NUREG-1635, Vol. 3

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
with contributions from the
ADVISORY COMMITTEE ON NUCLEAR WASTE
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

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INTRODUCTION

This report is the third annual report by the Advisory Committee on Reactor Safeguards (ACRS) to the Nuclear Regulatory Commission (NRC) in which we respond to the Commission's request (Staff Requirements Memorandum dated September 9, 1997) that we evaluate the research being performed by the agency. Our 1998 and 1999 research reports each reviewed activities in about a dozen areas, covering most of the programs identified by the Office of Nuclear Regulatory Research (RES).

In this report, we present more of an overview. We examine the internal and external contexts that together determine the needs for research and the corresponding responses of the agency. We discuss how the role of NRC research has evolved and may develop in the future. Along the way, we describe some major issues that the Commission may face and that we believe will require the development of a better knowledge base through appropriate research.

Our 1998 report made several recommendations about how the NRC should conduct its research, one of which was the need to achieve a closer tie between research activities and agency needs. In this report, we make some suggestions about how this goal could be achieved.

In the latter half of the report, we present specific evaluations of research requirements in response to what we view as the more significant of the future issues. This list is not intended to be comprehensive; lack of mention of a research project does not imply an assessment of the value of that project.

THE EXTERNAL CONTEXT

The predominant issue for the NRC during the past year has been to improve the effectiveness and efficiency of its regulatory programs. In this regard, it has improved enforcement, inspection, and oversight processes (we note that some of the groundwork for this was done by RES in the 1980s and early 1990s) and has taken steps to expedite its processing of licensee submittals.

The industry and the NRC are still gaining experience with risk-informed regulation and are just beginning to learn, for example, from recent experiences with risk-informing inservice inspection (ISI) and quality assurance (QA), that there may be significant rewards from obtaining changes in the regulations by risk-informing 10 CFR Part 50. The need for reliable and comprehensive probabilistic risk assessments (PRAs), with a robust resilience to criticism, for the evaluation of risk measures and margins at individual plants has not yet been essential. As PRAs become more frequently used as the basis for licensing decisions, it is crucial for the agency to establish how good the PRA basis must be.

License renewal is an activity of great importance to the nuclear power industry and consumers. It is currently consuming about 20 percent of the resources of the Office of Nuclear Reactor Regulation (NRR). License renewal appears to be readily achievable by assuring proper management of aging through existing and planned programs. The technical basis provided by two decades of research on aging issues by the NRC and the industry has been adequate for addressing most of the issues that have arisen in the review of the first two license renewal applications (Calvert Cliffs and Oconee). Although there are a few technical issues, such as void-swelling of austenitic stainless steels, remaining to be resolved, no major new questions have appeared that might lead to several years of delay until research results are available to answer them.

The interested public, particularly the group of stakeholders that attends NRC meetings, is dominated by representatives of the regulated industry and related parties. The NRC has not had to face major legal challenges or serious technical critiques by the professional engineering community (e.g., concerning limitations in computer models of the sort that occurred in the modeling of delayed neutrons). Historically, RES has played a major role in convincing this broader community that there is a strong technical basis for regulations.

A climate of confidence has grown up that most issues brought to the NRC can be resolved by engineering judgment and changes in regulations, rather than by developing new ideas, knowledge, and methods. This apparently technically undemanding environment has led to a decline in appreciation for the products of research.

This situation is unlikely to persist for long. The nuclear industry is far from static. It is likely to face major economic challenges, particularly in the aftermath of deregulation of the electrical utilities. These challenges will lead to pressures to improve efficiency and reduce costs associated with regulatory paperwork, large personnel inventories, and those required structures, systems and components (SSCs) that are perceived to make little or no contribution to public safety. Licensees will also have incentive to enhance income by such measures as increased power output from a given installation, higher fuel burnup, use of improved fuels, greater use of on-line maintenance, and reduction in outage times. Obsolescence of analog instrumentation will encourage the adoption of digital instrumentation and other design changes. Public policy on proliferation may lead to the use of mixed oxide fuels, which have not been licensed in this country.

Although review of the two current license renewal applications has not revealed new technical challenges, it is possible that research may be required to respond to issues that may arise during the review of the large number of anticipated future applications.

The regulations that govern this industry are essentially first generation. They have been built up over the years and are sometimes inconsistent and of marginal safety significance. Risk-informed regulation is still in its infancy. The more straightforward applications, such as focusing inspections on the more risk-significant components, have been completed. Bigger changes have just begun to be contemplated and researched. If large changes are made, they may give the appearance of permitting excessive reduction in safety margins. The NRC must have sound technical bases on which to defend its decisions.

Consolidation of nuclear facilities under a few large operating companies, rather than the dozens of the past, as well as the increasingly assertive role of the Nuclear Energy Institute (NEI), has potential to make the nuclear industry more articulate, insistent, and aggressive in seeking regulatory changes for its own benefit. In response, the NRC must ensure that its knowledge base and tools for technical evaluation keep pace with the sophistication available in industry, which can change very rapidly once incentives are in place and appreciated. The NRC needs to plan research now in order to be prepared to respond to proposals that more adaptive and demanding licensees may make in the future.

The cost of failure to anticipate these issues and prepare for their resolution on a sound technical basis could be extensive delays while the requisite knowledge is acquired. Moreover, there can be unanticipated long-term benefits from research, for example, risk-informed regulation would have been impossible without the pioneering Reactor Safety Study (WASH-1400); beyond design basis accident regulation depends heavily on research reported in NUREG-1150; and current relicensing decisions are being facilitated by the results of anticipatory research on aging.

THE INTERNAL CONTEXT

The NRC operates in an environment of high technical content. Many regulations, although incorporating the necessary legalistic framework, eventually come down in practice to the assessment of whether some parameters (e.g., pressure, temperature, dose, probability of failure) meet or are sufficiently far from an acceptance criterion. The agency must have the base of technical knowledge and analytical tools to keep pace with the current and anticipated questions it is called upon to answer about the evaluation and interpretation of these parameters. Building and maintaining this base is the primary objective of research.

If one relied only on the recent annual reports of the NRC, it might be concluded that this technical base was established long ago and requires no further extension or improvement. There is little acknowledgment that a significant output of a major part of the NRC is the improved knowledge and methods that will enable it to function effectively in the changing nuclear world. We cannot find statements in the annual report about need for the various research projects that are derived from the agency's goals, nor do we see measures defined for determining whether these projects are adequate and appropriate. This may be an indication that the line organizations do not devote enough resources to defining anticipated benefits from research, or it may be that RES needs to more completely articulate the connection.

As an example of one of the Commission's objectives that may depend on improved analytical methods, consider the statement (p. 40 of the 2001 performance plan) that one of the agency's goals, "reduce unnecessary regulatory burden," is to be achieved by improved regulations and consultation with stakeholders. How is one to determine which burden is "necessary" and which is "unnecessary"? The relationship between a regulation and definite measures of safety is often remote and tenuous. A great deal of work and analysis is necessary to establish a basis for reducing burden in a defensible way (e.g., how are the current prescriptive requirements related to risk metrics?). Reduction in burden can perhaps be most rationally achieved when the margins in prescriptive regulations are justified in terms of uncertainties in the evaluated risk metrics. Risk information, in the form of PRAs, is only part of the needed technical base. Better representation is also needed of actual physics and more realistic modeling is needed of the course of events during accident scenarios. The credibility and precision of this information will have to be improved as burden reduction decisions become sensitive to its accuracy. It is unrealistic to assume that much progress can be made beyond the more trivial reductions of burden without supporting research and development of the appropriate tools for evaluation and decisionmaking. This research and development will require much stronger links between the developers of these tools in RES and the line organizations that will use them. We could make similar comments about other goals.

The 2001 performance plan includes descriptions of many research areas, all of which appear reasonable and are justified by very general reference to the agency's performance goals. However, there is no assessment in the plan as to their value or answers to questions such as:

- Is this issue delaying or otherwise restricting the achievement of performance goals?
- What specific results will improve definite measures by which performance goals are met?
- What are the consequences of not having the knowledge that the research is designed to provide?

Answering such questions is not solely the responsibility of RES. Line organizations need to identify how research will pay off in terms of measures of success, such as efficiency, timeliness, maintenance of safety, and reduction of unnecessary burden. Specific objectives, examples, technical issues, and assessments of quantifiable benefits should reflect agency-wide awareness and cooperation in establishing them.

THE EVOLVING ROLE OF RESEARCH

In 1974 Congress mandated the existence of the Office of Nuclear Regulatory Research to ensure "an independent capability for developing and analyzing technical information ..in support of the licensing and regulatory process." Because of the great interest at the time in loss-of-coolant accidents (LOCAs) and an acute awareness of the need for technical information, RES enjoyed generous budgets and great opportunity to assert its "independent" role. The regulatory actions of the NRC were clearly seen to depend on the results of this research. The accident at Three Mile Island, Unit 2 provided additional stimulus in the 1980s to turn attention to research on severe accidents.

Today the situation is different. According to Direction Setting Issue-22, "..there is a mature industry in place and the research conducted in industry provides a substantial part of the information needed by NRC to meet its responsibility.....the objective (of NRC research) is to have a clear and sufficient knowledge of the issues involved which then allows the NRC staff to either confirm or deny the position or analysis put forward by industry."

We only agree partially with this assessment and disagree with the implied inference that the NRC should relax its research activities. In many cases, a proper review can only be performed by professionals who are actively engaged in using tools that are equally or more sophisticated than those developed by the industry. Otherwise, the agency could be viewed as a rubber-stamp machine, easily convinced to go along with whatever selected results industry chooses to provide. The technical basis for these results is often dependent on assumptions and choices with implications and limitations that are only apparent to active practitioners in the field. This is why, for example, ACRS strongly favors NRC's development and use of its own calculational tools, such as thermal-hydraulic codes and PRA methodology, and an ability to knowledgeably test, by active participation, methodologies that are submitted by applicants. These tools include methods such as those being used by licensees to plan work during refueling and forced outages.

We also question if it is wise to rely too much on industry as the major source of definitive research. In the past, it was often viewed as the role of NRC to do the research necessary to define critical criteria, while the role of industry was to demonstrate that its designs met those criteria. Under current budgetary constraints, this process is no longer possible. The NRC still must be able, however, to independently define the information that needs to be developed to demonstrate safety and to properly review that information. We believe that an active NRC research program is needed to perform these functions.

Certainly the nuclear power industry is more mature in the sense that there is a bigger base of operational experience now than there was when most of the regulations were written. The industry is, however, not static. Regularly the industry asks the NRC to approve changes in the licenses of plants. The NRC staff's examinations of these licensee applications range from simple reviews to thorough independent evaluations to confirm the validity of licensee contentions using tools and methods at least as sophisticated as those used by the licensee. The efforts needed to maintain the capabilities to perform these two types of reviews are quite different. Ongoing research to develop and advance tools for in-depth, independent confirmatory analyses forms the enduring or core capabilities of NRC research. Examples of these core capabilities include computational thermal hydraulics and probabilistic fracture mechanics. The ACRS has, however, never seen clear criteria for the selection of areas that merit detailed, independent confirmatory reviews mandating the maintenance of ongoing research programs to develop and validate analytic tools and capabilities for line organizations, compared with those for which a review of industry-supplied results is sufficient. The agency should establish such criteria.

Although the primary role that we see for the Office of Research at the NRC is to support the line organizations (for example, providing the tools to enable risk-informed regulation to become a reality), this does not mean that it should be relegated to a service role of providing mere technical assistance on demand based on existing knowledge. It will also have to be a proactive organization seeking new knowledge to respond to unresolved current problems and likely future needs, having the foresight to ask the appropriate questions before the agency is under pressure to supply the answers. It will have to retain the independence to draw attention to important issues and opportunities outside the planned work scope of the agency and occasionally take unexpected or unpopular positions when these are justified by resulting clear benefits to nuclear safety and improved regulation. It should also conceptualize what to do if current approaches encounter unexpected difficulties.

At the same time, the line organizations of NRC must have more stake in, appreciation for, and confidence in these research efforts. They must understand and play a role in defining the return on investment from products of research. RES, in isolation, cannot realistically anticipate, justify, evaluate and prioritize its activities; it would be forced to be continually on the defensive, which will hurt its morale, effectiveness and, eventually, the technical integrity of the entire agency. This does not mean that all, or even a majority, of the research should necessarily be initiated by the user-need pathway. RES should also have the capacity to develop proposed research and obtain a fair hearing on its potential value.

The agency needs to establish mechanisms whereby all its offices contribute to a climate in which key uncertainties and opportunities are discovered, debated, assessed, and resolved and in which appropriate new insights, analytical tools, and decisionmaking methods are developed to a functioning maturity.

Recently, RES has made considerable efforts to relate its research programs to the performance goals of the agency. However, these goals are so general in nature that the connection may lack the specificity needed to evaluate the work. For example, evaluation of a program's contribution to "maintain safety" would require an assessment of the consequences of success or failure of the research on some specific measures of safety at individual plants. Evaluation of "reduction of burden" would require a preliminary analysis of likely requests from industry and the resulting savings if certain results were achieved. Evaluation of "timeliness" would involve an analysis of which decisions need to be made on what timetable, the costs of delays, and how research might influence these outcomes. We have seen little of this type of justification for research activities.

In the area of "public confidence", the NRC appears to emphasize relations with the general public, which we view as important and too often neglected by preoccupation with the internal mechanics of regulatory decisionmaking. However, there is another professional public composed of NRC contractors, scientists and engineers in the nuclear and related industries, professors and students at universities, workers at national laboratories, and others, including the agency's own personnel. Perhaps nothing could be worse than for this knowledgeable public to have the perception from contacts such as dealings with the NRC, review of its rationale for decisions, documentation of approved applications and safety evaluation reports (SERs), research reports, presentations at professional societies, and so on, that the agency is willing to compromise its technical skills and understanding by giving inordinate weight to the other desirable attributes of efficiency and economy.

RES has recently been asked by the Commission to define its role. In response, it has undertaken a self-assessment and has formulated a vision statement. We have had the opportunity to review these activities, and we hope our review will be useful for relating the activities of RES to the goals of the agency. We look forward to seeing how criteria developed from this study are actually applied to decisionmaking processes.

EVALUATION OF RESEARCH NEEDS AND RESULTS

The NRC needs effective agency-wide methods for:

- Identifying, formulating and expressing its needs for additional information, methods, and decisionmaking tools,
- Planning research activities in response to these needs, including a clear vision of the most useful forms of output from these activities,
- Evaluating the effectiveness of its research, redirecting efforts if appropriate, and determining whether the resulting products adequately satisfy the identified needs.

RES presently bears a large share of the burden of meeting these three needs. It is expected to be visionary in determining agency needs beyond those formally furnished in user-need requests, diligent at fulfilling them, and rigorous in the self-assessment of its own activities. Although RES should resolutely and imaginatively propose solutions to the problems that it perceives, the first and last of these tasks are, and should be appreciated to be, more appropriately shared by the entire agency and are ultimately the responsibility of the Office of Executive Director for Operations (EDO).

The NRC has partly responded to this situation by creating the Research Effectiveness Review Board (RERB) by way of SECY-97-224 (October 1997).

The RERB has met three times and asked some important questions (several resembling those we have raised in this report). Its output appears to have been a suggested revised user-need request form that may not have been implemented. The RERB has, based on comments in its minutes, experienced difficulty relating the authorization of the research, based on user-need letters, to how the work supported the Strategic Plan and whether the work was appropriate and timely.

We support the use of a universal user-need request form suggested by RERB as a replacement for the traditional requests, each of which has a different format. This step should enable each task to be more clearly related to the broader perspective of agency needs. However, this minor change does not go far enough to address the fundamental problem.

To ensure that the original objectives of the RERB are met, we recommend that the EDO be more actively involved in ensuring that proper attention is paid to the first of the three tasks, the identification of research needs, particularly those that anticipate future agency-wide concerns. Some of the issues to be addressed would be:

- Definition of why the need is important, preferably with measures of this importance in terms of specific value expected in return for the investment of effort and a vision of the form that the results should take to be most useful,

- Criteria for evaluation of alternative ways to achieve the desired objectives,

- Indication of how success is to be measured or assessed.

The information should be reported in a form that is useful for the following purposes:

- For users to be satisfied with the stated objectives and to buy in to the expected achievements,

- For performers of the work to plan their efforts appropriately,

- For managers to evaluate when the efforts are focused and likely to succeed,

- For all parties to be able to assess whether and when the results of the work are adequate.

Articulation of these objectives should help the Commission, Congress, and the general public to understand the need for and the benefits from the NRC's research program.

RESEARCH REQUIREMENTS

We will now sketch out and attempt to justify some of the major concerns we believe require the Commission's attention, and which should be addressed by RES. Our aim is to supply perspective and rationale, not detailed plans or priorities that must be determined through the internal processes of the NRC.

I. RISK- INFORMED REGULATION

Evolution towards risk-informed regulation has been declared by the Commission to be a major thrust of the agency (Staff Requirements-COMSECY-96-061). We support this objective. In addition to increasing the efficiency of the regulatory process, risk-informed regulation can lead to a greater public understanding of the risks of nuclear power. It can also provide a connection between the prescriptive deterministic framework of regulations and public safety. In addition, risk-informed regulation provides the means to evaluate the impact of regulatory decisions on individual plants.

The development of Regulatory Guide 1.174 was a significant step forward toward implementing risk-informed regulation. At the same time, it was a somewhat tentative step. It dealt with small changes in the licensing basis. It contained qualitative advice about PRA scope and quality, adequate defense-in-depth, sufficient safety margins, and treatment of uncertainties. In our view, this advice must evolve to a set of procedures that are more definite, quantitative, and derived from a consistent analytical and logical base that is clearly understood and endorsed by all parties.

SECY-98-300 defined several options for proceeding toward the risk- informing of 10 CFR Part 50. A year ago, we felt that the problem was just beginning to be defined. In the past few months, the RES staff has exhibited intellectual leadership. The desired characteristics, scope and limitations of an improved set of regulations have begun to be laid out and a framework for approaching them developed. The real work is being initiated with efforts to select candidate regulations to be revised. This process is forcing the staff to face up to the questions of what specific safety functions are performed by existing requirements, such as prescriptive specifications and design basis accidents (DBAs), and how each function is to be performed by whatever is proposed as an improvement. It has been appreciated that words like conservative, margin, safety, defense-in-depth and so on will have to be given working definitions that are consistent, quantitative as much as possible, and suitable for incorporation into an analytical and logical framework for decisionmaking. This is a major task that requires sufficient commitment of resources. In particular, the analytic tools available to the staff for both broad and in-depth risk analysis will have to improve.

II. PROBABILISTIC RISK ASSESSMENT

PRA is a tool for the logical evaluation of risk. It is what makes risk-informed regulation possible. As is the case with other engineering tools, an extensive infrastructure of techniques, examples, empirical information, experience, verification, and formal procedures has to be built up to make the link between the basic concepts and widespread practical application. Until the technology is mature, this infrastructure must be developed by suitable research. As stated recently by John Ahearne in his discussion before the Commission of the report "The Regulatory Process for Nuclear Power Reactors," prepared by the Center for Strategic and International Studies (CSIS):

"...this risk-informed performance based regulation has to be based on solid understanding, and that's research.... ..unless there is a base of research to support this new trend, sooner or later a major problem is going to arise and you will find that the foundation is very weak."

PRAs continue to evolve and improve. The ongoing development of the ASME and ANS standards for PRAs should help to make them more widely accepted and used. At the same time, PRAs continue to be viewed with skepticism in some quarters. Some of the reasons are:

- Incompleteness or omissions in probabilistic models (e.g., those for human performance, fires, low-power and shutdown modes),

- Uncertainties in the supporting physical models (e.g., thermal-hydraulic codes, structural degradation models, fission product dispersion models),

- Exclusion of issues that entail risks but have not been included in PRA space (e.g., safety culture, instrumentation and control, aging of SSCs, and control room habitability),

- Limitation of current risk-importance measures for ranking some SSCs,

- Limited ability to perform plant-specific uncertainty analyses that include both parameter and model uncertainties.

Research is the remedy for these ills. RES has the lead for the majority of activities in the PRA Implementation Plan. We support its effort to restructure the plan and suggest the following objectives:

- Continual development of probabilistic models, based on additional data, experience, and quantitative analysis, in order to reduce dependence on qualitative elements such as judgment and expert opinion.

- Reexamination of all supporting mechanistic models and codes to determine the risk significance of assumptions, analytical frameworks, empirical coefficients, and other elements in the mathematical representations or solution procedures. The results should guide prioritization of upgrades and modifications to these codes and establish criteria for the successful completion of the work. For example, the reflood research program at Pennsylvania State University addresses an area with several recognized modeling defects that both the NRC staff and the ACRS intuitively sense play a key role in establishing PRA success criteria. It should be possible to quantify this intuition, develop corresponding measures of progress achieved, and explain the usefulness of the results to other components of the agency that will rely on them for making decisions.

- Development of creative ways to incorporate shutdown and low-power operations risk into a PRA methodology that accounts for representations of future unknown but likely configurations and durations.

Specific examples of why the PRA Implementation Plan needs revision include:

- Scoping risk assessments suggest that accidents during low-power and shutdown make contributions to plant risk comparable to all initiators during power operations. Without improved models of shutdown risks, results of the scoping studies cannot be discounted as NRC evaluates the safety importance of SSCs. Furthermore, without improved models, the NRC cannot independently evaluate the safety assessments made by licensees for its operations under low-power and shutdown operations.

- RES has developed a strategy to examine the adequacy of human performance modeling and whether current capabilities to predict human error need to be improved and, indeed, can be improved in technically justifiable ways. Unfortunately, this plan is not being expeditiously developed because of resource constraints that arise as a result of a lack of endorsement for work on what is undoubtedly the single biggest contributor to risk-human error.

- Common-cause faults are a large contributor to risk during normal plant operations, but the models used for predicting common-cause fault rates are now some 20 years old and still lack definitive verification.

We recognize that PRA research objectives will need to be prioritized. This prioritization must be based on the need for risk-informed decision making, which, in turn, will depend on the risk metrics the Agency will use in its decisionmaking process. These risk metrics will be derived from the Safety Goal Policy Statement, the revision of which we have recommended. We expect, however, that, regardless of the formulation of a revised Safety Goal Policy Statement, core damage frequency (CDF) and large, early release frequency (LERF) will be important metrics. We, therefore, recommend that priority be given to the needs of Level 1+ PRA, which leads to the calculation of CDF and LERF.

These activities should be guided by some ultimate goals or visions of what kind of future regulatory environment will exist when PRAs are fully established as robust, reliable, everyday tools. One might, for example, envisage a time when every staff member has immediate access, on a personal computer, to PRAs at appropriate levels for every plant in the country and has a supporting set of physical models, requiring only a few minutes to run, with which to address any emerging issue involving risk.

Fire Protection Research

Early results from the individual plant examination of external events (IPEEE) submittals by licensees show that fire can be an initiator of core damaging accidents at expected frequencies comparable to those predicted for operational events. Pursuit of risk-informed regulation and the assessments of the risk importances of SSCs will require that there be the capability to carry out defensible fire risk assessments. Fire risk assessment capabilities will also be needed to define risk-informed inspections for fire protection and to evaluate the significance of any violations that are detected by the inspections. If NRC is to independently evaluate the adequacy of the analyses and the fire protection capabilities of a licensee, it will need to have reliable fire risk assessment methods of its own. Indeed, many of the issues that have arisen concerning fire protection between the NRC staff and licensees, such as circuit analysis, could be resolved quickly if the agency had high-quality fire risk analysis tools based on well- validated phenomenological models.

NRC has identified needed improvements in its fire risk assessment methods. It has prioritized these needs and has begun a limited research program to meet some of these needs judged to be most important. We have been impressed with the quality and the care taken in the identification of the needs in this area. Indeed, the quality of the work now going on seems quite good. The program of research on fire risk assessment has not been shown, however, to have the breadth or to go to the depth needed to meet agency needs. The NRC needs risk assessment capabilities for fire that are comparable to those used in the study of operational events; this includes quantification of the uncertainties in a defensible manner. In light of budgetary restrictions on NRC research, it might take several years of work to reach this state of competence in fire risk analysis. The research program may be constrained more with an eye toward the calendar and the work done in the past than with the current agency needs in mind. We recommend, then, that the Commission encourage the staff to develop and carry out a defensible strategy for the improvement of its capabilities to perform fire risk assessment. This strategy should include the capability to perform accident sequence precursor analysis for fire events similar to what is now done for operational events.

III. LICENSE RENEWAL

License renewal will continue to be a major task of the Commission for the coming decades. Fortunately, because a great deal of anticipatory research has already been performed, both by the NRC and by industry, and gathered in the Generic Aging Lessons Learned (GALL) report, it appears that the majority of aging degradation issues, such as stress corrosion cracking, are adequately understood and are being suitably managed.

As we noted in our 1998 report, the staff's evaluation of the integrity of the reactor pressure boundary, reactor internals, and steam generators, has used a regulatory approach of compensating for insufficient information with added conservatism. This approach has resulted in highly prescriptive and taxing requirements. As the industry proceeds to expand its understanding of the degradation mechanisms affecting these components and to propose less restrictive requirements, the NRC must be able to independently verify that any changes to the regulatory criteria will not increase the probability of failure for these components to unacceptable levels. The identification of the modes of steam generator tube degradation and of water chemistry discipline applied to reduce corrosion rates has contributed to the stability of these issues that allows utilities to make informed decisions on overall plant license renewal. Research programs are needed in these areas to provide the staff with the technical expertise to perform adequate independent verification of the licensee's findings and to provide a clear rationale linking the "acceptable levels" of degradation to established measures of public safety. We also support efforts to risk inform the license renewal process so that it will be streamlined when a large number of applications are submitted in the near future.

IV. LICENSEE INITIATIVES

As noted earlier, we expect that economic pressures will lead the industry to press for reductions in regulatory burden and other economically advantageous changes. While we cannot anticipate all developments, we cite some areas in which we believe the agency needs to be prepared by way of a well-structured research plan.

Power Uprates

Power uprates of existing reactors are but one of the more obvious ways in which licensees can increase their income from a given facility. Small upgrades (5-10%) involve typically minor changes in the reactor, such as modification of the neutron flux profiles, and also in the balance of the plant, such as more precise feedwater flow meters and modified turbines. Such small upgrades have already been approved on the basis of qualitative arguments that no significant changes in design basis accidents (DBAs) would ensue. It is likely that larger upgrades cannot be justified without a more comprehensive analysis. The economics of nuclear power in a deregulated environment have reached the point where significant investment in increasing the capacity of the balance of plant (e.g., larger high pressure turbines, steam generators, and condensers with more heat transfer surface, more feed water heaters, etc.) may be justified. Such modifications could accommodate much higher power increases of up to perhaps 20 percent. This will require a marked improvement in understanding the real margins of safety and how they are influenced by uncertainties in the knowledge base and calculational tools, such as thermal-hydraulic codes, used by both the NRC and the licensees. The replacement of "conservative" methods by "best estimate" methods requires careful consideration of what is meant by the latter, what criteria they must satisfy, and what implications they have. If such understanding is not available, the agency will find itself in the uncomfortable position of relying progressively more on judgment to make decisions, when in reality the supporting logical substance becomes ever more tenuous.

Fuels

Using reactor fuels to higher burnups has significant economic advantages to the power production industry as well as advantages to society since less spent fuel would need to be disposed of. It has been found, however, that there are substantial changes in fuel morphology and fuel cladding fracture toughness as burnup exceeds about 48 GWd/t. NRC will currently allow licensees to use fuel to burnups of about 62 GWd/t. Safety concerns about these changes were raised by tests of fuel integrity during reactivity insertions conducted in France, Japan, and Russia. Analyses have suggested that there may be safety issues associated with other design basis accidents, such as large loss of coolant accidents and anticipated transients without scram (ATWS) in boiling water reactors. RES has undertaken a research program to confirm the safety of allowing licensees to burn fuel to 62 GWd/t. We support this program.

The nuclear industry believes that newer fuel claddings may well make it possible to take fuels to burnups higher than 62 GWd/t, perhaps as high as 75 GWd/t. NRC has indicated to the industry that the burden of providing data on fuel behavior at these higher levels of burnup, including behavior under accident conditions, will fall upon the licensees applying for higher burnups. NRC has not provided the industry with an indication of the type of information that will be required to support an application for burnups that go beyond 62 GWd/t. ACRS has suggested that RES should develop technically defensible information requirements including requirements for experimental data to validate analyses. RES has undertaken a Phenomena Identification and Ranking process using an impressive array of experts from around the world to help define these requirements to ensure safe fuel performance at high levels of burnup. The work is complicated by the move within the regulatory approach away from conservatively evaluated DBAs to more realistic analyses of accidents thought to have higher frequencies. Because future regulatory activities in connection with fuel may be focused on more probable accidents than DBAs, it is important that the RES efforts to understand the issues of high burnup fuel include understanding of the issues of radionuclide release as well as issues of fuel integrity and clad oxidation and embrittlement.

Another fuel issue on the horizon for the NRC is the possible use of mixed oxide fuel (MOX) as a means of disposing of some of the Nation's excess, weapons-grade plutonium. There is very limited experience with MOX within the NRC. There is some greater experience in Europe with MOX fabricated with reactor-grade plutonium. Experimental studies of MOX under severe reactor accident conditions have just begun. MOX behavior is sufficiently different from that of usual urania fuel that some European regulatory authorities have been moved to impose more limiting burnup restrictions on MOX than they impose on conventional urania fuel.

Use of MOX in the USA is currently a very limited effort concentrated at just a few (~4) commercial nuclear power plants. The burden of demonstrating the safety of the fuel will fall upon the Department of Energy and the reactor operators where the fuel will be used. A need for detailed, experimental investigations of MOX sponsored by the NRC has not been established. NRC does need to develop an understanding of the safety issues raised by the use of MOX and be prepared to define for applicants the information needed to support applications to use MOX. The Phenomena Identification and Ranking effort undertaken by NRC for high burnup fuel could be augmented to include the issues associated with the use of MOX. The Commission needs to find a way to free the RES staff to raise these issues with the experts it has assembled for the Phenomena Identification and Ranking activity.

Reduction in Margin

In the past, regulators have compensated for uncertainty by introducing conservative margins between expected behavior and challenges to safety. As knowledge improves, it is reasonable to seek reductions in these margins. Safety margins in the deterministic regulations are provided by the choice of acceptance values for certain parameters and by the conservative methods that are often prescribed for the calculation of the parameters.

The immediate issue is how the NRC should deal with licensee requests to reduce margin in DBA space by reducing the conservatism in calculational methods. RES needs to develop tools to ensure that this task is appropriately performed. These margins are based on the use of licensee-developed, and NRC-approved, calculational tools and on the judgmental conservatism required in the calculations. When a licensee applies for a reduction in the previously approved margins to the acceptance limits, the NRC needs to determine what the actual (as contrasted to licensee-calculated) margins are and what, if any, margin is needed, as well as specifying acceptance values for the associated uncertainties in the analytical determinations. NRC needs a "standard" set of calculational tools with quantifiable uncertainties (e.g., upgraded TRAC code, SCDAP, and

CONTAIN) that it can use to evaluate any such requests on a consistent basis and not have to rely on variable licensee-developed results with unknown uncertainties. Acceptable margins need to be clearly defined in terms of the uncertainties in the calculations.

As the agency moves more into a risk-informed regulatory system, there will be need for defining more global margins in terms of the risk metrics and the uncertainties in their determination. For the licensees that opt to make a transition to the risk-informed arena, the NRC will need to develop more definitive risk acceptance criteria that capture the full spectrum of releases and include some general criteria on societal risk as well as incorporating confidence limits.

New Technology

We anticipate that competitive pressures will spur the development of new technology by the industry. An example is the development of Electrosleeving to repair steam generator tubes; in that case, RES provided valuable input into regulatory decisions. Further examples are: digital instrumentation and control (I & C) which is displacing outmoded analog equipment, more accurate flow meters which may justify relaxation of conservative requirements due to uncertainties in the energy balance for the reactor circuit, and better in-core monitoring that will reduce uncertainties in reactor power output.

There may be even more innovative developments, such as high heat transfer cores, that will need evaluation by appropriate thermal-hydraulic models.

V. EFFECTS IN THE FIELD

It is important for the agency to have a clear awareness of how the intent of regulations is reflected by their actual impact in the world of plant operations (i.e., did the agency's output achieve the desired outcome?). We therefore support the ongoing information-gathering and analysis that RES has taken over from the former Office for Analysis and Evaluation of Operational Data (AEOD). This function includes not only the performance of equipment but also the behavior of the humans who run it.

The impressive steps taken by the NRC to clarify and improve its oversight and inspection programs need to be complemented by ongoing research into measures of success of such programs and a continued questioning about how things might be done better.

RES has had the lead for many of the activities associated with the implementation of PRA in the field. In a risk-informed regulatory environment, licensees will need to expand their use of PRAs. It is reasonable to expect that the quality of PRAs will improve and that research will need to play a part in order to make PRAs more widely accepted.

VI. INTERNATIONAL PROGRAMS

The NRC relies on a number of international cooperative programs to meet important research needs, for example: (a) the French-PHEBUS and VERCORS tests, which provide source term data for severe accidents, and (b) the Japanese-NUPAC 1/8-scale seismic containment experiments. Cooperation in these international programs is beneficial, particularly from a budgeting viewpoint. Indeed, without participation in such international programs, the NRC would not have some of the supportive data base to formulate regulatory positions in areas such as design basis criteria for high burnup fuels (>50,000 MWD/t), revised source term guidance for severe accidents, and seismic containment criteria.

Severe accident related programs have the potential to keep NRC current on issues that are likely to become more important in a risk-informed regulatory climate, particularly if risk acceptance criteria become more restrictive than the current Safety Goals. This is likely to happen in the context of risk-informing 10 CFR Part 20 and Part 100 that contain regulatory objectives involving radiation doses. If societal risk goals are added to the current safety goals, the current interpretation of LERF will have to change and involve better characterization of fission product release and transport behavior. The practical approach for NRC to keep current in these areas is to participate in the related international research programs.

A particular program that the NRC should evaluate in terms of its future needs is the Halden Reactor Project (HRP). While most international programs are limited in scope, the HRP is a continuing program that deals primarily with high burnup fuel technology, inpile materials experiments, human factors and digital instrumentation and control. The fuels work is considered as very valuable to RES and the materials research is directly related to NRC work at Argonne National Laboratory. The digital I&C and human factors work relates to both the needs of NRC and the industry.

The human factors program at Halden involves computer-assisted operation of nuclear power plants with a goal to improve operation of plants (fewer errors, more timely decisions, more rapid identification of changing conditions, etc.) where traditional operator training is seemingly approaching an asymptotic limit. We would like to see evidence that this work is actually utilized by the agency; we recently reviewed a technique for human event analysis (ATHEANA) and found no such evidence.

The digital I&C program involves surveillance, diagnostics, thermodynamic efficiency improvement, and the application of virtual reality to nuclear plants. ACRS recommends that NRC exercise its participatory managerial influence to ensure that experiments carried out at Halden meet the needs of the NRC to the maximum extent possible.

VII. NUCLEAR WASTE-RELATED RESEARCH[1]

The Advisory Committee on Nuclear Waste (ACNW) is charged with reviewing the safety research in waste management. There is a relatively small ($2.6 million a year in Radionuclide Transport and $1.3 million a year in Radiation Protection and Health Effects) research program in the Office of Nuclear Regulatory Research (RES) in this area. The Office of Nuclear Material Safety and Safeguards (NMSS) contracts with the Center for Nuclear Waste Regulatory Analyses (CNWRA) for technical assistance ($15.7 million a year), much of which is, in essence, research related to licensing and regulating the proposed repository for high-level radioactive waste (HLW) at Yucca Mountain, Nevada.[2, 3] Thus, the ACNW also considers that the work at the CNWRA that is related to HLW management is included in its review. This report on nuclear waste research is very brief as there has been little change in the programs from last year.

We base our update on our interactions with staff on issues related to decommissioning and the proposed Yucca Mountain repository. In particular, the RES staff made presentations to the ACNW at its 112th and 114th meetings in September and November 1999, respectively. The ACNW held its 110th meeting in June 1999 at the CNWRA facilities in San Antonio, Texas.

Office of Nuclear Regulatory Research

During its presentation at the 112th meeting, the RES staff discussed its role in developing performance assessment tools for waste-management and decommissioning applications. At the 114th meeting, the RES staff presented the other components of its Radionuclide Transport program and research prioritization.

During an office-wide self-assessment exercise, RES used the Analytical Hierarchy Process to rank all of its projects. We reported last year that we thought that RES should adopt a formal prioritization scheme to help guide its efforts. We are encouraged that RES has moved to such a scheme and will be interested in learning about the effectiveness of the process as experience is gained. We believe that a presentation of an agency-wide ranking of technical assistance and research programs and other activities would afford an opportunity to assess the relative need for RES programs.

We stated last year (NUREG-1635, Vol. 2) that the waste-management program in RES may be too small to accomplish what the NRC may need. We understand that RES is developing a research program plan that may allow us to evaluate more fully the adequacy and utility of the program.

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[1]This section was contributed by the ACNW.

[2]Until FY 1996, RES sponsored HLW research at the CNWRA and at other facilities.

[3]The FY 2000 CNWRA budget for HLW work is $14 million. The remaining NRC- sponsored work at the CNWRA supports other NRC activities related to waste management.

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In NUREG-1635, Vol. 2, we stated that we were favorably impressed with specific projects of the ongoing HLW work by the NMSS and CNWRA staffs. At our 110th meeting, held at the CNWRA in San Antonio in June 1999, we had additional opportunity to learn about some of the ongoing work. We also toured some of the facilities and met informally in small groups with scientists and engineers at the CNWRA to discuss specific areas of research.

At the 110th meeting, the NMSS and CNWRA staffs made extensive presentations on work on near-field chemistry, including corrosion. Other discussions involved hydrological studies (including thermal hydrology), studies related to igneous activity, and work on performance assessment modeling (including issues of quantification of individual barriers). The work appears to be of high quality and appropriate to the NRC's needs.

In summary, we think that the agency's efforts in research concerning waste management are fundamentally sound. We remain concerned about whether the resources available to the programs in both RES and NMSS are adequate and anticipate that we will review this issue as more information becomes available.

CONCLUDING REMARKS

The NRC needs a strong, highly motivated, research operation in order to be prepared to respond to changes in an industry and in a set of regulations that are by no means static.

We have sketched out the major roles and desirable features of such a program and compared them with our observations of the actual situation.

We have tried to provide the Commission with a perspective on what the needs of the agency are and how well research is responding to them.

We have emphasized the need for the entire agency to have more ownership in its research activities and their outcomes.

We have inclined towards a high-level assessment because that appeared to respond best to current concerns of the Commission and of its several offices, and because more detailed comments can be found in our previous evaluations of the research program (NUREG-1635, Volumes 1 and 2) and in the transcripts of our meetings with the professionals actually conducting the research.

We hope that the Commission will find our advice to be helpful as it makes future choices that influence the course of the agency and the technical base that it relies on to support its regulatory decisions.

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APPENDIX A: ACRONYMS

ACNW	Advisory Committee on Nuclear Waste
ACRS	Advisory Committee on Reactor Safeguards
AEOD	Analysis and Evaluation of Operation Data
ANS	American Nuclear Society
ASME	American Society of Mechanical Engineers
ATHEANA	A Technique for Human Event Analysis
ATWS	Anticipated Transient Without Scram
CDF	Core Damage Frequency
CNWRA	Center for Nuclear Waste Regulatory Analyses
CSIS	Center for Strategic and international Studies
DBA	Design Basis Accident
EDO	Executive Director for Operations
GALL	Generic Aging Lessons Learned
GWd/t	Giga Watt Days/Ton
HLW	High-Level Waste
HRP	Halden Reactor Project
I&C	Instrumentation and Control
IPEEE	Individual Plant Examination of External Events
ISI	Inservice Inspection
LERF	Large, Early Release Frequency
LOCA	Loss-of-Coolant Accident
MOX	Mixed Oxide Fuel
NEI	Nuclear Energy Institute
NMSS	Office of Nuclear Material Safety and Safeguards
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
PRA	Probabilistic Risk Assessment
QA	Quality Assurance
RERB	Research Effectiveness Review Board
RES	Office of Nuclear Regulatory Research
SECY	Office of the Secretary of the Commission
SER	Safety Evaluation Report
SSCs	Systems, Structures and Components
TRAC	Transient Reactor Code Analysis

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This report is the third annual report by the Advisory Committee on Reactor Safeguards (ACRS) to the Nuclear Regulatory Commission (NRC) in which we respond to the Commission's request (Staff Requirements Memorandum dated September 9, 1997) that we evaluate the research being performed by the agency. Our 1998 and 1999 research reports each reviewed activities in about a dozen areas, covering most of the programs identified by the Office of Nuclear Regulatory Research (RES).

In this report, we present more of an overview. We examine the internal and external contexts that together determine the needs for research and the corresponding responses of the agency. We discuss how the role of NRC research has evolved and may develop in the future. Along the way, we describe some major issues that the Commission may face and that we believe will require the development of a better knowledge base through appropriate research.

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