REINVENTING NUCLEAR POWER PLANT REGULATION

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Unless nuclear regulation can improve its effectiveness and efficiency, the future of nuclear power is questionable. Although this is well known, the way to accomplish it is not. Nuclear regulation has improved incrementally over the past several decades, but the inadequacy of these improvements has made it clear that nuclear regulation must be fundamentally *reinvented*. *Reinventing* moves beyond improving current regulatory processes to changing the basic approach to regulation (Osborne and Gaebler, 1994).

This paper describes and critiques the current approach to nuclear regulation, evaluates possible alternatives, and advocates a *self-assessment approach* to regulation (not to be confused with self-regulation). A self-assessment approach to regulation is being encouraged in several regulatory domains, including nuclear regulation in some countries. This form of regulation has the potential to greatly increase both the effectiveness and the efficiency of nuclear regulation. However, substantial work will be necessary to develop this approach into a viable regulatory alternative.

BACKGROUND

The literature distinguishes between two different types of regulation and the basic regulatory models corresponding to each: (1) economic regulation which tends to be performance-based (specifying and monitoring outcomes); and (2) environmental, safety, and health (ESH) regulation which tends to be compliance-based (specifying and monitoring inputs). Whereas the big question in economic regulation is "whether to regulate," in ESH regulation the big question is "how to regulate." ESH domains must be regulated, but regulation is more difficult because outcomes do not provide an adequate basis for regulation. The relevant outcomes are typically too rare and/or too difficult to measure directly, such as nuclear power plant safety events. Moreover, since the paramount regulatory purpose of most ESH regulation is to *prevent* the occurrence of highly adverse events, a performance-based approach that relies on *detection* is inappropriate. Compliance-based regulation, a less direct and thus often more difficult form of regulation, arose as a substitute.

The more complex the regulatory domain, the greater the difficulty. Compliance-based regulation necessitates ***establishing a link between the regulatory requirements and the desired regulatory outcome(s)*** (i.e., the prevention of unacceptable adverse consequences). In complex regulatory domains, establishing this link is particularly difficult because, in addition to the problem that outcomes are not easily measurable, the factors affecting the desired outcomes are likely to be both numerous and interactive. Even if all factors contributing to the desired outcome were clearly known, translating this knowledge into a manageable set of regulatory requirements may not be feasible. Complexity, exacerbated by the potential severity of the adverse consequences, has made regulation of nuclear power plants particularly difficult.

COMPLIANCE-BASED APPROACH TO NUCLEAR REGULATION

Nuclear regulation in most countries is, to varying degrees, compliance-based. The initial, and still primary, focus of this form of nuclear regulation has been to specify and monitor technological requirements. Because of the technological complexity of nuclear power plants, technological requirements have been continually modified and expanded. After decades of experience, fundamental technological issues are still being addressed, such as the rate of embrittlement of the reactor core, vessel plates, and welds. In addition, there appears to be a never ending discovery of significant technological deficiencies even in the most advanced nuclear societies, such as fire protection materials in U.S. plants and filtering systems in Swedish plants. Even if all safety-significant technological issues could be adequately specified and effectively monitored, the technological complexity of these systems precludes the ability of regulators to "guarantee" nuclear safety. There is always the possibility that undetected errors lying dormant in the system will interact in ways to bring about a significant safety

event. Technological issues may be too complex to regulate effectively using a compliance-based approach.

In addition there has been a growing awareness that regulatory oversight of human factors (including management and organizational issues) is essential to assure nuclear power plant safety. These factors are even less amenable to a compliance-based approach. Any attempt to specify management and organizational compliance requirements would be highly contentious and, most likely, inadequate.

Although compliance-based nuclear regulation has been continually improved and systematized through more clearly and appropriately defining minimal standards and criteria, the costs of these improvements have been great and their pay-offs insufficient. Over past several decades attempts to improve regulation have been estimated to account for approximately 70% of the increase in operations and maintenance costs for U.S. nuclear power plants (Hewlett and Mayes, 1989) and the public is still not sufficiently assured of nuclear safety. Improvements that assume a compliance-based approach may never be sufficient since the complexity of nuclear regulatory domain exacerbates many of the problems typically associated with compliance-based regulation. These problems include:

- A *proliferation of regulatory requirements* as deficiencies are discovered over time;
- *Regulatory intrusiveness* as a result of both the many imposed regulatory requirements and the need for comprehensive inspections to monitor compliance to these requirements;
- *Adversarial relations* between regulators and the regulated organizations due to the regulator dictating requirements and acting as a policing agency to ensure compliance;
- *Information asymmetry* between the regulatory staff and industry personnel who, as a result of their direct operational experience, have a greater ability to accumulate knowledge — efforts on the part of the regulated organizations to conceal operational information to avert the detection of compliance violations further contribute to this information asymmetry and inhibit the regulators ability to regulate effectively;
- The *encouragement of minimal performance* and the *discouragement of learning and improvement* which results from imposing static compliance-based behavioral expectations;
- *Split responsibility* between the regulator and the regulated organizations that results from regulators being responsible for specifying requirements and regulated organizations only being responsible for complying to these requirements — regulated organizations can, consequently, lack a sense of responsibility and "ownership" for performance; and
- *Inflexibility* due to the need to standardize requirements across plants (resulting in an inability to respond to diversity and adapt to plant specific circustances) and slowness in implementing change (the burden for change is placed on the regulatory agency which requires lengthy rule-making processes).

These problems have greatly affected the effectiveness and efficiency of nuclear regulation. Many experts have come to believe that the basic approach to regulation must be fundamentally changed if nuclear power is to have a viable future. Although variations from the compliance-based model exist, they have tended to be less clearly defined and systematic. More serious consideration is not being directed at developing alternative approaches to nuclear regulation.

ALTERNATIVE APPROACHES

Two basic movements can be identified in efforts to reinvent nuclear regulation, and ESH regulation in general: (1) a move away from a *compliance* toward a *performance* orientation and (2) a move away from an *external* toward an *internal* orientation (Baker, Morris, Durbin, & Melber, 1994). The U.S. Nuclear Regulatory Commission (NRC) has emphasized a more "performance-oriented" approach to nuclear regulation whereas the Swedish nuclear inspectorate (SKI) has emphasized a more internal "process-oriented" approach.

Performance-Oriented Alternatives. Although traditional performance-based regulation is not suitable for nuclear regulation, three variants of performance-based regulation are being developed to address the needs of nuclear regulation: the performance indicator program, the accident precursor program, and the probabilistic risk assessment (PRA) program.

In lieu of focusing on nuclear safety outcomes directly (such as accidents or safety-significant off-normal events), the performance indicator program attempts to determine and monitor *early indicators* of these outcomes. The NRC has identified a set of performance indicators (including scrams, safety system failures, safety system actuations, forced outages, and combinations of events that may be particularly safety significant) which it has monitored for approximately 2 decades. Performance, as measured by these indicators, has improved over time, but it is not clear whether plants have become safer or whether they have merely learned how to perform to these particular indicators. **In either event, this limited set of indicators no longer effectively discriminates between good and bad plants.** Moreover, statistical analyses have demonstrated the tenuousness of these indicators in terms of constituting a valid measure of safety performance (Baker, Schoenberg, Bittner, 1994).

Some NRC staff have proposed expanding the performance indicator program to make it more effective, however this approach faces several problems. Although a performance-oriented approach is intended to simplify and streamline regulatory oversight, identifying an adequate set of performance indicators could prove more difficult than specifying an adequate set of compliance-based regulatory requirements. The selection of the existing set of performance indicators was based as much on their availability and ease of monitoring as on their apparent relation to nuclear power plant safety performance. Additional performance indicators are not readily available, nor can they be easily created by an external regulatory agency. It is also increasingly recognized that an effective expansion would need to involve human factors indicators. Specifying these indicators, particularly indicators that would accurately tap managerial and organizational components of safety performance, would be an extremely difficult task.

The second variant of performance-oriented regulation investigates accident precursors in order to identify *common* root causes of nuclear safety events. Progress has been made both in systematizing and in broadening accident investigation to include human factor elements. Of special note is the Human Performance Indicator Program (HPIP), a methodology to guide the investigation and determination of whether various types of human factors (including management and organization) have contributed to an accident.

The accident precursor approach could possibly help provide a basis for identifying early indicators of nuclear safety performance, but it too has some basic problems. First, while this approach may help individual plants identify weaknesses, it may not lead to generalizable root causes that can serve as performance indicators because safety events are likely to be caused by highly diverse combinations of technological and human factors. Second, like the performance indicator approach, it focuses on weaknesses in the system and ignores the ways in which technological and human factors help prevent or mitigate accidents. To fully appraise safety performance, it is necessary to look at safety performance strengths as well as weaknesses. Third, it has tended to limit the focus of performance indicators to accident investigations when a greater understanding could be obtained from a more comprehensive investigation of how various factors promote or inhibit desired safety performance objectives.

The third and primary variant of performance-oriented regulation is PRA. Rather than trying to monitor actual performance outcomes, PRA attempts to predict the likelihood of severe safety outcomes (risk of core meltdown or discharge of radioactive elements into the environment). The NRC has required that all plants conduct *Individual Plant Evaluations* (IPEs) which include assessments of each system and system component in terms of their potential to inhibit or contribute to these "worst case" scenarios. Many IPEs have been completed and plant-wide PRA scores estimated.

Although PRA is considered to be the major mechanism for achieving performance-oriented nuclear reform in the U.S., this approach also has problems. The estimated PRA scores vary by orders of magnitude across plants and, in many cases, these variations do not correspond to what knowledgeable observers believe to be the actual safety differences. One reason for this lack of correspondence is that assessment processes are highly complex and difficult to standardize across plants. Assessments of the potential for systems to inhibit or contribute to a serious accident are largely based on expert opinion that has not yet been formalized into a standard methodology. Another reason is that human factors are not included.

There is an attempt to supplement PRAs with *human risk assessments* (HRAs) but the contribution of human factors tends to be overwhelmed by the technologically focused PRA assessments in determining overall plant scores. In addition, human factors do not lend themselves well to a PRA-type model. Even the lowest level of human factors, human/machine interface factors, may not be adequately addressed by a PRA model, and this type of model is far less appropriate for management and organizational factors. Formalizing a methodology to adequately assess these areas is important, but even if this was accomplished, reducing these assessments to single outcome scores may not be particularly useful. Finally, PRA assessments focus on worst case scenarios and, although much can be learned in conducting these assessments, it may be advantageous to look at less severe, more probable scenarios as well.

In addition to the methodological issues associated with each of the three performance-oriented regulatory efforts, the basic objective of performance-oriented regulation may be questioned. This basic objective is to reward good performers by reducing regulatory oversight while increasing regulatory oversight over poor performers. The ensuing result may be that regulators will become less cognizant of *how* good performers achieve exemplary performance and, thus, less able to assist poor performers improve performance deficiencies. The NRC has found that increased oversight is not always an effective means of promoting improved performance, since regulatory interference can be yet one more problem the plant must address. Because the goal of ESH regulation should not be to merely monitor performance but to promote performance improvement, regulators need to maintain a high level of involvement with plants that are performing well. The recognition that performance-oriented regulation may not be sufficient to encourage and promote performance improvement on the part of all plants has led some to emphasize a more process-oriented approach to regulation.

Process-Oriented Alternatives. Process-oriented regulation has been criticized as vague and ill-defined and, for this reason, has not received much attention in the U.S. However, there have been efforts, particularly by the Swedish nuclear inspectorate (SKI), to systematize methods for regulating processes critical to the safe operation of nuclear power plants. Though not yet a rigorous, systematic regulatory program that can supplant current compliance-based regulation, these efforts provide important insights for developing a new model for nuclear regulation.

Process-oriented regulation is not altogether new. The role of management and organizational processes in assuring compliance has been recognized and regulators have increasingly required quality and administrative control processes that promote higher levels of compliance. However, process-oriented regulation moves beyond compliance-oriented quality control and administrative processes, emphasizing the importance of management and organizational processes in promoting total quality, continuous improvement, and a safety culture. This orientation, however, has not been able to effectively discriminate between activities that are critical to safety and those that are not. The total quality, continuous improvement, and safety culture perspectives tend to depict all processes and activities as potentially important and deserving of attention (Rogers, 1994).

SKI is attempting to systematize the process-oriented approach by identifying critical processes and determining how these processes should be reviewed and assessed by the regulatory agency. Efforts have been directed at systematizing the oversight of maintenance processes, quality system processes, and management and organizational processes. The more complex the organizational processes, the more difficult it is to develop a systematic approach to guide regulatory oversight. The broader levels, such as quality system processes that cross functional areas and management and organizational processes, have been particularly difficult to adequately systematize. So far, process-oriented efforts have not yet been developed into a systematic regulatory model that can serve as an alternative to compliance-based regulation.

A SELF-ASSESSMENT APPROACH TO NUCLEAR REGULATION

A self-assessment approach to regulation can both (1) provide a clear model for regulation and (2) incorporate useful aspects of all of the above approaches. The regulatory model consists of clear roles and responsibilities for the regulated organizations and the regulatory agency. The

regulated organizations are responsible for conducting internal self-assessments; the regulatory agency is responsible for guiding and approving the design and implementation strategy and for evaluating and verifying plants' self-assessments. In addition, the regulator can follow up self-assessments to assure that they are being effectively used to improve future plant safety performance. Because the regulator plays an active role in overseeing the regulated organizations' self-assessments, a self-assessment approach differs significantly from self-regulation. The regulator does not relinquish regulatory oversight. In fact, regulatory oversight could become significantly more effective, as well as more efficient, than the current compliance-based approach.

There are two main components of a self-assessment. Self-assessments begin by developing performance measures that correspond to performance objectives. While performance measures can include compliance-based performance criteria, they will most likely extend beyond these criteria. In particular, performance measures can be extended to include a full range of human factors (including management and organizational issues). The industry can work with the regulatory agency to jointly develop guidance regarding appropriate performance measures. Individual plants should also be able to modify and expand these to suit their particular performance objectives. For example, some of the performance measures should be tied to the plant's strategic plans to accomplish specific safety objectives in each functional area over the next several years. The formulation of these strategic objectives should increasingly be based on weaknesses discovered in earlier self-assessments and the achievement of these strategic objectives should be evaluated in subsequent self-assessments.

A second major component of self-assessments involves developing strategies to assess how existing processes and changes in these processes promote or inhibit desired performance objectives. If self-assessments are to be effective mechanisms for directing future performance, it is not sufficient to merely measure and monitor performance objectives. Assessments must also address factors that contribute to these performance objectives and attempt to measure causal factors as well as performance outcomes. The capacity for internal self-assessments to address the underlying causes of performance is yet another way in which this approach goes beyond existing regulation that relies on external assessments (inspections).

A well designed self-assessment approach combines the best aspects of the compliance-oriented, performance-oriented, and process-oriented approaches, while avoiding the problems associated with each. It can incorporate compliance-based regulatory control by making some of the performance measures conform to existing regulatory requirements. In addition, it provides a means of improving and moving beyond the current form of compliance-based regulation. Self-assessments permit the incorporation and refinement of critical management and organizational attributes. They also can be used to refine the specification of regulatory requirements over time. Moreover, a self-assessment approach avoids many of the problems associated with compliance-based regulation by making plants more responsible for their performance, permitting flexibility, being less intrusive, promoting learning and improvement, reducing information asymmetry through more systematic analysis and shared cumulative knowledge, and potentially facilitating cooperative relations between the regulator and the regulated organizations.

A self-assessment approach incorporates but moves beyond existing performance-oriented efforts by providing a mechanism for developing an expanded set of performance measures, as well as for developing measures of potential causes of desired performance outcomes. A more comprehensive set of performance measures is possible because individual plants conduct the self-assessment activities necessary for creating, monitoring, and analyzing these measures. Self-assessment regulation is therefore not as constrained by regulatory resource limitations nor by the need to standardize across plants. By allowing expanded performance outcome measures as well as measures of potential causal contributors, the self-assessment approach moves beyond merely monitoring for minimal performance to promote learning and improvement.

Finally, a self-assessment approach incorporates and improves upon process-oriented efforts by explicitly linking processes to performance objectives and by providing a clear focus to process regulation. Performance criteria and measurement strategies need to be developed for critical processes as well as for desired safety outcomes. Processes can then

then be analyzed in terms of their contributions to the desired safety outcomes. In this way the self-assessment approach is able to ensure that all critical processes are being monitored, analyzed, and improved as necessary, without having to directly regulate these processes. Rather regulatory attention can focus on plants' self-assessment processes. Self-assessment processes are pivotal because they take into account all other processes critical to safety performance and because they promote continuous learning. By focusing on self-assessment processes, the regulator plays a key role in helping plants to become better learning organizations and to continuously improve processes critical to safety. The greatest strength of the self-assessment approach is that it actively promotes learning and continuous improvement.

The self-assessment approach does have a few limitations. Designing good self-assessment processes may require expertise that is not readily available at every plant. Also, verification and evaluation of self-assessment processes requires expertise that may not be readily available among regulatory staff. These limitations can be gradually overcome. Also a self-assessment approach can be implemented in an evolutionary or graded manner, with simpler compliance-oriented assessments preceding more expanded performance-oriented assessments.

The conduct of PRA assessments has substantially contributed to the expertise available at U.S. plants. In fact, there is wide agreement that the process of conducting these PRA assessments may be far more useful than the PRA outcome scores. There is also agreement that improvements to the assessment process are still needed. The regulator should promote activities to improve assessment processes and adapt them for purposes of periodic self-assessment. The industry could also take the initiative to refine and improve assessment techniques and to develop assessment strategies directed at management and organizational factors. These assessment strategies should be seen as being subject to continuous evaluation by the regulator and continuous improvement on the part of the plants. Although regulation will be oriented toward continuous improvement, improvements should be less costly for plants than the mandated improvements of the past. Improvements should also be more preventative than reactive and more effective in promoting plant improvement.

CONCLUSION

The self-assessment approach is a clear, workable model for reinventing nuclear regulation, as well as other types of ESH regulation. According to Osborne and Gaebler (1994), the key to reinventing government is to limit government to *steering* (i.e., directing and overseeing) activities, rather than assuming responsibility for *conducting* activities. In ESH regulation, governments have not performed a limited oversight role similar to that of economic regulation, but have assumed ever increasing responsibility for making decisions and conducting activities that may be better left to the regulated organizations. The problem has been how to relinquish responsibility for these activities to the regulated organizations without relinquishing regulatory control. The self-assessment approach to regulation, as described above, provides a solution to this problem. By limiting the regulatory role, it may also provide a solution to shrinking regulatory resources that will result from plant closures over the next several decades.

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