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SAFETY AND LICENSING
FOR SMALL AND MEDIUM POWER REACTORS*

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SAFETY AND LICENSING FOR SMALL AND MEDIUM POWER REACTORS

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Abstract

Proposed new concepts for small and medium power reactors differ substantially from traditional Light Water Reactors (LWRs). Although designers have a large base of experience in safety and licensing, much of it is not relevant to new concepts. It can be a disadvantage if regulators apply LWR rules directly. A fresh start is appropriate. The extensive interactions between industry, regulators, and the public complicates but may enhance safety. It is basic to recognize the features that distinguish nuclear energy safety from that for other industries. These features include: nuclear reactivity, fission product radiation, and radioactive decay heat. Small and medium power reactors offer potential advantages over LWRs, particularly for reactivity and decay heat.

Keywords

high temperature gas-cooled reactors
investment protection
light water reactors
liquid metal reactors
medium power reactors
public risk
reactor licensing
reactor safety
small power reactors

The features of small and medium power reactors offer substantial advantages in safety and licensing. Smaller amounts of decay heat, when combined with fuels and structures having higher temperature capability and improved ability to dissipate thermal energy, make possible the innovative designs for current High Temperature Gas-Cooled Reactor (HTGR) and Liquid Metal Reactor (LMR) concepts. These designs include methods for dissipation of decay heat more directly to the atmosphere and, in the case of Boiling Water Reactors (BWRs) and Process Inherent Ultimately Safe Reactors (PIUS), to large bodies of water. The safety features of these designs permit the following changes: eliminating conventional containments and engineered safety systems, clustering modules, using common control and power-generating units, and extensive shop fabrication, all of which result in cost savings. Some of these cost-saving changes partially offset the increased cost of the smaller-sized units that results from loss of the economy of scale enjoyed by larger units. Except for shop fabrication, the changes entail new issues that must be resolved in licensing a lead plant. Although the proposed designs may increase the margin of safety, they will require new methods for review at the outset. Licensing revision or reform appears necessary if these otherwise attractive units are to be economically competitive in the near term.

Any consideration of safety must include an awareness of other factors. In a task by the Oak Ridge National Laboratory entitled, "Nuclear Power Options Viability Study (NPOVS)," designed to examine the possibilities for nuclear power in the United States in the time period, 2000-2010, criteria were developed as broad guidelines for designers.[1,2] The criteria were augmented by a list of characteristics that provide further guidance for properties judged to be important for nuclear power viability. Several of the criteria and many of the characteristics are not readily quantifiable but are intended to provide useful guidance for the design and development of acceptable nuclear power plants. The criteria are as follows: (Some elaboration is offered for Criteria 1, 5, and 7 since they relate specifically to safety and licensing.)

1. Public Risk - The calculated risk to the public due to accidents is less than or equal to the calculated risk associated with the best modern Light-Water Reactors (LWRS).

   This is a fundamental public safety criterion. To implement it strictly, a probabilistic risk assessment (PRA) employing acceptable methods and data bases would be necessary for each new concept and for the "best modern LWRs." However, other approaches based on judgment can be useful. Compliance with this criterion is essentially a prerequisite for licensing.

2. Investment Protection - The probability of events leading to loss of investment is less than or equal to 10^{-4} per year (based on plant cost).

3. Economics - The economic performance of the nuclear plant is at least equivalent to that for coal-fired plants.

4. Design - The design of each plant is complete enough for analysis to show that the probability of significant cost/schedule overruns is acceptably low.

5. Certification - Official approval of a plant design must be given by the U.S. Nuclear Regulatory Commission (NRC) to assure the investor and the public of a high probability that the plant will be licensed on a timely basis if constructed in accordance with the approved design.

   This criterion addresses concern for delays and associated risk for fully designed or replica plants. This criterion's prime concern is with the licensing process, including potential further changes in requirements and regulations. Today's cumulative experience with licensing is extensive and should be sufficient to permit the introduction of one-step licensing at the completion of design. Verification of quality control during construction, of course, would be required.

6. Marketability - For a new concept to become attractive in the marketplace, demonstration of its readiness to be designed, built, and licensed and begin operations on time and at projected cost is necessary.

7. Competence of Owner/Operator - The design should include only those nuclear technologies for which the prospective owner/operator has demonstrated competence or can acquire competent managers and operators.

For the operation of a new or substantially different concept to be satisfactory, utility plant managers and operators must have acquired an adequate background and experience with the technology, equipment, maintenance, and plant surveillance. For operation, simulator training has proven effective for current power plants, and simulators would be necessary tools for new concepts. Where the concept, such as the small BWR, derives from a prior system, this criterion should be relatively easy to meet.

The characteristics, which augment the criteria and provide further guidance to designers, are divided into two categories, essential characteristics and desirable characteristics. The essential characteristics involve construction costs and lifetime projections, investment risk, cost for reliable and safe operation, availability of financing and other resources, and public acceptance. The desirable characteristics that are related but not readily determined quantitatively are: practical research, development, and demonstration requirements; ease of siting; load-following capability; resistance to sabotage; ease of waste handling and disposal; good fuel utilization; ease of fuel recycle; technology applicable to breeder reactors; high thermal efficiency; low radiation exposure to workers; high versatility relative to applications; resistance to nuclear fuel diversion and proliferation; on-line refueling; ease of decommissioning; and low visual profile.

Most of the criteria and essential characteristics apply to Sessions I and II of this meeting; however, Public Risk (Criterion 1), Certification (Criterion 5), and Competence of Owner/Operator (Criterion 7) are directly relevant to the safety discussions of this session. Investment Protection (Criterion 2) has safety implication since most accidents that would cause loss of investment also represent a safety concern.

The logic for using a level of safety equivalent to that of Light Water Reactors (LWRs) as the standard of Public Risk (Criterion 1) was twofold. First, we considered conventional LWRs to be safe. Second, we observed that a different concept could be compared with an LWR on the basis of specific properties or components. Such comparisons include reactivity effects, stored energy, thermal capacity to absorb decay heat, temperature limits for fuel and cladding, and security of primary systems containment. Although such comparisons are not a substitute for a probabilistic risk analysis (PRA), they can provide quantitative means for comparative evaluation. These comparisons may even be preferable until the data base for component reliability and system integrity are adequate to perform an effective PRA.

The Certification (Criterion 5), was written to be specific to U.S. systems. The difficulty in this application will vary widely from country to country, depending on the licensing system used. In the U.S. context, it implies acceptance of standardized plants and one-step licensing. For others, it would depend on how closely their licensing system compares with that of the U.S.A.

The Competence of Owner/Operator (Criterion 7) is important, as illustrated by the Three Mile Island 2 and Chernobyl accidents as well as by the long, costly outages experienced by many nuclear plants. Errors in management and by operators will always be of concern since the human factor cannot be totally eliminated.

Small and medium power reactors offer benefits of potentially simpler systems and greater automation. The latter is particularly important since parallel units in a common facility are postulated to require automation. Judgments about licensability will focus on the design and safety features of these small, multi-unit reactors. As the overall complexity of the reactor station is reduced by smaller and more passive designs, the operational problems will be correspondingly reduced.

Multi-unit plants require standardization within the station complex. Extension of standardization to all station units of a given concept offers advantages for both licensing and factory assembly. The NRC in their 1985 policy and planning guidance on advanced nuclear power plants[3] said:

Such designs can benefit public health and safety by concentrating the resources of designers, engineers and vendors on particular approaches, by stimulating standardized programs of construction practice and quality assurance, by improving the training of personnel and by fostering more effective maintenance and improved operation. The use of such designs can also permit more effective and efficient licensing and inspection processes. Therefore, the Commission strongly encourages industry to pursue standardization in future reactor designs.

A companion to the reactor standardization policy is a preapproved siting policy. The time gained in the construction schedule by referencing an approved standard design could well be lost in a dispute over the adequacy of a proposed site. It should be possible to gain site approval in advance of applying for a construction permit; some regulations governing early site reviews have been adopted by the NRC.

> "As choice and remote sites for reactor stations are depleted and as the generation of thermal energy for process operations and district heating are considered, safety and licensing assume an increased importance. The requirement for atmospheric dilution factors must be reduced and compensated by designs to reduce potential source terms. The smaller sizes generally contribute at least proportionately to smaller source terms, although this is always a design-specific feature. However, in many cases, passive safety features must be emphasized in order to meet acceptable standards for siting in more populated locations. All in all, the small and medium power reactors offer siting opportunities for the safe utilization of nuclear plants in convenient locations."

The advent of smaller units has lead to a concept of licensing by demonstration; i.e., to subject the first reactor of a concept to unusual stress and thus snow its capability to accommodate potential accident initiators. There is great merit in demonstration units to identify problems in design and construction as well as to obtain licensing experience. However, there are limitations to licensing based primarily or totally on demonstration. Not all safety claims or hypothetical accident sequences can be demonstrated; substantial analysis will still be required. Also, a license may be required for the test prototype. The demonstration tests would be complex and expensive. The test module may have to be sited remotely because of the potential risk of test failures. Savings in analysis may be minimal or even negative once the design needs for a successful set of tests are defined.

At the time the NPOVS report was prepared, little information was available from PRA studies for small and medium power reactors. We noted, however, that the designers of passively safe concepts responded to safety considerations in the following ways:

- Many small and medium power reactor concept proponents, relying as they do on passive safety features to prevent adverse effects of accidents, claim that nuclear safety-grade equipment can be limited to the nuclear island.

- Proponents of some of the concepts believe that minimal or no containment can be justified because of a lack of credible severe accident sequences. In fact, some of the proposed passive decay-heat-removal systems would be precluded by the use of conventional containments.

- Some proponents believe that a safety demonstration plant would greatly facilitate licensing.

- There is considerable support for the proposition that very rare accident precursors, with frequency below some particular value such as 10^{-7} per reactor year, need not be considered as design basis events. However, current experience and PRA methods may not be adequate to establish such values.

The use of performance-based regulation to replace the present prescriptive systems should be considered as a long-term objective. The concept can contribute to plant simplification (and reduced cost) while retaining a high degree of protection against public risk. The objectives are similar to those for many small and medium power reactor designs. Several of the following actions could be included in such an initiative:

- Adoption of passive safety systems to replace or supplement active safety systems. The use of passive systems makes verification simpler in that safety becomes more deterministic and less probabilistic.

- Performance standards can be applied to the plant's response to certain accident initiators such as an earthquake of a specified intensity or a pipe break of a particular timing and size. A combination of test and analysis can then be used to determine that a severe accident will not result.

- As experience is gained with the application of performance standards of limited scope and in the use of PRA, greater weight can be placed on the use of PRA to verify the overall achievement of safety goals.

- The response of plants to actual challenges to safety systems (Licensee Event Reports) can be analyzed to verify that the PRA is soundly based.

Current nuclear regulations require that there be a containment system, independent of reactor design, to mitigate the release of an arbitrary fraction of the reactor's fission products independent of reactor design. It is noted that this fraction is probably much greater than the actual release that would be experienced in most accidents; however, the regulation is intended to be conservative. Containment features for confinement of small and medium power reactors, particularly those designed without leak-tight containments, may require extensive research and demonstration to convince regulatory bodies that the proposed safety measures are adequate. At the time of the NPOVS, the following research and development areas were identified:

- Development of quantitative risk criteria for advanced reactors.
- Consideration of the significance of passive safety features to risk reduction.
- Determination of the frequency of rare events that would constitute a lower limit for design basis.
- Appropriate treatment of source term and containment for very safe designs.
- Appropriate focus on safety and risk reduction in the development and application of standard designs.

The NPOVS also addressed the question of market acceptability for new nuclear technologies. Case studies and interviews with public utilities, public utility commissions (which regulate electric rates), and interest groups were utilized to explore the market acceptability for new technology. From this research, a set of major issues were identified that are likely to be at the core of the acceptability question for new reactor technologies. It was concluded that for a new technology to be acceptable in the U.S.A. after the turn of the century, three necessary but not sufficient conditions would be required; these are:

- A projected need for new baseload capacity
- A narrowing of the gap in construction costs between environmentally acceptable fossil and nuclear plants; and
- The absence of a third, more environmentally and economically acceptable option for baseload power to compete with nuclear.

Even if all three necessary conditions are satisfied, there is no guarantee that nuclear options will be chosen. There is a further set of facilitating conditions that would substantially improve the position of nuclear technologies within the market. These include improvements in the following areas:

- Stability of the regulatory environment
- Improved accuracy and reliability of load-forecasting techniques
- Improved cost controls in nuclear construction and operation, including standardized or turnkey plants; and
- Demonstrated technical feasibility of new nuclear reactors.

Stability of the regulatory environment has been identified as important, but, in general, we received the impression that if economic incentives are strong enough, regulatory difficulties will eventually be overcome.

In summary, concepts for small and medium power reactors offer features for passive safety. Designers have and should continue to emphasize:

- Accident prevention as opposed to accident mitigation,
- Few or no operator actions required following an initiating event and, if required, scheduled to occur hours or days later,
- Simplified engineered safety systems having few critical components,
- Tests of safety features in demonstration reactors.

In addition to these objectives, the industry must strive to assure the public as well as the regulatory bodies that nuclear energy is safe and affordable.

The thrust of this session should be to consider the most basic factors affecting safety and licensing. It also should be dedicated to establishing the judgment of licensability on a basis appropriate to each concept. It is self-evident that advanced LWRs, HTGRs, and LMRs have very different safety characteristics and very different licensing concerns and possibilities; each must be treated appropriately.

The contributions by participants in NPOVS, from which much of this paper has been derived, are gratefully acknowledged.

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