NUREG-1635
Vol. 1

Review and Evaluation of the Nuclear Regulatory Commission Safety Research Program

A Report to the U.S. Nuclear Regulatory Commission

Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

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IPE HRAs have little credibility (p. 37)

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Date Published: June 1998

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ABSTRACT

This report provides a response to the Commission's request for the Advisory Committee on Reactor Safeguards (ACRS) to review the NRC Safety Research Program. The Commission asked the ACRS to examine the need, scope, and balance of the Reactor Safety Research Program, among other things, in the Staff Requirements Memorandum of September 9, 1997. This report provides observations and recommendations on engineering the Safety Research Program, comments on specific research activities, waste management research at the NRC, and the continued need for the Nuclear Safety Research Review Committee (NSRRC) function.

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EXECUTIVE SUMMARY

The Advisory Committee on Reactor Safeguards (ACRS) review of the NRC Safety Research Program is presented in this report. This review was undertaken at the request of the Commission. In the Staff Requirements Memorandum (SRM) dated September 9, 1997, the Commission requested that the ACRS:

1. Examine the need, scope, and balance of the Reactor Safety Research Program.

2. Examine how the Office of Research is positioned for the changing environment.

3. Examine how well the Office of Research anticipates research needs.

4. Take on active role in reviewing ongoing Research Program initiatives, such as those discussed in SECY-97-075 and in SECY-97-167.

5. Recommend whether the Nuclear Safety Research Review Committee (NSRRC) function is still needed.

The ACRS responses to these requests except for the fourth are presented here. Review of research program initiatives is viewed as an ongoing obligation. The ACRS will provide responses as initiatives arise.

The Advisory Committee on Nuclear Waste (ACNW) volunteered to assist the ACRS by providing a review of waste management research activities managed by the Office of Nuclear Regulatory Research (RES) and by the Office of Nuclear Material Safety and Safeguards (NMSS).

Analyses of the directions from the Commission are presented in Chapter I of the report. The analyses include the ACRS understanding of the terms "scope" and "balance." Changes in the environment that the ACRS believes could affect the nuclear industry and the NRC are listed in this Chapter.

Directions that have been given to the Research Program by the Commission were analyzed to define three functions for the NRC research:

- Provide the technical bases for regulatory activities of the line organizations of the NRC and policy initiatives of the Commission.

- Conduct anticipatory research to enable the Commission and line organizations to address issues that are anticipated to arise.

- Maintain technical capabilities necessary for the Commission and line organizations to address issues that arise in the future.

The top-level requirement for the NRC Research Program is to focus on the issues of most risk and regulatory significance.

Chapter II provides a summary description of the role of research at the NRC and current research programs. Research has been essential to establish firm technical foundations for the NRC regulations. The existence of technically based foundations provided by research is responsible for the considerable respect which other countries accord to NRC regulations. ACRS is convinced that research will continue to be essential to the NRC as changes occur in the nuclear industry, applicable technologies, and even in the NRC itself.

Chapter III presents ACRS observations and recommendations concerning the ways NRC identifies research needs and plans the research programs. It is observed that there is no agreement throughout the agency that research results are needed to conduct the NRC mission adequately. Line organizations often do not depend on research results to meet their programmatic obligations. As a consequence, the NRC does not use research optimally and risks the imposition of unnecessary burdens on licensees or the possibility of inadequate levels of safety in its regulation. Research is funded by an entitlement process, but the funds are diverted to meet agency needs considered to be of higher priority. RES is not positioned to compete with other NRC Offices for resources.

The NRC has not adopted a systematic process for designing the research programs so that there is a clear relation to mission needs of the agency and so that there are requirements concerning scope, accuracy and urgency, and specifications to judge when research has met its objectives and should be terminated. Other government agencies and private institutions have found it useful to adopt formal systems for engineering their research programs. Such systems do enforce a close tie between a research activity and a mission need that can be the basis for rational allocation of resources to research. ACRS makes the following recommendation:

Recommendation:

> The NRC should adopt a systematic framework for the design and engineering of its Research Program that enforces a close tie between research activities and agency needs, assesses the value of the results to be achieved by the research, defines the requirements of the research, specifies the functions of the research activities, and defines the urgency of the results.

Research programs are often initiated by adopting and quickly committing to engineering and scientific approaches that are assumed to work and are assumed to be adequate. Assumed solutions to engineering issues are risky in technological areas that are complicated and not thoroughly developed. The NRC will face issues of this nature more often in the coming years. ACRS, therefore, recommends:

Recommendation:

> The NRC needs to adopt a practice of scrutable comparison of alternatives in addressing technical issues that require innovation in fields that are not well established.

A key role for research is to anticipate future needs of the line organizations of the NRC. Yet, research relies primarily on the intuition and knowledge of its managers to anticipate these future needs. There is no established program that identifies those likely proposals from licensees that cannot be handled effectively by line organizations with their tools, databases, and procedures. RES relies on the user-need process to identify line organization research needs. This does not provide an adequate depiction of research needs. ACRS recommends:

Recommendation:

> The NRC should devise a process for identifying and prioritizing research needs that encompasses considerations of long-term benefits as well as short-term user needs. The user-need process itself should be revised so that it better represents the full range of research needed by line organizations. In addition, the NRC should more formally identify likely industry initiatives and determine if these will require research before the agency can respond with effective and minimally intrusive regulation.

The Commission has asked that research focus on the most risk-significant activities. Currently, the NRC justifies research activities with only qualitative, subjective assessments of risk significance. ACRS recommends:

Recommendation:

> The NRC needs to develop its in-house risk assessment capability to the extent that it can be readily used throughout the agency. The in-house capability can be used to assess requests and to improve the planning of research.

The NRC is becoming more committed to the use of probabilistic risk assessments (PRAs). The Office for Analysis and Evaluation of Operational Data (AEOD) collects and analyzes operational events and data that could be used to validate aspects of PRAs. These studies are not being optimally used. ACRS recommends:

Recommendation:

> The development of PRA methods should be better supported by the activities of AEOD with the aim of validating and improving PRA methods and results.

Chapter IV of the report provides ACRS comments and recommendations on the following current research activities:

- Probabilistic risk assessment
- Human factors and human performance research
- Management and organizational factors research
- Fire safety research
- Severe accident research and consequence analysis
- Containment integrity
- Individual Plant Examinations (IPEs)/Individual Plant Examination of External Events (IPEEEs) follow-up and PRA standards
- Thermal hydraulics research
- Advanced instrumentation and control
- Reactor fuels research
- Reactor pressure vessel integrity
- Environmentally assisted cracking and degradation of steam generator tubing
- Aging research

Chapter V includes ACNW observations and recommendations on the waste management research. The ACNW provides comments on each of 10 key technical issues (KTIs) addressed in the waste management research which is managed by NMSS. The ACNW concludes it is important that the NMSS research maintain an unquestioned stature in the national and international high-level waste communities. The ACNW recommends the following:

Recommendation:

> NMSS should continue to use results from total systems performance assessment to guide the technical work contracted to the Center for Nuclear Waste Regulatory Analyses (CNWRA). This approach contributes to a rational plan to focus on important issues. NMSS should maintain procedures with CNWRA that allow for a great deal of flexibility in the definition of tasks. Reliance on contracts outside CNWRA can enhance flexibility. It is essential for well-known scientists and engineers who have an outstanding reputation in the waste field to assist NRC in the resolution of waste management problems.

ACNW also examined waste management research which is managed by RES and made the following recommendation:

Recommendation:

A formal organizational structure that identifies and prioritizes research needs and subjects these needs to peer review should be put in place to ensure close coordination and collaboration between the developers of research results and the users of those results.

Chapter VI includes response to the question posed by the Commission concerning the continued need for the function performed in the past by the NSRRC. ACRS recommends:

Recommendation:

The NRC no longer needs most of the functions of the NSRRC. The Commission does need a Research Program and needs to ensure that this Program conforms to the NRC philosophy of research and to directions given to the Program by the Commission. Review of the need, scope, and technical content of research activities can be fulfilled by the ACRS, supplemented by the Research Effectiveness Review Board's oversight of the Research Program and by the peer-review practices adopted by RES.

I. REVIEW DEFINITION

A. The Charge to the ACRS

The Advisory Committee on Reactor Safeguards (ACRS) throughout its existence has reviewed the Reactor Safety Research Program at the NRC. Review has been essential for the ACRS to carry out its statutory mandate to report to Congress annually on the Reactor Safety Research Program [1]. Episodic reviews of individual research activities have been necessary for the ACRS to provide reliable technical advice to the Commission on specific regulatory and safety issues.

Comprehensive, structured review of all the NRC research activities by the ACRS has atrophied over the last decade. During this period, this review function was assumed by the Nuclear Safety Research Review Committee (NSRRC) which was established to advise the Director of the NRC Office of Nuclear Regulatory Research (RES) [2]. Establishment of the NSRRC was in response to a review of research management conducted by a Committee of the National Research Council [3]. Still, the ACRS reviewed and discussed with the NRC staff and with the Commission individual research activities that were focused on topics of specific regulatory interest.

In 1997, the RES staff recommended that the review of the Research Program by the NSRRC was no longer needed. The staff felt that any beneficial functions of this review of the Research Program as a whole could be reassumed by the ACRS [4]. Shortly thereafter, the Commission charged the ACRS to conduct a thorough review of the NRC Research Program [5]. The initial charge to the ACRS included five elements that are described individually below. Following the written charge to the ACRS to review the Research Program, the ACRS received oral questions related to the Research Program from Commissioners. These questions have been interpreted by the ACRS to be additional requirements for its review of the NRC Research Program. These additional requirements are listed in item 6 of this Chapter.

1. Examine the need, scope, and balance of the Reactor Safety Research Program

The charge to the ACRS to examine the Research Program in terms of need, scope, and balance requires some interpretation. The ACRS has interpreted the term "need" to mean that the Research Program should:

- support current Commission initiatives,
- provide the technical basis for future, anticipated regulatory actions, and
- maintain essential technical capabilities that can reasonably be anticipated as being needed for future regulatory activities.

The ACRS has interpreted the term "scope" to mean that research activities should span, to the extent practicable, the range of Commission activities and still provide sufficient depth to ensure that optimal candidate solutions to regulatory issues are developed. The term "balance" has been interpreted to mean that the Research Program should have an appropriate mix of activities dealing with current issues and future, or emerging issues. "Balance" could also mean that the Research Program has an appropriate mix of activities both to support and to challenge the existing regulatory structure. Balance of this type has been endorsed in the past by reviewers of the NRC Research Program [3]. While the ACRS did not detect consideration of this type of balance in the directions given to the Research Program or in the planning of the research activities, the most prominent, growing initiative in regulation, the emphasis on risk-informed, performance-based regulation, is, in fact, a direct challenge to the traditional approach to regulation.

2. **Examine how the Office of Research is positioned for the changing environment**

To understand how the Office of Research is positioned for the changing environment, it was necessary for the ACRS to specify for itself the changes in the environment that could reasonably be expected to affect the NRC in general and the Research Program in particular. The ACRS believes that the public expectation for ever greater protection by its public institutions is an ongoing trend that has for several years had an effect on all regulatory agencies including the NRC. In addition, ACRS feels changes are occurring that are likely to affect the NRC and the regulation of nuclear power. Among these changes are:

- economic deregulation of electrical energy production requiring higher productivity from existing nuclear power plants,
- aging of the existing fleet of nuclear power plants,
- premature retirement of nuclear facilities prior to expiration of their licenses,
- renewal of some nuclear power plant licenses,
- maturation of probabilistic risk assessment (PRA) technologies,
- Congressional actions to mandate performance-based regulation and more rational regulation in terms of realistic measures of risk,
- continued improvements in the average performance of licensees,
- continued efforts by the nuclear industry to develop consensus standards and uniform approaches to the safe operation of nuclear power plants,
- continued efforts by the nuclear industry, including the cost of regulation,

- emergence of new technologies such as digital electronics and software that could replace and improve upon technologies available at the time plants were designed and constructed,

- continued pressure exerted by the Commission on the NRC staff to incorporate risk considerations into the regulatory process where it is supported by the current state of the art in PRA and to consider performance-based measures where practical,

- more opportunities for the Commission to endorse consensus industrial standards as encouraged by Public Law 104-113 [6] in place of regulations and guidance developed by its staff, and

- declining NRC resources for inspecting and monitoring licensee activities.

The ACRS attached particular significance to economic deregulation of electrical energy production with respect to the need for research. Already, the nuclear industry has made moves toward greater productivity while reducing costs in ways not anticipated when the existing regulations were formulated. These activities include:

- extending the burnup of reactor fuels,
- proposing power upgrades for some plants,
- expanding online maintenance activities, and
- improving the planning and execution of shutdown activities.

There are indications of further efforts by the nuclear industry to improve the economic performance of nuclear power plants. Of particular interest with respect to safety may be any measures taken to reduce further the manpower involved in the engineering, maintenance, support services, and operations of power plants.

The ACRS also attaches significance to the need for the NRC to achieve greater efficiency in the processing of licensee applications. The means to achieve this efficiency have increased with the development of procedures that allow licensees to apply for risk-informed alternatives to existing requirements [7]. It also appears that the NRC will need to achieve greater efficiency in the inspection and monitoring of licensee activities. The development of improved tools and methods to achieve efficiency is, of course, a classic mission of a research program for any institution.

The ACRS views the current Commission effort to improve its regulations based on quantitative risk assessment to be a noble experiment that has ramifications within the Federal regulatory community well beyond the regulation of nuclear power. The ACRS has a long history of supporting the extensive use of quantitative risk assessment. It is essential that the research be done to provide adequate technical support for initiatives undertaken in this direction of improved, rational regulation based on quantitative risk assessment.

3. **Examine how well the Office of Research anticipates research needs**

The ACRS interpreted the charge to "examine how well the Office of Research anticipates research needs" to include anticipation of future needs and anticipation of current needs of the line organizations for research support in the execution of ongoing agency initiatives and Staff Action Plans. The Staff Action Plans currently being pursued by the NRC staff that might benefit from research support are listed in Table I-1. Generic communications and compliance issues that are being handled by the NRC staff and that might require research support are listed in Table I-2.

4. **Take an active role in reviewing ongoing Research Program initiatives such as those discussed in SECY-97-075 and in SECY-97-167**

The initiatives of the Research Program discussed in SECY-97-075 [8] are to define areas of core competency. The 39 candidate areas of core competency identified by the RES staff are listed in Table I-3. The ACRS interpreted this charge to participate in the definition of core competencies to be an ongoing task and chose to not explicitly address this charge in this report. Rather, the ACRS will report its activities and reviews of research program initiatives in later communications to the Commission, once the RES staff has had the opportunity to refine its ideas and approaches. The initiatives in SECY-97-167 [9] deal with the movement of the responsibility for developing rules and regulations from RES to the line organizations. The ACRS views this as an internal management issue and will adopt a performance-based strategy for reviewing these changes.

5. **Recommend whether the NSRRC function is still needed**

The ACRS has interpreted the question concerning the need for the NSRRC function to encompass the need for the function as it was performed in the past, the need for the function as conceived when the NSRRC was originally recommended to the NRC, and the ACRS view of the need of an analogous function at the present time.

6. **Additional Requirements**

Questions concerning the Research Program posed orally by the Commissioners have been interpreted as additional requirements for the ACRS review of the Research Program. The Commissioners have asked the ACRS to address:

- the programmatic issues of research at the NRC,
- suitable criteria for terminating research programs,
- the rationale for the high priority for participating in international cooperative research programs,

- the staff plans for using information gained from the individual plant examinations (IPEs) and individual plant examination of external events (IPEEEs),

- methods for prioritizing research activities,

- risk-informed applications of research results,

- plant aging research program, environmentally assisted cracking and steam generator tube integrity,

- safety issues of electrical components, and

- research needs in connection with piping integrity.

7. Topics Excluded from the ACRS Review of the Research Program

Items A.1 through A.6 above list the topics addressed by the ACRS review of the NRC Research Program. It is important, however, to specify topics explicitly excluded from the review. The ACRS did not address issues of an exclusively management and policy character. That is, the ACRS review did not address issues of the allocation of resources to specific research activities. The ACRS did not address issues concerning the placement of research contracts. The ACRS does note that the Commission has directed the staff to consolidate the number of contractors used to conduct research on behalf of the agency. The Commission has also directed the staff to find innovative ways to gain greater involvement in the agency's Research Program by researchers from academic institutions. The ACRS did not attempt to review efforts in these regards, nor did the ACRS attempt to formulate advice to the Commission on these matters.

B. Directions to the NRC Research Program

Directions to the NRC Research Program have been provided by the Commission [**10**] and are listed in the documentation for Direction Setting Issue 22 [**11**]. These directives are listed also in the Strategic Plan for the NRC [**12**]. The ACRS has identified three top-level functions for the Research Program from these sources:

Function 1:

Provide the technical bases for regulatory activities of the NRC line organizations and for the policy initiatives of the Commission.

Function 2:

Conduct anticipatory research to enable the Commission and line organizations to address issues that are anticipated to arise.

Function 3:

Maintain technical capabilities necessary for the Commission and line organizations to address issues that arise in the future.

The ACRS has been able to identify one top-level, quantifiable requirement for the NRC Research Program:

Top-level Requirement:

The Research Program should focus on the issues of most risk and regulatory significance.

In addition to the obvious constraints of budgetary and manpower allocations, the Research Program is also subject to the unquantified constraint that it provide the necessary support to the line organizations.

The Commission has provided special requirements for the severe accident research program [13]. These include:

- establish clear criteria for bringing the remaining issues to closure,
- prepare a prioritized list based on risk and other considerations describing the work required for closure of the remaining severe accident issues, and
- provide an indication of the degree of closure and whether there is sufficient understanding to manage the issues.

C. ACRS Review of Research Activities

To conduct its review of the NRC research activities, the ACRS Subcommittee on Safety Research Program met with representatives of RES, NRR, and AEOD on November 4-5, 1997 [14]. At this meeting, presentations were made by representatives of the Electric Power Research Institute and the Nuclear Energy Institute on industry-sponsored and managed research programs. The objective of this Subcommittee meeting was to collect data and develop draft positions for review by the ACRS. At the time of the meeting, the NRC Research Program had just sustained additional budget reductions and was experiencing some reorganization. The requirements of the Government Performance and Results Act had only recently been imposed on the Research Program. Consequently, most of the plans for research were not firmly established.

The ACRS met with representatives of RES on March 5-7, 1998 to discuss the Research Program in detail [15]. Several of the topical Subcommittees of the ACRS met with the RES staff to discuss aspects of the overall Research Program.

D. ACNW Review of Waste Management Research Activities

The Advisory Committee on Nuclear Waste (ACNW) volunteered to assist the ACRS by reviewing research activities under way at the NRC in the area of waste management. The ACNW reviewed work on waste management being managed by RES and NMSS, as well as work by the Center for Nuclear Waste Regulatory Analyses (CNWRA), a federally funded research and development center that provides independent technical assistance to the NRC. The ACNW elected to examine technical assistance work by CNWRA in connection with the Yucca Mountain high-level waste disposal project in addition to basic research work sponsored by the NRC.

The ACNW met with RES staff on October 22, 1997 **[16]** and on April 21, 1998 **[17]** to discuss the RES program on radionuclide transport and decommissioning. The ACNW also had presentations on waste management research by representatives of the Electric Power Research Institute and the Environmental Waste Management Program of the Department of Energy on March 24, 1998 **[18]**.

Table I-1. Current Staff Action Plans That Could Require Research Support

Accident Management Implementation
Boiling Water Reactor Internals
Core Performance
Dry Cask Storage
Environmental Qualification
Environmental Standard Review Plan Revision
Extended Power Uprate
Fire Protection
Grid Reliability
Heavy Load Control and Crane Issues
High Burnup Fuel
Industry Deregulation and Utility Restructuring
Modification of 10 CFR 50.59
New Source Term for Operating Reactors
PRA Implementation Plan
Steam Generators
Wolf Creek Draindown Event

Table I-2. Generic Communications and Compliance Issues that Might Require Research Support

Augmented Inspection for Small Diameter Class 1 Piping in PWR HPI System (GL)
Boron Precipitation in B&W Reactors
BWR Containment Bypass Flow during Purging
Charging/Discharging of Safety Related Round Batteries
Clarification of NUREG/CR-5055, "Atmospheric Diffusion for Control Room Habitability Assessments"
Cold Weather Operations Experience
Containment Recirculation Spray & Quench Spray Piping Outside Design Basis
Containment Structure Settlement due to Degradation of Porous Concrete (GL)
Control Rod Insertion Problem
Cool Down Following Reactor Shutdown after ATWS Event
Criticality Analysis of Fuel Storage
Deficiency of Electric Cable Connections
Degradation of ECC Recirculation due to Foreign Material in the Containment (GL)
Dose Calculations for an Array of Casks on a Pad
Environmental Qualification Deficiency for Cables and Penetration Pigtails
Equipment Operability & Containment Integrity during Pipe Break in Circulating Water System
Errors in Containment Code Analysis
Failure of Type DS-206 Circuit Breakers
Fire Protection Actuation System
Fuel Gap Reopening
Hardened or Contaminated Lubricants Cause Metal Clad Circuit Breaker Failure
Implementation of Appendix VIII of Section XI of the ASME Boiler and Pressure Vessel Code (GL)
Induction Heat Stress Improvements for Stainless Steel Piping
Interpretation of HEPA & Charcoal Filter Testing Frequency
Issues Identified during Recent NRC Design Inspections
Laboratory Testing of Nuclear Grade Activated Charcoal (GL)
LPSI Pump Mission Times
Main Control Room Envelope Unfiltered Inleakage
Modification of the Requirements for Post-Accident Sampling (GL)
Operability Requirements For Dual Function Valves (GL)
Post-Fire Safe Shutdown Circuit Analysis (GL)
Quality Assurance of Electronic Records (GL)
RCIC Governor Valve Stem Binding
RCS Chemistry Effects on Flaw Growth Estimates (GL)
Reactor Coolant Inventory Loss While Shutdown (GL)
Reactor Water Cleanup System Study

Reference Leg and Condensate Pots Causing Level Errors
Reversed Current Transformer Leads
Seismic Capability of Thermolag Panels (GL)
Set Point Drift in ITT Barton Gauge Pressure Transmitters
Site Specific Vulnerabilities due to Gas Accumulation during Shutdown
Slow Scram Solenoid Pilot Valves
Steam Generator Tube Integrity (GL)
Technical Specification Discovered not to be Sufficient to Assure Plant Safety (GL)
Turbine Valve Failure at Vandellos

Table I-3. Candidate Areas of Core Competency

Plant transient analysis
Code development, validation, and maintenance

Core transient analysis
Code development, validation, and maintenance
Fuel design and behavior

Digital I&C systems performance
Software and hardware reliability and qualification

Human reliability
Training, staffing, and qualifications
Human-system interface and procedures
Organizational performance
Fire protection and safety

Radiation damage/annealing
NDE Procedures and techniques
Fracture mechanics
Environmentally assisted cracking
Structural integrity
Behavior of structures and components in response to seismic and external events
Steam generator integrity

Mechanical
Electrical
Piping

Fuel-coolant interactions
Core degradation
Core concrete interaction and debris coolability
Hydrogen distribution and combustion
Lower head integrity
Fission product chemistry, release and transport
Code development, validation, and maintenance

Methods development for assessment
Regulatory analyses
Guidance and standards development
Decisionmaking under uncertainty

Radiation dosimetry
Radiation effects (relationship between dose and risk)

Fuel fabrication
Radionuclide transport and behavior in the environment
Spent fuel storage
Decommissioning and decontamination

II. RESEARCH AT THE NRC

A. Role of Research at the NRC

The Office of Nuclear Regulatory Research (RES) is a statutory Office that has been a part of the NRC since the agency was established. Research Program has served the agency well for over 25 years. There is no question that the depth and quality of the NRC Research Program have been essential elements for the development of a regulatory framework that established a safe nuclear industry in the USA and established the USA as an international leader in the safe regulation of nuclear power and materials. This preeminent position of international leadership is exemplified by the NRC development of probabilistic risk assessment (PRA) methodology, technology to ensure pressure vessel integrity, leak-before-break (LBB) techniques, and severe accident analysis--all products of the NRC research and all key elements in the safe use of nuclear power.

In addition, the Research Program has developed, and continues to upgrade and maintain, the infrastructure that provides the agency with the analytical tools, data, and expertise to make independent assessments of safety issues and licensee proposals.

The NRC Research Program has had an impact on setting the agenda for nuclear regulation that goes beyond just technical foundations and databases. The influence of the results of research penetrates to the way the line organizations of the NRC do their work including monitoring, inspection, and enforcement. Today, this agenda for regulation is being established in terms of quantitative analysis of risk. Calls for the move to risk-informed regulation and more rational bases of regulation are heard frequently for all Federal regulatory functions. The NRC is well ahead of other agencies in making this transition. The technology that makes this possible is a product of the NRC research. The crude initial concepts of PRA were first borrowed from the aeronautics industry. Over the years, the NRC has developed, tested, refined, and applied this technology. The impact of the PRA technology is shown not only by the evolutions taking place in the NRC regulatory agenda, but also by the enthusiasm with which PRA has been espoused by the nuclear industry and the role PRA is beginning to have in the regulation of nuclear power elsewhere in the world. With continued development of PRA, which will require continued research, the technology is positioned to focus the resources of the NRC for all of its tasks on those factors most important to continued nuclear safety. This modernization of regulations is already taking place based on results and insights that have come from research done in the past. The outstanding recent examples of this include development of the technical bases for:

- risk-informed technical specifications,
- risk-informed inservice testing and inspection of safety systems,
- general guidance for risk-informed changes to the licensing basis, and
- graded quality assurance, to a limited extent.

The shift to more risk-informed regulation makes possible increased safety and reduced costs to the nuclear industry. Recent information from a licensee evaluating the application of risk-informed inservice inspection to its plant indicates a cost savings of about $100,000 per year at each nuclear power plant, in addition to reduced radiation exposures to plant personnel. The ACRS has been told by one licensee that implementing a graded quality assurance program would save over $1,000,000 per year.

Research has been essential in bringing improved technical sophistication to the regulatory arena. The replacement of crude concepts of catastrophic pipe ruptures by the LBB concept is an example of this type of research product. More recently, the replacement of simplistic accident source terms with a revised accident source term and the revision of 10 CFR Part 100 firmly founded on research results are additional examples of improved technical sophistication brought to regulation by research. This increased sophistication has included establishing that timing is an important parameter characterizing accidental releases of radionuclides and offers the promise for relief from overly restrictive regulatory constraints on emergency equipment availability.

Research has also been essential for coping with the effects of aging of the nuclear power facilities and the appearance of unexpected vulnerabilities of these facilities. The contribution made by the NRC research to the development of screening criteria for PWR vulnerability to pressurized thermal shock is an example of this type of research product. Studies now under way of stress corrosion cracking of PWR steam generator tubes and radiation-assisted stress corrosion cracking of reactor internal structures are examples of research needed when vulnerabilities are encountered that were not anticipated when regulations were written.

In the course of conducting a research program, RES creates a technical infrastructure involving its own staff and contractors. Line organizations have found that they can tap this pool of knowledgeable manpower to get very cost-effective assistance for regulatory activities. This assistance to the line organizations would not be available without the substantial investments from the Research Program. This is, then, a derivative benefit of research that has often been unappreciated despite valuable contributions to major activities of the line organizations, including recent work on certification of the AP600 design.

There can be no question that research will be an essential function of the NRC in the future. Research will be needed because of changes taking place in the NRC and the nuclear industry, as well as improvements in applicable technologies. The industry is changing because of the aging of the nuclear facilities and because of economic deregulation. The changes the industry has to make will have an effect on safety and will require responses from the NRC. Three important examples of this are the extended burnup of reactor fuel, power upgrades in some plants, and much shortened outage times in all nuclear power plants. Technology changes will also occur and inevitably be adopted by the nuclear industry. The development of digital electronic systems for the instrumentation and control of nuclear power plants is an example of such technological changes that is already on the NRC agenda. It is an important example because it requires research to provide line organizations with substantially revised tools for the review and analysis of the safety implications of the use of digital instrumentation and control systems.

Finally, and of great importance, the NRC is changing. The policy to use insights from quantitative risk assessment wherever possible in regulatory activities is a change in the agency that receives significant attention throughout this report. This change is but an example of society's imperative that its institutions do their jobs better, faster, and cheaper. This social imperative will require a strong research function at the NRC to produce modern tools, data, and procedures to expedite and improve the NRC's regulatory activities.

The current research activities sponsored by the NRC are described in this Chapter. Most of the research activities at the NRC are managed by RES and these activities are discussed in Section B of this Chapter. The ACRS and the ACNW believe strongly that there are activities in other organizations within the NRC that can legitimately be termed as research. Research activities managed by the Office for Analysis and Evaluation of Operational Data (AEOD) and by the Office of Nuclear Material Safety and Safeguards (NMSS) are discussed in Sections C and D of this Chapter.

B. Research Managed by RES

Research activities managed by RES are distributed among the following four research programs:

- Reactor and Plant Performance Program
- Reactor Materials and Component Behavior Research Program
- Materials Research and Regulation Development Program
- Decommissioning Research and Regulation Development Program

The research activities in these various programs are listed in Tables II-1 to II-4, respectively. Note that these programs include other support activities that were not addressed in the ACRS review of the Research Program. Each of the activities listed in the tables includes a number of projects. Often the individual projects are not clearly related to the title of the program. But, equally often the projects have apparent relationships to agency needs. The projects that make up the activities listed in Tables II-1 to II-4 are listed in Appendix A.

The Reactor Safety Research Program activities are differently grouped into the following 14 categories for the purposes of planning and prioritization:

1. Mechanical/Electrical/Piping Components
2. Steam Generator Integrity
3. Environmentally Assisted Cracking of Components
4. Reactor Vessel Integrity
5. Containment Integrity

6. Severe Accidents
7. Structural/Civil Engineering
8. Nondestructive Examination Procedures
9. Human Factors
10. Advanced Instrumentation and Control
11. Fuel Behavior
12. Thermal Hydraulics & Physics
13. Probabilistic Risk Analysis
14. IPE & IPEEE Reviews

At present, there is no agency-wide agreement that research is needed in each of these 14 areas if the NRC is to carry out its mission. Although much of the research is based on "user need" requests from line organizations, these requests do not amount to declarations that regulatory actions depend on the availability of research results of prescribed detail, accuracy, and urgency. Whereas managers of each research project can articulate a mission need of the agency that is addressed by a given research activity, this need is seldom manifest in the planning of activities of the line organizations or in the plans by the Commission itself. As a result, resource commitments to research activities cannot be allocated based on an analysis of mission need. Consequently, RES finds it must resort to a prioritization process to apportion resources to the research areas from the allocation made by the Commission.

Prioritization is being attempted now based on multiple criteria and multiple evaluators drawn from both RES and from the line organizations. The Analytic Hierarchy Process, which has been designed for individual decisionmaking rather than group decisionmaking, is the formal structure for the prioritization. This Process appears to suffer from all of the well-known deficiencies and inconsistencies of group decisionmaking processes. It can, however, provide insights into an individual manager's preferences that would be useful in a deliberative process that leads to prioritization. Criteria used in the prioritization are:

- **Regulatory Significance**

  Will the work be of use to, or vital to, enactment of various sorts of regulatory guidance or to the issuance of new or modified industry codes and standards?

- **Success Likelihood**

  How likely is the work to be successful in resolving issues of concern?

- **Safety Significance**

  What is the relevance of the work to current or projected safety issues?

Only subjective, qualitative evaluations of research activities are made in terms of these criteria. There is no attempt to make use of quantitative methods to assess risk significance. Consistency of assessments is attempted only through discussions by the evaluators. Bases for the evaluations are not scrutable.

Management of the Research Program has found results of this prioritization to be unsatisfactory to date.

Another aspect of the definition of research activities has been the identification of core research capabilities needed to support current and foreseeable regulatory activities. Clear definitions of what is meant by "current and foreseeable regulatory activities" have not been provided to support this effort to define research topics for the NRC. The time horizon used to define foreseeable regulatory activities was not long. Certainly, radical changes or alterations of the NRC mission, such as regulation of Department of Energy activities, were explicitly excluded from consideration of the assessment.

The 14 criteria used to assess core capabilities are listed in Table II-5. Again, evaluations were done by subjective, qualitative methods. Quantitative measures of the risk significance were not explicitly included in the evaluations. Consistency of the assessments of various items in the list of candidate core competencies is questionable.

The 29 core capabilities defined by this process are shown in Table II-6. Two of the candidate core capabilities shown in Table I-3 were eliminated and several of the candidate areas were combined with others. One capability was added to make up the final list. The staff has divided the core capabilities into those now well-supported and those in "sunset" because there are no sufficient user-need requests associated with the areas and funding has fallen below the minimum thought necessary to support a viable core capability. The identification of these areas as "sunset" does not necessarily mean that they are unimportant.

C. Research Managed by AEOD

Activities managed by AEOD, which the ACRS believes are research and essential support activities for other NRC research programs, are listed in Table II-7.

D. Waste Management Research

Waste management research under way within RES is categorized in terms of "elements" which are:

Element 1. Characterization of Environmental Contaminants
Element 2. Transport Processes
Element 3. Containment, interdiction and stabilization

Element 4. Performance Assessment

The focus of much of the waste management work managed by NMSS is on the proposed Yucca Mountain repository for high-level nuclear waste. The waste management research has been structured according to 10 key technical issues (KTIs) which are shown in Table II-8.

Table II-1. Research Activities in the Reactor and Plant Performance Program

Thermal Hydraulics/Reactor Physics

Advanced Instrumentation and Control

Human Factors and Organizational Performance

Severe Accidents

Reactor Probabilistic Risk Analysis

Fuel Behavior

IPE/IPEEE Reviews

Reactor Radiation Protection

Educational Grants*

Technical Information Exchange*

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* Not considered in the ACRS review of the Research Program.

Table II-2. Research Activities in the Reactor Materials and Component Behavior Research Program

Reactor Vessel Integrity
Environmentally Assisted Cracking in LWRs
NDE Procedures and Technologies
Steam Generator Integrity
Mechanical/Electrical Components and Piping
Containment Integrity and Structural Aging
Structural and Civil Engineering
Generic Safety Issue Resolution

Table II-3. Research Activities in the Materials Research and Regulation Development Program

Materials Probabilistic Risk Analysis
Materials Structural and Civil Engineering
Materials Radiation Protection

Table II-4. Research Activities in the Decommissioning Research and Regulation Development Program

Radionuclide Transport and Behavior in the Environment
Decommissioning and Environmental Protection

Table II-5. Criteria for Core Capability Assessment

- Provide the technical basis for agency decisions on regulatory or safety issues stemming from events and requests.

  1. Frequency of occurrence.
  2. Safety or regulatory significance of occurrence.

- Provide the technical basis for agency decisions on regulatory or safety issues from new or evolving technologies and research results.

  3. Likelihood of change
  4. Safety or regulatory significance of changes.

- Develop, maintain, and apply analytic tools and databases.

  5. Breadth and frequency of application.
  6. Degree of improvement necessary.
  7. Value to the regulatory process.
  8. Need to improve requirements or guidance.
  9. Need to support new NRC regulatory initiatives.

- Improve technical basis of regulation through involvement with domestic and foreign organizations.

  10. NRC's commitment.
  11. Value of contribution to regulatory program.
  12. Leverage factor for NRC resources.

- Respond to oversight groups.

  13. Likelihood of occurrence
  14. Complexity and significance of subject matter.

Table II-6. Core Capabilities

ACTIVE AREAS

- Thermal hydraulics - plant transient analysis
- Reactor physics
- Thermal hydraulics code development, validation and maintenance
- Fuel behavior
- Digital I&C systems
- Organizational performance

- Fire protection and safety
- Radiation damage
- Fracture mechanics
- Containment integrity and structural aging
- Steam generator tube integrity

- Electrical
- Piping fracture
- Structural and civil engineering
- Lower head integrity
- PRA guidance development, risk analysis tools and decisionmaking under uncertainty

- Radiation dosimetry research
- Radiation effects research
- Radionuclide transport and decommissioning

SUNSET AREAS

- Human performance
- NDE procedures and techniques
- Environmentally assisted cracking
- Fuel-coolant interactions and debris coolability

- Hydrogen distribution and combustion
- Fission product chemistry, releases and transport
- Severe accident code development
- PRA methods development for assessment

- Materials criticality safety
- Mechanical

Table II-7. Activities Managed by AEOD that are Research

- Nuclear materials operational data analysis, collection and dissemination.

- Risk and reliability assessment
  - Conduct system reliability studies to gather risk insights into the performance of important safety systems

- Analysis and evaluation of operating reactor experience
  - independent review of the operating experience reported in licensee event reports (LERs), Immediate Notifications, daily reports, etc.
  - long-term, detailed analysis of the safety-significant issues to identify root causes and corrective actions

- Operating Reactor Event Database
  - integrated database to assess regulatory effectiveness
  - collect reliability and availability data to gather risk insights into plant-specific and industry-wide safety performance
  - common-cause database

Table II-8. Research Activities Managed by NMSS - Key Technical Issues

- Igneous Activity
- Structural Deformation and Seismicity
- Evolution of the Near-Field Environment
- Thermal Effects on Flow
- Total Performance Assessment and Integration
- Radionuclide Transport
- Activities Related to the EPA Standard and the NRC Rule
  (Activities Related to Development of the EPA Yucca Mountain Standard)
- Unsaturated and Saturated Flow Under Isothermal Conditions
- Repository Design and Thermal Mechanical Effects
- Container Life and Source Term

III. OBSERVATIONS AND RECOMMENDATIONS ON ENGINEERING THE REACTOR SAFETY RESEARCH PROGRAM

In this Chapter, the ACRS makes observations and recommendations on the processes used at the NRC for identifying and conducting research. Observations and recommendations on particular elements of the Reactor Safety Research Program are made in Chapter IV.

Observation:

> Research activities at the NRC are not recognized to be tied sufficiently to the mission needs of the agency to make rational allocations of resources to research.

The NRC Research Program has suffered in recent years for two fundamental reasons:

- there is no agreement throughout the agency that research results are needed to conduct the NRC mission adequately so that they are cost effective in terms of value added, and

- line organizations do not depend usually on research results to meet their programmatic obligations.

Because there is no common view that research is essential and that it is tied in an explicit way to the mission needs of the agency, there is no basis for rational allocation of resources. There is a willingness to treat the resources available for research as fungible. That is, research can be delayed or deferred in favor of other activities without penalty. As a consequence, research is not positioned to compete for resources with other parts of the agency.

The view that research results may be desirable but not essential comes about because line organizations can conduct regulatory activities without the research results. There is not usually a prior constraint on the conservatism that can be applied to regulatory activities when there is not sufficient knowledge or understanding. There is not an imperative to modernize felt by the line organizations to a sufficient extent that they are willing to share resources to get research results that will allow regulatory activities to be done better, faster, and cheaper. Research may or may not yield results that immediately assist the line organization. Research has become a repository of resources that can be withdrawn to support activities that are recognized as essential throughout the agency.

As a result, the research programs are not organized to support crucial, new initiatives undertaken by the Commission and the line organizations. It would be difficult, for example, to detect from the current research planning the emphasis the Commission has been placing on applying risk information to regulatory activities. There is no evidence in the research planning of unusual efforts to develop risk information and risk analysis tools for application to regulatory activities or to expand the range of regulatory activities where risk analysis methods can be applied (for example, elimination of regulations marginal to safety). The recent failure to devise a rule for low-power and shutdown operations well-founded on risk and the deferral of the development of a risk-informed revision to 10 CFR 50.59 show how limited are the capabilities of the agency as it seeks to undertake an important change toward rational, risk-informed regulation. The NRC's risk assessment tools are not even sufficiently well-developed to use them as essential features of the effort to prioritize elements of the Research Program as directed by the Commission and promised in the Strategic Plan.

The NRC Research Program is, instead, organized to house expertise in the many disciplines that have arisen in past regulatory activities. This might be an acceptable goal for the NRC Research Program. The ACRS can well imagine that the agency needs in-house expertise in areas where it cannot reliably obtain such expertise from other sources. For example, in the area of reactor fuels, expertise within the academic and commercial sectors is largely retained by the nuclear industry to an extent that the independent advice the NRC needs cannot be sought from these sources. Expertise from traditional sources such as the National Laboratories is disappearing with retirements and reduction in support from the Department of Energy. Consequently, the NRC might well find it has to develop in-house expertise. Similar arguments could be made concerning radiation effects on materials, reactor physics, fission product chemistry, seismic response of reactor structures and probabilistic risk assessment (PRA).

It is also possible that the NRC would want to maintain in-house expertise in areas where there are frequent demands placed on line organizations to apply rapidly evolving technologies. Assuredly, digital instrumentation and control is an example of such a rapidly changing field where the NRC might find it essential to have in-house expertise. On the other hand, it may not be essential for the NRC to have well-supported in-house expertise in relatively static fields that are not peculiar to the nuclear safety field such as fracture mechanics, fire protection, and civil engineering. In such areas, the NRC can augment its on-role expertise through technical assistance contracts if major initiatives involving risk-informed changes to regulations and regulatory guidance are not anticipated.

Observation:

> The NRC has not adopted a systematic process for designing and engineering the Research Program so that the research activities are related clearly to mission needs of the agency; have requirements that are as quantitative as possible concerning scope, accuracy, and urgency; and indicate when enough research has been done.

The NRC relies on the skills and intuition of individual managers to define the standards for engineering its research activities. Other Federal agencies and institutions in the private sector, on the other hand, have found it advantageous to adopt uniform systems for engineering research and development activities. Successful systems for engineering programs now exist. Note should be taken of:

R. Shishko, *NASA Systems Engineering Handbook*, SP-6105, National Aeronautics and Space Administration, June 1995.

Defense Systems Management College, *Systems Engineering Management Guide - Technical Management*, U.S. Department of Defense, December 1989 and *Draft Military Standard Systems Engineering*, MIL-STD-499b, May 6, 1992.

U.S. Department of Energy Order 4700.1, *Project Management System*, Change 1, June 2, 1992.

IEEE P1233, *Guide for Developing System Requirement Specifications*, Institute of Electrical and Electronic Engineers, Inc., NY, NY, 1993.

These systems engineering approaches to the engineering of research and development impose a rigor on planning activities that include:

- establishment of a clear connection between an activity and the mission need of the organization,
- comprehensive definition of the functions of the activity,
- definition of the requirements of the activity,
- attention to the interfaces among activity functions,
- identification of alternative engineering solutions and the defensible comparison of these alternatives in terms of rational criteria,
- synthesis of optimal engineering solutions, and
- identification of when research has met its objectives and should be terminated.

These systems approaches address areas where the NRC has had difficulty in planning or defending its research activities. Seldom is a useful tie (that is, a tie that can be the basis of resource allocation) established between a particular research activity and an agency mission need. For example, there is not a clear tie between the planning of research on human performance and a mission need of the agency to regulate to improve human performance. Seldom do user-need requests define requirements for research activities in sufficiently quantitative terms to provide a basis for engineering the research. Often, research programs proceed in isolation of other pertinent activities. Very often, unrealistic time schedules are established for the research relative to the expectations of the research and then these schedules are changed annually.

The annual overhaul of the Research Program combined with the unavoidable disruptions of the Federal budget cycle greatly disrupt the continuity of research at the NRC. Research is a longer term activity. Seldom are research products completed within a single planning cycle. Inefficiencies in the Research Program necessarily arise when there are annual changes in the research agenda. A more formalized planning process for engineering the Research Program would, at least, reduce the disruptions of the research caused by processes internal to the agency.

Recommendation:

The NRC should adopt a systematic framework for designing and engineering its Research Program that enforces a close tie between research activities and agency needs, assesses the value of the results to be achieved by the research, defines the requirements of the research, specifies the functions of the research activity, and defines the urgency of the activity results.

Observation:

The Office of Nuclear Regulatory Research (RES) routinely relies on "assumed" solutions to address technical issues.

Routinely, RES adopts and quickly commits to engineering and scientific approaches that are assumed to work and assumed to be adequate, if not optimal. Peer review is used near the end of a project to assess the qualities of work in pursuit of the assumed solution. It may well be true that experienced program managers conduct mental evaluations of alternatives and conduct mental trade studies of these alternatives. There is, however, not a tradition within RES to conduct scrutable comparisons of well-founded alternatives in terms of agreed-upon criteria. Assumption of solutions may be an efficient approach for minor technical issues or when there are well-established technical standards for issue resolution. Assumption of solutions is riskier for issues in more adventurous areas or for topics involving new, less-thoroughly developed technologies where best technical practices have not been established. Since the NRC is doing so much ground-breaking work in the innovation of regulation, the agency will increasingly have to confront issues that do not fall within single, well-established technical disciplines. Disciplined, quantitative comparison of viable alternatives (that is, alternatives that meet all requirements) in terms of agreed-upon criteria is more likely to yield high-value solutions. Early peer review of these comparisons and "synthesis" of a preferred alternative from the best features of the other alternatives are good engineering practices.

Recommendation:

The NRC needs to adopt a practice of scrutable comparison of alternatives in addressing technical issues that require innovation in fields that are not well-established.

Observation:

RES does not have a well-developed process for identifying future agency issues that will require research support.

RES is not using a rigorous process to anticipate initiatives that will be undertaken by the nuclear industry and will require NRC approval. RES is further handicapped in its anticipation of research needs by the "user-need" process. Line organizations are not submitting, or there is a reluctance if not inhibition to submit, user-need requests when the pertinent portion of the research budget is fully subscribed. RES is uninterested in defining research needs when it knows current budgets are inadequate to address such needs. As a result, when RES attempts to prioritize its research activities, it is not prioritizing the full range of potential activities. This deprives the agency of the chance to optimize its research resources to improve its regulatory activities.

Recommendation:

The NRC should devise a process for identifying and prioritizing research needs that encompasses considerations of long-term benefits as well as short-term user needs. The user-need process itself should be revised so that it better represents the full range of research needed by line organizations. In addition, the NRC should more formally identify likely industry initiatives and determine if these will require research before the agency can respond with effective and minimally intrusive regulation.

Observation:

The NRC does not now have the tools to assess the risk significance of its research activities.

The Commission has asked that research focus on the most risk-significant activities. Repeatedly, the ACRS has encountered research activities justified in terms of risk significance in subjective, qualitative terms. Seldom can the subjective justification be scrutinized. This comes about simply because the NRC has not developed its in-house risk assessment capabilities, supplemented by the wealth of information from the individual plant examinations (IPEs) and individual plant examination of external events (IPEEEs), to allow project managers facile means to make quantitative risk assessments of the impact of research. Quantitative assessments would be extremely useful for the prioritization of activities and the rational allocation of resources to activities. The NRC staff expects rigorous applications of risk assessment by licensees to justify proposed changes to regulations and regulatory guidance. Ought not the NRC's research, which in many cases has the same objectives of justifying changes and modifications of regulations and regulatory guidance, also be expected to rigorously apply risk assessment?

Recommendation:

The NRC needs to develop its in-house risk assessment capability to the extent that it can be readily used throughout the agency. The in-house capability can be used to assess requests and to improve the planning of research.

Observation:

The NRC does not use operational data adequately for improving the PRA methods.

The Office for Analysis and Evaluation of Operational Data (AEOD) has been collecting and analyzing data on systems and issues pertinent to the predictions of PRA. Some examples of recent AEOD studies that the ACRS has found valuable are:

- High Pressure Coolant Injection (HPCI) System Performance, 1987-1993, Final (S95-02)
- Emergency Diesel Generator Power System Reliability 1987-1993 (S96-03)
- Assessment of Spent Fuel Cooling (S96-02)
- Reactor Core Isolation Cooling System Report (S97-06)
- Reactor Coolant System Blowdown at Wolf Creek on September 17, 1994 (S95-01)
- Industry Efforts to Manage PWR Feedwater Nozzle, Piping and Feedring Cracking (4/97)

Reports on these studies receive careful peer review and appear to be resources for the validation of PRAs done by the NRC. This validation does not seem to be a priority activity for research and, indeed, the products of work done by AEOD do not appear to get widespread use within the agency or even within the larger PRA community. Furthermore, studies undertaken by AEOD need to be selected based on criteria involving risk significance.

Recommendation:

The development of PRA methods should be better supported by the activities of AEOD with the aim of validating and improving PRA methods and results.

IV. COMMENTS ON SPECIFIC RESEARCH ACTIVITIES

This Chapter discusses some of the more visible individual research activities and projects. The discussions are presented in terms of need, scope, and balance as described in Chapter I. In general, the needs for the research activities have been described to the ACRS in plausibility terms. Rarely is there a clear description of a mission need for the NRC that depends upon the outcome of a particular research effort. In general, there is only the assurance that the research will assist in the regulatory activities of the line organizations. This is most apparently true when the research activity provides specialized engineering expertise that the line organization draws upon. It is less apparent for other activities such as those that are being done in anticipation of future issues.

The staff has not been required to develop quantitative measures of the risk significance or regulatory significance of the research activities. It is, then, quite impossible to comment defensibly on the cost/benefit of the research activities except, perhaps, in the most qualitative terms. Similarly, it is impossible to provide defensible advice on the relative importance of the many research activities of the agency except in qualitative terms. It is possible to identify research that directly supports Commission initiatives or prepares tools and processes that will make it possible for line organizations to address anticipated proposals from licensees.

A. Probabilistic Risk Assessment

It is the policy of the NRC to utilize quantitative methods of probabilistic risk assessment (PRA) whenever it is feasible to do so in regulatory activities. The agency wants to increase the use of these methods both to make its regulatory activities more defensible and to make them more cost effective. This is a major change in the way nuclear power is regulated, and it may well stand as an example for other Federal regulatory agencies. The regulatory vehicles that will allow licensees to make changes in their current licensing bases using risk insights are nearly in place. The NRC staff and management, including those involved in inspection of nuclear power plants, are being trained in the methods and results of PRA. It would have been expected, then, that research to develop and apply PRA to regulatory activities would have been portrayed as the centerpiece of the NRC research rather than just one among many activities.

Most of the tools now available to the NRC for probabilistic risk assessment of nuclear power plant operations have become sophisticated and yield detailed and useful results. These tools are, however, as yet incomplete even for the purposes of evaluating licensee proposals. The planned research into PRA methods does include efforts to enhance these tools. Plans to develop the capabilities to assess risk during shutdown and low-power operations are most welcome even though initiation of the work is deferred to FY 1999. Plans to research fire risk assessment (discussed further below) are also welcome. Research to permit the inclusion of quantitative measures of human performance into PRA (see the discussion of Human Factors and Human Performance Research, below) is another important undertaking.

There are, however, many other avenues that could be pursued to improve the use of risk assessment methods within the NRC. Some of these avenues have been revealed in the course of developing regulatory guides for the use of PRA in licensee proposals. There is, for example, a clear need to understand the risk implications of quality control and quality assurance. The requirements of 10 CFR Part 50, Appendix B place burdens on both the NRC staff and the licensees. A first step in reducing these burdens and focusing on issues of real safety significance has been made with the development of Regulatory Guide 1.176, "An Approach for Plant-Specific, Risk-Informed Decisionmaking: Graded Quality Assurance." How much better, more defensible a step could have been taken confidently had there been available quantitative risk results indicative of the risk reduction worth of quality assurance and quality control measures? The NRC has imposed rules on licensees with respect to Station Blackout, Anticipated Transients Without Scram, and Maintenance. It should now be possible for the NRC to assess the risk effectiveness of these rules. This would be a first step in a process that leads eventually to routine assessment of the risk effectiveness of rules imposed by the NRC.

An essential element missing from the planning of research on PRA is a vision of what capabilities the agency wants to have available to it in the future. The ACRS recommends that an effort be made to define the PRA capabilities the agency needs to bring risk insights to bear on as many of its regulatory activities as possible. Does the NRC want its staff to have the capability to assess easily the risk implications associated with the regulatory process? A similar issue of vision for the long-term aspirations of the agency arises in connection with the development of simplified models for the Accident Sequence Precursor Program conducted in the Office for Analysis and Evaluation of Operational Data (AEOD). Research is regularly revising and improving the risk assessment models used in this Program. No long-term goals for the accuracy and span of applicability of the codes used in the program have been established. The absence of these "aiming" points for research must degrade the efficiency of the code development program.

A practical approach to developing a comprehensive research program on PRA may be to start by asking why there is a need for an expert panel to make the ultimate decisions regarding the acceptability of a proposed action, as, for example, the provisions of Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Current Licensing Basis." At the present time, it is recognized that this is necessary because of the lack of quantitative information regarding some aspects of risk. What are these unquantified elements? While the ACRS recognizes that a subjective evaluation of the decision options is unavoidable, it believes that this should be minimized. An examination of the decisionmaking process could be the basis for a more complete research program into the development of PRA methods.

Risk is becoming a central issue of regulation. Planning of a more complete and meaningful research program at the NRC is handicapped now by an uncertainty in the metric for risk. Is the metric to be risk as used in the Safety Goal Policy, or is the metric to be core damage frequency as used in the Regulatory Guide 1.174. Resolution of this issue has implications on the continuation of research in areas such as severe accidents and containment integrity.

B. Human Factors and Human Performance Research

Human factors and human performance activities are found in various elements of the NRC Research Program. ACRS has found it useful to categorize the proposed research into concerns over operational events and concerns over the modeling of human performance in PRAs.

An often cited feature of operational events at nuclear power plants is that most of them involve some element of human performance failure. Given the general process used by the NRC to evaluate events, it is surprising that not all events are found to involve less than adequate human performance. This observation of the continuing contribution of human errors to operational events is the basis for proposals to do more work in the area of human performance. The NRC staff has struggled in recent months with the development of an agency-wide plan to deal with human performance. The current incarnation of this plan lists some 22 research activities that should be undertaken:

- support line organizations on issues involving human performance,
- collect and disseminate within NRC insights on human performance from other agencies and institutions,
- determine how workload transitions affect team performance,
- determine the effects of short-term changes in lighting conditions on performance,
- evaluate the impact of alarm system design on operator performance,
- implement hybrid human/systems interfaces,
- develop guidance for the review of the interface management aspects of advanced human systems interactions,
- update and revise NUREG-0700, "Human-System Interface Design Review Guidelines,"
- develop state-of-the-art human factors engineering test and evaluation guidance, ?
- determine effects of computer-based procedures and software controls on crew performance,
- evaluate effectiveness of audio signals in nuclear power plant control rooms,
- review guidance and acceptance criteria for crediting operator actions in place of automated system or component actuations, BNL

- evaluate the feasibility of using task network modeling techniques to support reviews of medical uses of radioactive materials,

- evaluate the potential for linking a task network model of operating crew actions to simulation models of a nuclear power plant and its applicability to human reliability analysis,

- improve root cause investigations,

- endorse ANSI/ANS-3.1-1993, "Selection, Qualification and Training of Personnel for Nuclear Power Plants,"

- identify principles of risk communications,

- conduct a study to identify the potential implications of licensee downsizing on human performance, deregulation ?

- ? use PRA information to support regulatory activities,

- identify state-of-the-art behavioral evaluation methods, implementation strategies, and task contexts for determining fitness-for-duty changes,

- develop a general capability to address human factors issues in ultrasonic inspection and radiological survey activities, and

- develop methods to quantify management and organizational factors.

To ACRS, most of the above activities appear to be research to identify topics for research. Indeed, the biggest barrier to the definition of an agency-wide human performance program plan is the failure to identify the purpose of the plan. Does the NRC feel that human performance is now inadequate? Does the NRC feel the risk-worth of the operator is too high? Does the NRC feel that cost-beneficial improvements in human performance can be made? Are licensees likely to propose sufficiently dramatic changes in the operator environment or the operator characteristics that will have to be evaluated by the NRC and for which existing regulations and review guidance are not adequate? Without some definition of what the NRC wants to accomplish in the area of human performance, it is impossible to evaluate the merits of most of these proposed research activities. Most are completely open-ended. There are no real requirements that could be used to design the research.

that is 18

The staff has informed the ACRS that the document that had been proposed as a "plan" will be renamed as the "NRC Program to Assess Human Performance" and is an inventory of human performance projects within the agency. It also defines a mission statement for the Human Performance Program, as follows:

To ensure effective risk-informed and performance-based regulation and oversight of human performance in the design, operation, maintenance, and decommissioning of nuclear reactor sites and other NRC-regulated facilities by: 1) identifying human performance issues important to public health and safety; 2) increasing understanding of the causes and consequences of degraded human performance in such settings; and 3) implementing the appropriate regulatory response to such issues.

This may be an adequate mission statement. The ACRS does not believe, however, that the staff has a systematic approach for achieving the three goals of the mission statement.

At the opposite extreme is the modeling of human performance in PRAs. Rates of human errors during routine operations are modeled reasonably well in current PRAs. In contrast, the models for human performance after the occurrence of an initiating event are widely recognized as being poor. Experts in the field are referring to these models as "first-generation human reliability models." Review of the individual plant examination (IPE) submittals shows that a variety of first-generation models have been adopted, but these models yield numerical results that have little credibility. Yet, the human actions that are purported to be modeled are critically important to safety.

A significant feature of the proposed research on human factors is the development of a method to model human performance (ATHEANA) that utilizes the recent research results on human error. There has been a significant change in the paradigm of human performance. Instead of focusing on the "human error," the emphasis has shifted to the investigation of the "context" within which the human operates. It is the context that may "force" the human to commit unsafe acts. This context consists of many elements, some of which depend on hardware, such as the supply of wrong information by instruments, and some depend on the environment that management policies have created. Identifying the "error-forcing contexts" is now the focus of human performance models.

The ACRS encourages continued research into human performance modeling in PRAs. The ACRS feels that this is a topic that must receive serious attention as the regulatory process becomes more dependent on risk information.

C. Management and Organizational Factors Research

There is a widespread belief that the management and organizational structure of a nuclear power plant can affect safety of plant operations. Indeed, more than once weaknesses in the operation of individual plants, made evident to the NRC by performance, have been corrected by changing both the management and the organization. There is, then, an interest in including assessments of management and organizational structure in PRAs. The means of doing this has not been developed.

Research on management and organizational factors is a sensitive subject. The principal argument against research in this area is that the responsibility for good management of nuclear power plants lies with the licensees. The NRC should not attempt to regulate licensee management.

If the objective of research on management and organizational factors were to provide the NRC with technical bases to regulate management of nuclear power plants, the research would be unnecessary and objectionable. The ACRS certainly supports this view. In fact, the ACRS believes that as the NRC moves toward more performance-based regulation, the NRC involvement in management matters will decrease.

The International Nuclear Safety Advisory Group of the International Atomic Energy Agency has introduced the concept of "safety culture" into the nuclear safety arena. A safety culture has many elements. Some of these elements are influenced by management policies and organizational factors. The objective of research on management policies and organizational factors should be to develop the knowledge and methods necessary to quantify the effects of safety culture on human performance and risk. The effects are not currently modeled in PRAs. There is not now a good understanding of how to measure safety culture quantitatively nor how safety culture affects plant risk. There is, however, an intuitive feeling that safety culture does affect risk. For example, a plant's safety culture is thought to affect the "error-forcing context" that is part of the modeling of human error being developed for the ATHEANA model. This research, then, is intended to provide a quantitative understanding of the risk impact on safety culture. Without this quantitative understanding, safety culture remains one of the "unquantified" elements the expert panels and the NRC must address subjectively, and it remains one of the hurdles on the path to risk-informed regulation.

D. Fire Safety Research

For some time, it has been anticipated that the existing, deterministic regulations for fire protection at nuclear power plants would be supplemented, if not supplanted, by risk-informed regulations that emphasize performance. Initially, it was thought that licensees would welcome such evolution of the fire safety regulations. It now appears that licensees find the existing regulations to be satisfactory, although they have an interest in developing and applying probabilistic methods of fire risk analysis to parts of plants that are not important to safety. Nevertheless, there is still the need to have the technology for quantitative fire risk assessment if, indeed, the NRC wants to move its regulatory activities to a more risk-informed basis.

Methods to quantitatively assess the risk posed by fire at nuclear power plants during both normal and shutdown operations have languished in recent years. Certainly, these methods have not been as actively developed, debated, and refined as have the methods used for usual risk assessment of power operations. Early results coming from the individual plant examination of external events (IPEEEs) program suggest that the need for reliable fire risk assessment methods is acute. The early results suggest that the risk of core damage as a result of fire is larger than many had anticipated. Indeed, at some nuclear power plants the risk is large and is comparable to the risks from other types of initiators during power operations. At least one site (Quad Cities) has been found to be a risk outlier. Generic vulnerabilities to fire may be found to exist for plants that employ the self-induced station blackout procedure in response to some types of fires.

At first examination, the early results of the IPEEE effort appear to raise concerns about the adequacy of the existing fire protection regulations (10 CFR 50.48 and Appendix R). But, the quantitative and qualitative methods used in the IPEEE analyses are, themselves, questionable. Certainly, the NRC has raised a number of questions about the adequacy of the qualitative Fire Induced Vulnerability Evaluation (FIVE) methodology developed by the nuclear industry. The Office of Nuclear Regulatory Research (RES) staff has identified some 42 weaknesses and omissions in the quantitative methods of fire risk assessment that could be resolved by further research.

It is likely that the IPEEE results will lead to more regulatory activities in the area of fire protection. If these regulatory activities are to have the benefit of risk information, reliable fire risk assessment methods must be available. Indeed, activities now under way could benefit from reliable risk insights. For example, the pilot fire protection functional inspections are nearing completion. These inspections have identified deterministically some vulnerabilities that are questioned by licensees based on qualitative perceptions of risk. These pilot inspections have proved to be expensive for licensees and have taxed the NRC resources. Is it risk beneficial to take regulatory actions on the findings of the pilots, and is there a risk benefit to extending the functional inspections to all plants?

The ACRS supports the ongoing planning for research to improve quantitative methods of fire risk assessment. This work should not be delayed in anticipation of a performance-based fire protection standard being developed by the National Fire Protection Association.

E. Severe Accident Research and Consequence Analysis

The NRC has sponsored an heroic investigation of severe reactor accident phenomena. The results of this work are now embodied in the MELCOR computer code as well as several specialized computer models. These models find their principal use as support for level II and level III PRAs. The models are also used as the technical bases for simpler models used by the line organizations.

The current severe accident research program is a mere shadow of the past effort. The NRC program consists of maintenance of some computer codes:

- integrated model of severe accident phenomena MELCOR,
- the SCDAP/RELAP model of core degradation,
- the VICTORIA model of radionuclide release, transport and behavior,
- the CONTAIN model of phenomena in containment and containment loads, and
- the IFCI model of melt coolant interactions,

the participation in two international severe accident research programs:

- the FARO tests of molten fuel interactions with water, and
- the RASPLAV tests of molten fuel behavior in the lower plenum of a reactor vessel,

and the completion of three studies:

- application of the new source term to LWRs,
- direct containment heating, and
- lower vessel head failure.

Resources have not been allocated to the continued work with the European PHEBUS tests of radionuclide release and behavior in the reactor coolant system and containment.

It is evident from the current plans that all severe accident research sponsored by the NRC will soon be concluded. Currently, there is no severe accident research program sponsored by the nuclear industry or by the Department of Energy. There are, however, fairly active programs continuing in Europe and Asia.

There have been numerous calls and plans for the closeout of severe accident research based largely on the time and money spent on this research. Quantitative, measurable criteria for declaring aspects of the severe accident research complete have never been defined. The current understanding of severe accidents is far from complete. It is incomplete, if for no other reason, because the understanding now is restricted to accidents during normal plant operations. There has been no examination of severe accidents initiated during shutdown operations. Even for operational events, the uncertainties found in the NUREG-1150, "Severe Accident Risks: An Assessment for five U.S. Nuclear Power Plants," PRAs do not inspire confidence in the ability of the NRC to quantitatively estimate risk with useful uncertainty bounds. The crucial question, then, is has the NRC stopped its severe accident research prematurely?

The answer to this crucial question depends to a great extent on the Commission's selection of a metric for risk. Certainly, the Safety Goals formulated by the Commission are cast in terms of risk and would seem to require a significant capability to predict the course of severe accidents. A capability to predict quantitatively the nature of reactor accidents seems also inherent in the cost/benefit analyses used for regulatory analyses. On the other hand, regulatory guides proposed by the NRC staff to allow licensees to include risk in proposals for changes to their current licensing basis rely on core damage frequency and estimated large, early release frequencies as metrics for risk. With these metrics, the current, incomplete understanding of severe accidents may well be adequate. It may be only practical now to use core damage frequency and estimates of large, early release frequency for risk information. If, in the future, the Commission would prefer to bring its practices into line with its Safety Goals and use risk as the metric, it will probably be necessary to reactivate severe accident research.

A somewhat similar situation exists with regard to the predictions of accident consequences. The NRC has a useful computer model for such predictions, MACCS. An essentially distinct modeling effort is used for predictions of radiation dispersal in the NRC's emergency response operations. The MACCS computer code may require further development to reach the state-of-the-art in this field. On the other hand, if actual risk is not the metric of choice for risk information, there really is no need to maintain and improve this model.

F. Containment Integrity

The NRC has sponsored experimental studies to validate computer codes used to predict reactor containment vulnerabilities especially to pressure loads. The NRC is now engaged in such research in a highly leveraged experimental program with Japan.

The experimental results that have come from the research programs consistently show that containment models fail at construction details and flaws that are below the level of resolution used in the computer models. Gross failure of the models, however, is predicted to occur by the computer codes at pressures only slightly greater than the observed failure pressures. It appears, then, that the computer codes are becoming reliable and that containment failure probability distributions will be dominated by flaws and deteriorations in the containment structures which are not examined in the research. In any event, uncertainties in containment failure probabilities do not appear to be dominant contributors to uncertainties in risk. Nor is it apparent that the NRC needs to undertake research to maintain specialized expertise in the area of containment integrity predictions.

Japan is forced by circumstances of its geography to require especially robust containments for its nuclear power plants. Hence, the leadership in the understanding of the challenges to the structural integrity and the response of plant structures is to be expected from the Japanese nuclear safety program. The ACRS feels that the current experimental research in the highly leveraged program with Japan will be cost-beneficial and ought to be continued to completion. Initiation of other research or follow-on work should depend on the identification of needs that can be shown quantitatively to be met by cost-effective research.

G. IPE/IPEEE Followup and PRA Standards

The NRC staff has completed its review of the IPE submittals and has prepared an outstanding "insights" report that shows:

- methods used for plant PRAs are diverse and diverse methods yield different results,
- risks posed by the operations of nuclear power plants are about what had been suspected and come from the operational events that have been identified in the past; there are no significant risk outliers in the population of current plants,
- any plant PRA used to support a licensing submittal will have to be carefully reviewed by the NRC staff for completeness and adequacy of methods.

The IPE insights have led the RES staff to support the development of an industry consensus standard on PRAs. This, of course, is a prudent step. But, the consensus standard is likely to be devised with aims of generality of application at the expense of the specificity that will be needed by line organizations of the NRC to accept the results of a PRA for regulatory purposes. The NRC still needs to define for itself and for its licensees what will be needed for a PRA to be of use for regulatory purposes. The ACRS feels that this definition of what will be needed to be a preferable path for the staff to pursue than any further work with the IPEs or attempts to distill further insights from these submittals. Intercomparisons of IPEs for "sister" plants, too, seems an activity of minimal significance to the NRC mission needs.

The IPEEE process is still under way. Not all submittals have been received or reviewed. The effort to develop insights comparable to those derived from the IPEs is ongoing. Nevertheless, the IPEEE process has shown that the risk from fire at nuclear power plants may exceed expectations of the past. There are risk outliers with respect to fire safety. As discussed above in connection with fire protection research, early results from the IPEEE process raise concerns over the existing fire protection regulations and questions about the adequacy of current methods for fire risk assessment.

The ACRS believes that a great deal of work remains to be done to derive and interpret insights from the IPEEE effort. This work will be more difficult and may well be more controversial than similar work done with the IPE submittals. Results of this work may have greater impact on the definition of the NRC research needs.

H. Thermal Hydraulics Research

Thermal hydraulics has been an important element of the NRC Research Program since the agency was founded. The focus of the current thermal hydraulics research program is on the formulation of a single, modern thermal hydraulics code (coupled with neutron transport modeling) for use in the agency. This consolidation effort has been the subject of a protracted and quite good planning effort. Much of the design of the program has followed guiding principles set forth in the Commission's Direction Setting Issue 22. Creative ways have been found to bring the academic thermal hydraulics community into the work. The NRC staff with the capability to do thermal hydraulics research is being developed in the program. The code consolidation should save the NRC research resources in the long run, since it will not be trying to maintain separate codes for different types of nuclear power plants. Assuredly, the consolidation effort as now planned will give the NRC greater control over its thermal hydraulics calculational capabilities and will foster in-house use of the code.

The current thermal hydraulics research program is often characterized as just a code consolidation effort. In many respects, this is not true. In the course of work for the certification of the AP600 advanced light water reactor design, the NRC staff and the ACRS uncovered many deficiencies in the existing suite of thermal hydraulics codes and databases for the application of these codes to new designs. Confirmatory research and technical assessments by the RES staff were essential to reaching the judgment that Westinghouse test and analysis program and the Westinghouse NOTRUMP computer analyses provided sufficient technical basis to show that the

AP600 design meets regulatory criteria. The consolidation effort now under way will also correct some of the identified deficiencies of the available thermal hydraulics codes.

The availability to the NRC of a reliable best-estimate thermal hydraulics code will become essential if, as is now anticipated, licensees take advantage of the option to use best-estimate methods to show compliance with Appendix K to 10 CFR Part 50 in their applications for reactor power uprates. A consolidated thermal hydraulics code will facilitate routine analyses by line organizations such as reviews of changes to Safety Analysis Reports, reviews of operational events, reviews of accident management strategies, and assessments of proposals for changes in licensing bases and license extensions. There is, then, a need for a calculational thermal hydraulics capability and the proposed research program appears to be an essential modernization and improvement in this capability.

The scope of the thermal hydraulics research program needs to be expanded. Coupling of the thermal hydraulics of the reactor coolant system to the thermal hydraulics of the reactor containment remains a difficulty. This difficulty has affected the ability of the agency to assess thermal stratification and hydrogen distribution in the containment. It has also slowed the agency response to the issue of debris generated during loss-of-coolant accidents (LOCAs) and clogging of strainers. It is probably safe to assume that it will continue to be a problem for the agency if this coupling of reactor coolant system thermal hydraulics and containment thermal hydraulics is neglected.

One problem consolidation of calculational capabilities can introduce is that the calculational structure can become rigid and make it difficult to respond to issues not anticipated as the consolidation was done. The ACRS encourages the staff working on the consolidation of the thermal hydraulics codes to build into the code modularity and flexibility in the types of issues the code can address. Consideration should be given to automatic time step variations in both time and space, use of "plug-in" modules, variable node sizing, and automated determination of uncertainty distributions.

The ACRS does not see a pressing need for the NRC to maintain its support of large-scale thermal hydraulics test facilities such as PUMA and APEX. These facilities have now served their functions and probably will not be optimal facilities for future experimental studies. Future testing that may be needed to validate the consolidated thermal hydraulics code is very likely to come from cooperative research ventures with the international nuclear safety community.

The technical foundations of the thermal hydraulics computer codes used by the NRC are now several years old. There is interest in the possibility of upgrading thermal hydraulic computational capabilities to utilize modern computational fluid dynamics (CFD) techniques. The ACRS does not perceive there to be a need for major revamping of the technical bases of the existing thermal hydraulics codes to utilize CFD methods. There are, however, occasional, detailed thermal hydraulics issues that do not require modeling of the entire reactor coolant system for resolution. It would be beneficial to have CFD codes available for addressing these very detailed issues. There would be some benefit for research to have a small effort to adapt a commercially available CFD code for these purposes.

I. Advanced Instrumentation and Control

A change that is occurring, that is inevitable, and will result in improved reliability and functionality is the replacement of analog instrumentation and safety control systems with digital hardware and software systems. Although the basic framework for regulation and safety review of digital systems was established in the update to Chapter 7 of the Standard Review Plan in July 1997, numerous issues remain. These issues must be addressed so that the NRC can effectively regulate and review safety systems employing this rapidly evolving digital technology. Vulnerabilities of digital systems are different than those of analog systems. Failure probabilities and the failure characteristics of these systems are also different. Appropriate methods to include digital and software systems in PRAs do not exist. Quality control and quality assurance expectations of the NRC are not compatible with the use of commercial off-the-shelf hardware and software, even though there may be excellent justification in terms of reliability for the use of the commercial systems. There can be little doubt, then, that the NRC line organizations will need substantial specialized engineering and research support to deal with the safety regulation of digital systems.

The RES program on advanced instrumentation and control systems involves three categories of work:

- responses to current user needs,
- anticipation of user needs, and
- development of technical bases for regulation of new technologies that may be introduced into nuclear power plants.

The NRC is also participating in the advanced instrumentation and control research in the Organization for Economic Cooperation and Development's (OECD's) Halden project.

The ACRS has been able to identify clear agency mission needs for research related to user needs. This work includes:

- providing regulatory guidance related to the qualification of instrumentation and control systems with respect to such things as lightning, smoke, electromagnetic interference/radiofrequency interference (EMI/RFI), thermal loads, camera flash, and relay arcing,
- investigating the effects of smoke on digital electronic systems,
- reviewing guidance on requirements for software-based digital safety systems,

- reviewing guidance on the use of commercial off-the-shelf hardware and software,
- providing technical bases and review guidance for evaluating the quality of software used in safety systems, and
- developing an integrated digital system safety assessment methodology that can be used to evaluate system performance, fault tolerance, reliability, availability, and probability of failure.

The ACRS also perceives and supports a clear agency need for the development of methods to include digital systems and software failures in PRAs.

Human interfaces with computer-based systems may well be a topic deserving NRC research attention. Decisions in this regard need to be made within the context of an overall agency approach to human factors and human performance. Certainly, it can be argued that work on human interfaces with computers in nuclear power plants is an issue that belongs on the licensees' agenda and that the NRC needs to take only a performance-based attitude toward these interfaces.

The ACRS has not identified an urgent mission need for research now planned to develop regulatory guidance on emerging technologies. The ACRS does, however, recommend that development of such guidance for emerging technologies in advanced instrumentation and control be considered in the overall prioritization of research consistent with recommendations made in Chapter III of this report.

The ACRS has not had the opportunity to review the value of the NRC involvement in the Halden project with regard to advanced instrumentation and control systems, but will do so in the coming year. In doing so, the ACRS will address the issues of whether products from the Halden project are relevant to the NRC's mission, are of sufficient quality to be of use to the NRC, and are being adequately distributed and used within the NRC.

J. Reactor Fuels Research

In the past, the NRC maintained an active experimental research program to study the performance of reactor fuels under accident and off-normal conditions. The NRC developed codes (FRAPCON and FRAPTRAN) for predicting changes in fuel and fuel cladding with burnup and these models are used in the review and approval of licensee proposals for core reloads. Funding reductions for research and the press of other research interests forced the NRC to curtail its fuel performance research at a time when the experimental database extended to fuel burnups of less than 33 GWd/t. Similarly, models of fuel and cladding properties were restricted to this limited database.

There are large economic incentives for licensees to extend the burnup of reactor fuels. Over the last two decades, the burnup of fuel at discharge from reactors has steadily increased. Today some reactors are approved to burn fuel to 62 GWd/t (peak rod average). Prediction of the safety performance of these higher burnup fuels even with the limited database available to the NRC might still be acceptable were there no major changes in the physics of fuel or the properties of clad at high burnup. Unfortunately, such changes do occur. Fuel develops a highly voided "rim" of low thermal conductivity. Fission gas concentrations increase at the periphery of fuel pellets. Zircaloy cladding becomes more extensively oxidized and is embrittled by the precipitation of zirconium hydrides. The effects of these changes on the performance of fuel under design basis accident conditions were made apparent by French and Japanese tests of reactivity insertions such as might occur during control rod drop accidents or control rod ejection accidents. Clad rupture and dispersal occurred at energy inputs 1/3 to 1/10 of what would be expected based on current regulatory guides. Analyses of the test results show that cladding oxidation and embrittlement are important contributors to the poor fuel performance. These findings raise questions about whether high burnup fuel can satisfy regulatory criteria for design basis accidents such as LOCAs and anticipated transients without scram (ATWS). The test findings have been augmented by operational events such as control rod insertion problems and neutron flux anomalies. Together the test findings and operational events show that high burnup fuel does not behave in ways anticipated by simple extrapolation of data for lower burnups.

The Office of Nuclear Reactor Regulation (NRR) has now limited fuel burnups to less than 62 GWd/t and has asked RES to conduct research to verify the regulatory decision that no significant risk to the health and safety of the public is posed by fuels of this burnup. RES has formulated an experimental and analytic research program tightly coupled to this confirmatory research need. Major elements of the research are:

- experimental studies of high burnup fuel behavior under LOCA conditions,
- experimental studies of high burnup fuel behavior under ATWS conditions,
- determination of the mechanical properties of cladding as a function of burnup,
- upgrade of the empirical correlations of fuel and clad properties in the FRAPCON and FRAPTRAN computer codes, and analyses of uncertainties in neutronic codes used by NRC.

The ACRS finds this to be a well-planned program that has used risk insights to focus work on areas of greatest importance. The ACRS does suggest that tests of fuel behavior under LOCA conditions use more realistic conditions that are likely to place greater thermal and mechanical strains on cladding and the oxide coating on the cladding. The research program should be augmented to investigate the suggestion that the properties and behavior of high burnup fuel depend on the rate of burnup as well as the extent of burnup. Considerations should be given to other factors that could influence high burnup fuel performance such as water chemistry, core power levels, and coolant temperature. Test matrices for the LOCA studies and for other experimental activities could well benefit from the use of formal experiment design methods. The testing and analysis to be done for high burnup of fuel under ATWS conditions need to be defined. The decision to exclude consideration of burnup effects on reactor accident source terms should be reexamined in light of published findings of other investigators.

The ACRS finds also that the research program does not have the breadth to anticipate agency needs in the future. The nuclear industry has every intention to propose fuel burnups in excess of the current limit. A rather large research program (~$50 million) has been initiated by the nuclear industry to develop proposals for even more extended burnup. The ACRS agrees with the staff's decision that it is the responsibility of the industry to develop databases to support such proposals and that the proposals should include a program of fuel performance monitoring. The NRC, on the other hand, still needs to have the ability to independently evaluate industry proposals for extended fuel burnup. The NRC audit codes FRAPCON and FRAPTRAN do not have capabilities to predict the properties and behavior of fuel and cladding beyond the range of the underlying database. The models do not predict, in the detail needed, the precipitation of zirconium hydrides within the cladding. Furthermore, the models do not realistically model the loads placed on fuel and cladding during accidents. The ACRS feels that the research program needs to be augmented to include development of models suitable for independent evaluation of anticipated industry proposals of extended fuel burnup.

It is likely that the NRC line organizations will require specialized engineering support from research on the issues of reactor fuel for the foreseeable future. The NRC may have to develop in-house expertise to meet this need. Expertise from the national laboratories is being lost due to retirements and reduced Department of Energy funding of reactor fuels research. Expertise from other sources is likely to be fully subscribed by the nuclear industry and not have the credentials of independence needed to support regulatory activities.

In the future, the Department of Energy may propose to use mixed oxide (MOX) fuel in commercial nuclear power plants as a means to dispose of some of the nation's excess plutonium. The ACRS agrees that it is premature for the NRC to initiate research in anticipation of such a proposal. The ACRS does note, however, that the neutron transport calculational capabilities now available to the NRC are not reliable for addressing issues of MOX fuels. As the new neutronic model adopted by the NRC is refined and integrated with thermal hydraulics models, attention should be given to improvements in this model that would be needed for addressing MOX fuel issues.

K. Reactor Pressure Vessel Integrity

Rupture of the reactor pressure vessel would be a catastrophic failure at a nuclear power plant. The NRC has devoted a great deal of research attention to assuring that the integrity of reactor pressure vessels is maintained with very high confidence. The primary threat to the integrity of reactor pressure vessels now is embrittlement caused by irradiation. Irradiation reduces the fracture toughness of the vessel steel (so-called "upper-shelf toughness") and increases the temperature at which the pressure vessel goes from brittle behavior to ductile behavior (the so-called "ductile-to-brittle transition temperature"). These changes to the steel properties increase with the age of the plant and have proved to be amazingly sensitive to the details of the composition of the pressure vessel steel. Prediction of the vulnerability of reactor vessels to failure has required the generation of data on irradiation-induced changes in material properties, development of fracture mechanics analysis methods, and the capability to characterize the distribution of flaws within the steel that could grow into cracks.

The research done in the past has largely met the immediate needs of the NRC. The work has produced Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials," which provides conservative estimates of the loss of upper shelf toughness and the shift in the ductile-to-brittle transition temperature. Generic analyses and owners groups submittals indicate that, with perhaps one or two exceptions, existing reactors will have adequate vessel toughness through the end of their licensing periods. The NRC research has developed conservative screening criteria for identifying the potential for vulnerability of PWR vessels to pressurized thermal shock (PTS). Almost all PWR reactor vessels will be well below the screening criteria throughout their current licensing periods. Should a plant want to limit its vulnerability to vessel embrittlement by annealing the vessel, models of embrittlement recovery due to annealing and re-embrittlement rates are available from the NRC research.

The success of the NRC research means that future needs of line organizations for research in these areas will be for assistance in responding to expected licensee proposals. A significant number of plants are projected using Regulatory Guide 1.154, "Format and Content of Plant-Specific Pressurized Thermal Shock Safety Analysis Reports for Pressurized Water Reactors," to exceed the PTS criteria during their license renewal periods. Alternative, less conservative criteria will need to be researched to assist line organizations with responses to licensee proposals for relief from the restrictions imposed by the current criteria. Licensees are expected to propose reductions in the conservatisms of analyses that restrict the range of heatup and cooldown rates of pressure vessels. Alternatives to the PTS criteria in Regulatory Guide 1.154 are being developed by the nuclear industry for proposal to the NRC. Though current PTS screening criteria are thought to be conservative, the nature and magnitude of this conservatism is not yet understood. It may be that large conservatisms in some parts of the analyses compensate for the lack of conservatism in other parts such as failure to consider the effects of biaxial stresses produced by thermal shock.

Materials available for monitoring the embrittlement of vessels by irradiation are coming in short supply as the plants age. Licensees can be expected to propose alternative test and analysis methods such as the "master curve" method to replace current practices and make better use of the limited supply of surveillance specimens. The licensees through their surveillance programs and other activities are responsible for the data on embrittlement needed to support proposals for license renewal and changes in current regulatory practices or for reactor vessel annealing. The NRC does need, however, to support a program on radiation embrittlement adequate to ensure that it can independently assess the validity and applicability of the results developed by the industry.

The NRC line organizations will have a continuing need for the specialized expertise in the analysis of reactor vessel material behavior. Research needed to maintain this expertise should be supported. The reactor pressure vessel integrity program should be reviewed, however, to avoid committing resources to work that is properly the responsibility of industry or that is not needed to support independent assessments in response to expected licensee proposals.

L. Environmentally Assisted Cracking and Degradation of Steam Generator Tubing

On the basis of surface area, by far the greatest portion of nuclear reactor pressure boundaries is made up of piping systems and in the case of PWRs steam generator tubes. The predominant mechanisms of degradation of primary system piping and steam generator tubes are:

- stress corrosion cracking (SCC), and
- corrosion fatigue.

These mechanisms are often referred to collectively as "environmentally assisted cracking." Recently, it has been recognized that irradiation produces changes in the steel microstructure and grain boundary compositions that enhance the susceptibility to stress corrosion cracking. This phenomena, which is peculiar to the nuclear environment, is called irradiation assisted stress corrosion cracking (IASCC) and affects reactor structural internals such as BWR top guides and PWR baffle bolts.

An understanding of cracking in nuclear piping systems is essential for probabilistic risk assessment of nuclear power plants. Indeed, steam generator tube rupture, coupled with human error or equipment failure, is often found to be a risk dominant though not frequency dominant accident in some PWRs. Small breaks in piping systems are found to be contributors to risk in all nuclear power plants.

Research on environmentally assisted cracking has been initiated at the request of NRR to provide an independent assessment of environmental degradation of reactor structural materials. The main elements of this research are:

- supply data and models for predicting the environmental effects on fatigue initiation of cracks and fatigue crack growth,

- supply data, models, and criteria for predicting susceptibility to IASCC, rates of crack growth and fracture toughness of irradiated materials,

- supply data, models, and criteria for predicting cracking of LWR primary system components made of nickel alloys,

- assess industry crack-growth models for environmentally assisted cracking, and

- assess capability of nondestructive examination (NDE) methods to detect and size SCC in steam generator tubing and the effect of SCC on leakage and structural integrity of steam generator tubing.

Work on fatigue life is nearing completion. This work has provided data based on materials in low flow rate water for predicting conservatively the effects of environment on fatigue life of reactor materials. The NRC and its contractor have worked with the Pressure Vessel Research Council to develop methods of incorporating consideration of environmental effects on fatigue life into design procedures and a new Appendix to Section XI of the ASME Pressure Vessel Code.

Much of the remaining work over the next several years will be focused on IASCC, though safety implications of this cracking mechanism are not expected to arise in the near term. In the longer term, IASCC is expected to affect BWR components that have importance to safety. The NRC has entered into a cooperative program on IASCC with the Electric Power Research Institute (EPRI), European and Japanese reactor vendors, and European regulatory bodies.

It is apparent that the NRC line organizations will require for some time specialized engineering expertise in the area of environmentally assisted cracking of structural materials and steam generator degradation. Sufficient independent expertise on these issues is available in the country and it is unlikely that the NRC will need to develop in-house expertise in these areas. The current research activities in the area of environmentally assisted cracking appear well-disposed to meet the needs of line organizations as they have been defined qualitatively.

M. Aging Research

Embrittlement of reactor pressure vessels, corrosion of reactor coolant system piping, and environmental qualification of cables are examples of research on the effects of aging of the existing nuclear power plants. Other areas of aging research can be envisaged. The NRC staff involved in the preparations for reviewing submittals for plant life extension has told the ACRS that it does not now have any major needs for research beyond those discussed in connection with reactor vessel integrity and environmentally assisted cracking.

The NRC can expect to face intense activity in the area of license renewal between now and the year 2010. Expected times for processing applications for license renewal are not short. Would not additional research be a means for the NRC to undertake its license renewal activities better, faster and cheaper?

V. OBSERVATIONS AND RECOMMENDATIONS CONCERNING WASTE MANAGEMENT RESEARCH AT NRC

Observations and recommendations by the Advisory Committee on Nuclear Waste (ACNW) concerning waste management research by both the Office of Nuclear Material Safety and Safeguards (NMSS) and the Office of Nuclear Regulatory Research (RES) are presented in this Chapter.

A. Waste Management Research and Technical Assistance Conducted by NMSS

Research and technical assistance being done for the high-level nuclear waste repository are categorized in terms of "key technical issues (KTIs)." Comments by the ACNW on work in each of these KTIs are presented in this Chapter. NMSS classifies some of the work done by the Center for Nuclear Waste Regulatory Analyses (CNWRA) and managed by NMSS as technical assistance rather than research. Much of this technical assistance is sufficiently innovative that the distinction between research and technical assistance is neither clear nor useful. The technical assistance work is of critical importance to the NRC as the Department of Energy (DOE) moves toward a license application for a high-level nuclear waste repository at Yucca Mountain. For these reasons, the ACNW included work done at CNWRA for NMSS in its review of waste management research.

KTI-1 Igneous Activity

The ACNW considers the work performed on this KTI to be excellent [**19**]. The work focused attention on the critical issues and influenced the approach taken by the DOE in its evaluation. The ACNW, however, recommended that the work be brought to an orderly conclusion, because the main objectives of the confirmatory research had been met.

KTI-2 Structural Deformation and Seismicity

This key technical issue addresses the need to improve the understanding of the risk associated with buried faults, which are not now addressed in the Probabilistic Seismic Hazard Analysis. The "sand box" experiment to evaluate structural deformation is one of the current experimental investigations at the CNWRA.

KTI-3 Evolution of the Near-Field Environment

This KTI deals with complex, coupled processes. For example, ground water chemistry affects the waste package integrity, and the thermal pulse from the waste package affects the surrounding host rock. The ACNW believes that greater attention is needed on the near-field chemistry [20] and on the entire engineered barrier system (EBS). The ACNW held a working group meeting in June 1998 to explore further needs in work associated with the near field.

KTI-4 Thermal Effects on Flow

The ACNW believes that the basis for a sound program has been established at the CNWRA. There is concern, however, that the models used may be less comprehensive than required for a proper evaluation and that the efforts are "data starved" [20]. Experimental work, coupled with state-of-the-art numerical modeling of results, is likely to be beyond the ability of the CNWRA, especially under the current restrictive budgets. The ACNW agrees with the suggestion of an expert peer reviewer that subcontracting is an efficient way to obtain the necessary high-quality work for the thermal-mechanical-hydrological program [21].

KTI-5 Total Performance Assessment and Integration

The ACNW has been following the development of the NRC code for total systems performance of the proposed Yucca Mountain repository. The ACNW has applauded the development of the code and has recommended that the code be peer reviewed [22].

KTI-6 Radionuclide Transport

The ACNW suggests that the NRC will need to perform confirmatory research in this area [23]. Issues of importance at Yucca Mountain include the effects of retardation of radionuclides in the EBS and in natural materials; matrix versus fracture flow; colloid transport in fractures; and so forth. Work related to Yucca Mountain under this KTI is relevant to low-level waste, uranium mill tailings, and decommissioning of contaminated sites. Close coordination with work being performed by RES should be maintained.

KTI-7 Activities Related to the EPA Standard and the NRC Rule

There is no ongoing work that can be classified as "research" under this KTI.

KTI-8 Unsaturated and Saturated Flow under Isothermal Conditions

The NRC and DOE sensitivity studies indicate that the amount of flux through the unsaturated zone entering emplacement drifts is the most important factor affecting repository performance. In addition, assumptions regarding groundwater flow through the saturated zone and groundwater use of future societies are critical factors affecting systems performance. Much uncertainty remains in understanding these issues. Unresolved issues include the magnitude and spatial distribution of ambient and future infiltration in the unsaturated zone, the role of faults and fractures in governing flux and spatial distribution of flow in the saturated and unsaturated zone, assumptions regarding matrix diffusion and saturated zone dilution, hydrologic properties of fractures and faults, methods to obtain properties of fractures and faults, methods to model groundwater flow in highly heterogeneous media, bounding the range of conceptual models of groundwater flow and the interplay of groundwater flow with elements of the EBS in assessing overall performance. Thus, important issues under this KTI will continue to require work [**23,24**].

KTI-9 Repository Design and Thermal-Mechanical Effects

The ACNW believes that repository design considerations will become more important in the near future. The NRC may need to add capabilities to allow proper evaluation of engineering considerations [**25**]. The ACNW will continue to monitor work in this area. The ACNW has unresolved concerns on work being performed on coupled thermal-hydrological-mechanical-chemical processes and will continue to evaluate progress in this area.

KTI-10 Container Life and Source Term

The objective of the NRC with respect to this KTI is to evaluate DOE's waste package performance assumptions; that is, the expected isolation of the waste for long periods of time before and after waste package breach. The task is complicated by multiple canister designs and configurations, which are functions of the type of spent fuel. Although much of the EBS research was cut in Fiscal Years 1995 and 1996, a modest corrosion testing experimental program continues and is focusing on the potential for waste package corrosion. The ACNW believes that research in this area is important and has commented on the CNWRA program in the past [**26**].

Some general observations and recommendations concerning the work managed by NMSS are:

Observation:

The NRC's role in high-level waste (HLW) research differs fundamentally from that of DOE. DOE must demonstrate, through extensive analysis and field investigations, the suitability of Yucca Mountain as a HLW repository. The NRC will judge the adequacy of this demonstration. Thus, although DOE's research budget may dwarf that of the NRC, NRC must be seen as fully capable of making the judgment on the adequacy of this demonstration. The judgment requires unquestioned stature in the national and international HLW communities.

Observation:

Given the relatively modest budget of the NRC, its research and technical assistance programs must focus on the most important issues for risk, must be flexible enough to handle new problems as they arise, and must be supported by top experts so that the results will carry the respect of the scientific community.

Recommendation:

NMSS should continue to use results from total systems performance to guide the technical work contracted to the CNWRA. This approach contributes to a rational plan to focus on important issues. NMSS should maintain procedures with the CNWRA that allow for a great deal of flexibility in the definition of tasks. Reliance on contracts outside the CNWRA can enhance flexibility.

Observation:

Several aspects of the NRC work on Yucca Mountain are viewed currently in the larger community as either overly conservative or simplistic. This attitude is due, in part, to a lack of involvement of senior, recognized experts in the technical investigation work. Exclusive reliance on the CNWRA to provide research and technical assistance is a limiting strategy, which could prove to be a stringent constraint at the time of licensing. Current provision allow 15 to 20 percent of the budget of the CNWRA to be devoted to contracting outside experts.

Recommendation:

The CNWRA is the primary designated source for contracting outside experts. It is essential for well-known scientists and engineers who have an outstanding reputation in the waste field to assist the NRC in the resolution of waste management problems. Funding commensurate with this objective needs to be provided.

B. Waste Management Research Conducted by RES

On the basis of presentations made by the RES staff, the ACNW concludes that work currently being performed in the areas of radionuclide transport and behavior in the environment and of decommissioning and environmental protection (e.g., in hydrology, engineered barriers, source term characterization, and geochemistry) is of good quality. The work being performed is likely to provide results useful to the NRC. The overall goal expressed by the RES staff, the development of a code to compute the transport of radionuclides in a "generic" environment, is one that could contribute very significantly to an efficient approach to licensing decisions.

The ACNW was not able to discern an objective planning mechanism for identifying the highest priority areas for research. The process for selecting specific projects to be undertaken appears to be based on the intuition and experience of staff and managers regarding topics that are likely to be important. Given the severe budget restrictions for work in RES, a more formal and transparent process for identifying the most important areas for research is needed. The presentation made to the ACNW by the Electric Power Research Institute (EPRI) highlights a possible approach for an organization with a modest research budget. EPRI uses a total systems performance model to generate candidate topics for important research areas. Evaluation by outside experts is used to refine and focus the topics. Particular attention is paid to work that is not already being performed by others. Competent researchers are identified and their participation is sought for the particular study. The key attributes for accomplishing these goals are to focus tightly on the most important issues, to remain flexible so that new issues can be addressed as they arise, to avoid duplication of effort, and to "leverage" investments by appropriate collaboration.

Observation:

For research to be useful in the NRC context, it is necessary that it be responsive to NMSS user needs and that it be timely and authoritative. It is not clear that the current research structure ensures that all of these conditions will be met.

Recommendation:

A formal organizational structure that identifies and prioritizes research needs and subjects these needs to peer review should be put in place to ensure close coordination and collaboration between the developers of research results and the users of those results.

VI. NEED FOR THE NSRRC FUNCTION

In this Chapter, the ACRS responds to the question posed by the Commission on the continued need for the function performed in the past by the Nuclear Safety Research Review Committee (NSRRC). To respond to this question, the ACRS first examined the functions recommended for the NSRRC and the functions actually performed by the NSRRC. The ACRS, then, compared these functions to the changed environment that exists now for research at the NRC. Based on this comparison, the ACRS arrived at its recommendation that the NSRRC function is no longer needed by the agency.

The NSRRC was established in response to a recommendation of a National Research Council review panel [3]:

> "The NRC needs a formal mechanism for acquiring external advice on the philosophy, management and content of its research program. The Committee therefore recommends: The NRC should impanel an independent advisory group reporting to the director of research, with expertise in the range of disciplines relevant to nuclear safety research. The group should be charged with independently reviewing for the director of research from the perspective of the general principles cited in this report, the overall structure and thrust of the research program."

The general principles considered in the report from the National Research Council included:

- The benefit of the research should be worth the cost.

- Research should be done with the best facilities and the best people without undue regard for whether they are affiliated with a national laboratory, a university, or industry.

- Use systems and procedures that will ensure the integrity and independence of the results; care should be taken to ensure that all laws relating to conflict of interest are obeyed, and procedures should be used that can guarantee, independently of the NRC staff, the quality and integrity of the results.

Functions specified in the charter of the NSRRC [2] included advising the Director of Nuclear Regulatory Research on:

- conformance of the NRC Safety Research Program to the NRC philosophy of Nuclear Regulatory Research, as stated in the Commission's Strategic Plan, and to specific Commission directions,

- likelihood that the Research Program will meet the needs of the users,

- appropriateness of the longer range research programs and their directions,

- whether there are other options, including cooperative programs, that would yield higher quality work or otherwise improve the research program efficiency, and

- whether the research programs are free of obvious bias and whether the research products have been given adequate, unbiased peer review.

A lot has changed with the NRC Research Program since the review by the National Research Council and the establishment of the NSRRC. Notable among these changes are the following:

- the NRC has become a full cost recovery institution so that, in fact, all the research is paid for by the nuclear industry,

- the Research Program is now budgeted at a level that is less that 1/3 what it was,

- the Research Effectiveness Review Board has been established to ensure that user needs are being met by the Research Program,

- the NRC has begun to do more research with its own staff as opposed to contractors,

- cooperative research with the Department of Energy (DOE), industry, and international institutions has been encouraged by the Direction Setting Issues **[11]** of the Commission as part of the research program,

- consolidation of the base of contractors used for research and greater use of academic institutions for research work have also been established by the Direction Setting Issues **[11]** and the Strategic Plan **[12]**, and

- the NRC has adopted for many of its research activities outstanding peer-review practices, especially for assessing the completed work.

These changes to the Research Program and the environment it operates within have largely supplanted the need for the NSRRC. The only remaining function of the NSRRC that is still needed is the review of the Research Program to ensure that it conforms with the NRC philosophy of research and directions given by the Commission. Review of the technical aspects of the research programs as they are initiated and as they progress is an essential process. The ACRS then makes the following recommendation:

Recommendation:

The NRC no longer needs most of the functions of the NSRRC. The Commission does need a Research Program and needs to ensure that this Program conforms to the NRC philosophy of research and directions given to the Program by the Commission. Review of the need, scope, and technical content of research activities can be fulfilled by the

ACRS, supplemented by the Research Effectiveness Review Board's oversight of the Research Program and by the peer-review practices adopted by RES.

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APPENDIX A: DETAILED BREAKDOWN OF RESEARCH ACTIVITIES

The tables in this appendix provides additional details on work in the various research programs managed within the Office of Nuclear Regulatory Research.

Table A-1. Activities and Projects in the Reactor and Plant Performance Program

Activity	Projects
Thermal Hydraulics/ Reactor Physics	
	Boron Mixing Experiments
	Analysis of Reactivity Transients
	Integral Test Facility Calculations with RELAP5
	Reactor Safety Data Bank
	Maintenance of TRAC-BWR
	PUMA Integral Test Facility
	OSU Integral Test Facility
	RELAP5 Maintenance
	Thermal Hydraulics Research
	Rod Bundle Heat Transfer
	TRAC-P maintenance and consolidation
	Two phase flow and heat transfer for CFD
	Development of models for CFD code

Activity	Project
Fuel Behavior	
	Code Development for High Burnup Fuel
	Cladding Metallurgy for High Burnup Fuel
	Fuel tests at the IGR in Russia
	Support for the Halden Fuel Program
	Support for a water loop in the CABRI reactor in France

Activity	Project
Advanced Instrumentation and Control	
	Membership in the OECD Halden Project
	Provide line organizations with regulatory guidance related to qualifications of instrumentation and control systems with regard to lightning, smoke, EMI/RFI, thermal loads, camera flash, and relay arcing
	Structured review guidance for requirements of software-based digital safety systems
	Provide the technical basis and review guidance for use by line organizations in the evaluation of the effectiveness of human-system interfaces at computer-based control stations; revise NUREG-0700
	Effects of smoke on electronic components
	Development of guidance to assess "commercial-off-the-shelf" (COTS) hardware and software
	Development of technical bases for review guidance on emerging issues and technologies
	Develop measures of software system reliability and methods for modeling digital systems in PRAs
	Provide line organizations with the technical bases and review guidance for assessing the quality of software used in nuclear power plant systems including development of tools for assessing software; Integrated digital system safety assessment.

Activity	Project
Human Factors and Organizational Performance	
	Root cause investigation improvements
	Management and organizational factors in plant performance assessments

Activity	Project
IPE/IPEEE Reviews	
	IPEEE submittal review for external hazards
	IPEEE insights
	Screening reviews of internal fires
	Screening reviews of seismic hazards

Activity	Project
Severe Accident Risk	
	SCDAP maintenance and assessment
	OECD RASPLAV
	MELCOR code development
	VICTORIA validation
	FARO molten fuel coolant interactions
	Lower head failure experiments
	CONTAIN Code Assessment
	IFCI Maintenance and assessment
	Direct containment heating issue resolution
	Implementation of revised source terms for LWRs

Activity	Project
Reactor Probabilistic Risk Assessment	
	SAPHIRE code maintenance
	Tech. Support in risk assessment
	MACCS maintenance
	Application of risk insights in regulatory activities
	Plant database
	Incorporate aging effects into PRA
	PWR Level 2 and 3 models for the ASP program
	Consequence model methods development
	ASP extension
	BWR Level 2 and 3 models for the ASP program
	Technical support for ASP models
	Statistical support for risk analysis
	Events analysis for HRA methodology
	Digital I&C
	Accelerated development of risk based regulations
	IPE Followup
	HRA methods based on operating experience (ATHEANA)
	Fire risk analysis
	Low power/shutdown risk analysis (FY 1999)

Activity	Project
Reactor Radiation Protection	
	ALARA center dose reduction implementation
	Radiation protection/measurement study
	NEA information system on occupational exposure
	Radiation protection issues
	Support collection and analysis of occupational radiation exposure data
	Deterministic effects of occupation exposure

Table A-2. Activities and Projects in the Reactor Materials and Component Behavior Program

Activity	Project
Reactor Vessel Integrity	
	Heavy section steel program
	Heavy section steel irradiations
	Elastic plastic fracture mechanics evaluations for LWRs
	Improved irradiation embrittlement correlations
	Vessel irradiation survey
	Embrittlement data base & dosimetry evaluation program
	Radiation embrittlement damage analysis and predictions
	International pressure vessel technical cooperation
	Design and metallurgical production of surrogate steel
	Nondestructive characterization of RPV steels
	International conference - NDE round robin
	Pressure vessel database in ACCESS format
	Dosimetry technology

Activity	Project
Environmentally assisted cracking	
	Environmentally assisted cracking of LWRs
	International cracking research

Activity	Project
Nondestructive Examination procedures	
	Assessment of the reliability of UT and NDE methods

Activity	Project
Mechanical/Electrical Components	
	Qualification of safety-related cables
	Test & inspect safety-related fluid system components
	LOCA testing of cables
	Effects of aging and emerging issues of MOV performance
	Integrity of nuclear piping-structural material issues
	Lightening effects
	environmental qualification and aging of electrical connectors
	transmission of grid stability/reliability
	LBB regulatory guide support

Activity	Project
Containment Integrity and Structural Aging	
	Containment integrity under extreme loads
	Capacity of aged/degraded containment
	Inspection of aged/degraded containment
	Japanese containment cooperation
	Seismic response of degraded structures and components
	Capacity of degraded bellows

Activity	Project
Structural and Civil Engineering	
	Hualien (Taiwan) soil structure interaction, large-scale seismic test program
	Seismic Analysis of piping
	Geological and Seismological Siting Studies
	Japanese collaboration on seismic issues
	Earthquake investigations
	Seismic data analysis and event selection
	Collaboration on seismic proving tests of concrete containment
	Garner Valley strong motion study
	Reevaluation of regulatory guidance for modal combinations
	Reevaluation of regulatory guidance for seismic category 1 concrete
	Displacement based seismic design
	Integrity of nuclear piping- structural - materials issues
	Finite element modeling of coastal storm surges

Activity	Project
Generic Safety Issues Resolution	
	TA for prioritizing and resolving generic issues
	Streamlining the codes and standards process

Table A-3. Activities and Projects in the Materials Research and Regulation Development Program

Activity	Project
Materials Probabilistic Risk Analysis	
	Methods for medical risk studies
	Technical assistance for sealed source risk study
	Dry cask PRA
	Risk methods for non-reactor facilities

Activity	Project
Materials Regulatory Standards	
	Development and applicability of criticality safety software

Activity	Project
Materials Radiation Protection	
	Technical basis to support a clearance rule
	Funding to support BEIR-VII
	Health physics TA - Materials

Table A-4. Activities and Projects in the Decommissioning Program

Activity	Project
Radionuclide Transport and Behavior in the Environment	Support for National Academy of Science workshop on fracture flow.
	Radionuclide solubilities.
	Low-level waste performance assessment methodology.
	Monitoring water movement through covers for near-surface radionuclides.
	Testing and evaluating conceptual ground water flow and transport models.
	Facility support for RES staff work being conducted at Johns Hopkins University on characterization of decommissioning slags.
	Extension of determination of sorption kinetics for anionic exchange capacity of soils to test model performance.
	Field test of surface complexation models of sorption.
	Evaluation of preferential flow through heterogeneous media.
	Radionuclide pathway and uptake studies.
	Determine thermodynamic data for radionuclides.
	Source-term characterization.
	Unsaturated zone monitoring and field studies.

Activity	Project
Decommissioning and Environmental Protection	Decommissioning support for rule implementation
	Guidance and models for reusing and recycling of materials.
	Environmental policy and decommissioning issues.
	Environmental modeling support.
	Radiological criteria for environmental effluents.

APPENDIX B: ACRONYMS

ACRS	Advisory Committee on Reactor Safeguards
ACNW	Advisory Committee on Nuclear Waste
AEOD	Office for Analysis and Evaluation of Operational Data
ALARA	As Low As Reasonably Achievable
APEX	Advanced Plant Experiment
ASME	American Society of Mechanical Engineers
ASP	Accident Sequence Precursor
ATHEANA	A Technique for Human Event Analysis
ATWS	Anticipated Transients Without Scram
BEIR	Biological Effects of Ionizing Radiation
B&W	Babcock and Wilcox
BWR	Boiling Water Reactor
COTS	Commercial-Off-The-Shelf
CFD	Computational Fluid Dynamics
CNWRA	Center for Nuclear Waste Regulatory Analyses
DOE	Department of Energy
DSI	Direction Setting Issue
EBS	Engineered Barrier System
ECC	Emergency Core Cooling
EMI	Electromagnetic Interference
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FIVE	Fire Induced Vulnerability Evaluation
GL	Generic Letter
HEPA	High Efficiency Particulate Air
HLW	High Level Waste
HPI	High Pressure Injection
HRA	Human Reliability Analysis
IASCC	Irradiation Assisted Stress Corrosion Cracking
I&C	Instrumentation and Control
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
KTI	Key Technical Issue
LBB	Leak Before Break
LOCA	Loss of Coolant Accident
LPSI	Low Pressure Safety Injection
LWR	Light Water Reactor
MOV	Motor Operated Valve
NDE	Nondestructive Examination
NEA	Nuclear Energy Agency

NMSS	Office of Nuclear Material Safety and Safeguards
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
NSRRC	Nuclear Safety Research Review Committee
OECD	Organization for Economic Cooperation and Development
PRA	Probabilistic Risk Assessment
PTS	Pressurized Thermal Shock
PUMA	Purdue University Multidimensional Integral Test Assembly
PWR	Pressurized Water Reactor
RCIC	Reactor Core Isolation Cooling
RCS	Reactor Coolant System
RES	Office of Nuclear Regulatory Research
RFI	Radiofrequency Interference
RPV	Reactor Pressure Vessel
SCC	Stress Corrosion Cracking
SRM	Staff Requirements Memorandum
TA	Technical Assistance

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG-1635, Volume 1

2. TITLE AND SUBTITLE

Review and Evaluation of the Nuclear Regulatory Commission Safety Research Program

A Report to the U. S. Nuclear Regulatory Commission

3. DATE REPORT PUBLISHED

MONTH	YEAR
June	1998

4. FIN OR GRANT NUMBER

5. AUTHOR(S)

6. TYPE OF REPORT

Annual

7. PERIOD COVERED *(Inclusive Dates)*

Fiscal Year 1998

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Advisory Committee on Reactor Safeguards
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division; Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Same as above

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report provides a response to the Commission's request for the Advisory Committee on Reactor Safeguards (ACRS) to review the NRC Safety Research Program. The Commission asked the ACRS to examine the need, scope, and balance of the Reactor Safety Research Program, among other things, in the Staff Requirements Memorandum of September 9, 1997. This report provides observations and recommendations on engineering the Safety Research Program, comments on specific research activities, waste management research at the NRC, and the continued need for the Nuclear Safety Research Review Committee (NSRRC) function.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Nuclear Reactors
Nuclear Reactor Safety
Reactor Operations
Safety Engineering
Safety Research

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)
Unclassified

(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

Printed on recycled paper

Federal Recycling Program

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001