

Licensing and Deployment of Advanced Reactors

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Abstract - *The deployment of advanced reactors of the type proposed for Generation IV will require a new strategy for licensing and demonstration. One of the requirements for NRC certification is that for technologies, for which there is not a regulatory history or an experience base, demonstration plants are a requirement.*

The current regulatory process as codified 10 CFR Parts 50, 51 and 52 has to be met by law. This process is largely focused on the light-water reactor technology and would make introduction of these new reactor technologies very difficult. What is required is a technology-neutral regulatory regime that will allow the timely licensing of advanced reactor technologies. One of the difficulties that the introduction of new technologies brings is that if they are truly new, the regulators are not typically engaged in the development of the technology, which greatly hampers their ability to perform a review. What is necessary is the development of a new approach in which the regulator can participate in the development of the technology as well as the development of a risk informed regulatory process in which high-level safety goals can be demonstrably attained. In addition, since these new technologies will require a demonstration, there needs to be an efficient process in which the regulator is engaged early in the process, to allow for learning about the technology, and participating in the specification of tests to satisfy the technical and safety needs of the regulators so that they can make a finding of reasonable assurance of public health and safety.

What will be proposed is a process whereby new technologies can be deployed in a reasonable period of time, consistent with an independent regulatory review, applying new risk-informed principles to guide the regulator and the designer to assure that the fundamental safety functions can be realized in a technology-neutral approach. This is particularly important since many of the proposed Generation IV technologies include concepts such as high temperature gas, liquid metals such as sodium, lead and lead bismuth, molten salt reactors and even vapor core reactors. These will surely challenge the existing regulatory system if changes are not made.

1. BACKGROUND

Under the existing regulatory structure, the applicant for an advanced reactor must demonstrate compliance to all of the regulations as written or seek exemptions to those particular regulations. As early as 1988, General Electric proposed (Ref. 1) a new process for certifying advanced reactors by calling for a new appendix to Part 50 to address the differences in licensing technologies that are not water based. In 1988, General Electric was seeking to license an advanced liquid metal breeder reactor called PRISM. More recently, Exelon has developed a Proposed Licensing Approach for Pebble Bed Modular Reactor in the United States (Reference 2) that points out the difficulties in the process of attempting to comply to current regulations with non-water technologies. They have spent a considerable amount of time identifying which regulations might be applicable to the Pebble Bed Modular Reactor (PBMR), and for those that are not applicable, they need to justify why not and request an exemption to that particular regulation. In addition, the General Design Criteria are cited in the regulations which identify certain high-level objectives. These 64 General Design Criteria also need to be addressed in terms of their applicability. Once those have been addressed, the implementing regulatory guides also have to be reviewed and justifications need to be made as to why the prescriptive implementation of the general design criteria for a new and advanced reactor are either applicable, partially applicable or not applicable.

Most recently, the Nuclear Energy Institute proposed a new licensing approach to all reactors (Ref. 3) by calling for a risk-informed performance based regulatory framework for all types of reactors by advocating a rulemaking to promulgate a new Part 53 that would greatly simplify and focus regulations on safety significant aspects of nuclear reactor design and operations. All these activities are based on risk informed processes to improve the overall regulatory process. While the NEI initiative provides an approach to making licensing basis decisions, it does not address the challenge of introducing new technologies.

Under any licensing scenario, the task facing a potential developer of an advanced reactor is quite

formidable. If one examines the entire process, one quickly concludes that to introduce a new technology under the existing regulatory structure is a task too formidable for the private sector to undertake, given the large investment and time required with no certainty in outcome. What is required is a new look at the entire process, to allow it to be technology-neutral and safety-based, without any preconceived notion as to the type of technology. The current regulatory structure is a patchwork of regulations that has been developed to respond to particular challenges that light-water reactors have faced, from fire protection to emergency planning, to pressurized thermal shock, in a more or less separable and not integrated regulatory framework. What we have before us with the introduction of new and advanced reactor technology, is an opportunity to rectify the existing very complex regulatory structure into a more logical safety-based framework that can address the fundamental safety issues that the NRC and the industry would clearly like to be the basis for future generation of nuclear power plants. The NEI proposed rule may be the basis for establishing such a structure.

The present NRC effort at risk-informing the regulations also can provide a sound basis upon which to move forward. What is extremely encouraging is that both the industry and the NRC believe that significant changes to the fundamental approach to safety and regulation is necessary to improve the process. If the high level safety goal principles are used as the guideline in conjunction with sound engineering practices as generically expressed in the general design criteria, one can formulate a sound technical basis for providing reasonable assurance that the public health and safety is protected.

Although this is a necessary condition, it is not sufficient for deployment of new nuclear technologies. One also needs to address how such technologies will be deployed. It is quite clear that the task of demonstrating, for certification, a completely new technology has a great many hurdles in terms of adequacy of the demonstration. For example, in the design of new advanced reactors, many new computer codes and models will be required to predict the performance of the reactor. In addition, transient and accident analyses that are tailored to the particular technology also need to be developed and supported by experimental research and data.

2. LICENSE BY A TEST

In a normal environment, such efforts would take 20-30 years. In an effort to provide a more logical and timely approach to introduction of such technologies, a license-by-test program has been proposed (Ref. 4) that would allow the technology to be developed in parallel with the licensing process, whereby the regulators as well as the developers and stakeholders would jointly participate in the research program, leading to enhanced confidence, not

only in the design of the plant, but also in the technical understanding of new technologies. The license-by-test concept is generically permitted by the Nuclear Regulatory Commission but it has not been defined. The license by test approach calls for building a research/demonstration plant (full scale if possible) and then performing a series of tests that would be established using a risk informed framework. This risk informed framework will use Probabilistic Risk Assessment techniques to identify critical safety systems, structures, and components and establish a basis for defense in depth.

3. ESTABLISHING THE DESIGN BASIS

Once the conceptual design of the proposed plant design is established, the application of risk informed methodologies would be used in combination with deterministic analysis to identify key systems, components and structures to assure that the objectives of the safety goals are met. This PRA should be at least a level 2 if not level 3 PRA in order to support the public health and safety goal philosophy. The PRA would be used to develop a risk-based technical basis for establishing risk dominant accident sequences (RDAS) that could form what are traditionally referred to as Design Basis Accidents (DBAs) The RDAS are used to formulate acceptable essential safety function unavailabilities and for judging defense in depth.

Defense in depth is a general and somewhat subjective philosophy used by regulators and designers to cover unquantified uncertainties. IAEA and the ACRS have recently begun to address this issue again (Ref. 5,6). The demonstration of defense in depth would be to assess the risk considering margins provided by innovative new designs may have inherent physical attributes that are demonstrably, rather than analytically, safe. An element of the establishment of the design basis is to examine the basis of defense in depth. The risk-based approach offers a method for doing this, by evaluating acceptable risks at a conservative confidence level rather than in terms only of expected outcomes.

This analysis will identify the importance of those systems and identify the sensitivity of outcomes on the components and system design. With new unproven technologies, performing a probabilistic risk assessment can only be approximated by making assumptions of performance of components using existing data sources. This is not a critical flaw but an important part of the design process. It can be used to establish an understanding of the sensitivity of the assumptions on performance. It is well understood that in the early stages the use of PRA cannot be assumed to be, as an absolute number, an indicator of the safety of the plant. But through a combination of deterministic and probabilistic techniques, key sensitivities to certain design features can be understood which would be used in the test

specification. The available data on components and reliability of systems can be, to a certain extent, extrapolated from other industries, but largely that is not the intent of the PRA and risk-informing process. The intent is to identify, in a sensitivity analysis, what systems are truly important. This is the key to the risk-informing of licensing for advanced reactors. The process provides an excellent method of understanding how the integrated plant works and this understanding should improve the overall design.

The NEI, Exelon or the NRC process for establishing the design basis using risk informed principles may be used. What is important in this process is the focus on the top-level safety goals, which generally means the ability to demonstrate the impact on people of the proposed technology. An assessment of accident scenarios leading to offsite releases should be the primary focus of this analysis and in the process developing a firm basis for the concept of defense in depth. This concept should go beyond the simplistic answer of a containment for all plants but explore the real nature of defense in depth. This would allow the designers to build in more inherent and deterministic design features that provide more "safety" than a containment can since it is assumed to fail 10% of the time.

At this point, there would be sufficient information to design and then build the research/demonstration plant. This research/demonstration plant would be used to confirm, on an integrated basis, the expected analytical results, especially in areas where small-scale tests may not prove to be adequate. The nature of the risk-informing of the regulations would play a role in identifying what the risk-significant systems are of the particular design, which would allow the regulator and the designer to focus on those systems that are crucial to the safety of the plant. This information is essential for specification of the tests. Based on the risk assessment identifying critical safety component, systems and structures, a test plan can be developed by identifying a series of subsystem and integral tests to confirm the performance of the components and systems as required to validate performance and computer codes. These tests will form the basis of the safety case for the technology. This test plan is expected to include the loss of coolant test, reactivity feedback tests, control rod withdrawal, turbine trips, overspeed, to name a few. What will be necessary for the testing program is a demonstration of the safety of the plant for the public, investors and the regulators.

In 1988, General Electric called for the issuance of a "Certification Basis Agreement" at this stage to allow for NRC concurrence in the fundamental design objectives that would be followed up by a "Certification Test Plan" that would identify what tests or experiments would be required to satisfy the NRC about the safety of the design. This approach forms the basis of what might be an

acceptable path forward for current advanced reactors as well.

Having established a detailed design of the plant and a test plan that is based on a risk informed approach, key areas of uncertainty and importance can be identified. The next step in the process is to build the research/demonstration plant.

4. REACTOR RESEARCH/DEMONSTRATION FACILITY

The process to actually build a reactor research /demonstration facility is equally difficult unless a new approach is taken. As the recent decision of Exelon to withdraw from the South African pebble bed plant demonstrates, the cost and risks of deploying new technologies are too high for the private sector to bear given the new de-regulated competitive electricity market in the US. The nuclear steam supply vendors of the past are also no longer able to bear the cost of developing new technologies since their infrastructure has long disappeared due to the lack of new orders for over 25 years. Thus, in addition to the need for a new regulatory approach to introduce new technologies for the future, we need to develop a new approach to deployment of advanced reactors that will be critical for the reestablishment of newer, safer and simpler reactors.

The approach proposed is that the Department of Energy take a leadership rather than a support role in research and demonstration of new technologies. This would require a major reversal of present policy in which the DOE assumes industry leadership with DOE research support. Unfortunately, as Exelon most recently demonstrated, the DOE model is not realistic. What is more realistic is that DOE provide the leadership with industry providing the cost sharing and technical support. The model proposed (Ref. 4) is that an industry, university, and national laboratory consortium be organized to design, build, test, and then operate a research/demonstration plant on a DOE laboratory site that would ultimately lead to a certification of the design for commercial application once the research and test missions are completed. The most likely candidate site is the Idaho National Engineering and Environmental Laboratory, where numerous first of a kind tests have been done for the nation.

The process for obtaining permission to build such a facility if the traditional NRC approach were followed would entail the same difficulties as that associated with licensing a new power plant. The NRC licensing process is not designed for the development and testing of new technology. The DOE nuclear safety management process is designed to accommodate a wide range of different types of facilities and technologies. Since this would be a research facility, in it's initial purpose, it is proposed that the Department of Energy be the approval

agent for the facility under its work authorization process in concert with the NRC.

5. BUILDING THE RESEARCH DEMONSTRATION PLANT

Englehart (Ref. 7) has proposed a workable process for building a research/demonstration plant within the existing Department of Energy authority for approvals of such facilities. DOE because of its diverse mission and facilities has a much more flexible safety basis set of criteria for approval of research facilities. Since this project will ultimately lead to NRC certification, close collaboration with the NRC will be required in both test specification, test oversight and independent evaluation.

In the DOE process, the first step is the completion of an Environmental Impact Statement (EIS) as required by 10 CFR 51. The good news is that such an EIS was completed for the National Production Reactor (NPR) at the INEEL site. Although the NPR project was cancelled before the Secretary of Energy approved the EIS, its existence would greatly expedite the construction of the research/demonstration plant.

The concurrent process of granting approval of the facility is found in DOE's orders and directives. Under the DOE system, these requirements (orders, standards, etc) are imposed on the contractors DOE employs to build and operate their facilities. The overall guiding design requirements are found in 10 CFR 830 subpart B, Section 830.206 that calls for compliance to DOE Order 420.1 on Facility Safety. These are high level performance criteria that must be demonstrated. In addition, more specific reactor design criteria are found in DOE Order 5480.30 entitled "Nuclear Reactor Safety Design Criteria". This criteria was written to cover many different types of technologies with which the DOE must deal. They are similar to the General Design Criteria of Appendix A of 10 CFR Part 50.

What DOE requires is the development of a Safety Basis which is found in the Preliminary Documented Safety Analysis (PDSA) and the Final DSA (FDSA). These documents are similar to the Preliminary and Final Safety Analysis Report of the NRC. For operations, a Technical Safety Requirements document similar to NRC's technical specifications is also required.

As can be seen the basic elements of the DOE and NRC process are quite similar but the DOE guidance documents are much more flexible allowing for different types of facilities with the burden of proof of safety made based on the technology not prescriptive regulations. It remains to be seen whether the DOE approach will recognize and accept risk-information as a basis for safety. It appears that it can readily do so given the high level requirements.

The key office in DOE that would be involved in granting the approvals is the Office of Environmental

Safety and Health. The lead office in DOE that would be the lead in the project would logically be the Office of Nuclear Energy, Science and Technology. Since there are two goals for this research/demonstration plant – research and demonstration that would eventually lead to certification, close cooperation with the NRC would be required. A means to formalize the appropriate regulatory interactions would be possible through a memorandum of understanding of the roles of each agency to be sure that the proper roles are maintained. NRC should be very interested in the specification of tests and research elements as well as the certification plan. DOE, as the lead federal agency, would be responsible for the overall program as carried out by the consortium of industry, university and national laboratories involved in the program. Due to the limited availability of expertise in the NRC and the DOE in advanced technologies, such a federal cooperative effort would not only develop additional expertise but also be more efficient in the utilization of taxpayer money.

Once the plant is completed, the research and test mission would begin for the facility. The tests would be conducted and design refinements made. Depending on the technology, the research and testing program could last for many years. Once the basic safety of the design is established, a demonstration program would begin to provide both the public, the regulator as well as the developer confidence in the safety of the plant. It is quite obvious that the design of the plant will play a key role in determining how effective such a process is. For example, should the design have many deterministically clear safety features, such as, in the pebble bed reactor, where the temperatures do not reach levels at which the uranium can melt, this would be a strong indicator of confidence in the design and in being able to establish the legal requirement of adequate protection.

During this entire process, as part of a license by test approach, it is expected that there would be close interaction with the Nuclear Regulatory Commission as it fulfills its mission to identify key safety and technology issues that they would need to understand to establish confidence in their regulatory approval process. Once this demonstration is completed, the regulator could with high confidence issue a certificate for construction, and future licensing actions would be based, as is presently proposed, on assuring that the plant is built as specified in the certificate. Whether the research/demonstration plant obtains a formal Part 103 commercial operating license will depend on its future mission. The plant will be capable of producing electricity that would allow for potential repayment of the government for its investment in the demonstration aspect of the plant, but it could also maintain its research status, since it could become the test bed of all innovations for the technology for the life of the plant. These innovations would include new component designs, new fuel types, as well as continuing to test the

capability of the plant for higher power levels, and other upgrades.

It is this process that has a reasonable chance of meeting not only the public's desire to have high confidence in the safety of plants, but also the developers' need to know that the investments that they are making can, in a much shorter period of time, lead to a technology that can be deployed. The great uncertainties in introducing new technologies are related to the actual performance of the components as well as the nature and length of the regulatory review. Past certifications of advanced designs have been largely focused on paper reviews with limited testing due to the very large experience base that already exists in the light-water reactor field. This base will typically not exist in advanced reactors, and should there be a desire or a need to deploy them in less than 20 to 30 years, it is extremely important that a new regulatory process be developed to accommodate such advancements. The risk-informing of the regulations, and to establish a new set of regulations for advanced reactors that are technology-neutral, will go a long step in that direction.

6. Conclusions

The introduction of new advanced and improved reactors will require three fundamental changes in the present system of regulation and deployment strategies. The first is changing the current prescriptive regulatory system that is geared to light water reactors to one that is risk-informed and technology neutral employing high level public health and safety goals.

Second, it is important to recognize that in today's competitive electricity market with no strong identifiable vendors who can afford to bring really new technologies to market, the government must take a leadership role if the benefits of new nuclear technologies are to be realized to combat global warming and provide some measure of energy security. This new role would require joint public and private support for the development and deployment of new technologies.

Third, a new process for deployment needs to be developed under Department of Energy leadership that allows for the construction of a research/demonstration reactor plant at a national laboratory site to provide the foundation for public and regulatory confidence in the new technology through a series of research projects, tests and ultimately demonstration, leading to an NRC certificate for construction. This would allow novel technologies to be deployed sooner than the 20 to 30 years it might take under the existing system.

If these changes are implemented, it is likely that true Generation IV plants can be deployed for the national good in our lifetime.

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