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Approaches to the safety of future nuclear power plants

Report of a Technical Committee meeting held in Vienna, 29 May – 2 June 1995

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FOREWORD

The safety of future generations of nuclear power plants is an important issue for nuclear plant suppliers, electric utilities, government authorities, and the public in general. General expectations are for improved safety in future plants, even though most current plants are considered to have achieved adequate levels of safety. What safety goals should be achieved in future plants, and what design approaches are preferred in reaching these goals are matters of intense discussion among nuclear experts.

Since the 1991 Conference on the Safety of Nuclear Power: Strategy for the Future, the IAEA has actively supported efforts of Member States to answer these questions, through various meetings and reports. The Technical Committee Meeting on Approaches to Safety of Future Nuclear Power Plants in Different Countries, held from 29 May to 2 June 1995, contributed to this process. Experts from 14 different countries and two international organizations participated in the meeting, which provided the opportunity to exchange information and to review the answers developed to date to these issues (primarily from the IAEA's technical document "Development of Safety Principles for the Design of Future Nuclear Power Plants" (IAEA-TECDOC-801) and the report of the International Nuclear Safety Advisory Group "Basic Safety Principles for Nuclear Power Plants" (INSAG-3). These references were then used as a starting point for answering the question "to what degree does general agreement (or harmonization) exist on these desired safety approaches for future reactors, and what opportunities remain for further harmonization?"

The Technical Committee found that a substantial degree of harmonization already exists, that further harmonization is desirable, and that progress is being made in areas where harmonization is lacking. This report presents specific information on harmonization in the various issues and approaches.

The IAEA is grateful to the many experts who contributed to this publication. The officer of the IAEA responsible for the TECDOC was L. Kabanov of the Division of Nuclear Installation Safety.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

The safety of the current generation of nuclear power plants (NPPs), designed and operated to existing safety principles, is in general already very high. Nevertheless, progress in safety research and development, improved risk assessment methods, and implementation of lessons learned from the many accumulated reactor-years of operational experience from current plants, will enhance the safety of the next generation of NPPs even further.

Enhancement of the safety of future plants is prompted by several factors. First is the tendency for industrial activities to become safer and more efficient as they are developed with time. Second is the desire to maintain the current low level of risk to the public from nuclear power, even in the event that the number of nuclear reactors is greatly increased in the future. Third is the desire to limit the likelihood and consequences of severe accidents in future plants. Minimizing the potential for large off-site radiological consequences minimizes the impact of NPPs on public health and safety, thereby reducing the need for off-site protective actions. Finally, in some countries, enhancement of safety is a prerequisite for public acceptance of a new or increased nuclear power programme.

The IAEA activities on the safety of future nuclear power plants were reinforced by the 1991 General Conference Resolution GC(XXXV)/RES/553 (para. 9) which invited the Director General to start activities on safety principles for the design of future NPPs.

A series of meetings organized by the IAEA since then have aimed at achieving agreement on safety definitions, terminology and classification of future reactors. At these meetings, desirable safety enhancements and topics relevant to the development of new principles were identified. Also identified was a general desire to achieve an improved level of harmonization among Member States on these safety principles.

The next step in these activities was the preparation by an expert group of a technical document on "Development of Safety Principles for the Design of Future Nuclear Power Plants", published in June 1995 as IAEA-TECDOC-801 [1], after incorporating the comments of the International Nuclear Safety Advisory Group (INSAG) and the comments of experts from various Member States.

It should be noted that the expert group used as its starting point the design related portions of INSAG-3, "Basic Safety Principles for Nuclear Power Plants" [2]. INSAG at its meetings in 1994/1995 agreed that a revision of INSAG-3 would be needed. INSAG tentatively agreed to an approach based on the original text with updates that would utilize text from Ref. [1].

Both References [1] and [2] were used extensively by this Technical Committee in its meeting and report. Further, the Committee was of the opinion that the update of INSAG-3, when issued, would represent a significant step toward further harmonization of safety principles for future plants.

During recent years, utilities and other organizations have worked intensively on the development of requirements for future nuclear power plants. One set of such requirements, the Utility Requirements Document (URD), has been prepared by the Electric Power Research Institute (EPRI), in a joint effort with utilities and organizations in the USA, Europe and Asia. A similar set of requirements, the European Utility Requirements (EUR), is being prepared by major European utilities. Various efforts to develop regulatory approaches for future reactors and to harmonize those approaches are underway in many countries, in some cases with co-ordination provided by the IAEA or the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA).

1.2. PURPOSE OF THE MEETING

The main purpose of the Technical Committee Meeting (TCM) was to exchange information on the development of safety approaches to enhance the safety of future NPPs, by utilities, regulators and other organizations; to note those areas where significant agreement already exists; and to consider further harmonization of these approaches in the future.

The purpose of this TCM is consistent with and supports recommendations made at two other recent IAEA meetings:

- The International Symposium on Advanced Nuclear Power Systems held in Seoul, Republic of Korea, in October 1993, on the desirability of wider international harmonization of design and safety objectives;

- The Technical Committee Meeting and Workshop on Review of Engineering Safety Systems of Advanced Light Water Reactors, held in Moscow in May 1994, on the necessity to clarify regulatory approaches for future nuclear power plants in various countries.

1.3. FORMAT OF THE REPORT

Most Member States participating in the TCM prepared and presented papers to the Committee in order to exchange information on different approaches to safety in various countries. These presentations were used to develop Section 2 on progress in international co-operation, and to develop short formatted summaries of each country's situation and safety approach, which are presented in Appendix I. The authors and titles of the presentations are listed in Appendix II. The full presentations are available from the IAEA as Working Material.

A comprehensive list of design features, design attributes, safety principles and approaches was prepared. The items were then grouped into broad categories and considered from the point of view of harmonization (Section 3). Areas in which further harmonization was required were then discussed (Section 4). Conclusions are presented in Section 5.

2. PROGRESS IN INTERNATIONAL CO-OPERATION

2.1. INTERNATIONAL ORGANIZATIONS

Harmonization of the approaches to safety of future NPPs among different countries is sought strongly in current international co-operation. This co-operation is promoted by utilities, regulators and designers, and supported by international organizations such as the IAEA, OECD/NEA, and the European Commission.

The development of nuclear safety standards for all nuclear activities is one of the tasks of the IAEA. The IAEA seeks to establish standards of safety, assisted by Member States with experience with nuclear power programmes. A broad consensus of opinion is sought to provide assurance that the safety objectives and standards thus defined and developed are acceptable to all Member States. These safety standards are published in the Safety Series in a hierarchy of four levels with safety fundamentals at the highest level. Other levels correspond to safety standards (or NUSS codes), safety guides and safety practices respectively.

An exchange of information on many aspects of research on nuclear safety also takes place within the working groups of OECD/NEA. In the European Community a Reactor Safety Working Group (RSWG) with representatives of safety authorities, vendors and utilities is active in the exchange of information and in promoting harmonization of rules and guidelines for the design and operation of NPPs. Other international organizations also provide a forum for exchange of information on nuclear safety matters, such as the World Association of Nuclear Operators (WANO) and various professional nuclear engineering societies.

National nuclear safety authorities regularly participate in bilateral and multilateral initiatives to exchange information and share experience. Many of these initiatives, directly or indirectly, seek to promote harmonization for future NPPs. As an example, within the European Commission a Nuclear Regulators Working Group (NRWG) is active in this field.

Multilateral exchanges of information among regulatory bodies also occur under the auspices of IAEA and OECD/NEA. The IAEA organized a system of peer review discussions among safety regulators. Twenty-two Member States participated in 1994 discussions on the policy used for setting and assessing of regulatory safety goals. The Committee on Nuclear Regulatory Activities (CNRA) of OECD/NEA prepared a review of regulatory requirements for advanced NPPs, with the participation of regulatory bodies from seven countries.

2.2. UTILITY REQUIREMENTS

The majority of nuclear utilities worldwide are engaged in defining their needs and goals for nuclear plants to be ordered in the future. In these efforts, many utilities have joined in co-operation with other utilities at the national and international levels. In this endeavor, two sets of utility requirements prepared by two groups from utilities of various countries are important: they are the Utility Requirements Document (URD) and the European Utility Requirements (EUR).

In 1985, the US utilities started an industry-wide effort to establish the technical foundation for the design of Advanced Light Water Reactors (ALWRs). This effort, the ALWR Program, is being managed for the US electric utility industry by the Electric Power Research Institute (EPRI), and includes participation and sponsorship of several international utility companies and of the US Department of Energy (DOE). The cornerstone of the ALWR Program is a set of comprehensive, full-plant scope utility design requirements which are contained in the ALWR Utility Requirements Document (URD).

The purpose of the URD is to present a clear, complete statement of utility desires for their next generation of nuclear plants. The anticipated uses of the URD are threefold [3]:

- establish a stabilized basis for future LWR regulation which includes the USNRC's agreement on resolution of outstanding licensing issues, and which provides high assurance of licensability;

- provide a set of design requirements for standardized plants which are reflected in individual reactor plant supplier certification designs;

- provide a set of technical requirements which are suitable for use in an investor bid package for eventual detailed design, licensing and construction, and which provide a basis for strong investor confidence that the risks associated with the initial investment to complete and operate the first ALWR are minimal.

The URD was sent to the USNRC in 1990 for review. In response, the NRC has prepared a Safety Evaluation Report [4] on its findings.

More recently, a number of the major European electricity producers and producer's associations have entered an agreement to write a common requirement document dedicated to future LWR nuclear power stations to be built in Europe. The EUR document, produced by this common effort, is intended to be a tool for promoting harmonization of:

- safety approaches, targets, criteria, and assessment methods
- standardization of design conditions
- design objectives and criteria for the main systems and equipment
- equipment specifications and standards
- information required for safety, reliability, and cost assessment.

A first draft (Revision A) was released in March 1994. Volumes I and II of the final version (Revision B) were issued in November 1995 and are to be discussed with the national safety authorities of the seven European countries directly involved. Even though these documents cover requirements in general for the overall plant, they also deal specifically with the main safety objectives and detailed safety approaches.

Thus it is hoped that at the end of the EUR process, utility requirements, including major safety requirements, will be identical throughout Europe, allowing an effective standardization of designs.

Since many utilities are participating in both the URD and EUR efforts, it is clear that many similarities already exist between the two sets of requirements. Comparison studies of the EUR (Rev. A) with the URD and IAEA documents have contributed to minimizing differences between these documents.

In drafting and reviewing both sets of requirements, many utilities of Asia, Europe and the USA have taken part. Utilities consider it essential that they play a major role in developing requirements for future reactors and in harmonizing these requirements within the utility community. Utilities will hold the ultimate safety and financial responsibility for these future plants, and hold the first-hand operating experience from current plant operations that they are now applying to the requirements for the design of future plants. Therefore, these utility requirements efforts can be seen as a very important contribution to worldwide harmonization of safety requirements for future NPPs.

2.3. REGULATORY APPROACHES

Important progress toward harmonizing safety approaches has been made by various regulatory groups. An effort on harmonization of safety approaches has been made by the expert nuclear safety organizations, Institute of Nuclear Protection and Safety (IPSN) in France and Gesellschaft fuer Reaktorsicherheit (GRS) in Germany, resulting in the publishing in 1993 of the document "GPR/RSK Proposal for a Common Safety Approach for Future Pressurized Water Reactors". GPR and RSK are the French and German nuclear safety advisory bodies, respectively [5].

In Russia, documents supplementing the basic "Atomic Power Plants General Safety Regulations" (OPB-88) have been developed. In this context, a 1993 regulation was issued by the Federal Nuclear and Radiation Safety Authority of Russia on Nuclear Power Plant Siting, dealing with the limitation of radiological consequences in case of severe accidents which are addressed in the design of the next generation of NPPs [6].

In 1989, the USNRC issued a new regulation, "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Reactors" (10CFR Part 52) [7] and is currently in the process of developing and issuing design certifications for two evolutionary ALWRs.

The UK "Safety Assessment Principles for Nuclear Power Plants" [8] is another example of a consistent safety policy document which is applied to both modern existing and next generation NPPs. Other regulatory activities on the development of safety approaches for future NPPs have also been pursued in some other countries.

3. AREAS WHERE SIGNIFICANT HARMONIZATION EXISTS

The topics and issues where significant harmonization exists can be grouped into the following categories:

- Fundamental design approaches
- Accident considerations
- Safety goals and decision processes
- Safety culture and human factors
- Miscellaneous issues.

Many of the items in Table I had already been discussed in IAEA-TECDOC-801 [1]. Citations from this publication are significant because this technical document covers this issue appropriately, and that harmonization already exists on the issue in question, at least to the level of detail that issue is presented in TECDOC-801. Therefore, many discussions in this report are intentionally brief, and the reader is encouraged to read the relevant citations in TECDOC-801.

What is important in the present context of this TCM is the effort to identify where harmonization on these matters exists today, and to jointly develop ideas in areas where harmonization does not exist that could be a first step toward an improved situation. These matters where consensus is only emerging or is only partly achieved are discussed in Section 4.

3.1. FUNDAMENTAL DESIGN APPROACHES

Proven technology

Future plants will employ proven technology wherever possible, and this has safety benefits. This goal is sufficiently flexible to achieve innovation and evolutionary improvements, based on new technology, proven by its use elsewhere or by testing. The introduction of significant innovation requires an increased emphasis on analysis and testing, and, with major innovation, the need for a prototype to be considered. There will also be effects on the safety analysis methodologies needed to deal with these innovations.

(see TECDOC-801, paras 114–116)

Simplification

Simplification is a fundamental goal in future plant design processes. Simplification is sought from the perspective of the operation of the plant, to reduce unnecessary complications from cross-connected and multi-function systems, etc. A simplified plant is one with logical, integrated system organization, layout, and operations.

(see TECDOC-801, para. 76)

Design margins

Future designs will include appropriate improvements in design margins for commercial and other reasons, e.g., investment protection, operational flexibility, improvements in aging management and long-life attainment, etc. These improvements are of benefit to safety.

Maintainability/inspectability/constructability

Future plants will be designed with improved maintainability, inspectability, and constructability in mind. This includes ample space and equipment access for maintenance, modern technologies and processes such as modularization to ease construction processes, etc. Part of the concept of improved constructability is the goal of achieving a high degree of design completion prior to commencement of construction. Emphasis in these areas is expected to reduce operating and maintenance expenses, reduce man-rem exposures to plant workers, and reduce the time and cost of construction.

(see TECDOC-801, paras 63, 76, 142, 143, and TECDOC-682 [3])

Standardization

Although standardization is primarily an economic and licensing stability issue, the achievement of a high degree of standardization also has benefits from the standpoint of operations and maintenance training, spare parts management, and other simplifications that could have indirect safety benefits. In general, future designs are expected to achieve a high degree of standardization within any specific reactor design type and product line, but not to achieve a degree of standardization that precludes competition, design innovation or local participation, or is wasteful by trying to envelope all considerations.

(see TECDOC-801, para. 64)

TABLE I. FUTURE NPP SAFETY APPROACHES DISCUSSED DURING THE TCM

Fundamental design approaches	
- Proven technology	- Standardization
- Simplification	- Plant type and size options
- Design margins	- Flexibility
- Inspectability/maintainability/ constructability	- Passive safety concepts
Accident considerations	
- Severe accidents	- Accident management
- Containment	- Simplified emergency planning
- External hazards	- Siting
Safety goals and decision processes	
- "How safe is safe enough?"	- Design basis approach and severe accident treatment
- Licensability	- Realistic/best estimate methods
- Balance among PSA, deterministic methods and engineering judgement	- Defence-in-depth
- Probabilistic safety targets	- Safety and economic competitiveness
Safety culture and human factors	
- Safety culture	- Grace period
- Man-machine interface	
Miscellaneous issues	
- Startup, low power, shutdown	- Decommissioning
- Spent fuel storage	- Quality and safety classification
- Security, sabotage protection	

Plant type and size options

Utilities have requirements for a range of options for future NPPs. This includes options in plant size (e.g., large or mid-size), plant type (PWR, BWR, PHWR, HTGR, ALMR, etc.), design philosophy (e.g, active vs. passive safety), and plant purpose (power production, process steam, district heating, desalination).

Flexibility

Future plants will have extra design and operational flexibility for anticipated future needs and technology development opportunities, such as various potential fuel design, fuel composition and loading options, load following, computing enhancements, etc.

Passive safety concepts

There has been a trend toward adopting passive safety features in at least some reactor designs, much more evident in the so-called "passive plants", but also evident in selected systems within some evolutionary designs. Passive systems based on natural physical laws have appeal to designers, operators, and the public. Passive safety approaches offer potential advantages to design simplicity, to human factors, etc. These approaches also present challenges to the designer, such as meeting cost goals for typically smaller plants, addressing the sometimes slower response of passive systems, especially when thermal driving heads become low, etc. Additionally, they present challenges to existing safety analysis methodologies.

(see TECDOC-801, paras 115, 119, and INSAG-5 [4])

3.2. ACCIDENT CONSIDERATIONS

Severe accidents

Severe accidents will be considered explicitly in the design of future NPPs. Based on formal criteria, appropriate severe accident sequences will be selected and formally addressed in the design as a separate category, with features that prevent or mitigate that sequence.

Severe accidents addressed in the design are treated with a balance between prevention and mitigation. The defence-in-depth concept requires attention to both. Prevention of severe accidents is pursued to the maximum feasible extent, because prevention represents the first line of defence and if successful also provides investment protection. On the other hand, mitigation and containment performance to cope with severe accidents addressed in the design are very important and are being effectively increased as well. When mitigative features for severe accident scenarios become extremely complex or difficult to demonstrate, primary emphasis is placed on preventing the sequence from occurring (e.g., as provided for by reliable depressurization systems).

Severe accidents will be considered on a best estimate basis. Part of this best-estimate approach includes the development of realistic source terms for each advanced design.

The systems, structures, and components (SSCs) used for features that are added to the design to address severe accidents are of high quality, but safety-grade quality levels are not required.

(see TECDOC-801, paras 12-25)

Containment

The containment design and its contribution to accident mitigation will be carefully considered and evaluated in the design process, with particular attention to those severe accidents addressed in the design. Mitigative features are designed and severe accident management is specified on the basis of representative severe accident conditions and correlated loads, to be identified.

The containment is commonly considered as a safety-grade feature, designed for design basis loads, but also evaluated and determined to be adequate against severe accident loads. For severe accidents addressed in the design, the containment is sufficient to meet safety and radiological objectives on a best-estimate basis. This includes both preservation of the containment integrity function, but also functional specifications for leak-tightness. Containment bypasses in severe accident conditions that would not be in compliance with these objectives are prevented.

(see TECDOC-801, paras 171–177)

External hazards

An appropriate set of external hazards is addressed explicitly in the design. The specific external sequences selected are determined on the basis of risk importance. External hazards, especially the natural ones, are very site specific, but customizing each future plant to the specific hazards appropriate to a specific site is not practical if standardization is to be achieved. Therefore, the design process achieves an optimum balance between standardization and site specific hazard protection. This is usually accomplished using a "site envelope" approach that requires the standard design to be protected against those external hazards most probable for a large number of potential NPP sites, and allows site specific treatment of those hazards unique to a smaller number of potential sites for that design.

Accident management

Accident management is treated comprehensively for future plants. Accident management augments design features to prevent degradation of an accident to severe accident conditions, and to mitigate accidents, if they occur.

Accident management is supported by design features of future plants, which provide grace periods for accident management and contribute to a smooth plant response in transients and accidents.

(see TECDOC-801, paras 260–270)

Simplified emergency planning

Future plants are designed so as to permit consideration of simplification of emergency planning requirements, including the capability for simplification, reduction, or elimination of off-site protective measures. Simplification of emergency planning generally means a reduction in exclusion areas and/or a reduction in major countermeasures such as evacuation, rapid notification, etc.

(see TECDOC-801, paras 21, 271–278)

Siting

Prudent siting is achieved through consideration of a variety of issues, such as availability of ample water sources for normal and emergency heat sinks, protection of the site from external hazards, land use, population density, etc.

3.3. SAFETY GOALS AND DECISION PROCESSES

"How safe is safe enough?"

There is general agreement that harmonization of approaches to the safety of future NPPs should include a consistent and stable understanding of what constitutes an acceptable level of nuclear safety, i.e., "How safe is safe enough?". The Technical Committee agreed that the answer to this question should be derived from public health and safety policies that are applied fairly to all sources of risk on a non-discriminatory basis.

Licensability

Future plants are designed to assure high confidence in licensability, of both the design itself, and of the operational aspects that are approved separately.

Balance among PSA, deterministic methods, and engineering judgement

The process for evaluating specific designs involves a careful balance of deterministic methods, probabilistic methods (including comparison to numerical safety targets), and the use of engineering judgment.

This balanced process is comprehensive in its review of the relevant operating experience, test information, etc.; and both the plant PSA and the plant's deterministic criteria are reviewed for completeness of scope and completeness of plant state coverage (e.g., low power and shutdown states).

(see TECDOC-801, paras 21, 24, 25, 83, 84)

Probabilistic safety targets

As part of the design process, comparison of the design to overall top level numerical safety targets has been established in INSAG-3, and has been specified as a requirement in all existing utility requirements for NPPs. Some regulatory authorities require the submittal of a PSA for licensing purposes, and many compare the results of the PSA to either government-specified or industry-specified numerical safety targets. Most countries do not treat probabilistic safety targets as formal regulatory requirements. However, the value of a PSA in safety evaluation is recognized worldwide as one of the important steps in design evaluation for future NPPs.

A concept agreed upon in the 1988 Report, INSAG-3, is that future plants should be able to achieve an order of magnitude improvement in safety over existing plants, as measured by probabilistic safety targets; this includes both those targets established for plant protection (i.e., core damage frequency), and off-site consequence limits (e.g, large off-site release frequency).

In their approaches, many countries have made reference to the probabilistic targets of INSAG-3. This can be considered as an important step toward international harmonization.

The detailed approaches with respect to methods and targets are different in different countries. There are several international activities which look into these differences (e.g., OECD/NEA, EC).

(see INSAG-3 and TECDOC-801, para. 25).

Design basis approach and severe accident treatment

The current design basis approach for current plants has been shown to be a sound foundation for the protection of public health and safety, in part because of its broad scope of accident sequence consideration, and because of its many conservative assumptions that have the effect of introducing highly conservative margins into the design. Even though experience and analysis have shown that some event sequences beyond the design basis also need to be considered explicitly in the design (i.e., severe accidents), there is a general agreement to preserve the design basis approach foundation, and to build on to it the additional consideration of severe accidents.

Since there is general agreement that "severe accidents addressed in the design" are not to be treated with the conservative methods and criteria used for design basis events, it is generally accepted that severe accidents are handled as a separate category, different than design basis accidents (DBAs) and their treatment in the licensing process. (Also included in this separate category, in most countries, are events beyond the design basis that do not result necessarily in severe core damage (e.g., station blackout, ATWS)). Countries variously call this separate category "beyond DBA", "safety margin basis", "design basis extension", etc. This matter is somewhat country specific because of different approaches, regulations and policies. The end result is that some countries make a strong distinction between these two classes of accidents, while others treat these two types of accidents as equivalent parts of the design process, with only the qualification being made that severe accidents are treated with best-estimate approaches.

(see TECDOC-801, paras 21, 39, 119, 129, 177)

Realistic/best estimate methods

Realistic methods and realistic acceptance criteria are used throughout the design process for future plants. In general, this means that realistic data, assumptions, methods, codes, models, etc., are used throughout the design process; and that sequences are mechanistic, that is, each event in a sequence, as well as the overall sequence, is logical and credible.

For design basis events, an appropriate degree of conservatism is added for safety margin, to deal with uncertainties, to provide sufficient bounding for design basis assumptions such as single failure, etc. The implementation of this conservatism in licensing rules differs from one country to another.

For severe accidents, and for all PSA applications, true best-estimate assumptions, methods, data, etc., are used throughout, because of the distortions to the outcomes that result from imbedding conservatism inside the analysis. Depending on the intended use of the PSA results or deterministic severe accident analysis results, some degree of conservatism may be added at the end to account for overall uncertainty.

Defence-in-depth

Defence-in-depth is a well-established safety principle for NPPs that is described in detail in INSAG-3 and other international and national documents. Future plants will adhere to this principle, in that they will maintain a strong defence-in-depth philosophy in the design. Some future plants may selectively increase emphasis on some levels within the concept (e.g., accident prevention or mitigation), and some designs may seek to adjust the approach to a specific level (e.g., simplified emergency planning). But all future plants will adhere to the principle of providing reasonable and independent protection at each level, for those event sequences considered in the design.

(see TECDOC-801, paras 39–48)

Safety and economic competitiveness

The Technical Committee agreed that no NPP will be built in the future unless it is cost competitive, as compared to other electricity generating sources available. There was strong agreement that this overriding consideration should not be allowed to compromise the levels of safety considered necessary for future plants. Consideration of cost–impact is appropriate during the design process when selecting the optimum design features that provide the overall level of protection required. Cost benefit analysis is and will be used to optimize the design, to help achieve simplification, and to adjust the emphasis to various levels in the plant's defence-in-depth, as long as overall defence-in-depth balance is maintained.

3.4. SAFETY CULTURE AND HUMAN FACTORS

Safety culture

This concept has long standing in the nuclear safety field. This fundamental safety principle is applicable to all activities and organizations related to nuclear power. This principle is understood and accepted globally as an essential element of safety for both current and future plants.

(see INSAG-3 paras 28–34; INSAG-4 [5])

Man–machine interface

There is general agreement that human factors considerations should be incorporated into every step of the design process for future reactors.

(see TECDOC-801, paras 73, 76, 128)

Grace period

This concept has traditionally focussed on the time interval between the onset of an accident condition and the first required human intervention in the functioning of safety systems that the designer is expected to accommodate in the design. This number has traditionally been 30 minutes, but the target grace period for some proposed designs has been extended significantly.

(see TECDOC-801, para. 76)

3.5. MISCELLANEOUS ISSUES

Startup, low power, and shutdown issues

Future plants are designed to more explicitly accommodate challenges to safety functions in non-power states.

(see TECDOC-801, para. 191)

Spent fuel storage

Future plants will have adequate capacity for on-site storage (both in-pool and dry storage), and will provide improvements for the spent fuel transfer process, with provision for the handling of damaged fuel.

(see TECDOC-801, para. 191)

Security, sabotage protection

Future plants will pay appropriate attention to this issue. Although regulatory requirements for future plants are not expected to be significantly different than for current plants, the new plant design process provides the opportunity to provide these capabilities in a more logical and cost-effective manner, often by taking advantage of newer technologies, improved plant layout, etc.

(see TECDOC-801, para. 191)

Decommissioning

Future plants are expected to be built using materials and technologies that will reduce radioactive waste and man-rem exposure during decommissioning.

(see TECDOC-801, para. 191)

Quality and safety classification

The safety classification of SSCs based on quality requirements in future plants is expected to expand the use of high quality, commercial grade equipment, due to greater emphasis on realistic approaches to both DBA and beyond DBA sequences and methods. There is general agreement regarding an increase in the level of attention given to the quality of design, manufacture, etc., of SSCs in future plants, particularly for features whose reliability is difficult to demonstrate quantitatively.

(see TECDOC-801, para. 119)

4. AREAS FOR FURTHER HARMONIZATION

4.1. FUNDAMENTAL DESIGN APPROACHES

Proven technology, standardization, and replication

Harmonization is needed to clarify the terms "standardization", "replication" and "proven technology". It is also recommended that consideration be given to the balance between standardization and innovative development, and to where the balance point is.

Plant type and size options

It is important that as various options are developed for future generating choices, that design principles and functional acceptance criteria are equivalent and fair to each approach, i.e., that they are not biased toward specific design categories unless equivalent safety outcomes dictate some degree of selectivity (e.g., deterministic criteria specific to different design types [PWRs, BWRs], and approaches [active, passive] should be applied consistently).

Passive safety concepts

No clear consensus has been reached on major shifts toward passive safety for future reactors, but at least the selective application of passive concepts for some systems is generally supported for future plants. The incorporation of passive safety features is not a means in itself and needs to be carefully evaluated and introduced when benefits are evident.

Innovative Reactors

Harmonization is needed in the area of the criteria for deciding when a prototype is needed for the testing of innovative reactor systems. It is also recommended that consideration be given to the challenges to safety analysis methodologies associated with significant innovative change.

4.2. ACCIDENT CONSIDERATIONS

Safety assessment, including severe accident assessment

The IAEA and many other industry and regulatory organizations have issued publications to help establish a more consistent framework for conducting accident assessments. There are some areas that still need further definition, but primarily what is needed is convergence among the many organizations that conduct safety assessments on more common approaches.

Specific areas that need concerted efforts toward greater convergence include:

- PSA methods and role of PSA in safety decision making, including convergence on the appropriate balance among PSA, deterministic methods, and engineering judgment. For example, many countries have made reference to the probabilistic targets of INSAG-3, and both the URD and EUR specify a PSA-based safety target. This can be considered as a step towards international harmonization. In some countries, however, there is no specific quantitative target for large releases.

- Methods and criteria for selecting those severe accident sequences to be addressed in the design of future plants, including which sequences receive containment performance assessments.

- Methods and criteria for treating uncertainties, and the practical implementation of policies that require best estimate analysis for all severe accident considerations.

- Approaches to 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. Some countries approach this distinction rather formally, based on a realistic evaluation approach, while others approach this distinction with less formal differences between design basis and beyond design basis considerations.

- Consideration should be given to harmonizing the safety approaches within the licensing process from country to country, including technical documentation requirements; and consideration 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.

- The role of probabilistic human error rate prediction is an area of disagreement.

Source terms

There is a need to improve consistency in source term evaluation methods and other methods for calculating radiological consequences of accidents.

External hazards

National approaches for dealing with external hazards vary substantially, and harmonization of practices for future plants seems to be difficult. 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.

Acceptable safety end state for accident evaluation

The criteria for a defined and acceptable end state for use in analysis of DBA and beyond DBA event sequences lacks harmonization. The ultimate objective is that after a design basis event or severe accident addressed in the design, the plant should be capable of returning to a safe and controlled state. The time required to achieve this end state may vary, depending on many factors such as availability of assured long term heat sinks, design margins, accident management provisions, etc.

Simplified emergency planning; radiological criteria for containment performance

Although designs that provide adequate protection of public health and safety also protect the environment, low-level contamination limits, as specified by various nations, differ greatly, so there is no common international approach for land contamination issues. The trend in some countries is to establish limits on land contamination in time and area. Other countries may rely on clean-up and recovery actions. A related issue is consideration for long-term cleanup and recovery following an accident. These issues are addressed in TECDOC-801 through the concept of the Complementary Design Objective.

4.3. SAFETY GOALS AND DECISION PROCESSES

"How safe is safe enough?"

It is very desirable that high level societal safety goals be defined that allow safety targets unique to NPPs to be derived from and compared to the broader issues of public health and safety protection for other enterprises. This process should be open, democratic, and non-discriminatory, that is, it should apply comparable care and conservatism to all technologies, all industrial processes, and all human endeavors that contribute to risk.

The difficulties in defining quantitative criteria should not prevent further effort to demonstrate the safety of nuclear power generation in comparison to other power sources or industries and technical enterprises.

Safety and economic competitiveness

As discussed in Section 3, a clear reality is that no NPP will be built in the future unless it is cost competitive, as compared to other electricity generating sources available. This overriding consideration should not be allowed to compromise the levels of safety considered necessary for future plants. Consideration of cost-impact is appropriate during the design process when selecting the optimum design features that provide the overall level of protection required.

Cost-benefit analysis can be used to optimize the design, to help achieve simplification, and to adjust the emphasis to various levels in the plant's defence-in-depth, as long as overall defence-in-depth balance is maintained. However, harmonization is lacking on both the methods for conducting cost-benefit analysis, and on how to properly balance safety and cost goals in ways that do not compromise either.

4.4. SAFETY CULTURE AND HUMAN FACTORS

(Substantial areas for further harmonization were not specifically identified in this category.)

4.5. MISCELLANEOUS ISSUES

Long term spent fuel disposal

Although not related directly to reactor safety or future plant approaches, it is clear that increasing importance is being placed on the question of long-term spent fuel disposal. With this issue taking on greater importance, overall plans for new reactor deployment should answer the question of whether or not adequate plans are in place for achieving ultimate disposition of spent fuel. This is generally a country-specific issue.

Quality and safety classification

The classification of SSCs based on quality requirements in future plants is expected to expand the use of high quality, commercial grade equipment, due to greater emphasis on realistic approaches to both DBA and beyond DBA sequences and methods. However, there is no general agreement regarding the type of safety classification to be used on future plants. Harmonization is needed in this area.

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Areas where significant harmonization already exists include:

- Fundamental safety principles such as defence-in-depth and safety culture are well established and will be applicable for future NPPs;

- Future NPPs will show improved standardization, simplification, design margins, maintainability, inspectability, constructability, and operational flexibility;

- The current design basis approach will be applicable for the design of future NPPs, with severe accidents treated as a separate category. For future NPPs, an appropriate set of severe accidents and external hazards will be addressed explicitly in the design, on a realistic, best-estimate basis.

Areas where opportunities exist to improve harmonization include:

- High level societal safety goals that are applied evenly to all technologies, industrial processes, and other contributors to societal risk;

- A balance between safety and economic competitiveness that ensures adequate safety is maintained for future plants, while allowing greater consideration for economics;

- Safety assessments, with better agreement on the appropriate role of PSA, safety targets, methods and criteria for treating uncertainties, use of cost-benefit analysis, etc.;

- Approaches for dealing with external hazards;

- Translation of the higher safety of future designs into improved, simplified emergency planning.

It should be noted that many of these areas are promising opportunities for increased harmonization, while others are not. Some areas that lack harmonization are likely to remain that way for many years because of large national differences in geography, culture, policy and regulatory precedents, etc. Other areas that lack harmonization are areas that are likely to remain flexible because of market forces. A range of options will be needed in the future for various applications for NPPs in different countries. Harmonization should not conflict with this need for flexibility. These aspects should be taken into account in aiming at further harmonization.

RECOMMENDATIONS

Further harmonization should be realized, as much as possible through ongoing international co-operation of utilities, regulators, and designers, and the support of international organizations, with the following objectives:

1. To continue efforts in international harmonization of the main safety objectives and safety principles that may influence the general safety level of future NPPs.

2. To exchange further information on utility, regulatory, and designer views on safety objectives and design approaches for future plants in different countries, highlighting areas of commonalty and divergence. It is recommended that in co-ordinating such an exchange of information, attention should be given to severe accident assessment, methods and procedures for evaluating the radiological consequences, and the applicability of the concepts.

3. To prepare an overview and inventory of regulatory objectives and regulatory practices in various countries, taking into account experience gained in licensing advanced power reactors.

4. To give guidance to the ongoing discussion on the question of "how safe is safe enough?" It is recommended that the efforts and achievements in different countries be reviewed with respect to answering this question. In doing this, the difficulties in defining quantitative criteria should not prevent continuing efforts in demonstrating the safety and economic competitiveness of nuclear power generation in comparison with other power sources, industries, and technical enterprises.

5. To provide co-ordination in reaching a greater degree of international consensus on how NPPs should be protected against external hazards. The issue of external hazards is especially important for future NPPs, since the levels of safety being achieved by these plants is improving to such an extent that the relative contribution to risk from external hazards is becoming more relevant.

Appendix I

SUMMARY OF NATIONAL PROGRAMMES AND APPROACHES

This appendix provides summaries of the activities and approaches for each country participating in the TCM, which are structured as follows:

1. Country

2. NPPs in operation, under construction, planned

3. Industry and/or regulatory standards, requirements or safety concepts under development or in effect for future plants

4 Co-operation in international activities on harmonization of safety approaches for future plants (e.g. IAEA activities, EUR, URD, OECD, etc.)

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1. **Country:** BELGIUM (contributed by J. de Beukelaer, Département Nucléaire de Tractabel)

2. **NPPs in operation:**

Doel 1/2 (twin unit)	400 MW(e)
Doel 3	1000 MW(e)
Doel 4	1000 MW(e)
Tihange 1	900 MW(e)
Tihange 2	900 MW(e)
Tihange 3	1000 MW(e)

NPPs under construction: None

NPPs planned: None

3. **Industry and/or regulatory standards:**

US Rules and Regulations have been followed for all Belgian NPPs.

4. **International activities:**

Belgium participates in: EPRI URD, EUR, IAEA activities, European Commission activities, European PWR (EPR), and European Passive Plant (EPP).

1. **Country:** CANADA (contributed by N. Spinks, Atomic Energy of Canada Limited)

2. **NPPs in operation:** (CANDU PHWR):

Pickering	2 × 4 unit stations
Bruce	2 × 4-unit stations
Darlington	1 × 4-unit station
Pt. Lepreau	1 unit
Gentilly	1 unit

NPPs under development:

The evolution of the CANDU PHWR is based on a continuous product development approach. Proven equipment and system concepts from operating stations are standardized and used in new products. The CANDU 9 design, which is currently under licensing review in Canada, is the single unit adaptation of the 900 MW(e) class CANDU of which there are 12 units operating in Canada. A high-level design objective of the CANDU 9 is to improve safety in a cost effective manner.

The safety design for CANDU 9 systems continues the emphasis on defence in depth and evolutionary improvement to proven concepts that maximizes confidence in their safety to the public. The requirements deal with the complete range of operating conditions from normal operation to low probability events such as severe accidents.

CANDU 9 heat removal capability for accidents is increased to add redundancy and to increase design margin. The pressurizer is increased in size, to cater to complete reactor coolant system depressurization and cooldown, from the full power operating condition to the zero power cold condition. In addition, the design of the emergency core cooling (ECC) system, which is based on the single unit system design used on the Wolsong plants, includes enhancements designed to increase reliability and to provide further performance margin via faster coolant injection. All process components, except for the pressurized gas tanks and recovery pumps, are located inside the reactor building, effectively increasing the injection pressure available during the initial core refill.

CANDU 9 incorporates a high degree of redundancy in heat sink capability, to ensure both a low severe core damage frequency (SCDF) and to ensure two redundant means of heat removal for any external event such as earthquake, etc. In addition to the emergency core cooling and moderator heat removal capability for LOCA events, the design includes a fully-qualified high-pressure feedwater system, and in addition, the separate shutdown cooling system is capable of heat removal from the hot standby condition immediately after shutdown. In addition to these heat sinks, a passive, gravity-fed emergency water supply to the steam generators is provided through the reserve water tank.

Relatively easy access to the reactor building during plant operation has been a traditional CANDU advantage, and by careful attention to segregation of higher activity water vapour from lower activity areas, this can be retained, while achieving the target of less than one man.Sv/year collective occupational dose for CANDU 9. A higher performance drier with reliable performance is being qualified for use in a reactor building environment to reduce the spread and emission of heavy water vapour.

3. **Industry and/or regulatory standards:**

The following summarizes the approach by AECL to improve the safety of future CANDU reactors. As a general principle, the development objectives of advanced HWRs will be guided by the requirements of the operating utilities.

The safety design objectives for advanced CANDU HWRs will be to continue the emphasis on defence in depth and evolutionary improvement to proven concepts that maximizes confidence in their safety to the public. The operational safety objectives during normal operation for future heavy water reactors include minimizing accident initiators and designing for ALARA (as low as reasonably achievable). Other operational improvement objectives include: improved maintainability, standardization and simplification.

The fundamental CANDU HWR safety philosophy has been to provide defence in depth. Verifiable (during operation) numerical targets have been set for the frequency of process failures and for the reliability of the four special safety systems, namely the two shutdown systems; the emergency core cooling system and the containment system. For common mode hazards which may extend over a significant area of the plant, a "two group" separation philosophy is used.

The safety design objectives for advanced CANDU HWR systems will be to continue the emphasis on defence in depth and evolutionary improvement to proven concepts that maximizes confidence in their safety to the public. The objectives also deal with the complete range of operating conditions from normal operation to low probability events such as severe accidents.

Inherent in the concept of heavy water moderated reactors is the separation between heat transport coolant and moderator coolant. This has significant safety advantages for low probability events such as postulated dual failures when normal heat transport systems becomes ineffective, e.g. loss of coolant accident coupled with loss of emergency core cooling system. For this postulated event, the pressure tubes balloon, contact the calandria tubes and thereby provide a heat transfer path to the moderator. Design improvements to the moderator heat sink will be made for these low probability events.

In a CANDU reactor, the probability of severe core damage is very low, because of two special shutdown systems and because of the separation of high temperature — high pressure reactor coolant from low temperature — low pressure moderator. Should a severe accident progress to the point of failure of core components, the debris from the failed fuel channels accumulates in the bottom of the calandria. The calandria tank is surrounded by a large volume of ordinary water, which is there primarily for shielding purposes. The presence of this shield water is capable of removing the heat from the molten core and preventing contact of the failed core with the containment boundary. Design improvement can be made to enhance the capability of the shield water heat sink to reduce the probability of a large release to even lower levels. In addition, robust containment designs with improved reliability for the containment atmosphere cooling function including passive containment cooling concepts, may be considered for future designs. "Core catchers", as proposed by some for some LWR are not required in CANDU HWR.

Improvement of the man-machine interface is a key factor in reducing the probability of operator or maintainer induced accidents. System design and equipment shall be simplified from the operator's viewpoint. For example, automation will significantly reduce the tedious manual manipulation required to perform operational testing for special safety systems. Improvement to the operating envelope in the advanced HWR design will make the plant response to off-normal transients more forgiving. This will minimize accident initiators and hence will reduce the probability of an event leading to fuel damage.

Future designs should take into account the operational feedback from maintenance activities in order to determine shielding requirements and design for ALARA. In addition, further improvement shall be made to reduce internal radiation dose. The use of more efficient vapour recovery dryers, the separation of reactor coolant and moderator support systems, and the separation of ventilation to the moderator heavy water management area are examples of improvements which will help to meet the objective of reducing occupational dose to plant personnel.

4. International activities:

Canada is involved in IAEA and OECD activities.

1. **Country**: EGYPT (contributed by A.A. El Kady, M.K. Shaat and S. Khattab, Atomic Energy Authority)

2. **NPPs in operation or under construction:** None.

   The nuclear power option is in the national strategic plan.

3. **Industry and/or regulatory standards:**

   The regulatory body is developing regulations regarding construction and operation of NPPs and other nuclear installations. Since the first NPP is expected to be a turn key project (with limited local participation), the main consideration is that of the safety requirements of the vendor country as the main reference, with the IAEA safety recommendations as guidelines. In addition, the reactor should be licensable in the vendor country. As the safety requirements are expected to change for the more passive features, the regulatory body will take this into consideration.

4. **International activities:**

   Taking into consideration the tendency on the international level toward harmonization of safety approaches, Egypt participates particularly in the IAEA activities.

1. **Country:** FRANCE (contributed by J.P. Berger, Electricité de France/Septen, and U. Krugmann, Nuclear Power International)

2. **NPPs in operation:**

In France, 57 units are in operation and will still operate for many years, so their safe operation is essential to the future of the nuclear industry.

NPPs under construction and planned:

Nuclear power plants of the N4 design have incorporated all the French and world experience feedback at the design level. Examples are:

- for DBAs, a more severe classification of events (SGTR in 3rd category, etc.),
- introduction of complementary design conditions,
- implementation of specific features for shutdown operating conditions,
- accident management and emergency procedures to mitigate and control severe accidents,
- resolution of material problems (Inconel 600),
- design of a revolutionary man–machine interface (computerized control room).

Based on all these improvements the N4 design is both an advanced and a proven reactor.

The lead unit N4 design (1450 MW(e)) Chooz B1 was connected to the grid in August 1996 and three units N4 design are under construction.

Coming NPPs will be designed from lessons learned from present and past reactors, taking into account increased knowledge, experience from operation, evolution in regulatory requirements, changes in technology, etc.

In order to maintain nuclear generation competitive with fossil energy with a very high level of safety, utilities have to prepare the next generation of NPPs. With safety, some factors will be permanent: proven technology, standardization, cost effectiveness. The European Utility Requirements document (EUR) is a tool to implement such a policy and to allow competition. In parallel the industry is preparing the European PWR (EPR), the most advanced of future projects.

The approach of the EPR is largely evolutionary in order to make best use of existing experiences in designing and operating PWRs in France and Germany. Furthermore, this enables large unit sizes and contributes to economics. However, innovative features have been considered necessary in order to improve the design compared to existing designs in some areas and to achieve a very low level of risk, both for core melt and for large releases.

3. **Industry and/or regulatory standards:**

Designed on the basis of French regulation and standards, (laws, fundamental safety rules, etc.), current plants are analyzed through a safety review programme which is mainly realized in three steps:

- definition of a set of reference documents applicable to the series,
- verification of conformity of units to that set of documents,
- evaluation of reference texts in comparison with newer rules.

It must be pointed out that from the beginning of plant operation, improvements have been continuously introduced through experience feedback, maturation of design and operational safety (implementation of post-TMI modifications, of the beyond-design procedures, of the accident management, etc.), progresses in technology and industrial organization (standardization for example). Thus the safety level of older plants is very close to that of the most recent ones.

An important precondition for future plants at the start of the basic design phase of the EPR was the harmonization of safety requirements in those areas where the requirements would drive the design. It was important to achieve harmonization without systematically enveloping existing requirements. This made the early involvement of French and German safety authorities and their advisory bodies and experts necessary; they have published two major documents: "Common safety approach for future, pressurized reactors" and "Recommendations concerning the common French-German safety approach for future PWRs".

A balance of deterministic and probabilistic requirements is considered necessary. The design is based mainly on deterministic requirements. Probabilistic considerations contribute where failure data exist and their uncertainties are known.

Severe accidents are considered as a design basis for the containment in order to prevent the need of stringent countermeasures (evacuation, relocation) outside a small exclusion area (<2 km) and to enable the use of agricultural products in the medium term. For this purpose, energetic scenarios which would lead to large, early releases are practically eliminated by preventive features and the containment resists the consequences of representative low pressure core melt sequences in order to meet the radiological targets.

4. **International activities:**

The possibility of worldwide standardization, open competition and public acceptance will depend on the similarity of regulatory and utilities requirements in the world (Europe, USA, Asia). France, through its involvement in the EPR and EUR projects and in the international programmes (IAEA, EC, OECD, etc.), contributes actively to the exchanges necessary to identify a mainstream of common objectives.

1. **Country: GERMANY** (contributed by W.L. Frisch, M. Simon, Gesellschaft fuer Reaktorsicherheit (GRS) mbH, and R.H.K. Horstmann, Siemens AG, Erlangen)

2. **NPPs in operation:**

There are 20 NPPs in operation (13 PWR, 7 BWR).

For the BWR two series of plants exist:

- the 1969 series (5 units) with a power output of up to 900 MW(e)
- the 1972 series (2 units) with a power output of 1300 MW(e).

For the PWR one has to distinguish between two generations of plants:

- the old design (5 units) with a power output ranging from 300 up to 1250 MW(e)
- the new generation (7 units) with a power output of 1300 to 1400 MW(e).

With the aim of simplification of licensing and standardization of design, a series of standardized plants was constructed within a new generation of PWRs which is called

- Convoi plants (3 of the 7 units) with power output of 1400 MW(e).

NPPs under construction or planned:

The advanced PWR project regarding future NPP is the EPR project which is a common project between France and Germany. The French–German safety approach for this evolutionary PWR started in 1992. The safety concept for the EPR contains safety objectives and general principles. The most important objectives are:

1. A further reduction of the core melt frequency.
2. The "practical elimination" of accident situations which could lead to large early releases of radioactive material.
3. For low pressure core melt scenarios the design has to be such that the associated maximum conceivable releases would necessitate only very limited protective measure in area and time (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long-term restrictions in consumption of food).

While objectives I and II are in principle a continuation of the present philosophy and practice in both countries, the third objective represents a new quality in the sense of extending the defence-in-depth strategy by an additional level above that of design basis accidents.

Some of the general principles derived in the first safety approach, are:

- Enhancement of the defence-in-depth principles
- Deterministic design basis, supplemented by use of probabilistic methods
- Use of experience feedback from plant operation in both countries.

Based on this general safety approach and considering the EPR safety concept of the designer, more detailed recommendations have been developed meanwhile on the following priority items:

- Severe accidents and associated radiological consequences
- System design and use of PSA
- Integrity of the primary circuit
- External hazards
- Radiological consequences of reference accidents.

In Germany the conceptual design phase for a BWR which includes extensive use of passive safety features has been completed and the basic design phase (scheduled for 4 years duration) has just started in co-operation with interested German utilities. The concept has already been discussed with the German Reactor Safety Commission (RSK). A number of European countries expressed their interest in being involved in the design activities of the new BWR concept.

3. **Industry and/or regulatory standards:**

The current plants have been designed and licensed on the basis of German regulations and laws, and they will be subjected to a safety review programme every ten years to ensure that the operating plants will meet present safety standards in accordance with the existing level of knowledge and technology.

In operating plants, improvements have been continuously implemented (e.g., backfitting measures to cope with beyond design basis accidents) with the aim to improve plant safety.

The official German Energy Act has recently been extended towards the limitation of radiological consequences of beyond-design basis accidents. For these events, the radiological consequences should be limited such that no stringent measures are necessary outside the site boundaries. The events to be considered have to be laid down in guidelines.

4. **International activities:**

Germany contributes to different international activities on harmonization of safety approaches, such as:

NPI: Joint company of Framatome and Siemens
French-German Directorate of Licensing Bodies
EUR: European Utility Requirements
IAEA and INSAG: Participation in several activities with respect to future reactors
OPEN: Participation in Working Groups of the Organization of European Nuclear Energy Producers
OECD: Participation in various OECD activities, e.g., code validation matrix.
European Commission: Activities on the safety of future reactors.
ALWR URD: German utilities participate in the US ALWR program.

1. **Country:** INDONESIA (contributed by A.R. Antariksawan, National Atomic Energy Agency)

2. **NPPs in operation, under construction, or planned:** None.

In Indonesia, energy consumption since 1970 has been increasing constantly in support of development in all sectors. In the case of electricity, the increase of consumption during the last two years has been more than 15% per year. This poses serious challenges to both the natural and financial resources of the country. Indonesia has some fossil energy resources which are limited, and therefore energy resources are far from abundant. Hence, it is necessary for us to exercise our option for diversification by including nuclear energy.

In order to give strong justification to NPP's introduction in our electricity system, a comprehensive and in-depth feasibility study has been undertaken since November 1991. This study will be completed in a four and one-half year period. The scope of the study covers both techno-economic and safety aspects as well as site and environmental aspects. Additionally, the feasibility study will clearly delineate the main features of the requirements for future NPPs in Indonesia.

3. **Industry and/or regulatory standards:**

For the moment, no major codes or guidelines are in effect. The following summarize our general view regarding requirements for future NPPs:

In the future that is the next 50 years, the system will be dominated by the present proven systems, notably LWRs, and to a lesser extent PHWRs, with some evolutionary improvements in technology and safety of the systems.

The requirements for the next NPPs that will be stressed are the enhancement of safety, environmental quality, technical performance, and economic viability. In this regard, implementation of defence in depth philosophy for systems and procedures, and application of a quality assurance programme in all steps of the activities should be enforced and enhanced consistently and effectively.

The main safety objectives are, among others: a significant reduction of the core damage frequency, reduction of dose rate at the site boundary, and simplification/minimization of emergency plans. Special stress should be given to human resources development for engineers and managers, to the public acceptance programme, and also to safety culture enforcement.

Beyond the 50 year period, revolutionary type reactors may emerge with very special characters in terms of conceptual, safety, fuel, and performance aspects. These novel systems will challenge our innovation in research and development.

4. **International activities:** Indonesia participates particularly in IAEA activities.

1. **Country:** ITALY (contributed by A. Ferreli, Agenzia Nazionale per la Protezione dell'Ambiente, and I. Tripputi, Ente Nazionale per l'Energia Elettrica)

2. **NPPs in operation:** Four NPPs in operation until 1986: After the Chernobyl accident all NPPs were shut down.

3. **Industry and/or regulatory standards:**

   The political commitment is to consider an enlarged set of reference severe accidents in future designs for which the radiological consequences are reduced to such low values that pre-planned measures for evacuation and relocation should not be needed. Preference is given, as much as possible, to passive safety features. At present the focus is placed on PWRs and the designs taken into consideration are AP-600 on the USA side and EPR on the European side.

   Activities are carried out separately by the industry (ANSALDO), the utility (ENEL) and the Regulatory Body (ANPA), but with frequent exchange of views among the parties.

   Among the ANPA initiatives in the field of severe accidents it must be mentioned that a study was carried out, on behalf of ANPA, by Professors Corradini and Theofanous, on the Containment of Severe Accidents in Advanced Passive Light Water Reactors. The results of the study have been distributed to other international experts in order to reach a consensus as large as possible in this field.

4. **International activities:** ANPA and ENEL are participating in different international activities on the harmonization of safety approaches; in particular, ANPA is represented in:

   - the IAEA Technical Committee on "Approaches to the Safety of Future NPPs";
   - the Group on the European Pressurized Reactors, sponsored by the European Commission;
   - the Nuclear Regulator Working Group within the European Commission;
   - the OECD activities pertinent to the design of the next generation (specialists meetings on severe accidents, PRA, etc.)

   ENEL is represented in:

   - the IAEA
   - the RSWG within the EC
   - the OECD activities
   - the ALWR URD program
   - the EUR programme.

1. **Country:** JAPAN (contributed by M. Aritomi, Tokyo Institute of Technology, and K. Matsushita, Nuclear Power Engineering Corporation)

2. **NPPs in operation and under construction:**

48 nuclear power plants are in operation
4 light water reactors are under construction

3. **Industry and/or regulatory standards:**

The current plants have been designed and licensed on the basis of Japanese regulatory standards, codes and guidelines, which are basically harmonized internationally.

Since the requirements for future LWRs seem to be different between the regulatory side and the utility side, they are being discussed now, respectively. Ater settling the requirements, they will be combined and unified. After establishing the requirements, conceptual designs of future LWRs, (i.e. post the ABWR and the APWR), will be started for their construction in 2010 to 2030. In parallel with the conceptual design works, industry and/or regulatory standards for future LWRs will seem to be discussed. Even before conceptual design works will be completed, ABWRs and APWRs may be constructed, which may introduce advanced systems and components developed from the future LWR works.

Basic targets for development of future LWRs in Japan are (1) enhancement of safety and reliability, (2) cost reduction, in both construction and operation (3) efforts toward difficulty in maintaining human resources (e.g., enhancement of maintainability) coping with gradual decrease in productive population, (4) promotion of plant siting, (5) action from the international viewpoint in NPP development. Effective measures against these targets should be established by taking into account the needs of the public.

The safety levels in current Japanese plants including the ABWR and the APWR are satisfactory for demonstrating core damage frequencies of less then 10-E6/reactor year (INSAG-3 target for future plants is 10-E5/reactor year).

4. **International activities:**

Japan co-operates in international activities on harmonization of safety approaches through the IAEA activities. Japanese utilities participate in the US ALWR program through JAPC.

1. **Country:** NETHERLANDS (contributed by B.Th. Eendebak, N.V. KEMA and R. Jansma, Energy Research Foundation)

2. **NPPs in operation:**

Dodewaard since 1968
Borssele since 1973

Realization of modification programmes for both plants in 1997 will enable these reactors to continue operation until at least 2004. There are no current plans to build new NPPs.

3. **Industry and/or government standards:**

Dutch regulations are largely based on the safety codes and guides of the NUSS programme, with amendments made by the government. Amendment and codes and guides together form the Dutch Nuclear safety rules, the NVRs.

For the purpose of the Dutch risk management policy regarding major accidents, there are special criteria for individual risk and societal risk. These criteria are officially issued by the government. In principle, the government will accept the industrial codes and standards of the country of the vendor of a NPP.

4. **International activities:**

Dutch representatives are participating in many committees of the IAEA, OECD, European Commission, etc.

The utilities are also involved in UNIPEDE, the ALWR URD program, and the EUR programme.

1. **Country:** RUSSIAN FEDERATION (contributed by A.V. Ageev, V.P. Astakhov, Gosatomnadzor, V.S. Ionov, Kurchatov Institute, and N.S. Rabotnov, Institute of Physics and Power Engineering)

2. **NPPs in operation, under construction, or planned:**

The Russian Federation currently has the following power units:

- Operating:
  WWER - 13
  RBMK - 11
  BN-600 - 1
  EGP-6 - 4

- Under construction or moth-balled at the construction stage:
  RBMK - 1
  WWER - 1

- Planned (siting and basic design stage):
  WWER-640 - Kola NPP (2nd series)
  WWER-640 - Far East
  WWER-640 - Sosnovy Bor
  AS-92 - Novo Voronezh NPP

3. **Industry and/or regulatory standards:**

A set of regulations and technical documents is in force and applied to the new generation of nuclear plants. Below are listed some of the basic ones:

- "Basic Regulations for the Assurance of Safety of Nuclear Plants", (OPB-88) PNAEG-1-011-89;

- "Radiation Safety Standards", NRB-76/87;

- "Nuclear Plant Siting. Basic Criteria of and Requirements for Safety Assurance", PNAE G-03-3-93;

- "Requirements for the Content of the Safety Analysis Report for Nuclear Plants with WWER Reactors";

- "Nuclear Safety Rules for NPP Reactors" (PBYa -RYu-AS-89), PNAE G-1-024-90;

- "Rules of Design and Safe Operation of Equipment and Piping of Nuclear Power Plants", PNAE G-7-008-89;

- "Rules of Design and Operation of Localizing Systems".

The Parliament of the Russian Federation approved the following laws:

- "On Radiation Safety of the Population of the Russian Federation";
- "On Radioactive Waste Management"
- "On the Utilization of Atomic Energy".

According to the approaches adopted in the Russian Federation, the compliance of the operating NPPs with the requirements of new safety regulations is being analyzed now. The necessity, time and amount of work required for bringing the operating (including those which are backfitted) NPPs and NPPs under construction into compliance with the new regulations shall be established on the case-by-case basis.

4. **International activities:**

Within the scope of co-operation programmes between different organizations and agencies of Russia and its foreign partners, mutual familiarization and comparison of national approaches to safety of future NPPs has begun (IAEA; USNRC; BMU and GRS, Germany; IPSN, France, etc). The Russian Federation supports the necessity of future efforts to compare and harmonize national approaches to safety of future NPPs.

1. **Country:** SLOVAK REPUBLIC (contributed by P. Brocko, Nuclear Power Plant Mochovce)

2. **NPPs in operation, under construction, planned:**

4 in operation
4 under construction

3. **Industry and/or regulatory standards:**

Slovak "Nuclear Act": work is in progress to create an act on peaceful use of nuclear power, and on binding legal regulations for the act's execution. The creation of the Nuclear Act is the task of the Nuclear Regulatory Authority, based on Governmental Decree No. 190/94. This act will comprise 10 main chapters. The act is under development and is not especially developed for future plants.

National activities carried out by utilities and the Nuclear Regulatory Authority in recent years were focused primarily on the assessment and inspection of nuclear safety and reliability of nuclear power plant operations, the training level of selected NPP personnel and the continuous enhancement of nuclear safety of nuclear power installations.

Relevant scientific research institutions of the Slovak Republic also participate in the assessment of the complex issue of NPP safety enhancement, as well as the assessment of complicated operational events.

Independent foreign experts (mostly from the IAEA) provide technical assistance. The IAEA document "Safety issues and their ranking of WWER-440, Model 213 NPPs", (WWER-SC-108) is very important from the point of view of safety improvement of WWER NPPs in the near future.

Regarding PSA studies, in 1993 Mochovce made efforts to include the level 1-PSA study in the PHARE Programme. This study has to be used as a reference study for the WWER 440/213 type reactor for the purpose of harmonizing a methodology and to reach a high level of art of the PSA studies for this type of NPP.

The scope of the study covers also low-power and shut-down events, including dominant internal events (fire, flooding, missiles, pipe whipping and explosions).

The study shall also confirm that planned design safety enhancements resulting from deterministic approach are able to bring the plant to the required safety level.

The output of this study should also be a "living" model for future plant systems and equipment modifications, and for Technical Specification optimization. The PSA study for the Bohunice NPP has already been completed.

As for the completion of Mochovce Unit 1 and 2 (at present the levels of completion are 90% and 80%, resp.), Mochovce plants will be completed, based on two basic alternatives listed below. Whichever option the Slovak Government will choose, international standards will be met.

There are two basic alternatives:

(1) the originally proposed EdF and EC-backed project;
(2) the Skoda-Prague offer backed by Czech banks.

Slovakia is insisting on changes to the latest EC-backed offer which imposes unacceptable conditions. Notably, Slovakia rejects the shut-downs by 1999 at the other Slovak plant in Bohunice (V-1), regardless of whether Mochovce is operational by then or not.

4. **International activities:**

The Slovak Republic has been involved in IAEA activities such as the preparation of TECDOC-801.

1. **Country:** SWITZERLAND (contributed by W. Kroeger, Paul Scherrer Institut)

2. **NPPs in operation, under construction, planned:**

   5 in operation
   1 under construction
   1 planned

3. **Industry and/or regulatory standards:**

   - "Active observation" of international efforts
   - Relationship of future approaches to current plants: selective applicability, etc.
     Ongoing improvement of safety by intensive backfitting

4. ***International activities:***

   Switzerland has contributed to TECDOC-801 at the IAEA and has made a large scale contribution to the certification of SBWR by integral testing of passive systems for afterheat removal and fission product retention required by USNRC, done for General Electric.

   Swiss representatives have participated in meetings of the Utility Steering Committee for the ALWR Program.

   Switzerland maintains an exchange of information with the EUR Programme, and is a member of CSNI.

1. **Country:** UNITED KINGDOM (contributed by J.L. Summers, Nuclear Installations Inspectorate)

2. **NPPs in operation:**

16 NPPs in operation and 5 being decommissioned.

3. **Industry and/or regulatory standards:**

In 1992 the NII published its Safety Assessment Principles (SAPs) against which the adequacy of safety of any new design proposed for construction in UK is assessed. The primary purpose of the SAPs is to provide guidance to NII's own assessors (but are also helpful to designers and prospective licensees) and they do not, except for a few which embody statutory limits, place mandatory requirements on licensees.

IAEA Codes and Standards and other international standards were being developed at the same time as SAPs were being revised and there has been a general convergence of views. We have tried to feed our awareness of these standards into the revision of SAPs. The SAPs are based on five fundamental principles and these are in line with the IAEA's three safety objectives.

The SAP contain deterministic (engineering) and probabilistic principles and include numerical criteria. Engineering (deterministic) principles are those good practices which lead to a robust, fault tolerant plant based on sound safety concepts; they comprise about 75% of the SAPs. Probabilistic methods are the use of quantitative methods to seek out weakness and to demonstrate the achievement of certain numerical objectives. Deterministic and probabilistic principles complement one another.

A key concept in the SAPs is the of ALARP — As Low As Reasonably Practicable. This is an important feature of UK health and safety legislation and gives a flexibility to the approach which enables licensees to make their own arrangements for safety and designers to take initiatives in design as long as they can demonstrate the adequacy of safety.

The SAPs were used in 1993 as the basis for reviewing several designs, complete detailed assessments were not carried out, but useful views on their licensability in UK were obtained.

4. **International activities:**

The UK is deeply involved in international harmonization of standards and believes that mutual co-operation will enable differences to be understood and possibly removed. However, some differences may always remain because of different national approaches and legislation. The UK Utility, Nuclear Electric, participates in both the EUR and URD programmes.

1. **Country:** UNITED STATES OF AMERICA (contributed by J. Wilson, United States Nuclear Regulatory Commission, and G. Vine, Electric Power Research Institute)

2. **NPPs in operation, under construction, or planned:**

- 108 NPPs with operating licenses (>100 000 MW(e) capacity)
- 6 units with construction permits,
- No new units planned (prerequisite is successful certification).

3. **Industry and/or regulatory standards:**

The USA has a major, sustained programme to design and license advanced light water reactors (ALWRs) that has been underway since the mid-1980s, with the expectation that four advanced LWR designs would be licensed (or certified) in the mid- to late- 1990s, for construction/operation shortly after the turn of the century.

Major codes, guidelines, utility requirements, etc. relevant to the USA are:

- Existing reactor regulations (10CFR Part 50)

- NRC Commission Policy Statements on: Standardization, Regulation of Advanced NPPs, Safety Goals, Severe Reactor Accidents

- New regulation, "Early Site Permits; Standard Design Certifications, and Combined Licenses for Nuclear Power Reactors" (10CFR Part 52)

- EPRI ALWR Utility Requirements Document (Vol. II and III), and NRC Safety Evaluation Reports on URD (NUREG-1242)

- Various SECYs and SRMs containing implementation policy.

Together, these rules, policies, utility requirements, etc., result in the following key principles for the safety of future reactors:

- Future NPPs should achieve a higher level of safety (enhanced safety) than currently operating plants. Since current plants are judged to provide adequate protection of public health and safety, this enhanced safety for future plants is stated by NRC as an "expectation", beyond current regulations, for suppliers of future designs. The utilities have also imposed this expectation for enhanced safety on future designs as a commercial requirement.

- For future reactors, severe accidents will be considered and addressed as appropriate in the design process. The URD has established PSA safety goals similar to those of INSAG-3 for future plants, and more conservative than NRC safety goals for current plants by a factor of 10 or more. Both NRC and the URD require a complete PSA of the design. Both require a balance between prevention and mitigation.

- Accident management measures will be identified in the design process and will play an important role in the resolution of severe accident issues.

4. **International activities:**

The USA is actively involved in most international activities on harmonization of safety approaches. The NRC is involved in IAEA activities (e.g. TECDOC-801), and in an NEA Working Group effort on resolution of severe accident issues. The US industry is also deeply involved in harmonization efforts, leading the major programme to create the Utility Requirements Document that included the active participation of six European and Asian utilities. The US industry is working with the European utilities creating the European Utility Requirements (EUR) to identify and reduce differences between the URD and EUR (increasing harmonization). The US industry actively participates in IAEA activities.

Appendix II

LIST OF PAPERS PRESENTED BY PARTICIPANTS

CANADA

"Diversified Emergency Core Cooling in CANDU", by P.J. Allen and N.J. Spinks, Atomic Energy of Canada Ltd

EGYPT

"Pressure Behavior in a Nuclear Reactor Containment following a Loss of Coolant Accident", by M.S. Khattab, N.A. Ibrahim and S.D. Bedrose, AEA Cairo

"The Role of Expert Systems in Enhancing Safety of the Next Generation of PWR", by M.K. Shaat, A.A. Elkafas, AEA Cairo; and M.-N. Aly, M.E. Nagy, Faculty of Engineering, Alexandria University, Alexandria

FRANCE

"Development of EdF's Nuclear Policy: The Coming Units", by J.P. Berger, EdF Septen, Villeurbanne

FRANCE-GERMANY

"EPR Safety Approach", by U. Krugmann and M. Yvon, NPI, Paris; J. Czech, Siemens, Erlangen, and P. Lauret, Framatome Paris

"Progress in the Development of the Common French-German Safety Approach", by W. Frisch, GRS Garching and G. Gros, IPSN, Fontenay-aux-Roses

Appendix to GRS/IPSN Paper "GPR/RSK- Recommendations concerning the Common French-German Safety Approach for Future PWRs"

ITALY

"Italian Approach to Severe Accidents" Consideration for Reactors of the Next Generation", by A. Ferreli, ANPA

"ENEL Participation to the Development of Common Utility Requirements for Future Plants", by I. Tripputi, ENEL Roma

INDONESIA

"Indonesian Requirements and Safety Objectives for Future NPPs", by A.R. Antariksawan and I. Subki, NAEA Batan

JAPAN

"Current Status of the Study on Design Concept for Future LWRs in NUPEC", by K. Matsushita, NUPEC and M. Aritomi, TIT (Tokyo Institute of Technology)

NETHERLANDS

"Approach to the Safety of Future NPPs in the Netherlands", by B.Th. Eendebak, KEMA

RUSSIAN FEDERATION

"Legal and Technical Aspects of New Requirements Application for Nuclear Installation. Experience and Forecast", by V.S. Dickarev, V.S. Ionov and N.E. Kukharkin, RRC Kurchatov Institute, Moscow

"Requirements for the Assurance of Safety of Future NPPs in Russia", by A.V. Ageev and A.M. Bukrinsky, Federal Nuclear and Radiation Safety Regulatory Authority of Russia

SWITZERLAND

"NPP Safety in the Framework of Future Energy Systems", by W. Kroeger, Paul Scherrer Institute, Villigen

UNITED KINGDOM

"Safety Assessment Standards for Modern Plants in the UK", by J. L. Summers, HM Nuclear Installations Inspectorate, London

UNITED STATES OF AMERICA

"Approach to Safety of Future NPPs", by J.N. Wilson, USNRC Washington, D.C.

"Status of Advanced Light Water Reactors in the United States; Utility Requirements Document Safety Policy", by G.L. Vine, EPRI Washington, D.C.

OPEN

"The Organization of the European Nuclear Energy Producers (OPEN)", by M. Kleinpeter

IAEA

"IAEA Activities on Safety of Future NPPs", by L. Kabanov, Nuclear Safety Installation Division, "Development of Safety Principles for the Design of Future NPPs" by M. Gasparini, Nuclear Safety Installation Division

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