extended license is 2029 (Dresden 2 and Ginna). Therefore, 2009 is the earliest that a request could be received. However, plants have typically submitted their renewal applications 10 – 15 years before their license termination date so that, once the NRC has rendered the final decision on the request, there is sufficient time to either complete necessary applications to satisfy other federal, state, and local requirements, or plan for decommissioning. Considering this schedule and the anticipated near-term focus on evaluating license renewal requests up to 60 years of operation, 2014 – 2019 is a reasonable timeframe for expecting the first requests for license renewals beyond 60 years of operation. Any pre-application topical reports would be submitted for review 1 – 2 years before the license renewal applications.

2.2.2 Regulatory Uses

The safety issues for current license renewal applications are regulated by 10 CFR 54 while environmental issues are regulated by 10 CFR 51. There is no regulatory limit in either regulation which specifically precludes additional life renewal beyond 60 years as long as the regulatory requirements in Parts 51 and 54 and all other licensing conditions are met. The applicant is required to address the technical aspects of plant aging and describe how those effects will be managed. The applicant must also evaluate the potential impact on the environment from an additional 20 years of operation.

The principal technical bases for evaluating applications for plant license renewal beyond 40 years include:

- The Generic Aging Lessons Learned (GALL) report (NUREG-1801);
- The standard review plan (NUREG-1800); and
- Regulatory Guide 1.188.

for the safety review, and:

- The "Generic Environmental Impact Statement for License Renewal of Nuclear Plants" (GEIS) report (NUREG-1437);
- A standard review plan (NUREG-1555, Supplement 1); and
- Regulatory Guide 4.2.

for the environmental review. The GALL report documents the basis for determining when existing programs are adequate and when existing programs should be augmented for license renewal. This report is the basis for identifying those programs that warrant particular attention during NRC's review of a license renewal application. The GEIS report assesses the scope and impact of environmental effects that would be associated with license renewal at any nuclear power plant site such as endangered species, impacts of cooling water systems on fish and shellfish, and ground water quality. A plant-specific supplement to the GEIS is required for each application for license renewal.
The regulatory process for evaluating applications for license renewal beyond 60 years is expected to be similar to the current license renewal process. However, current evaluations do not address the adequacy of the technical basis for plant life extension beyond 60 years. Therefore, a technical basis will be required to support the evaluation of license renewal applications and pre-application topical reports. It is anticipated that research will be performed to develop this technical basis by building on the existing information contained in the GALL and GEIS documents, modifying these reports as necessary to extend the technical basis to 80 years. As appropriate, this information will be used to make corresponding changes to the associated standard review plans and regulatory guides.

2.2.3 Technical Areas and Activities

The technical areas currently identified for evaluation of license renewal up to 60 years are expected to be applicable for additional life extension. For instance, issues related to aging of passive system components and electrical and instrumentation systems are of obvious concern. Also, ensuring that long-term environmental and health issues are appropriately considered will be important.

Aging-related effects to structures, systems, and components will need to be independently evaluated by the NRC to support license renewal requests. For instance, critical passive system components should be assessed to ensure that sufficient safety margins remain when accounting for continued material degradation. Some components and locations with existing and likely future degradation concerns include welds; building structures; equipment supports; anchorages; buried pipes and tanks; reactor vessel internals; nozzles and penetrations; and steam generator tubes. While many locations having materials susceptible to active degradation mechanisms are evident from operational experience, it is possible that operation beyond 60 years could result in other combinations of materials, degradation mechanisms, and locations that should be considered.

Aging of electrical and instrumentation systems will also need to be evaluated. Continued degradation of insulation and connections is expected. Examples of specific possible research activities in this area include the following:

- Study the rate of failure of instrumentation and control cables and evaluate the service life beyond 60 years,
- Identify a zone of influence and a range of factors where component failures or electrical transients could cause a nuclear plant trip,

### Research Technical Areas

- Passive system and structural component aging.
- Electrical and instrumentation component aging.
- Environmental modeling and radiation protection.

### FY 2009 Proposed Research

- Identify possible supporting extended in-situ and real time instrumentation and monitoring techniques. (Section 2.4.6).
- Conduct scoping study to assess and prioritize technical issues.
- Develop research plan.
• Determine how breaker failure rate changes with time from 60 up to 80 years. Correlate the failure rate with cycles of operation, operating environment and age (480V, 5kV, 8 kV, 10 kV and 15kV).

Evaluation of environmental issues may also require research in environmental modeling and radiation protection.

Specific research needs will be identified by: (a) evaluating principal technical limitations to license renewal beyond 60 years, ensuring that a sufficient understanding of related aging and environmental issues has been or can be developed; and (b) implementing, as applicable, more realistic, yet adequately conservative, models to support the renewal evaluation. Through this study, methodologies and degradation acceptance criteria can be developed to provide guidance to the NRC staff for making a timely assessment of the risk-associated degraded conditions identified at specific plants. A scoping study will be initiated in FY 2009 to identify principal technical limitations and develop research plans to assess any important knowledge gaps associated with extending the existing technical basis. Research on advanced instrumentation and monitoring techniques (Section 2.4.6) will also be used to determine if possible technologies exist that could support license renewal. Research should begin at least 5 years prior to the receipt of an application, or pre-application topical report, related to license renewal beyond 60 years in order to support the agency’s effectiveness goals.

In the interim, outreach to the nuclear industry is planned to explore possible timelines for license renewal. Also, collaboration with DOE and coordination with the nuclear industry will be pursued to begin to identify key technical and any associated regulatory issues. A joint workshop between DOE and the NRC is being proposed for later in 2007 to begin this dialog.

2.3 Test Facilities

2.3.1 Background

Test facilities that provide empirical data on the performance of systems comprise an important part of the technical infrastructure supporting regulatory decisionmaking. The data generated by such facilities can be used in a number of ways, including the direct evaluation of proposed systems and design concepts, and the validation of models supporting safety cases. In the latter role, as the industry and NRC make increasing use of sophisticated computer-based modeling, it becomes increasingly important that the agency obtains empirical data needed to ensure that the models are solidly grounded in reality, and that the uncertainties in the model predictions are adequately understood.

The development, operation, and maintenance of test facilities can require considerable resources. To leverage its resources, the agency has entered into cooperative agreements with a number of U.S. and international organizations. Although this has proven to be an effective strategy for addressing many problem areas, the reduced degree of control associated with cooperative programs can be an impediment to the timely development of data directly focused on NRC needs.
2.3.2 Agency Needs

The facilities and associated activities discussed in the following sections are intended to support the development of technical bases for a range of regulatory decisions (e.g., licensing of upgraded control rooms, design certification for advanced reactors) regarding currently operating and potential new reactor and fuel cycle facilities.

2.3.3 Integrated Digital I&C and Human Machine Interfaces Research Facility

To improve the realism and applicability of the ongoing research in the areas of digital instrumentation and control (I&C) and human machine interface (HMI) technologies, an integrated digital I&C and HMI research facility that could house state-of-the-practice digital instrumentation and control systems, as well as a full-scale, reconfigurable research simulator would be beneficial. Currently, NRC research activities in I&C and HMI are performed at a number of different national laboratories, universities and international research facilities. The NRC is acquiring a number of digital safety systems that are being used in the industry or have been proposed for use, for evaluation at these different facilities. However, a single integrated test facility would create synergies and efficiencies that are not possible in current programs and provide NRC with the capability to independently confirm licensee and applicant analyses of proposed I&C systems. This facility would also be able to provide data needed to validate digital system risk and reliability models currently being developed by both the industry and the NRC. Additionally, a modular reconfigurable human factors research simulation capability would permit NRC to evaluate the expected variety of plant control room and HMI designs (including digital I&C systems).

A detailed options paper will be developed in early FY 2008. If approved by the Commission, the NRC would, in concert with the nuclear industry and the research community, establish facility requirements and initiate development of the facility in FY 2009. A detailed plan for the development and operations of the facility will be completed at that time.

2.3.4 Integral Effects Test Facilities for Advanced Non-Light Water Reactors

NRC has the responsibility to ensure the adequacy of the safety criteria that are used for licensing advanced non-lightwater reactors (non-LWRs - e.g., very high temperature gas reactors, fast sodium-cooled reactors) as well as the adequacy of the analytical tools that applicants propose to use to demonstrate that the safety criteria are met. Early LWR licensing experience shows that independent safety research by the NRC at separate effects facilities or large integral effects test facilities are needed to provide the data to achieve an adequate technical basis to support licensing decisions. Historical examples for LWRs include testing required to validate the safety criteria for reactivity accidents and loss of coolant accidents, and safety criteria and analysis methods for BWR power oscillations. For non-LWR licensing, it should be anticipated that safety testing at separate effects facilities and integral test facilities will also be used to evaluate safety issues related to the adequacy of the proposed criteria and analytical methods. Test facilities may be needed to establish and verify regulatory limits on the fuel, graphite, metallic and composite components as well as integral test facilities to resolve analytical code modeling issues associated with specific postulated accidents for the advanced non-LWR designs. These might involve graphite oxidation models for air-ingress events for high temperature gas reactors or sodium–water reaction models for fast sodium-cooled reactors and fission product transport models for
both reactor technologies. Specific issues which may warrant examination should be based on risk impacts and uncertainty and should be identified as part of the pre-licensing reviews of advanced non-LWRs. FY 2009 activities will focus on scoping and initially prioritizing research needs. These needs will likely span a wide range of different technical areas, as discussed above. FY 2010-2012 activities will focus on further prioritization of these issues and examination of the options for obtaining such data (including cooperative testing programs).

2.4 Cross-Cutting Research

2.4.1 Background

Cross-cutting regulatory research (i.e., research that addresses technical issues common to multiple regulatory programs and initiatives) is an important component of NRC’s research portfolio. By its nature, cross-cutting research can provide a broad technical base supporting the agency’s decisionmaking. For example, as shown by past cases (in the text box on the right), cross-cutting research can, in addition to answering the immediate problem posed to the staff, enable the development and execution of broader NRC initiatives.

The NRC’s current cross-cutting research activities include experimental and analytical investigations of key phenomena; the development of improved analytical methods and models, software tools, and data; and the performance of integrated systems analyses. These activities are identified using input from a variety of sources (including Commission directives, program office user need letters, recommendations from technical advisory groups, lessons from operating experience and inspection findings, research results, and recommendations from oversight committees and peer review panels) and are assigned resources following an agency-wide prioritization process which considers the potential impact of the research on the achievement of NRC’s strategic goals.

Example Long-Term Benefits of Cross-cutting Research:

- Reactor Safety Study (1975) - PRA methods, data, and insights developed for this 3-year landmark study (documented in WASH-1400), enabled the development of the NRC’s 1995 PRA Policy Statement and numerous subsequent risk-informed initiatives regarding the licensing, regulation, and oversight of commercial nuclear power plants.
- Materials research - Experimental and analytical work related to heavy-section steel reactor pressure vessels conducted in the 1970s - 1990s enabled the initiation of a multidisciplinary project in 1999 to develop the technical basis to support an ongoing risk-informed revision of the pressurized thermal shock rule (10 CFR 50.61).
- Severe accident research - NRC activities in the 1980s and 1990s led to more realistic conclusions regarding the likelihood of early containment failure due to certain phenomena (e.g., steam explosions, direct containment heating). Severe accident research has also served as the technical basis for developing an alternate source term for design-basis offsite dose analysis, which led to both cost-savings and greater regulatory effectiveness.
Many of NRC’s current cross-cutting research activities are quite useful in either addressing the agency’s long-term needs or in providing a foundation for future work to address these needs. However, these activities were generally not identified, scoped, or prioritized with long-term applications in mind.

2.4.2 Agency Uses

In general, the cross-cutting research activities discussed in the following sections are aimed at preparing the agency for future decisionmaking regarding the licensing, regulation, and oversight of facilities. In particular cases identified below, the research will address specific regulatory needs. All of the research products (e.g., methods, tools, data, guidance documents, technical results and insights) will be developed to address the needs of staff users.

Note that, in a number of cases, it is expected that the research activities will have potentially significant staff development benefits. Active participation in a research project can be helpful in developing broader problem-solving skills related to technical issues, as well as in developing/strengthening technical expertise needed to address specific problems (e.g., knowledge regarding the limitations of current methods and tools in particular applications). These benefits are of increasing importance to the agency as it loses expertise due to staff retirements.

2.4.3 Long-Term Research Activities

This section describes specific long-term, cross-cutting research activities identified using the process described in Chapter 1. In general, these cross-cutting activities:

- Address issues associated with anticipated or proposed new safety technologies (e.g., nanotechnology) that may impact a number of NRC programs; or
- Enable the agency to develop state-of-the-art tools that take advantage of ongoing or anticipated developments in analysis technologies (e.g., simulation methods) and supporting infrastructure (e.g., computers and software).

Note that in some topic areas, the technical issues underlying the research are well understood and the research activities are well-defined. In other areas, the issues are less well-defined, and scoping studies will be performed to inform the direction of future research activities in the area.

2.4.4 Advanced Analytical Capabilities

Advanced Computational Methods - In recent years, the NRC has made increasing use of the results of realistic, best-estimate analyses (including characterizations of uncertainty) to support decisions involving complex processes. This trend has been enabled by improvements in the external and internal computational environment (including computer hardware, software, and numerical methods). It is expected that these improvements will continue, and that they will enable improvements in the speed with which technical information is delivered to the user (e.g., an inspector) and the quality of this information (including accuracy, characterization of uncertainties, identification of important underlying mechanisms, and implications for safety).
The staff’s current research activities to improve its computational capabilities are focused on the needs of particular applications and technical disciplines. This reflects the general observation that the optimal numerical techniques for solving a given problem can be quite specific to that problem (or class of problems). There is, at this point, no structured research activity to identify and evaluate external developments that may be useful to address problems relevant to a broad range of applications (e.g., sensitivity analyses for multiparameter problems, quantitative uncertainty analyses, decomposition and aggregation of results), or provide improved capabilities for integrated, cross-disciplinary analyses (e.g., through direct system simulation).

In FY 2009, the staff will perform a scoping level assessment to identify, evaluate, and recommend, as appropriate, potential research activities supporting the development of improved computational capabilities. This assessment will evaluate (in the context of the agency’s activities) the potential for advances due to internal and external developments, the work needed to take advantage of this potential, and whether this work should be pursued by specific application or through a broader scope program.

Multiphase Computational Fluid Dynamics Capability - Computational fluid dynamics (CFD) is used widely in a number of fields, including chemical processes, environmental transport, and power generation. CFD provides detailed three-dimensional predictions of flow velocity, pressure, and heat transfer and is already used by the agency to study specific single-phase issues of interest. Currently, the system analysis tools used by the agency (e.g., TRACE) do not account for most three-dimensional and/or developing aspects of multi-phase flows in the reactor system, and there is no agency multiphase CFD capability to address these shortcomings. These issues could be addressed with CFD, provided that models and capability for two-phase flow in a boiling/condensing system are developed. In addition, there is increasing interest in multiphase CFD among the nuclear industry and international regulators, and the staff expects to receive safety analyses in the future which rely on multiphase CFD (e.g., departure from nucleate boiling analysis, pool heat exchanger performance). To address these issues, work in FY 2009 will focus on implementation of a program to:

- Stay abreast of domestic and international initiatives related to the use of multiphase CFD (e.g., the French NEPTUNE project);
- Build upon the state-of-the-art summary of CFD methods for two-phase flow generated by a recent Committee on the Safety of Nuclear Installations (CSNI) Working Group;
- Examine the various research and commercial codes available and evaluate their strengths and limitations for performing multiphase CFD analyses; and
- Perform benchmark calculations against simple but well-characterized data and participate in international benchmarking efforts as appropriate.

The overall objective of the program is the development of a multiphase CFD analysis capability suitable for a range of safety-significant applications.

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1 The TRAC/RELAP Advanced Computational Engine (TRACE) is a thermal-hydraulic systems analysis tool used by the agency.
2 A multi-scale thermal-hydraulics code being developed jointly by CEA, EdF, Areva NP, and IRSN (NETUNE is not an acronym).
Advanced Modeling Techniques for Level 2/3 PRA - Model improvements have been incorporated into the agency’s severe accident computer code (MELCOR) based on:

- A better understanding of severe accident progression (extent and timing of core damage and radiological release), and
- An increased emphasis on integral best-estimate analysis.

While these detailed phenomenological models have substantially improved the agency’s capability to assess plant response for selected accident scenarios, the detailed best-estimate predictive capability has not been integrated into all key agency activities. In particular, the current state of Level 2 PRA does not, in an integrated fashion, utilize the phenomenological MELCOR modeling to quantify the likelihood of containment failure or the offsite radiological release. Often, the response of containment and the radiological release (when it is quantified) is based on accident progression event trees (APETs) which are logic-based, simplified approximations to complex interrelated phenomena. While this APET approach allows for the approximate quantification of many probabilistic accident pathways, it sacrifices realism. Advanced computing capability allows for the development of a MELCOR modeling approach consistent with level 2/3 PRA, in a way that will fully integrate such modeling into risk quantification. This effort is a counterpart to the faster than real-time accident progression modeling capability needed for the NRC Operations Center. The development of this capability would also eliminate the reliance on a simplified or qualitative LERF (large early release frequency) determination, and replace it with consistent phenomenological analysis for evaluating LERF. This would give the Commission the flexibility to consider alternative risk metrics. Work in FY 2009 will focus on MELCOR developments that will specifically facilitate this type of analysis, as well as scoping out issues related to the coupling of the phenomenology-based tool in to a Level 2/3 PRA framework.

Advanced Offsite Consequences Code - The agency currently has two codes that it uses for offsite consequence analysis resulting from a postulated nuclear power plant accident. The MELCOR Accident Consequences Code System (MACCS) is used for licensing and research purposes. The Radiological Assessment and Consequence Analysis (RASCAL) code is used for incident response purposes. Each code uses a different, but somewhat analogous, simplified modeling approach (e.g., Gaussian plume modeling for MACCS and Gaussian puff modeling for RASCAL) to provide reasonable results in an acceptable computational time. Both codes are evolving to incorporate incremental increases in accuracy and flexibility. However, the fundamental underlying assumptions made during the original code development will not allow for revolutionary changes in their capabilities. Such changes could have important benefits with regard to the agency’s capability for performing realistic, best-estimate offsite consequence predictions, and the subsequent effect that this has on agency effectiveness. The FY 2009 work will focus on:

- The evaluation of available models (e.g., atmospheric transport and dispersion);
- The feasibility of implementing such models for licensing, research, and incident response functions;
- The benefits in realism and effectiveness that the models might provide; and
- The plan for development of tools that utilize the selected models.
2.4.5 Advanced Fabrication Techniques

Many new fabrication and construction techniques have been developed for shipbuilding, large civil structures, and general component manufacturing applications since the existing commercial nuclear fleet was completed. Several of these techniques are being considered, or have already been proposed, for subsequent construction of new LWR systems, structures, and components in the US. Others techniques may not be sufficiently mature until Generation IV and GNEP reactors are planned for construction. In many cases, these techniques hold the promise of greatly decreasing the construction schedule and relative cost compared to existing nuclear plants, while simultaneously improving quality by either minimizing the amount of site construction necessary or enhancing the component performance within the intended environment. Examples of construction advancements include steel-plate reinforced concrete structures; advanced concrete admixtures; high deposition rate welding; robotic welding; open-top construction; pipe bending vs. weld elbows; cable splices; and prefabrication, preassembly, and modularization. Component manufacturing advancements include polymeric, diffusion, and thermal spray coatings to increase wear resistance and corrosion prevention, improve surface finish and reduce fouling. Nano-coatings are also starting to be used in commercial applications. In concert with these new techniques, many industries (e.g., cement and materials) are moving from prescriptive mix design specifications to performance-based specifications.

However, it is currently not known if the newer, planned construction fabrication techniques and the move to performance-based specifications result in any potential performance implications that are unique to nuclear applications. Research will support staff reviews and allow guidance to be updated for utilizing these new techniques in new nuclear power plant construction. For example, high deposition rate welding could lead to fundamentally different weld microstructures that may be more susceptible to certain degradation mechanisms than current nuclear applications. A systematic evaluation of each technique and its performance in other industries with similar environments would be useful to identifying any concerns. Also, many of the newer component manufacturing technique are unproven in nuclear operational environments. These environments could degrade the anticipated performance gains as well as potentially cause unintended consequences if, for example, the coating substance breaks down.

In FY 2007 and 2008, the NRC will coordinate with both DOE and the nuclear industry to identify viable construction and component manufacturing techniques that are being considered for new reactor construction. Also, several promising techniques under development that could support later reactor construction will be identified. Preliminary identification of technical and regulatory issues will also be conducted. In FY 2009, a more systematic scoping study will be performed to more fully identify and prioritize technical issues that may have adverse nuclear safety ramifications. An evaluation of the performance of existing techniques under both relevant laboratory conditions and within existing commercial applications will be determined and the use of performance-based specifications will be assessed. A detailed research plan in this area will then be developed to identify and prioritize any technical issues that need to be addressed through subsequent research. For example, the performance of current advanced concrete materials, design and construction, fabrication, maintenance, and repair practices represents a specific area applicable to, and which needs to be understood, for new nuclear plant construction.
2.4.6 Extended In-Situ and Real-time Inspection & Monitoring Capabilities

The last 15 years has witnessed a revolution in manufacturing and processing techniques which has resulted in miniaturized, cost-effective, and advanced sensors capable of performing real-time monitoring of critical systems and components. These sensors have seen wide-spread use in automotive, chemical processing, aerospace, and a variety of other commercial industries. Many commercial nuclear and material facilities, however, rely on technology developed during initial construction in the 1970's and 80's. The possibility exists to greatly expand the monitoring and evaluation of critical systems and components both during normal and accident conditions to better inform subsequent automated and human responses. As part of the Department of Energy's Nuclear Energy Research Initiative (NERI), a number of these new sensors and monitoring and diagnostic methods have been investigated. Many of these sensors are designed to support needs of both advanced light water reactors and high temperature gas reactors. In FY 2009, work will be performed to identify, in concert with the nuclear industry, those sensors and techniques that have the most likely current commercial viability that also fill a critical inspection or monitoring need. Possible candidates include sensors to monitor:

- Real-time material degradation;
- In-situ characterization of residual stress;
- In-situ, real-time ground water and soil conditions to assess long-lived radionuclide and associated chemical species concentrations;
- In-situ characterization of fuel properties; and
- Severe accident conditions.

For severe accidents, examples of important parameters that warrant investigation of advanced monitoring techniques include core temperatures up to core failure and relocation, PWR vessel water levels, and steam generator water levels during loss-of-DC events. The use of miniature sensors released after the accident initiates will also be explored. Wireless communications technology is expected to be essential for many of these advanced sensors, and may be beneficial for providing local monitoring during an accident by both plant and NRC staff. A few of the most promising sensor candidates for industry use will be selected for characterization and evaluation, starting in FY 2009. The evaluation will focus on regulatory and safety aspects to allow staff to verify their reliability, accuracy, and acceptability for nuclear power plant service. A detailed research plan in this area will be completed at that time.

2.4.7 Offsite Mitigation Strategies

Plant improvements, procedures, training and offsite protective measures (emergency planning) have reduced the risk (i.e., public health consequences) from severe accidents at nuclear power plants. Even so, in the event of an accident with containment failure (even delayed failure) the potential consequences of a radioactive release are not trivial and mitigation of those releases would be a national priority. Technologies to utilize airborne mitigation systems are currently being developed to address environmental (including radiological aerosol) releases. The application of those mitigation systems to potential nuclear plant releases is a feasible approach as part of a federal response capability. Research in FY 2009 will focus on monitoring external activities related to the development of technologies (e.g., scavenging agents) for the capture and cleanup of radioactive material.
and the demonstration of their effectiveness for a variety of release and meteorological conditions. The program will also monitor the development of non-airborne, on-site delivery systems.

2.4.8 Nanotechnology for Nuclear Power Applications

Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. At the nanoscale, the physical, chemical, and biological properties of materials differ in fundamental and potentially valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties. The NRC has been participating in the National Nanotechnology Initiative (NNI), a cross-cutting nanotechnology research and development program among 25 Federal agencies. One principal NNI objective is to identify the applied research and development needed to rapidly transition scientific discoveries in nanoscale phenomena, process, and materials into commercial applications. In FY 2009, the NRC will continue to participate in the NNI to monitor developments having potential applications within the nuclear industry. If the NRC determines, in concert with input from the nuclear industry, that any of these applications are potentially viable, research plans will be developed to assess the potential regulatory applications of these technologies and develop acceptance criteria for their use. Possible candidate applications include

- Ultra-sensitive and selective sensor devices;
- Nanotechnology for the security of information technology systems, including identification of security threats, objectives, and requirements, as well as associated security metrics;
- Nonvolatile, radiation-hard, low-power, high-density, random access memory;
- Condition-based sensing for early potential fault detection; and
- Enhancement of containment or reactor coolant system heat transfer during accident conditions.

2.4.9 Fire Effects on Fiber Optic Cables

In recent years, NRC- and industry-sponsored research results have enabled considerable progress in the resolution of long-standing issues (e.g., the selection of post-fire, safe-shutdown electrical circuits for inspection) and the development of a risk-informed, performance-based option for the fire protection regulations for operating reactors. However, new challenges to current fire safety methods, tools, and data are provided by new technologies anticipated in future facility designs. In FY 2009, work will be initiated to develop and validate fire models addressing the effects of heat and smoke on fiber optic cables (which may replace conventional electrical cables in many control applications). This work will support assessments of the acceptability of fiber optics cables in new designs, as well as assessments of fire risk for these designs.

2.4.10 Risk Assessment for Advanced Reactor and Fuel Cycle Facilities

In recent years, much of the agency’s risk assessment research has been aimed at addressing needs (e.g., risk assessment quality guidance and standards, risk assessment software tools to support the evaluation of operational events and licensee submittals)
associated with the risk-informed regulation of current reactors. Potential issues associated with advanced reactor and fuel cycle facility designs (e.g., appropriate data for risk assessment models, methods and software to analyze passive safety systems; criteria for determining system success or failure, risk metrics and criteria for co-located facilities) challenge the current technology for performing risk assessment.

In FY 2009, research will involve: a) the initiation of an activity to identify and analyze potentially relevant empirical data (including non-nuclear industry data) and to evaluate the ability of the data to support risk assessments for advanced facilities; b) a scoping study to evaluate the ability of current human reliability analysis (HRA) methods to address emerging issues associated with future designs; and c) scoping studies addressing the costs and benefits of advanced quantitative risk assessment methods (including Binary Decision Diagrams, Bayesian Belief Nets, and simulation-based approaches).

**Empirical data for risk assessment** - Nuclear-industry specific empirical data suitable for benchmarking PRA models for key issues (e.g., human reliability, passive system reliability) are often sparse or non-existent, due to the rarity of failure events (for current systems) or the lack of operational experience (for systems under design). One approach to address the lack of data is to collect and analyze operational data from other industries. Such an approach needs to address potential technical concerns regarding the quality and applicability of the data, as well as potential organizational obstacles to the collection and use of data. In FY 2009, a project will be initiated to identify, collect, and analyze non-nuclear industry operational data relevant to the assessment of human performance during accidents. The analysis will provide qualitative information regarding observed failure mechanisms and the implications for risk assessment, and will evaluate the ability of the data to support quantitative reliability and risk estimates. If this effort is successful, future activities may be initiated to address other PRA data needs.

**HRA methods for advanced facilities** – In recognition of the potential risk significance of human errors and the uncertainty in predicting such errors, the NRC, industry, and other organizations have put considerable effort into the development of HRA methods suitable for use in risk assessments. As with other risk assessment research, the focus of this work has been on methods suitable for addressing potential accidents in current reactors. The applicability of these methods and supporting data to the design and operational characteristics of advanced reactor and fuel cycle facilities has not yet been determined. In FY 2009, a scoping study will be performed to identify key HRA-relevant issues associated with such facilities, and to evaluate the ability of current HRA methods and data to support risk assessments for these facilities.

**Advanced quantitative risk assessment methods** – In recent years, efforts by the risk assessment research community to develop improved methods to develop quantitative risk estimates (through improved numerical techniques and formal representations of causal relationships) have resulted in potentially promising approaches not yet embodied in most current risk assessments. A number of these approaches appear to have the capability to deal with issues relevant to quantitative risk assessments of advanced facilities (e.g., the treatment of passive safety systems, the treatment of process systems). In FY 2009, a number of scoping studies will be performed to assess the state, costs, and benefits of the following advanced quantitative risk assessment methods: Binary Decision Diagrams, Bayesian Belief Nets, and simulation-based risk assessment approaches.
2.4.11 Formal Decision Analysis Methods

Formal decision analysis methods have proven useful in fields ranging from medicine to finance by improving the rigor with which situational analysis and decisionmaking are conducted. The ACRS has suggested that the staff should increase its use of such methods, and the staff has done this in the development of guidance for performance-based regulation and for such applications as prioritization of research. However, the practical application of these methods can be complicated and resource intensive; research is needed to identify and overcome the barriers to more widespread use in the agency. In FY 2009, a pilot study will be performed (using currently available methods) to identify key implementation issues, and to develop recommendations for follow-on work. A detailed research plan in this area will be completed at that time.

2.5 Summary of Identified Research Activities

Table 1 provides a compilation of the various activities identified earlier in this chapter.

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