Future nuclear power plants: Harmonizing safety objectives

Through a number of co-operative avenues, technical features of tomorrow's nuclear reactors are drawing close attention

by Leonid Kabanov

Today's generation of nuclear power plants that are designed and operated to current safety objectives and principles achieve a high level of safety. Even though the majority of operating plants have a good safety record, there is considerable debate among safety and nuclear power experts on how to do even better.

This quest for excellence rests upon several factors. First, there is a tendency for any industrial activity to become safer and more efficient as it develops over time. For the nuclear industry, this has meant upgrading plant safety levels by incorporating the lessons learned from the many accumulated reactor-years of operating experience, including accidents that have occurred. Additionally, safety issues are being identified through research, testing, and other analysis, such as probabilistic safety assessment (PSA). Second, there is a desire to maintain the current low level of risk to the public from nuclear power, as the number of nuclear plants grows in the future. Third, there is a desire to further reduce the likelihood and radiological consequences of any potential large off-site release. By minimizing the potential impact on public health and safety, the need for off-site protective actions can be reduced. Finally in some countries, efforts to raise the level of safety is a prerequisite for public acceptance of a new or expanded nuclear power programme.

In 1992, the International Nuclear Safety Advisory Group (INSAG), a body advising the IAEA Director General on safety issues, proposed desirable features for enhancing the safety of future nuclear power plants.* They incorporate improved safety concepts including those addressing human factors and specific design features.

In the area of human factors, the features state that the design should be user friendly, consider operating and maintenance procedures, and reduce dependence on early operator actions. The implementation of these features will allow operators more time to perform safety actions and thus provide even greater protection against any possible release of radioactivity to the environment.

Regarding plant design, the features state that it should, in particular, reduce the probability and consequences of severe accidents, have confinement systems to cope with pressures and temperatures occurring during severe accidents, and adequately protect against sabotage and conventional armed attacks. Consideration should also be given to passive safety features that are based on natural forces, such as convection and gravity, making safety functions less dependent on active systems and components like pumps and valves.

In practice, some of these features are already being incorporated into modern plants that are under construction or have been recently commissioned. Incorporation of other features are envisaged in new designs being developed now.

This article reviews efforts that are being made internationally to develop safety objectives and principles for future nuclear power plants. The work is directed towards contributing to an international harmonization of safety approaches and to help ensure that future reactors worldwide meet a high standard of safety.

Types of future nuclear plants

Tomorrow's nuclear power plants are being referred to in a number of different ways: "next generation", "advanced", or "future" nuclear plants are the terms most often used. The terms,

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*See *The Safety of Nuclear Power*, INSAG-5, published by the IAEA (1992).

which are used interchangeably in this article, are primarily time-related and generally refer to plants that comply with national or international safety objectives and principles being developed for nuclear power reactors that are not yet operating or under construction.

Advanced designs under development comprise three basic types:

- water-cooled reactors, utilizing water as coolant and moderator;
- fast reactors, using liquid metal, e.g. sodium, as coolant; and
- gas-cooled reactors, using gas, e.g. helium, as coolant and graphite as moderator.

Most, about 85%, of today's operating nuclear power reactors are water-cooled reactors. Most advanced designs that are well developed also are water-cooled reactors. They are of two basic types: light-water reactors (LWRs) with ordinary water as moderator and coolant, and heavy-water reactors (HWRs), which use deuterium oxide (D_2O). LWRs are in turn subdivided into boiling and pressurized water reactors (BWRs and PWRs). Advanced LWRs (ALWRs), sometimes called *evolutionary* reactors, are being developed along two lines: large units in the size range of 1300-1500 megawatts-electric (MWe), and medium-size units of about 600 MWe. As being developed mainly by Atomic Energy of Canada Ltd., advanced HWRs similarly can be divided into large-size units, those with a power level of some 900 MWe, and smaller units with a power level of about 500 MWe.

The first class of large ALWRs comprises many designs and some of them are a joint effort of different countries. In general, the large units are similar to existing ones but incorporate advanced features (relevant to safety, control, etc.) and design changes to make the plant more resistant to severe accidents. Examples of some advanced PWRs and BWRs which are at a developed stage of design and are under regulatory consideration include: the Advanced Boiling Water Reactor (ABWR), a 1300-MWe plant being developed by General Electric in the United States; the System 80+, a 1300-MWe PWR being developed by ABB Combustion Engineering in the United States; and the European Pressurized Water Reactor (EPR), a 1500-MWe plant being developed by Nuclear Power International, France, and Germany. The final safety evaluation reports and design approvals for the ABWR and System 80+ were issued in 1994 by the US Nuclear Regulatory Commission (NRC).

The second class of ALWRs are plants which mainly use current technology but include significant changes in order to make intensive use of passive safety features. Some of them are at an advanced stage of design and can be considered representative examples. They include the Advanced Passive PWR (AP-600), a 600-MWe plant being developed by Westinghouse in the United States; the Simplified Boiling Water Reactor (SBWR), a 600-MWe plant being developed by General Electric in the United States; and the WWER-640 (V-407), a 640-MWe plant being developed by Atomenergoproject and Gidropress in Russia. The AP-600 and SBWR are presently under review for design certification by the NRC, and the WWER-640 is in the stage of preliminary licensing by the Russian regulatory body, Gosatomnadzor.

From the standpoint of nuclear plant safety, this *evolutionary* process of development has gained wide acceptance. At the same time, there is an ongoing discussion on the need to create a new generation of *innovative* plants that incorporate radical changes in design philosophy to avoid severe accidents. Such proposals are still in early design stages, and their development particularly faces problems associated with financial and technical requirements for testing and verifying the designs.

Harmonizing safety objectives

Global efforts to harmonize safety objectives for future nuclear power plants involves many countries and organizations. In addition to the IAEA, inter-governmental organizations including the Nuclear Energy Agency of the Organization of Economic Co-operation and Development (OECD/NEA) and the European Commission are closely involved in the work.

One of the IAEA's tasks is the development of nuclear safety standards for all nuclear activities. In the nuclear power field, these standards are developed with assistance from Member States as part of efforts to bridge different points of view and obtain consensus. The agreed safety standards are hierarchically organized in four levels: at the highest level are Safety Fundamentals, followed by Safety Standards, (or NUSS codes), Safety Guides and Safety Practices.

The exchange of information on nuclear safety research takes place within the working groups of OECD/NEA. Within the EC, a Reactor Safety Working Group (RSWG) of representatives of safety authorities, vendors, and utilities is active in exchange of information and promoting harmonization in the field of rules and guidelines for the design and operation of nuclear power plants. Bilateral and multilateral exchanges among regulatory bodies also occur, often under the auspices of the IAEA, OECD/NEA and Nuclear Regulators' Working Group (NRWG) of the EC.

A special effort on harmonization of safety approaches has been made by the Institute of Nuclear Protection and Safety (IPSN), France, and the Gesellschaft für Anlagen und Reaktorsicherheit (GRS, the nuclear reactor safety institute) in Germany. The work includes publication in 1993 of the document *GPR/PSK Proposal for a Common Safety Approach for Future Pressurized Water Reactors.*

Among nuclear utilities, many operators are interested in defining their needs and goals for nuclear plants to be ordered in the future. Toward this end, many utilities have looked to co-operative approaches, both at the national and international levels. In 1985, US utilities started an industry-wide effort to establish the technical foundation for the design of ALWRs. This ALWR programme is being managed by the Electric Power Research Institute (EPRI) and includes participation and sponsorship of several international utility companies and close co-operation with the US Department of Energy (DOE). The cornerstone of the programme is a document setting out utility design requirements (URD). Elsewhere, utilities also worked together to issue European Utility Requirements (EUR).

The URD and EUR define utility requirements, including safety goals set by them, in particular to promote licensing of new reactor designs. The URD, for example, presents a complete statement of utility desires for next generation nuclear plants and in particular addresses ALWR safety policy. The ALWR safety policy features an integrated design approach to safety based on defense-in-depth philosophy. It includes three overlapping levels of safety protection: accident resistance, core damage prevention, and accident mitigation. Top-tier safety design requirements are developed on the basis of the safety policy statement for each level of safety protection and for a specific type of ALWR.

The EUR is a product of major European electricity producers and associations and focuses on common requirements for future LWRs to be built in Europe. It is intended to be a tool for promoting harmonization, in particular of main safety objectives and safety requirements.

In drafting and reviewing both sets of requirements, many utilities in Asia, Europe, and North America have taken part. Even though these documents cover requirements in general for the entire plant, they deal specifically with main safety objectives and detailed safety approaches. These efforts also can be seen as an important contribution to global harmonization of safety approaches and objectives for future nuclear power plants.

Activities through the IAEA

The IAEA's efforts in this area received impetus in 1991 through a resolution of its General Conference. The resolution invited initiation of activities on safety principles for the design of future nuclear power plants using a step-by-step approach based *inter alia* on INSAG's work.

Since then, the Agency has convened a series of meetings aimed at achieving agreement on safety definitions, terminology, and classification of future reactors. The meetings identified desirable safety enhancements and topics relevant to the development of new principles. INSAG safety reports were reviewed as they relate to safety principles for future plants. Parts of these documents requiring clarification and parts requiring amplification were identified.

In June 1995, following INSAG's review and comment from its Member States, the Agency published a technical document, *Development of Safety Principles for the Design of Future Nuclear Power Plants* (IAEA TEC-DOC-801). The document proposes updates to existing safety objectives and principles which could be used as a basis for developing those recommended for the design of future nuclear power plants. Accordingly, it is intended to be useful to reactor designers, owners, operators, researchers and regulators. The proposals are intended to provide general guidance which, if carefully and properly followed, will result in reactor designs with enhanced safety characteristics beyond those currently in operation. They are derived from lessons learned from recent operational experience, research and development, design, testing, and analysis, as well as from attempts to reflect current trends in reactor design, such as the introduction of new technologies.

The proposals represent a contribution to the growing international consensus on what constitutes an appropriate set of technical principles for the design of future reactors. The document's starting point was the well-established set of objectives and principles for nuclear plants laid down in the INSAG safety report, *Basic Safety Principles for Nuclear Power Plants* published by the IAEA in 1988. According to definitions in this document, safety objectives state *what* is to be achieved. Safety principles are statements of *how* the objectives are to be achieved.

The safety objectives and principles for today's plants are to a large extent also valid for future designs. However, the 1995 technical document proposes some modifications of the technical safety objective and some new principles. The key proposal is that severe accidents beyond the existing design basis will be systematically considered and explicitly addressed during the design process for future reactors.

The document also emphasizes the need to further lower the risk of any serious radiological consequences and to assure that the potential need for prompt off-site protective actions can be reduced or even eliminated. Defense-in-depth remains the main strategy to deal with severe accidents for future nuclear plants and it is founded on measures for effective prevention and mitigation.

Areas of greater co-operation

A number of areas call for greater efforts to harmonize technical and policy matters related to future nuclear power plants. While many of these areas present promising opportunities, others do not. Some areas where a harmonized approach is lacking are likely to remain that way for many years because of large national differences in geography, culture, policy, and regulation. Other areas are likely to remain flexible because of market forces.

Overall, greater co-operation is needed to resolve important technical and policy differences. Increased harmonization would likely improve the safety, cost, and availability of future nuclear power plants, and would likely improve the consistency and efficiency of the licensing process. It might also have indirect benefits in the area of public acceptance. The technical convergence of safety experts, regulators, and utility operating organizations around the world on a consistent set of principles would likely increase confidence that the right conclusions have been reached.

Specific opportunities for greater harmonization lie in the field of safety assessment, including severe accident assessment. Primarily needed is agreement among the many organizations that conduct safety assessments on more common approaches. Specific areas that need concerted co-operative efforts include:

- probabilistic safety assessment (PSA) methods, and the role of PSA in safety decision making, including the appropriate balance among PSA, deterministic methods, and engineering judgment;
- methods and criteria for selecting those severe accident sequences to be addressed in the design of future plants;
- methods and criteria for treating uncertainties, and on the practical implementation of policies that require analysis for all severe accident considerations;
- approaches concerning the distinction between design basis accidents, as analyzed for the licensing case, and severe accidents that are also considered in the design and considered by the regulator;
- safety assessment procedures within the licensing process from country to country, including technical documentation requirements; consideration also should be given to harmonization steps that ease the complications inherent in licensing a plant designed to the codes and standards of a different country;
- improved consistency in source-term evaluation methods, and other methods for calculating radiological consequences of accidents.

It should also be noted that national approaches for dealing with external hazards vary substantially. Harmonization of practices for future plants seems to be difficult because types and levels of external hazards are site-specific. The issue of external hazards has emerged as an increasingly important one as greater safety levels are achieved for internal hazards, leaving the relative contribution from external hazards more relevant.

Additionally, high-level safety goals should be defined that allow safety targets unique to nuclear power plants to be derived from and compared to the broader issues of public health and safety protection for other enterprises. A step in this direction is the IAEA's publication of the technical document, *Policy for Setting and Assessing Regulatory Safety Goals* (IAEA TECDOC-831). It reflects peer group discussion of senior regulators from 22 Member States.

The work is part of the Agency's continuing effort to contribute to the process of wide international discussion on the harmonization of safety goals, objectives, and principles for future nuclear power plants. The process can help ensure that diverse and different views are fully considered and balanced through greater international co-operation in this important field. ❒