PERSPECTIVES ON REACTOR SAFETY

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Introduction

It gives me great pleasure to be able to address you today on the U.S. NRC's perspectives on nuclear reactor safety. Almost exactly a year ago, I visited India with former-Chairman Meserve, on a trip that marked the resumption of a U.S. - Indian dialogue on reactor safety issues. While cooperation between our two countries began about 10 years ago, it took a meeting between President Bush and Prime Minister Vajpayee in November 2001 to reenergize our bilateral efforts. Following that meeting, Chairman Sukhatme invited the NRC to send a delegation to India, resulting in last year's meeting and a commitment to expand our joint efforts from the three areas designated in the 1990s–fire safety, emergency operating procedures, and design modifications–to include risk-informed regulation and license renewal. We were pleased to welcome an Indian delegation led by Vice Chairman Sharma to the NRC in September 2003, to continue the dialogue; this trip provides us a further opportunity to help advance what Dr. Meserve referred to last year as "meaningful cooperation between our two countries in pursuit of nuclear safety." And I know that Chairman Diaz strongly supports the continuation and growth of our cooperative efforts, as well.

This trip also happens to follow closely the release, in January, of the joint statement by President Bush and Prime Minister Vajpayee on the "Next Steps in Strategic Partnership," or NSSP. The joint statement echoes Dr. Meserve's comments last year about our common values, built upon a commitment to democracy, and our common interests in science and technology, including the peaceful uses of nuclear power and the curtailment of proliferation. Accordingly, among the “next steps” specified in the NSSP is the continuation and expansion of the cooperative relationship in civilian nuclear safety and regulation that we have established over the last year, in areas of mutual interest and benefit.

India’s nuclear power program is clearly an ambitious one. The current plan calls for more than tripling the amount of nuclear electric capacity between now and 2012, and roughly doubling that amount between 2012 and 2020, with construction of more than 20 reactors in the next 16 years. At the same time, there is the continuing need to ensure the safe and reliable operation of the current nuclear fleet. We recognize the global nature of nuclear power safety; as we have seen repeatedly over the years, a nuclear-related accident anywhere in the world will affect the U.S., India, and the other nations who use nuclear power. Thus, we look forward to discussing our experiences with the AERB to enhance the safety of Indian reactors. And we also look forward to learning about how your nuclear regulatory experience can influence the U.S. NRC’s programs. I will be discussing these issues in more detail later in my remarks.

As we move forward in our joint efforts to ensure the safety of our nuclear plants–both those that are operating and those that may be built in the future–it is instructive to look back on our experiences over the past half century in the development and safety of nuclear power, to see what we have learned and to help anticipate future challenges. I would therefore like to devote the next part of my talk to a historical perspective on the evolution of nuclear power and nuclear regulation in the U.S.

Historical Perspective

The period just after World War II was an extremely active one in the development of nuclear reactor technology, and the U.S. was no exception. The experience gained during the war led many to believe that nuclear power was a technology that could be exploited to provide safe, economical electric power at a time when electricity demand was growing at very high annual rates. Legislation in 1954, which was passed in response to President Eisenhower's "Atoms for Peace" initiative--of which we have just celebrated the 50th anniversary--placed the development of nuclear power under civilian control and opened it up to industrial companies. Several major firms, including Westinghouse and General Electric, got involved almost immediately. I should also note that the 1954 law set up the beginnings of a nuclear power regulatory structure in the U.S. government.

The emphasis in those early days was on developing small, demonstration plants of various types, including water-, gas-, and liquid-metal-cooled designs. However, economies of scale quickly took over and began to dictate the use of larger reactors, with the placement of multiple units on a site, characteristics of nuclear power plant development that are with us still today. Furthermore, with control of the development of the technology in the hands of private industry, there was little pressure to come up with a standardized design. This eventually led to the development of two fundamental reactor types--pressurized water reactors and boiling water reactors--with each plant as essentially a "custom" design. The legacy of this approach to nuclear power development is, of course, with us today, as each of the nuclear plants we have today differs slightly from the others, even those designed by the same vendor.

The emphasis in regulating plants during these early days of nuclear power was design-oriented. The rules were established with an eye to ensuring that the designs had significant margins against failures, and had several "layers" of safety capability, which we refer to as defense-in-depth. In this way, the mandate of the Atomic Energy Act, to provide "reasonable assurance of adequate protection of public health and safety" would be fulfilled. To account for uncertainty and fundamental lack of knowledge--after all, there was no real operating experience for these new types of reactors--plants designs were intended to be highly conservative. Capital costs of the plants were not a major consideration because of the assumed low cost of operation once the plants started up.

Reflecting the emphasis on design, the concept of "design bases" guided the evaluation of plant safety. A set of hypothetical accidents was established to which the plant was required to respond with minimal damage to the reactor and minimal release of radiation. Although it was recognized that accidents beyond the design bases might theoretically be possible, these events were initially considered not to be credible.

Although the rationale for such an approach to regulation is fairly easy to understand, hindsight has amply demonstrated that a philosophy that is almost entirely design-based was insufficient, as was the belief that severe accidents were not credible. I will return to the latter point when I discuss the development of risk-informed regulation. For now, let me just note that our experiences in the 1970s demonstrated clearly that a conservative design was not the only thing about which we needed to be concerned. Both the Browns Ferry fire and the Three Mile Island accident showed that some plant designs had unanticipated weaknesses that might be unintentionally exploited by inadequately trained operators. TMI highlighted, in no uncertain terms, the key role that human factors plays in nuclear plant safety. Despite the seriousness of these events--TMI in particular--we can take some satisfaction in that the accidents also demonstrated that human initiative can help ameliorate weaknesses in design, and also that the designs themselves were exceptionally robust: despite destruction of most of the TMI core, little radioactivity escaped from the containment and there was no discernible impact on public health and safety. There are events that occurred outside of the U.S., which have served to reinforce the lesson that design vulnerabilities can be unintentionally discovered by human action, with catastrophic results. The accident at Chernobyl is perhaps the best illustration of this fact.

The lessons we have learned over the years, both from these serious events and many others with far smaller consequences, are that we must be constantly on guard against both known and unknown hazards, and that we can learn from these experiences to make both our regulations and our oversight of reactor operations more comprehensive and better able to ensure the health and safety of the public. In the next part of my remarks, I will expand upon the ways in which our experience has guided the development of our approach to regulation, up to the present day.

An Evolving Perspective

The TMI accident was clearly a watershed event for the NRC. It forced us to reexamine our processes for regulating power reactors and the underlying assumptions that had gone into the development of those processes. However, the NRC has always recognized and taken pride in the necessity of being a learning organization and of making the changes that are required to address the lessons that we learn. Many of our present-day activities derive from changes that were instituted after TMI, including the resident inspector program and our ongoing evaluations of operating experience and generic safety issues, which I will discuss in more detail.

We also saw from TMI that extremely conservative design criteria can sometimes actually lead to a decrease in safety. Prior to the accident, much of the NRC's concern relative to design basis accidents was focused on large-break loss-of-coolant accidents, and plants were required to have layers of safety systems to ensure that a large-break LOCA could be dealt with successfully. However, as TMI demonstrated–and, I should note, as was shown in Professor Rasmussen's Reactor Safety Study, the WASH-1400 report–a small-break LOCA was a more likely event, and the combination of design deficiencies and human error came together to create what was previously thought to be an "incredible" event. Although TMI was not the initiation of the NRC's study of risk, it certainly pushed us strongly in that direction.

As I mentioned, the NRC has ongoing programs to evaluate operating experience and generic issues. We see operating experience as a great resource to be mined for insights into the way nuclear power plants behave and the way operators respond to various types of problems and events. We also systematically evaluate events for their potential to result in accidents leading to core damage through our Accident Sequence Precursor Program. The Generic Safety Issues Program has been a one of our major emphases, as well, since it deals with issues and problems that can potentially impact many plants. For example, results of research on motor operated valves showed us that these components might not function as expected under design-basis loads. This generic issue was successfully resolved based on the development by the NRC and the industry of a comprehensive testing program to ensure that these valves would function as designed. Our evaluation of generic safety issues also led to our rules on anticipated transients without scram (ATWS) and station blackout (SBO); these rules reflect a focus on risk that is consistent with the way we address GSIs, and actually anticipated the establishment of our risk-informed approach to regulation, which I will address in more detail. More recent examples of generic issues include cable insulation degradation and the potential for blockages in containment sumps during LOCAs. The cable insulation issue is one that is not limited just to nuclear plants, but which has arisen in other industries, such as aerospace. We are using experience from those industries as well as our own to develop diagnostic and prognostic capabilities. The sump blockage issue has been informed from international experience, and clearly demonstrates the global aspect of nuclear safety performance: we learn not only from our own experience, but from experience outside of our own country, as well.

Another broad initiative that developed in part from the experience at Three Mile Island concerns the issue of nuclear plant risk. This is an area that has its own history, so let me take a few minutes and review what had happened prior to the TMI accident.

In the late 1960's, a paper by Reg Farmer started us down the road toward quantitative assessment of risk. He argued that it did not make sense to classify accidents as "credible" and "incredible." Instead, he advocated evaluating the entire spectrum of possible events and assessing the risk based on the probability of an event and its consequences. In 1972, the U.S. Atomic Energy Commission initiated the Reactor Safety Study, led by Norman Rasmussen of MIT, with the objective of quantifying the risks of nuclear plant accidents, along the lines originally proposed by Farmer. I already alluded to one of the insights from that study–that small break LOCAs were far more likely than previously believed–and although it generated a great deal of controversy at the time, WASH-1400 clearly demonstrated the value of PRA.

While PRA establishes a framework to evaluate the probability of severe accidents–which, after all, comprise the major contributor to plant risk–the other half of “risk,” that is, the consequences of an accident, can be determined only if the phenomena associated with severe accidents are also understood. Accordingly, the NRC has also been involved in severe accident research over a wide range of technical areas. A detailed discussion of the issues that we have investigated over the years would be far too lengthy to include here, but some of the programs have included in-vessel molten core behavior, molten core-concrete interactions, steam explosions, direct containment heating, and radionuclide transport in the environment. These research programs have allowed us to develop detailed analytical models that can assess accident consequences. The NRC has also had an active program to improve the techniques and broaden the applications of quantitative risk assessment. That program has included a detailed reassessment of severe accident risks, which was issued as NUREG-1150, and ultimately has served as the basis for moving forward into risk-informed regulation, a topic that I will discuss in detail very shortly. Another aspect of the NRC’s increasing focus on and appreciation of risk insights was the issuance by the Commission of the Reactor Safety Goal Policy Statement, which expressed in terms of individual and societal health impacts the level of risk from the use of nuclear power that the Commission considered to be acceptable.

Development and improvement of PRA techniques and phenomenological models have also served other important purposes, such as the development of processes and procedures for licensees to respond to severe accidents. These severe accident management strategies provide a systematic means of evaluating the use of both safety- and non-safety-related plant systems to deal with evolving severe accidents. In addition, changes to plant design or procedures can be contemplated to reduce severe accident vulnerabilities. Evaluation of these severe accident mitigation alternatives, or SAMAs, to find those that may be implemented in a cost-effective manner, is a required part of the NRC's license renewal process.

Of course, no discussion of the NRC's involvement with risk assessment can ignore what is almost certainly the most significant evolution in the NRC's approach to reactor regulation: the systematic incorporation of risk insights into the regulatory process, which we now call risk-informed regulation. This initiative acknowledges the great progress that we have made over the past 30 years in our ability to assess the risks associated with nuclear plant operations. However, I must emphasize that our knowledge is not perfect; there are still uncertainties and phenomena that are not well-understood. Thus, risk insights are used as one element of regulatory decision-making, not the only consideration; there is still a need to ensure defense-in-depth and adequate safety margins.

The ultimate objective of our move to risk-informed regulation is to allow both the NRC and our licensees to focus attention and resources on those areas associated with nuclear plant design and operation that have the largest contribution to plant risk. We often refer to risk-informed regulation as a two-edged sword. On one hand, we expect to find areas in which our regulatory requirements far exceed the risk posed by the target of the requirement. In those areas, a risk-informed approach would reduce the requirements without causing a significant increase in overall risk. However, we may also find areas in which our regulatory requirements have not been adequate to address the associated risk. In such cases, our risk-informed philosophy will result in an increase in regulatory requirements commensurate with the risk.

Risk-informed regulation has three "branches," if you will, with respect to the NRC's regulatory structure. First, risk insights are used as an integral part of the day-to-day oversight of reactor operations by NRC inspectors. This new Reactor Oversight Process, or ROP, was instituted about four years ago to replace our previous program for evaluating licensees, the Systematic Assessment of Licensee Performance, or SALP. SALP had been criticized over the years for having a number of shortcomings: it was overly subjective, based on inspector judgment; it was retrospective, looking backward over a licensee's previous operations while not necessarily reflecting current conditions; and it did not consider the risk associated with violations of NRC requirements. The ROP takes a two-pronged approach, based on our accumulated knowledge concerning both operating experience and risk. Licensee operations are assessed by means of objective performance indicators, where possible. These indicators are quantitative measures of plant performance, such as unplanned scrams, unavailability of critical safety systems, reactor coolant system activity, and so forth. Licensee performance is indicated by a color code: with green as the best performance, indicating a minimal level of risk, and proceeding through higher–and less desirable–risk levels coded white, yellow, and red. Operational issues that cannot be easily quantified by performance indicators are still subject to assessment through inspections–the second prong of the ROP. However, a systematic assessment of the risk associated with inspection findings is now an integral part of the oversight process. This significance determination process, or SDP, is based in part on simplified plant risk models that have evolved from our improved capabilities in PRA. Color coding is the same as that used for performance indicators. We believe that the ROP is a major improvement over the old SALP process, and feedback we have received from both our licensees and other stakeholders tends to confirm that belief. We continue to work on improvements to the ROP, such as new performance indicators and better risk models, but we consider this application of risk-informed regulation to be a significant success story.

The second branch of risk-informed regulation involves the incorporation of risk insights into the processes involved in reactor operation. Operational programs such as in-service inspection and testing have been modified, and risk is considered in the evaluation of licensee requests for license amendments, in areas such as safety system maintenance and required start time for emergency diesel generators. In conjunction with these activities, the NRC has issued a number of documents, including regulatory guides to inform licensees concerning the proper preparation of a risk-informed license amendment request, and guidance to the NRC staff for review of such requests. Since these risk-informed processes have been established, the Office of Nuclear Reactor Regulation, which reviews license amendments and similar requests, has handled literally hundreds of such applications.

The third, and last, branch of risk-informed regulation has also proven to be the most challenging: restructuring the NRC's regulations consistent with the risk associated with each one. This activity has proceeded at a much slower pace than the other two applications of the risk-informed philosophy, for reasons that are not, I think, difficult to understand. The NRC's regulations apply to all plants, but not all plants have the same risk profile. Thus, it is not necessarily a simple matter to determine the overall risk-impact of a fundamental change in a regulation. Furthermore, the NRC's regulations are not necessarily independent of one another; in fact, some are explicitly linked to other regulatory requirements. A change in one such requirement must therefore be examined to determine if it would conflict with requirements in other regulations, and to see if elements of other regulatory requirements would need to be modified as well. Changes in regulations also require that the NRC establish an adequate technical basis to support those changes, and the rulemaking process itself takes considerable time, since stakeholders must be given a chance to review and comment on regulatory changes before they are ultimately put in place.

Despite these considerable hurdles, we have made substantial progress in risk-informing some of our regulatory requirements. We have almost completed a new risk-informed rule on the classification of and requirements imposed on systems relative to their impact on safety–our so-called “special treatment” requirements. This moves away from the traditional “safety-related” and “non-safety-related” categorization to a more rational assessment of systems based on their contribution to risk. Thus, safety-related systems that have little risk impact will have reductions in regulatory requirements, while non-safety-related systems that are risk-significant will be subject to increased regulatory control. This is a clear illustration of the “two-edged sword” to which I referred earlier.

We have made changes in our rule addressing the treatment of combustible gases in containment to allow licensees to remove recombiners, since their operation after an accident was determined to have little impact on the overall likelihood of containment failure as a result of combustible gas deflagration or detonation. However, we are still evaluating whether additional requirements should be imposed on plants with containment structures that are more susceptible to failure by overpressure, such as ice condensers and non-inerted BWR containments. We are also in the process of risk-informing two other regulations: pressurized thermal shock, and our emergency core cooling system rule. The changes to the ECCS rule are potentially some of the most far-reaching and fundamental application of risk-informed regulation. As I indicated in discussing the TMI accident, our focus on ECCS requirements has rested largely on plant response to a large-break LOCA, although we have acknowledged for many years that the actual risk associated with that event may be significantly less than other events. Risk-informed changes to the rule would allow licensees to eliminate the large-break LOCA as a design basis accident upon demonstration that the risk associated with such an event is acceptably low. Ultimately, large-break LOCAs would likely be treated in much the same way as severe accidents are currently handled, and ECCS performance requirements would be based on the most limiting, but smaller, LOCA within the plant's design basis spectrum.

A Forward-Looking Perspective

My previous discussion has focused on how we have gotten to where we are today. I'd like now to spend a few minutes talking about where we will be going over the next several years.

Many of our programs as we look ahead will be built upon the progress that we have made so far. As we continue to accumulate operating experience at the rate of over 100 reactor years per calendar year, we will also continue to evaluate that experience for additional insights. This is a particularly important process as our nuclear power plants age; we need not only to be able to react to the effects of aging, such as materials degradation, but also to develop tools to allow us to anticipate and predict how such degradation is progressing. These insights will also be fed back into the license renewal process, so that we can be assured that plants operating beyond their original license terms will continue to maintain their licensing bases and will not pose an unacceptable risk to public health and safety. We also recognize that economics dictates that our licensees try to maximize the benefits that they can gain from their existing capital investments in operating plants, and be prepared to evaluate the impacts of other initiatives, such as power uprates, to ensure that safety margins are not compromised.

Along with our aging plants, we must frankly acknowledge that our people are aging, too. This is not just the NRC's problem; it extends to U.S. industry and internationally, as well. We must find ways to attract our brightest young people into the nuclear field, and we must also find ways to preserve and transfer the accumulated knowledge and experience of our existing professionals to those who are now or soon will be entering the field. This problem is made more difficult due to loss of experimental facilities caused by reduction in R&D resources in many countries.

We will continue to use what we have learned about risk assessment to improve the ways in which we regulate and oversee the operations of nuclear plants. But we must also be honest in assessing areas in which improvements are needed to allow us to extend our efforts in risk-informed regulation. We must always keep in mind the uncertainties that are inherent in risk assessments, and continue to do research to better understand and model severe accident phenomena for more realistic decisions. We must establish standards for PRA quality, so that we can have the necessary assurance that risk assessments are sufficiently rigorous to support their application to the resolution of regulatory issues. And we must always remember that nuclear power plants are operated by humans, and be able to account for the influence of those humans on plant behavior and risk.

We must also acknowledge that the terrorist attacks of September 11, 2001, have helped to elevate the issue of nuclear power plant security to one of considerable prominence, not only in the United States, but worldwide. As a result of the attacks and their aftermath, the NRC has required significant enhancements in nuclear plant security on the part of our licensees, and has undertaken realistic assessments of nuclear plant vulnerabilities, both to identify potential means to make the plants more resistant to terrorism and to evaluate the consequences of possible attacks. It is imperative that we make our existing nuclear plants as robust as possible, and we also hope to gain insights that can be applied to the design of new nuclear plants, to make them inherently less vulnerable to threats from terrorism and sabotage. The possibility of deploying such new designs is my next topic.

As we look forward, we also see on the horizon the possibility of new nuclear plants being built in the U.S. Of course, this is nothing exceptional from India's perspective, but we must consider that no new plants have been ordered in the U.S. for some 25 years, and the last plant to begin operation did so nearly 10 years ago. Thus, the NRC must prepare itself for the potential tasks ahead, and the challenges are considerable. Our regulations have been modified over the years to help streamline the licensing process by means of certifying a plant design before it is ever constructed, and by receiving a permit to build on a site in advance of a license application, as well. Three designs have been certified, and a fourth is currently in the process, and we also have three applications under review for early site permits. However, the final step in the process–an application for a combined construction permit and operating license–has not yet been put before the NRC. In addition, we must consider that our currently regulatory structure was developed primarily for the light water reactors in operation today. However, we may ultimately receive applications for plants cooled by gas or liquid metals, or for an advanced version of the CANDU reactor similar to the heavy water reactors in use in India. We must thus determine how such designs will be reviewed. In the longer term, we are working on a framework for advanced reactor licensing, with the goal of a risk-informed, technology-neutral regulatory approach for such plants. The effort associated with the development of such a framework is significant, and the framework itself is only the beginning. Once that framework has been developed, the details of how it is applied to each different type of design will have to be worked out, as well. We continue to take notice of developments not only in the U.S., where the Department of Energy is proposing to develop the "Next Generation Nuclear Plant," which will produce both electricity and hydrogen, but also around the world, including the work on thorium-based fuels in India. Most of all, perhaps, we must continue to understand that nuclear power is now a global enterprise, and that we in the U.S.–and you in India–have an abiding interest in seeing that the use of nuclear power is accomplished with a focus, first and foremost, on safety. We recognize that nuclear power can be an economic source of energy for many nations, but economic considerations can never be allowed to overtake safety as our primary concern.

U.S. and India Cooperation in the Future

Let me close today with a few remarks concerning future cooperation in nuclear safety and regulation between the U.S. and India. Although our nuclear power programs are in some respects quite different, it is clear that we still have many common interests. Working together to investigate those common interests and to resolve common issues will unquestionably lead to improved safety and economy for both of our countries. We have identified five areas in which to conduct our bilateral dialogue, and it is my hope that these represent just the beginning. With the NSSP in place, our future collaboration is set to expand beyond the initial five areas, to cover a broad range of technical topics on which we will be able to learn from one another.

Our shared history and common experiences, our joint commitment to democracy and freedom, and our interests in developing technology and exploiting its advantages to improve the lives of our citizens provide strong ties that will allow us to fulfill the vision of President Bush and Prime Minister Vajpayee as described in the joint statement on the NSSP. On behalf of Chairman Diaz, we welcome the opportunity to work with our counterparts in India to learn from our perspectives on ensuring safety. I am sure that we both will benefit from the examination of each other's experiences.

Thank you for allowing me to share my perspectives and thoughts on safety with you today.