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Guidance for preparing user requirements documents for small and medium reactors and their application

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FOREWORD

During the past decade, several countries with highly developed nuclear power programmes established user requirements documents (URDs) to guide the development and implementation of advanced light water reactors. These efforts built upon the extensive experience with operating reactors and included new insights from ongoing research and development (R&D) to enhance the economic performance and safety of future nuclear power plants (NPPs).

Subsequently, a number of developing countries with plans for introducing nuclear energy into their national programmes expressed strong interest in establishing analogous requirements. (The term “nuclear energy” in this publication denotes a range of applications, including the production of desalted water by “nuclear desalination”, whereas “nuclear power” refers to electricity generation). The IAEA has therefore taken the initiative to assist in the elaboration of such requirements.

Building upon relevant documents, this TECDOC recommends a URD structure and content outline to support developing countries in preparing their URDs for various applications of small and medium reactors (SMRs) (e.g. electricity generation and/or nuclear desalination). It was prepared by representatives from both developing and developed Members States, working in two parallel groups to address both the generic structure of a URD for SMRs and the aspects specific to nuclear desalination, through Consultancies and Advisory Group meetings convened by the IAEA.

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Chapter 1

INTRODUCTION AND SUMMARY

1. OBJECTIVE

The purpose of this publication is to provide guidance to developing countries preparing their requirements for small and medium reactors (SMRs) to be used for electricity generation and other applications (e.g. nuclear desalination (ND). It is intended to assist professionals involved in energy planning and in building and operating SMRs who will determine and specify these requirements. Consequently, this report has the character of a guide for preparing requirements rather than a statement of the requirements themselves.

The main recommendations arrived to this report taking the form of a proposed structure and suggested contents for a user requirements document (URD), as described in Chapter II. The scope of the proposed URD for developing countries covers the entire plant up to the interface where the product (i.e., electricity, heat, desalted water) is delivered to the distribution grid. Although the plant size for SMRs covers the entire spectrum up to 700 MW(e) (electrical equivalent for the case of non-electricity applications), emphasis is given to the upper end of this range as this is where current interest appears to be dominant in developing countries.

The proposed URD structure is based to a large extent on existing utility requirements documents to benefit as much as possible from the information they contain that is built on the operating experience accumulated with power reactors. However, the URD structure adopted here also addresses areas where developing countries may have different needs or additional requirements, and for this reason it is different from the existing precedents. The more generic term 'user' is adopted instead of 'utility' throughout this publication to reflect the large variation in structure and ownership that may exist between the organizations that employ nuclear energy in developing countries from those in developed countries.

The main body of a URD prepared according to the proposed structure and content addresses the essential requirements affecting the design of the SMR plant for the intended application. It will be preceded by an introduction giving the rationale for the implementation of SMRs in a particular developing country and a perspective of the related time frame and the degree of national participation. The last part of the proposed URD would address possible additional requirements that a developing country may have concerning manpower development, industrial infrastructure, financing, technology transfer and other such topics.

The application for which an SMR is used may impose additional requirements that need to be captured in the URD. Since several developing countries are presently interested in the application of SMRs for nuclear desalination, the specific additional requirements that would need to be addressed in a URD for a nuclear desalination plant (NDP) are considered in Chapter III of this TECDOC. This chapter builds upon the generic URD structure for SMRs developed in Chapter II and address application specific issues, such as the requirements for desalted water quality.

To the extent that specific technical characteristics and figures are given in this publication, they are examples that may differ depending on what type of SMR is under consideration. An example of a national URD prepared in accordance with the recommendations of this TECDOC is given in the Annex to this report, *Small and Medium Reactor User Requirements Document: Indonesia*.

2. BACKGROUND

In the early 1980s, a group of US utilities undertook an industry wide effort to develop the technical basis for the design of future nuclear power plants (NPPs), specifically for advanced light water reactors (ALWRs). This effort was managed by the Electric Power Research Institute (EPRI) in close co-operation with the US Department of Energy (DOE). The objective of the EPRI-URD programme was to present a clear, complete statement of utility desires for the design, construction and performance of future NPPs. It established a common set of technical and economic performance specifications to be met by any ALWR and expressed these in an EPRI-URD [1] that has been finalized and is available for general use.

In a similar manner, utilities in the European Union have prepared their own requirements document, the EU-URD [2], with a scope that covers ALWRs in the range of 600–1700 MW(e) and higher. Other countries with large nuclear power programmes, e.g. Japan and the Republic of Korea, are also developing their own URDs for next generation reactors on a national basis.

As noted above, considerable valuable experience exists within the nuclear industry on the definition of user requirements for the next generation of LWR type NPPs, especially as expressed in the comprehensive URDs prepared by EPRI and by the European utilities. However, these documents are primarily focused on the needs of electrical utilities in developed countries for medium to large LWRs to produce baseload electricity for large electricity distribution grid networks. Moreover, the existing URDs have been prepared by utilities with extensive prior knowledge in the design, construction and operation of NPPs in countries possessing a substantial nuclear infrastructure and other supporting technical skills and resources.

At the present time several developing countries are contemplating the introduction of SMRs as a practicable and economic means of satisfying their growing energy needs. The circumstances and needs of developing countries are in some ways different from those of developed countries and span a very broad range. Many developing countries are typically in the very early stages of introducing or contemplating the introduction of SMRs and have a strong need for assistance in key areas, such as manpower and infrastructure development, technology transfer, local participation and financing.

A logical and desirable first step toward the preparation of formal bid invitation specifications for the realization of an SMR project is the definition of user requirements. The definition and expression of detailed user requirements benefits the future owners of SMRs by refining and focusing their needs toward the implementation of specific projects and helps potential vendors and suppliers to develop and propose SMR designs that will satisfy the needs of the marketplace.

3. SCOPE AND APPROACH

3.1. Scope

The scope of this TECDOC is governed by the request of a number of Member States that the IAEA initiate a programme to assist developing countries to prepare their own URDs, recognizing their special needs, circumstances and particular interests in SMRs. The current status of SMRs is summarized in Appendix A.

The scope of SMR technology is very broad, encompassing the full power range up to about 700 MW(e) (electrical equivalent) and various reactor types intended not only for electricity generation but also for co-generation or heat only applications, such as dedicated heating reactors, or nuclear desalination plants. Several countries have also maintained a strong interest in innovative SMR designs for a diverse range of on-grid and off-grid energy applications, including seawater desalination using land based or floating nuclear plants, co-generation, district heating and industrial process heat. Some of these applications may be best satisfied by small or very small reactors.

In addition, the scope of this TECDOC is also very broad because the term “developing countries” stands in summary for many countries which may differ very much in terms of general development, infrastructure, and technological and financial capabilities, with concomitant consequences regarding the implementation of SMRs.

In part as a result of their development status, developing countries generally have a particular interest in SMRs since such plants can be better matched to the needs of relatively small distribution systems and because financing is expected to be easier to arrange in view of the lower total cost of SMRs. According to the present usage of the IAEA [3], a "small" reactor plant spans the output power range from about 150 to 300 MW(e), while a "medium" plant covers the range from about 300 to 700 MW(e).

3.2. Approach

Comparing these boundary conditions with the ones underlying the existing URDs referenced in the previous section for rather well defined (and in many cases proven) reactor systems for countries with generally good infrastructure conditions, there is considerable merit in the following considerations for defining the structure and content of this TECDOC:

- Direct application of existing URDs, although very tempting to maximize the benefit of existing information, maintain consistency and avoid duplication, may not adequately capture the wide range of conditions of developing countries. Hence, a different approach was adopted which, however, builds as much as possible on the existing URDs.
- For much the same reason, it is not advisable to attempt the creation of a "universal" URD for developing countries, as it would have to be extremely general to be useful for all. In addition, it is an accepted practice world wide that the owner/operator of a nuclear plant retains the ultimate responsibility for its safe operation and, hence, is also responsible for the specifications for the plant. From this consideration follows the intermediate step of creating a TECDOC which gives guidance on how to develop the desired URD in conformance with evolving practice.
- As this TECDOC defines the content and structure of the URD, it should itself exhibit the structure of the future URD as much as possible to facilitate its use when actually writing the URD. Yet this must be achieved without creating confusion about what text is part of the TECDOC and what belongs to the proposed URD. Consequently, it was decided to confine the proposed URD structure entirely within Chapter II of this TECDOC.
- Emphasis is placed on medium-size reactors designed mainly for electricity generation since this regime is of greatest near-term interest in several countries. Moreover, this segment of the SMR power spectrum represents the category potentially having the largest energy impact. Also, a number of commercial designs are available for mid-size plants for which the existing URDs provide relevant guidance. In part, this approach was

taken because the base of published knowledge and operating experience for small and very small reactors of modern design is much less compared to that for mid-size plants. In addition, small and very small reactors may, for reasons of achieving low capital cost per unit energy output, require design approaches that differ so much from those of current mid-size plants that only very top-tier requirements would apply.

– The specification of technical requirements and design parameters depends very much on the type of reactor, the site characteristics and the intended application. It is consequently beyond the scope of this TECDOC and most likely beyond that of the national URDs to be developed therefrom. Rather, it is expected that national URDs may be comparable in depth to Volume I of the EPRI-URD. In addition, top-level requirements for non-electricity applications that have an impact on the reactor power plant should be addressed at the appropriate places in the body of the proposed URD. An example of the manner in which the URD should incorporate additional requirements arising from non-electricity applications of SMRs is provided in Chapter III for the specific case of nuclear desalination.

To this end, and considering the above constraints, Chapter II “User Requirements Document: Proposed Structure and Content”, outlines a workable top-tier structure for a URD and suggests appropriate contents while pointing the way to other sources of more detailed information. Its intended readership is primarily those professionals who are charged with preparing a URD for a developing country.

A specific example of a national URD prepared accordingly is available in the Annex “Small and Medium Reactor User Requirements Document: Indonesia”. In addition, Chapter III, “Specific Aspects on the Preparation of User Requirements for a Nuclear Desalination Plant”, provides supplementary material that could be incorporated in part into the top-level requirements of the proposed URD for the specific non-electricity application of nuclear desalination.

The section headings in Chapter II represent the table of contents of the future URD. The breakdown is given up to a three-digit level to allow a reasonable degree of technical detail. The information provided under each heading describes what should be addressed in the respective chapter of the URD. In particular, the text under each heading generally describes the meaning of the heading (if not obvious), what could be given as an example or precedent, if appropriate, and sources of further information. Reference is also made to the large body of existing IAEA publications that directly address many of the key issues associated with the introduction of nuclear power programmes in developing countries, such as manpower development, safety, licensing, introduction of NPPs, fuel cycle and other relevant topics, e.g. nuclear desalination.

It is important to note that where specific technical characteristics and numerical values are given, they are intended as examples only, as it is up to the plant owner to state his requirements.

The structure proposed for the URD in Chapter II addresses three broad areas (neglecting in the present context a foreword and/or executive summary for the URD):

– the framework in which the URD is to be seen and used (Sections 1 and 2)
– the essential requirements affecting plant design (Sections 3–7), and
– the special requirements of developing countries (Section 8).

Because the TECDOC only provides guidance and suggestions, the word "should" is generally used throughout. For specific SMR projects in developing countries, the word "shall" would be used for firm requirements, "should" for desirable features and "may" for optional aspects.

Chapter II

USER REQUIREMENTS DOCUMENT: PROPOSED STRUCTURE AND CONTENT

1. INTRODUCTION TO THE URD

As this topic depends strongly upon the specifics of the case under consideration, only very general suggestions can be given here. It is up to the authors of the URD to emphasize the points which they consider important.

Nevertheless, they may wish to expand on the following items:

- purpose and scope of the URD,
- impact of the selected reactor type, capacity and the intended application, and
- relations to existing technical documents of a normative nature, e.g. licensing rules.

The reasons for these suggestions will be given under the respective headings.

1.1. Purpose and scope of the URD

The primary purpose of existing URDs is to specify the technical and economic requirements for advanced light water reactors that are more or less evolutionary developments of existing designs. The specifications they contain are primarily addressed to the vendors of such reactors.

The key purpose of a URD for a developing country will likewise be to specify to the potential vendor(s) all the requirements affecting the design of the plant. However, such countries may have additional requirements reflecting primarily the stage of industrial development prevailing in each country. Even though this topic is addressed in Chapter 8 of the URD, a general indication should be given here as to what those additional requirements entail. If the intended application is beyond that of generating electricity, e.g. nuclear desalination, the different or incremental scope in requirements should be indicated.

In general, the scope should comprehensively cover the entire plant up to the interface where the product (electricity, heat, desalted water) is delivered to the distribution grid. Thus, the URD should emphasize those requirements which are most important to the objective of achieving SMRs that are excellent with respect to safety, performance, constructability and economics. Nevertheless, the requirements laid out must be realistic goals that are consistent with industry practice elsewhere and be achievable in a pragmatic and economic manner.

1.2. Impact of selected reactor design and intended application

If the project under consideration involves a novel reactor concept and/or an application beyond that of generating electricity only, the key consequences regarding the top-level requirements affecting the design of the system should be briefly outlined in this chapter. Details would have to be addressed under the appropriate headings of the subsequent sections.

The prime purpose of briefly outlining possible extensions of existing technology is to identify at an early stage potential bottlenecks that may arise in the design and licensing of the contemplated facility.

1.3. Relation to existing technical documents

The technical requirements laid down in a URD should indicate that the design of a given facility has to be in conformance with applicable rules, regulations, codes and technical standards.

Typical examples of relevant documents include, as appropriate:

- the IAEA's Safety Standards,
- International Organization for Standardization (ISO) standards,
- vendor's country regulatory guides (e.g. US Nuclear Regulatory Commission (NRC), Canada's Atomic Energy Control Board (AECB), France's Institute de Protection et Surete Nucleaire (IPSN), etc.),
- engineering codes such as those of the American Society of Mechanical Engineers (ASME), and
- local industrial and building codes.

At this point in the URD, a summary statement should be given as to whether either exemptions are sought or additional requirements have to be codified. Details should be given under the appropriate heading of the URD to be developed.

Where possible, existing URDs or similar documents prepared by other utilities should also be taken into account.

2. NATIONAL NUCLEAR ENERGY PROGRAMME

As the implementation of an SMR in a developing country may involve more institutions (e.g. international banks, insurers) than has been the general practice in developed countries with substantial nuclear power programmes, it is very desirable to outline the rationale for the planned nuclear facility in the candidate country and how it would be embedded in the national nuclear energy programme. Such information is expected to give greater credence to the nuclear programme to be implemented.

A brief statement should therefore be given as to the need for nuclear energy, as provided by SMRs, within the framework of the National Energy Plan and/or the National Industrial Development Plan for the developing country. It is intended to establish the rationale underlying the introduction of an SMR programme and its national context. Energy and nuclear power planning in developing countries are specifically addressed in the IAEA Technical Reports Series Nos 217, 241 and 245 [4–6].

The following topics should be mentioned:

- demand projections for energy and water, as appropriate, including underlying factors, such as population growth and industrial development,
- the priority of power generation expansion as a national economic development goal,
- national energy resources including estimated reserves of economically recoverable uranium and thorium,
- energy supply diversification options,
- the role of nuclear energy in terms of energy supply, industrial development and environmental impact (e.g. air pollution and greenhouse gas control targets),
- geographic factors, such as the proximity of existing energy and water resources to population centres and the availability of suitable sites for SMRs,
- the expected scope of application of nuclear energy, including thermal energy applications such as seawater desalination, district heating, etc.,
- the expected size and scope of the SMR deployment programme, and
- the anticipated schedule for implementation of the SMR programme and the extent of existing preparatory work.

The criteria used for national decision making as to the preferred source of energy supply should also be clearly identified. For example, national policy considerations and goals such as technical self-sufficiency, national participation and security of energy supply may sometimes outweigh short term economic considerations.

The rationale for the choice of an SMR relative to a large NPP programme should also be addressed with reference to specific country conditions (e.g. grid capacity, intended application, whether there is a preferred technology and why, safety, economic and financing aspects, etc.).

It generally takes many years of determined effort to establish a successful nuclear energy programme, sometimes with setbacks along the way. The history of the national nuclear energy programme could be outlined here to put the current state of affairs into proper context and to indicate the rate of progress.

2.1. Role of nuclear energy

This section further develops the rationale for choosing nuclear energy relative to other energy source options in a particular developing country. Potential reasons of a fundamental nature include [6, 7]:

- cost effective energy supply option,
- low adverse environmental and public health impacts, especially concerning air pollution and greenhouse gas emissions,
- improved energy resource self-sufficiency and long term security of fuel supply, possibly by cost effective exploitation of domestic uranium and thorium reserves,
- improved energy supply diversification,
- reduced requirements for fossil fuel transportation, and
- benefits to national industrial development and technology advancement goals.

In general, large nuclear energy programmes are more readily established when no practicable alternatives exist for reasons of cost and geography, for example when other means such as hydroelectric power have already been exhausted and increased reliance on fossil fuel energy imports would create unacceptable economic vulnerabilities or intolerable environmental impact and public health consequences. The number of viable alternative energy supply technologies may be especially restricted in small, remote and/or isolated areas with limited resources and lacking interconnection with supply grids (e.g. electricity, natural gas, water).

2.2. Incentives for SMRs

This section of the URD should explain why an SMR may be the preferred nuclear energy option for the country preparing its document. The main arguments for deploying SMRs in developing countries include [3, 8, 9]:

- low capital requirements per reactor unit, hence the expectation of easier financing,
- shorter construction schedule and easier project management,
- more suitable for domestic participation,
- better match to the electricity grid requirements,
- easier siting, bulk ordering of parts, and efficient sequencing of construction, commissioning and maintenance programmes,
- better match of system output for process heat and seawater desalination,

- potential for simpler design (e.g. fewer components and systems) and easier operation and maintenance,
- increased safety margins resulting from lower total heat loads and/or reduced power density leading to longer grace periods, and
- potential for low severe-core-damage frequency and minimal accident consequences.

2.3. Additional considerations

In order to embark on an SMR programme, a country is expected to adhere to certain international treaties, legal obligations and conventions. Some of these, such as the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Convention on the Physical Protection of Nuclear Material and the Convention on Nuclear Safety, could be essential when engaging in nuclear activities with supplier nations, while others refer to specific topics that may not apply to a particular developing country. Consequently, the status of national ratification and adherence to such agreements should be clearly identified.

Domestic policies and legislation also need to be established concerning the regulation of nuclear technology and defining the responsibilities and limitations of legal liability for damage from nuclear reactor accidents.

Other considerations related to the available national nuclear support infrastructure can also facilitate the introduction of nuclear energy, such as the existence of:

- an independent national nuclear regulatory authority, having oversight responsibilities in accordance with international practice,
- a domestic research reactor programme and university level training in nuclear science and engineering and/or foreign attachments or exchange programmes to train nuclear professionals,
- national and regional emergency response plans and organizations responsible for their execution,
- national programmes for personnel radiation dosimetry and environmental monitoring of potential nuclear reactor sites,
- adequate documentation and information about nuclear reactor technology in the language used in the developing country for use in personnel training and public information programmes,
- established engineering codes and standards based on recognized international industry practice, such as nuclear codes and quality assurance standards,
- plans, procedures and facilities to manage various categories of radioactive waste, and
- qualified domestic suppliers and contractors capable of managing or participating in complex, large scale construction projects.

3. SITE-IMPOSED REQUIREMENTS

This section treats the main characteristics of the site-selection criteria and the environmental data associated with the nuclear energy programme. The resulting requirements should be formulated in such a way that the nuclear energy programme will be designed and optimised to accommodate site specific criteria as well as possible extreme external events (both of natural origin and man induced).

For many developing countries the extreme environmental conditions and expected frequency of natural external events will likely differ from those specified in the URDs for typical nuclear plant sites in developed countries. For example, in several developing countries coastal tsunamis, severe seismic events, higher condenser cooling water temperature and/or arid desert conditions or sandstorms present significant site-dependent considerations. In addition, the frequency spectrum of man-made disturbances and perturbations can also be expected to differ as a consequence of technical differences and the overall stability of the grid distribution system and, possibly, as a result of differences in the level of staff training, experience and professional discipline.

3.1. Site conditions

Site requirements will be prepared as a result of investigations performed in accordance with established codes and practice, e.g. as described in the IAEA's Safety Standards, Series No. 50 SG-S (Siting of Nuclear Power Plants) documents (a list of the IAEA's Safety Standards is provided in Appendix B). The site data and characteristics to be provided cover the following areas:

- site survey,
- foundations,
- atmospheric dispersion characteristics,
- thermal discharge limits,
- hydrological dispersion and hydrogeological aspects,
- population distribution and traffic patterns, and
- natural and man-induced external hazards.

3.2. External events

A description should be provided of potential hazards to the plant arising from natural events, such as:

- earthquakes and volcanoes
- external flooding of river and coastal sites, and
- extreme meteorological events, such as tornadoes and tropical cyclones, as appropriate, and man-induced activities, such as:
- hazards from adjacent installations and transport activities (missiles, gas cloud explosion, etc.),
- aircraft crash, and
- electromagnetic interference.

3.3. Site infrastructure

A short description should be given of the facilities and services available or to be provided at the site, especially those that are essential for a large construction project [4]:

- electricity grid and/or other energy distribution system connection(s),
- site access by road, waterways and rail,
- telecommunications,
- cooling water availability,
- access to public services, such as a fire brigade, medical care, and
- others, like potable water, housing for construction workers, services reliability (power, gas, equipment and materials, etc.).

The needs of developing countries concerning the general national infrastructure (as distinct from the site infrastructure) are addressed in Section 8.2.

3.4. Allowable radioactivity release

Allowable operational radioactivity release limits for gases and liquids should be specified here in accordance with the national regulations. Exemplary industry practice and the ALARA (as low as reasonably achievable) principle may also be referenced. This topic may also be addressed in the sections on safety design requirements (e.g. Section 5.1.5 “Good Neighbour Policy”) and/or performance requirements.

Allowable radioactivity releases reflect the quantitative safety objectives. The URD describes the following items:

- overall approach to the specification of utility targets, within the national regulatory limits,
- radioactive discharge criteria for normal operation and incident conditions,
- radiological impact for normal operation and incident conditions, including doses from direct radiation, and
- off-site release targets for accident conditions and for severe accidents.

3.5. Emergency preparedness

It is common practice in many countries to have emergency plans for large industrial facilities, including nuclear reactors. The details of such plans depend on many factors, such as type, size and risk posed by the facility and by the demographic characteristics surrounding the site. The URD describes the key features of the emergency plans that are envisioned.

Some countries employ the concept of having an exclusion zone around the nuclear facility to simplify certain elements of emergency planning (e.g. early evacuation after a severe accident). If this concept is adopted, a relatively small exclusion zone may be considered for an SMR as a result of its lower risk (e.g. smaller source term compared to a large nuclear plant). Nevertheless, the exclusion zone should be specified such that the off-site consequences of any foreseeable accident are consistent with modern safety goals (i.e., minimal off-site impact).

A brief description of the site boundary and vicinity should be provided in the URD, including:

- the minimum radius of the owned site,
- the minimum radius of the exclusion zone within the site, and
- the means used to control access to the exclusion zone, including physical barriers and security measures.

These considerations should also reflect future expansion of the production capacity at the site.

4. LICENSING REQUIREMENTS

The objective of this section of the URD is the presentation of the licensing process and associated requirements in a particular developing country. Appropriate reference should be made in the URD to the government legislation, laws, acts or decrees from which the authority of the national regulatory body stems.

The national regulations should be consistent with the regulations and norms in the country of origin, where the plant was designed, and should comply with international guidelines, such as the Convention on Nuclear Safety and those developed by the IAEA. Such consistency would give good assurance that the SMR is licensable for its intended application in the developing country without the need for significant changes in the original design or a lengthy licensing review. An efficient licensing process is also important for keeping total project costs under control.

4.1. National regulations

The national regulatory authority has the responsibility for ensuring the health and safety of the general public, nuclear workers and the environment against possible adverse effects arising from the activities associated with nuclear reactors. Thus, it establishes regulatory standards, codes and criteria, and reviews and evaluates the safety analysis documentation and the environmental monitoring reports submitted by the utility/owner. It also issues licences or authorisations for activities and facilities, certifies qualified staff and conducts a comprehensive programme of inspections to ensure that everything conforms to the established rules and regulations.

If there are special health protection requirements associated with non-electricity applications of SMRs, such as nuclear desalination and district heating, these would have to be described in the URD in an appropriate manner.

It is the owner's task to apply for licenses and authorisations, as it bears the ultimate responsibility for compliance with the national regulations. But, the supplier(s) have to provide the owner with all data and information necessary to complete the licensing application to the regulatory body. The main steps in the licensing process for an SMR should be outlined in the URD including the identification of specific permits and licenses.

To avoid a lengthy regulatory process for a first of a kind plant, thorough documentation of the technical safety case should be provided in advance by the plant designer and confirmed by the authorities. The licensing process for a small and simple reactor will, in general, be simpler than the process for a large plant. However, the use of innovative technologies or technical solutions may require additional investigations during the safety assessment and licensing process.

Provided that the fundamental safety objectives are achieved, exemptions or relaxation of certain prescriptive details (e.g. classification of systems) might be sought from the national regulatory authority for plants incorporating enhanced safety features.

4.2. Licensability in the country of origin

If a foreign SMR design is introduced, the purchasing country should define the requirements as to the licensability of the proposed design in the country of origin. In cases where such licensability is required, the extent of the documentation to be provided by the supplier must be delineated. Such documentation will need to take into account local site and infrastructure conditions in the developing country.

4.3. International guidelines and technical documents

The IAEA's Safety Standards and related technical documents may be used as a consistent basis for formulating national regulations, policies and procedures. The most relevant IAEA Safety Standards are listed in Appendix B. A leading document in this field is "The Safety of Nuclear Installations" [10], which was issued as a Safety Fundamentals document and formed the technical basis for the Convention on Nuclear Safety. Other documents include those by the International Nuclear Safety Advisory Group (INSAG), such as "Basic Safety Principles for Nuclear Power Plants" [11], "Safety Culture" [12], "The Safety of Nuclear Power" [13], "Probabilistic Safety Assessment" [14], "Defence in Depth in Nuclear

Safety" [15], and those of the International Commission on Radiological Protection (ICRP) [16].

5. TECHNICAL REQUIREMENTS

This section of the URD describes the basic technical requirements which define the main characteristics of a given type of nuclear reactor. It is suggested that these requirements be grouped into three main categories: safety requirements, performance requirements and plant design requirements.

In issuing their own detailed technical requirements, developing countries can select some of the common targets which are already included in the existing URDs of developed countries, particularly when the project in the developing country involves medium-size, water cooled reactors for electricity generation.

5.1. Safety requirements

Modern safety approaches emphasize a defence in depth philosophy with five levels of defence [15]. The first three levels are: prevention of abnormal conditions (accident resistance), control of abnormal conditions, and control of accidents within the design basis (core damage prevention). The fourth and fifth levels of safety objectives address the control of severe plant conditions and the mitigation of the radiological consequences of significant releases of radioactive materials. Defence in depth is achieved technically by providing a series of physical barriers to confine the radioactive material and by preventing challenges to these barriers.

A very high degree of assurance that the safety objectives laid down either in the national regulations and/or in those of the country of origin will be met, is obtained if the design follows internationally accepted safety principles, e.g. as defined in the INSAG-12 report [11] and the safety requirements of the IAEA's Safety Standards "The Safety of Nuclear Power Plants: Design Safety Requirements", Safety Standard Series No. NS-R-1 [17]. The safety approach should be based upon established deterministic methods, augmented by probabilistic methods using appropriate numerical targets and analysis, and make use of the defence in depth principle. In general, the safety objectives are met providing, in a graded or step wise manner, that the consequences of accidents up to and including severe core damage events remain below a prescribed set of (country specific) dose limits for a range of cumulative frequencies of occurrence, both of which are specified in the respective national regulations. This spectrum of radiological consequences and event frequencies defines a risk-curve envelope within which the safety analysis results for the SMR design in question must reside.

While the risk-curve envelope defines a unique set of limits, the optimal technical and economic solutions to ensure compliance within these limits depend on a number of design features and parameters, such as reactor size, system configuration, emergency cooling system(s) and type of containment. Nevertheless, the numerical requirements should be taken care of in the design in an appropriate manner and compliance demonstrated through supporting analyses.

Taking the above considerations into account, the most important general safety design requirements should be specified in the following sections. Much of the subsequent material is derived from the vast amount of IAEA literature devoted to this topic [18, 19].

5.1.1. Accident resistance

This section describes the provisions and features that would be incorporated into the design to ensure adequate margins for assuring: the stability of the core configuration, the capability of controlling neutron power, cooling the core and the confinement of radioactive by-products. Such features may be achieved by the plant designer, for example, through the specification of appropriate core power rating, operating pressure and temperature, thermal capacity, coolant inventories and other design parameters. The range of operating conditions and circumstances for which these safety margins are applicable should also be identified.

In addition, design characteristics are required which minimise the occurrence and propagation of initiating events that could challenge the performance of items important to safety. In some cases, the configuration of an SMR may have been specifically selected to eliminate the possibility of certain classes of accident events, such as large pipe breaks. Appropriate credence should be given to such solutions.

Accident resistance is also enhanced through measures to reduce the likelihood of operator error. Thus, the operator should have appropriate information to make decisions and adequate time to take corrective action to avoid incidents and accidents. In general, SMRs in developing countries should provide relatively longer grace periods to expand the time period before operator action becomes necessary and to reduce the load on the operator and the importance of the human factor. For reference, the EPRI-URD specifies a minimum time of 30 minutes for the operator to act after indication of the need for action. The use of passive and simple systems should be encouraged.

5.1.2. Core damage prevention and mitigation

This section describes the design measures that should be provided to arrest the neutron fission chain reaction, cool down the reactor core, thereby preventing and mitigating damage to the core, and assure the confinement of radioactive by-products during incidents and accidents. It may be achieved using both active, engineered systems and through passive design features and inherent characteristics, with the latter approach being generally enhanced in the design of SMRs. The range of design basis accidents (e.g. size of postulated instantaneous pipe breaks on the reactor primary cooling system) for which core damage does not occur may also be specified here.

Probabilistic safety analysis (PSA) of the frequency of initiating events and the availability of safety systems to arrest them effectively determines the likelihood that incidents will progress to core damage accidents. With respect to core damage prevention, a limiting value for the calculated mean cumulative core damage frequency (CDF) may be stated as a requirement for the SMR design, e.g. equal to or lower than 10^{-5} events per reactor year, including internal and external events. The fact that the frequency of initiating events, e.g. loss of electricity grid load, may well be different in a particular developing country than in the country of origin should be considered in the analysis.

Any required features of the SMR design that have an important accident-mitigation function should also be specified here. Safety features mitigate the consequences to the public and the environment of postulated design basis accident events and beyond design basis accidents by limiting the magnitude and rate of any radioactivity releases. Such features may also provide additional time to mobilise on-site and off-site resources to take corrective measures, such as the establishment of long term cooling and electricity supply, or to implement emergency plans.

For example, many of the existing SMR designs incorporate redundant barriers to the release of fission products from the fuel to the environment and a large coolant inventory to guarantee adequate cooling and to provide long term passive residual heat removal based on natural coolant circulation. In the special case of SMR designs based on coated-particle fuel, fission product retention is maintained even at very high temperatures for extended periods of time; this is achieved through the selection of appropriate coating materials and the use of high quality fabrication methods.

5.1.3. Passive safety

It is anticipated that SMRs of advanced design will incorporate several passive safety features [20]. Such features rely on natural forces like gravity and natural circulation, energy from batteries and compressed fluids, check valves and non-cycling valves. For example, a plant that emphasises passive safety should not rely on safety related AC power.

The EPRI-URD specifies no need for operator action for at least 72 hours for transients and accidents analysed under the limiting-event plus single-failure Licensing-Design-Basis assumptions. Moreover, beyond the 72-hour time frame, only relatively simple operator actions and minimal off-site assistance would be necessary to prevent core damage and maintain investment protection.

The URD should identify the degree to which passive safety features are required in the design.

5.1.4. Radiation protection

As stated in Reference [10], the objective of radiation protection is to ensure that, in all operational states, radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and is as low as reasonably achievable (ALARA), and to ensure mitigation of the radiological consequences of any accidents.

This objective will be met in the design by:

- appropriate layout and shielding of structures, systems and components containing radioactive materials,
- attention to the design of the plant and equipment so as to minimise human activity in radiation fields and reduce the likelihood of contamination of the site, and
- arrangements to reduce the quantity and concentration of radioactive materials produced and spread within the plant or released to the environment, during both normal operation and accidents.

Appropriate dose limits and access requirements to components and systems should be specified in the URD.

5.1.5. Good neighbour policy

The selected SMR should be designed to have minimal off-site impact as a result of accidents, for example with radioactivity release levels less than those which would require evacuation of the public and/or long term land disuse as a result of contamination. Methods should also be provided to ensure that radiation doses to the public and site personnel do not exceed prescribed limits for any operational states and are in accordance with the ALARA principle.

5.1.6. Protection against sabotage

Modern nuclear plants take sabotage protection into account through system configuration, plant arrangement and properly designed physical protection systems. The user may specify additional requirements in the URD to address sabotage and other intentional threats.

5.2. Performance requirements

This section should specify the expected performance of the SMR for the intended application in terms of its main output characteristics, availability/reliability, inspectability and maintainability, design lifetime and manoeuvrability. It also addresses the methodology to be used to assess operational performance.

5.2.1. Applications

The principal uses of a SMR could include electricity production, cogeneration including heat supply for seawater desalination, district heating and industrial heat supply. For the medium range of output powers the principal applications are expected to be electricity production and cogeneration. Dedicated heating reactors could also be feasible and economically attractive for particular applications. If the intended applications have performance requirements that go beyond, or are different from, those that are typical for electricity generation, they should be outlined here or in other sections of the URD, as appropriate.

5.2.2. Interface

This section describes the interface between the SMR and the end user energy distribution network and the requirements that must be met to ensure compatibility.

A URD typically refers to the entire plant up to the interface point where the connection is made to the external distribution network, for example the circuit breaker which connects the switchyard to the transmission lines or to the grid reception switchyard. For a thermal energy application of an SMR, the interface occurs at the heat exchanger connected to the heat or desalted water distribution network.

This section should also identify the important grid characteristics, such as voltage and frequency requirements, range of variability and grid stability. For non-electricity applications, their respective interface requirements should be mentioned here.

5.2.3. Availability/reliability

This section specifies the availability targets for the SMR during its operational lifetime, which in turn have a major impact on the generation cost target. A high availability is required to achieve economic competitiveness with alternate fossil-fuelled energy sources, especially for small reactor plants.

The main requirements refer to:

- annual average availability factor,
- refuelling interval and outage duration, if applicable,
- inspection and maintenance intervals and their duration, and
- planned and unplanned outages and their duration.

A reliability analysis should be required as an integral part of the design process and included as part of the design documentation of the plant.

5.2.4. Design lifetime

The plant should be designed for as long a lifetime as is technically and economically feasible in accordance with its intended services. However, the plant design-lifetime requirement should generally be chosen to minimise lifetime generation costs and should be consistent with current industry practice.

The plant designer should provide a design-life classification system and a list that categorises systems, components and subsystems according to their design-life capability. The designer should also provide a strategy to achieve the overall plant design-life requirement. The design-life classification system should be incorporated into the planning of preventative maintenance and in-service inspection programmes.

To support the design lifetime, the URD should require:

- means to monitor the conditions of components, systems and structures,
- adequate instrumentation to monitor and record significant transients,
- measures to avoid or minimise the frequency of exposure to adverse or life-limiting environments, and
- initiation of a lifetime record system including computerised data collection and processing.

5.2.5. Manoeuvrability

The plant manoeuvring capabilities that should be provided to accommodate transients associated with the operating modes of the energy distribution system (electricity and/or heat) should be outlined.

The requirements should address the following:

- startup and shut-down cycles between the cold condition and rated power,
- unit loading and unloading between minimum output and rated output,
- step load changes and power ramps for different power ranges,
- load-following capability including frequency (e.g. daily), and
- load-rejection capability (e.g. the EPRI-URD specifies loss of load without reactor trip or turbine trip from 100% power for pressurised water reactors (PWRs) and from 40% power for boiling water reactors (BWRs)).

5.2.6. Assessment methodology

This section should specify the requirements for the methodologies to be used to assess plant performance (e.g. availability) and the resulting impact on the SMR design. Performance assessment methodologies may also be of interest for non-electricity applications.

5.3. Plant design requirements

The following sections describe the main technical design requirements which help to assure that the safety and performance targets are achieved [14, 18–22].

5.3.1. Design simplicity

Design simplicity is an important performance and safety requirement. The design should aim for simplicity to minimise the possibility of operator and maintenance errors and eliminate potential adverse safety-system interactions. The manner in which the safety of the plant is achieved should be transparent and easy to understand. Experience has shown that design simplicity also leads to improved human performance and may result in low investment cost.

Design simplicity should address the following:

- using the minimum number of components to perform a particular function,
- minimising the demands on operating staff during normal operation and during transients, incidents or accidents,
- providing simple logic and unambiguous condition indications at all times,
- providing equipment layout and arrangements which simplify and facilitate access, inspection, maintenance and/or replacement,
- taking measures to assure simplification of construction and decommissioning,
- optimum use of inherent safety characteristics (e.g. negative core reactivity coefficients, thermal inertia) which do not rely on the control or safety systems, and
- measures which extend the time available for operator action during unforeseen events.

5.3.2. Design margins

Adequate design margins should be provided where they have a clear impact on accommodating fault sequences, reducing the frequency of unplanned reactors trips, providing ample response time for operators, as well as enhancing maintainability. Some of the technical areas where adequate margins are important include fuel thermal margin, primary coolant temperature and inventory, and provisions for assuring ac power. An overall plant design requirement is that the sensitivity to potential initiating events should be as low as reasonably achievable (ALARA).

Design margin requirements should address:

- the designed-in capabilities to accommodate transients without causing initiation of engineered safety systems and to minimise the potential for exceeding limits,
- the time available for the operator to assess and deal with upset conditions to minimise the potential for damage, and
- the need to achieve the desired component and system reliability so that the design lifetime and other performance targets can be met.

5.3.3. Human factors and man–machine interface

Proper attention to human factors in the design stage can help to reduce the likelihood and consequences of human error. Therefore, it should be a requirement that the plant be designed according to accepted ergonomic and ergometric principles. Adequate information should be provided to the operators to enable ready assessment of the general state of the plant in all operating conditions. The design should facilitate successful operator actions, taking into account the available time, the expected physical environment and the potential for psychological stress. The need for operator intervention on a short time scale should be kept to a minimum.

The requirements for human factors include those concerning the man–machine interface as an important subset. The man–machine interface is particularly important in the design of the main and auxiliary control rooms. This suggests an advanced instrumentation and control (I&C) framework which is ergonomic and highly automated, using well organized displays, control panels and user friendly operator manuals (e.g. on-line).

In the design of the I&C system and the reactor protection system, advantage should be taken of advances in electronics and information processing technology, such as microprocessors, video displays, multiplexing, fiber optics, etc., and in the use of the artificial intelligence techniques. Similar considerations apply to the plant diagnostics systems.

Specific topics that should be addressed in the URD are:

- monitoring, controlling and protection functions assigned to plant operators,
- monitoring and diagnostic functions performed by plant personnel during normal, upset and emergency conditions,
- inspection, on-line and off-line surveillance testing, preventive maintenance and corrective functions assigned to maintenance personnel, and
- appropriate operator training, emphasizing safety culture.

Experience in several countries has shown that appropriate operator motivation is also an important factor for safe and reliable nuclear plant operation.

Relevant information can be found in INSAG-12 [11], INSAG-4 [12], INSAG-5 [13] and INSAG-6 [14].

5.3.4. Standardization

Standardization has important impacts on constructability, operability, maintainability, economics, reliability, and safety and licensing and therefore merits consideration in appropriate requirements. Such requirements should address all phases of the plant lifetime from design conception, through construction, operation and decommissioning [22].

A standardized design would ensure that components can be interchanged and that the number of different types of components is reasonably limited. Standardization could broaden and help assure sources of supply, shorten construction schedules and simplify spare parts inventories.

The concept of standardization may be expanded to include siting requirements through the specification of reference site conditions (environmental conditions and site associated hazards: earthquakes, external explosion, aircraft crash, etc.). Similarly, standardization can also be applied to assessment methodologies.

5.3.5. Proven technology

Nuclear technology for an SMR should be based on engineering practices that are proven by testing and experience, and that are reflected in approved codes and standards and other appropriately documented statements. The URD may require the supplier to demonstrate that the SMR fulfills the above general requirement, for example, based on experience from a reference nuclear plant or one with similar conditions [18]. This could include plants in non-nuclear industries that use similar components and systems at conditions that are representative of those for the intended SMR application.

If materials, components or systems are intended for service under conditions which are far beyond the range of proven capability or are new in terms of their application, then an appropriate test and development programme should be provided.

5.3.6. Constructability

Constructability generally refers to the ease and speed with which an SMR project can be brought to commercial operation from the contract effective date (CED). Depending on the type of contract, this period typically encompasses all project phases from site preparation to final commissioning and operation for warranty purposes.

Efficient construction practices are desired to minimise the cost of SMR projects, particularly in developing countries. For example, a short construction schedule will reduce the interest during construction (IDC). However, the construction plan will also need to take into consideration the requirements to achieve agreed levels of local and national participation.

The main requirements having an impact on the construction schedule that should be addressed are:

- design approach (e.g. design for easy construction in a developing country),
- detailed plans for optimal construction sequences, recognising local capabilities and site conditions, and
- design status at start of construction (e.g. basic design complete, as a minimum).

Pre-assembled or modular units should be considered to facilitate the achievement of high quality construction and assembly and to reduce on-site construction work, time and manpower. Barge-mounted reactor plants may have merits in this context.

5.3.7. Maintainability

Experience has shown that plant maintainability has a significant impact on both safety and economics. The plant should thus be designed with explicit considerations to facilitate inspection and maintenance, including potential major repairs or replacement of components. The user's preferences in the following areas should be described in the URD:

- use of equipment needing minimal maintenance,
- monitoring equipment to reduce the need for routine maintenance,
- automated inspection tools to minimise operator dose,
- appropriate layout and radiation shielding for easy access to components for repair or replacement, and
- consideration of robotics.

5.3.8. Quality management

Quality assurance (QA) and quality control (QC) programmes should be established according to recognized standards and applied throughout the lifetime of the nuclear plant, e.g. during design, supply and installation, and for the control of procedures used in plant testing, commissioning, operation and maintenance. This is part of a comprehensive system to ensure with high confidence that all items designed and delivered, structures and systems constructed, and services and tasks performed meet the specified requirements.

The QA and QC requirements related to safety and to operational reliability may follow the IAEA's Safety Standards, particularly Safety Series No. 50-C/SG-Q (see Appendix B), and the International Organization for Standardization (ISO) publications (e.g. the ISO-9000

[23] and ISO-14000 [24] series). It should be stated in the URD which QA and QC programmes will be followed.

5.3.9. Codes and standards

The codes and standards used in nuclear projects differ from country to country, even though their general intent is the same. An internationally accepted set of codes pertaining to nuclear safety is the IAEA's Safety Standards listed in Appendix B. The URD should indicate the hierarchy and structure of the codes and standards to be adopted for the SMR project, unless the developing country chooses to adopt those of the supplier.

If codes and standards have not yet been established in the developing country, they may be based on those of the supplier country, potentially in combination with those documents established by the IAEA.

Codes and standards which are used for the design, manufacture and testing of systems and components related to the nuclear plant may be those applicable in the reactor vendor's country and/or those established in the receiving country. Application of local codes and standards should be agreed upon with the vendor in a pre-contractual phase to achieve consistency and to avoid schedule delays.

5.3.10. Decommissioning

Current practice addresses plant decommissioning at the design stage, so that decommissioning and removal of contaminated or activated plant parts can be carried out in such a manner that the radiation exposure of the personnel and radioactive releases to the environment can be kept at an acceptable level and at reasonable cost.

The URD should identify any additional decommissioning requirements.

5.3.11. Investment protection

Investment protection refers to the prevention of the economic loss of the plant following an accident if adequate insurance cannot be obtained. Economic loss could also arise from circumstances where a plant may not be completed, or does not operate at rated conditions, for technical or licensing reasons. These risks will be minimised if the requirements to be detailed in the URD are satisfied.

A high degree of investment protection should be provided through design margins and the incorporation of accident-resistance features that extend beyond those provided to meet regulatory requirements and minimise the safety-related environmental impact of the plant. For example, both the physical damage and the spread of radioactive contamination arising from accidents should be minimised to ensure that economic loss of the plant is avoided as well as to protect the health and safety of workers and the public. The design measures taken to achieve investment protection should also facilitate the acquisition of adequate property-damage insurance coverage at favourable rates.

If the safety design requirements described in other sections of the URD are met, then a high degree of investment protection will be achieved.

6. FUEL CYCLE AND WASTE MANAGEMENT REQUIREMENTS

This chapter of the URD addresses the requirements associated with the fuel cycle and waste management. The term "fuel cycle" refers to the complete set of processes undergone by materials used as fuel in nuclear reactors, including mining, fabrication and irradiation, through to final disposal. The main fuel cycle options involve either once through irradiation or reprocessing and recycling.

One important factor that influences the choice of reactor type is the adoption of a particular fuel cycle and related services and activities. Fuel cycle policy decisions not only affect the first nuclear power plant, but also — and possibly even more — the long term nuclear programme of the country. Although the decision for the first plant does not necessarily mean that all successive plants will have to be of the same type and use the same fuel cycle, there are obvious advantages regarding the buildup of national capabilities if a single line is followed throughout.

6.1. Fuel design

In many respects, the fuel design is independent of reactor size, but does depend significantly on reactor type. Hence, the detailed technical requirements may also vary substantially, and could only be specified in the URD once a particular reactor design has been selected.

Nevertheless, all fuel designs should be qualified for the intended service, including load following, if required. Qualification means, in essence, adequate irradiation experience.

6.2. Fuel supply

An assured fuel supply (i.e., from natural uranium ore up to finished fuel assemblies) is an important consideration for a developing country embarking on a nuclear power programme, particularly one whose policy does not support the development of an indigenous, complete fuel cycle capability.

For the most likely case in which the once through fuel cycle is adopted, the following essential activities should be considered:

- procurement of natural uranium, conversion and enrichment (if needed),
- fuel element fabrication,
- storage and disposal of spent fuel, and
- waste management.

The detailed technical requirements depend very much on both the specifics of the particular reactor design and the fuel cycle strategy desired by the developing country.

Because these two factors are interrelated, the developing country must clearly specify its requirements in the URD. This is particularly important if new approaches to fuel ownership (e.g. leasing) are contemplated.

6.3 Spent fuel management

Spent fuel management for the once-through cycle comprises storage, shipping and disposal or return to the supplier country if agreed. The detailed requirements for the implementation of spent fuel management depend on the type of plant selected and the policies of the developing country. Therefore, the general requirements of the respective country should be outlined in the URD. These will be used to formulate the necessary technical requirements in collaboration with the technology supplier.

6.4 Radioactive waste management

Radioactive waste management comprises collection, conditioning, storage, shipping and disposal, including radioactive by-products of future plant decommissioning. In general, the nuclear plant should be designed and constructed so that the amount of radioactive gas, liquid and solid waste generated in the plant will be minimised as much as practicable.

The developing country should specify its general radioactive waste management regulations for the various waste categories (i.e., low, intermediate and high level waste) in the URD. These can be used to formulate technical requirements in collaboration with the technology supplier. Guidance on radioactive waste management issues may be obtained from the IAEA's Safety Standards on radioactive waste safety listed in Appendix B and on the principles of radioactive waste management [25].

7. ECONOMIC REQUIREMENTS

Usually economic considerations constitute the dominant factor in any decision to undertake a nuclear energy project, although in a few exceptional cases there may be other overriding reasons for the introduction of an SMR. The economic requirements which are stressed in this section are those related to the targets for unit capital cost (US \$/kW(e), or US \$/kW(th) for heat-only applications) and production cost (e.g. US \$/kW·h, or US \$/m^3 of desalted water). Such costs can possibly be decreased through longer plant lifetime, shorter construction schedule, assuring design and regulatory licensing stability, etc. (see Section 7.3).

The developing country has to define its requirements in the URD to allow access to basic economic and technical information that is vitally important for accurate cost estimation and the determination of a predictable schedule for the SMR project. This information includes: structure of the capital costs, construction and commissioning schedule and associated costs, estimation of local participation, expected operating performance level, fuel and other special material (e.g. D_2O) utilization and their costs, estimated operation and maintenance costs, etc. Access to this information can be the object of some pre-contractual arrangements with potential vendors and/or based on consulting services contracts with specialised companies. Also, IAEA co-operation programmes can be useful means of obtaining input data for feasibility studies to determine where SMRs are economical within the range of variation for some parameters (i.e., specific capital costs, energy conversion efficiency, capacity factor, fuel prices, discount rates, etc.).

7.1. Criteria and evaluation methodology

The targets set for the technology and plant performance requirements discussed above have direct influence on the plant economics. The economic target can be simply stated as: the levelled electricity (or energy equivalent) generating cost from nuclear plants should be lower than, or comparable to, that from fossil plants with cleanup systems based on prevailing national regulations.

Factors that influence the economics of SMRs include:

- overnight capital cost,
- fuel cycle costs,
- operation, maintenance and administration (OM&A) costs,
- cost of special materials (e.g. D_2O), and
- decommissioning cost,

and a number of other parameters, such as:

- construction and commissioning schedule,
- commercial and contractual terms and conditions,
- financial terms and conditions, including payment schedule, interest rate(s),
- operating performance and capacity factor, and
- economic evaluation method and assumptions, including the plant lifetime, discount rates, escalation, inflation and currency exchange rates.

To establish the relevant criteria, the URD should specify the owner's scope and responsibilities for the desired domestic participation. Also, the technical and economic parameters needed from suppliers should be specified.

The economic evaluation for introducing SMRs is usually based on the following factors:

- present worth of the total proposed project calculated by the discounted cash-flow method at a certain discount rate, and
- production cost, which will be estimated (using a levelled method) with the capital recovery cost, the fuel cost and the O&M cost. Replacement costs of main components foreseen during the lifetime of the plant, waste management costs, as well as decommissioning costs are included in the calculation.

The financing aspects that are needed for the economic evaluation are discussed in Section 7.3. For the build-own-operate (BOO) and similar alternative financing schemes, an evaluation based on risk and benefit sharing should be considered.

Further information is available in Reference [26].

7.2. Measures for improved economics

The URD should address appropriate measures that could be taken to limit and potentially reduce the production costs. The approaches discussed below are based on information from the IAEA-TECDOC-682 [22].

Achieving design plant lifetime

The SMR should have a design lifetime that is as long as technically and economically feasible, although the economic evaluation may be based on a shorter amortisation period.

One of the ways of achieving the plant design lifetime target is through the specification of proper materials and operating conditions. Provisions could be made for component inspection, replacement (i.e., plant life extension) and possible upgrading.

Assuring design stability

High assurance should be given that the licensing and construction schedules can be met without delays. A relatively high state of completion of the detailed plant engineering (including site specific documents, vendor documents, etc.) should exist prior to the start of construction. For example, the EPRI-URD specifies that the design of standardized plants must be at least 90% complete at the time of initiation of construction.

Assuring regulatory licensing stability

The status of the licensing process should give confidence that the schedule for construction, fuel loading and operation will not be impeded by the regulatory process. A possible method to achieve licensing stability for standardized designs would be to obtain a one-step licence covering both plant construction and operation. A licensing process that permits up-front design certification on a basis separate from residual site dependent licensing issues may also have certain schedule advantages. Such an approach may not however be practicable for innovative reactor designs, since the necessary detailed information would still have to be developed.

Assuring construction schedules

In order to minimise the interest during construction, a maximum effort should be made to prevent delays and shorten the construction schedule. The pre-ordering of long lead items should be considered as well as reducing on-site work by increasing factory fabrication. Modularization and pre-testing of complete systems should also be considered.

Minimising operation and maintenance costs

Determined efforts should be made to reduce operation and maintenance (O&M) costs by examining the contributing factors for SMRs. Optimum staff levels, and replication and standardization to permit the sharing of some activities may be key factors that would help to reduce O&M costs.

Minimising decommissioning costs

Early consideration of decommissioning costs should be part of the design effort to optimise, where possible, the capability to decommission the plant and minimise the associated costs. These considerations should be factored into the plant design and operation so that the financial reserves that need to be accrued during plant operation can be determined accurately.

Providing enhanced investment protection

Investment protection has been addressed in Section 5.3.11. It is an explicit design requirement for many future reactor designs currently under development. As such, it should also be required for developing countries. Enhanced investment protection may be obtained by putting even greater emphasis on plant robustness relative to other performance parameters (e.g. load-following capabilities). Appropriate trade-off studies would be required.

7.3. Financing

The availability of adequate and secure financial resources is one of the most important requirements affecting the implementation of SMRs in developing countries. The key economic factors are the larger overnight capital costs of nuclear reactors compared with fossil-fuelled alternatives, longer construction periods and higher risk of delays and cost overruns.

Both foreign and domestic sources of financing are usually required. Generally there are two broad approaches that may be considered:

- conventional financing, and
- alternative financing.

The prospective nuclear plant owner may wish to have early discussions with the potential SMR vendors as to which financing scheme may be the most appropriate for the case under consideration. The topic of financing is complex as it is related to the contractual approaches considered in Section 8.4. Relevant references [26–28] should be consulted. The URD describes the financing approach to be used.

7.3.1. Conventional financing approaches

Financing arrangements are required for the domestic cost components and local construction, as well as for the foreign cost components. The financing sources available for establishing conventional power plant systems in developing countries could also be used for SMRs. The sources of national or local financing could be arranged from:

(a) investor's own resources, such as:
  - equity capital,
  - cash flow; and

(b) debt capital, such as:
  - domestic bonds,
  - local bank credits,
  - grants and credits from public entities,
  - standby funding of contingencies, and
  - prepayments from customers for future services of the project.

If domestic financial resources are insufficient to cover the expenditures, foreign financing may be required. International financial sources and the associated insurance agencies can provide financing as follows:

- export credits,
- international commercial markets,
- bilateral financing sources (government), and
- multilateral development financing institutions.

Such arrangements are additionally covered by sovereign guarantees, as appropriate.

A turnkey contract with project financing by equity and conventional loans (export credits and commercial borrowing) was used to finance the first nuclear plant in most developing countries.

7.3.2. Alternative financing approaches

The build-own-operate (BOO) financing approach may provide a new way to tap the resources of private-sector financing for a capital-intensive nuclear plant that might otherwise not be available to a developing country through its budget or from financial institutions. In the BOO concept, a number of investors form a consortium, which establishes a joint venture company (JVC) and sells the product generated to the utility. The investors in the JVC procure most of the funds for the project, which are used to:

- *build* a nuclear plant with foreign engineering expertise, and
- *operate* and manage the plant.

The BOO strategy does not involve transferring the plant to the host country. Instead, the plant can, in principle, remain in private hands throughout the useful life of the project or up to some earlier date agreed upon by the host government and the private owners.

A variant of this concept is the Build-Operate-Transfer (BOT) approach, for which the JVC:

- *transfers* ownership of the plant to the country in which it is built after all costs, debt service and equity are recovered by means of product sales.

For the BOO and BOT schemes, varying degrees of government encouragement or guarantees should be foreseen, such as third-party liabilities, tax reductions and risk sharing.

The counter-trade or barter-assisted financing approach can be applied in cases where the national products of the developing country have an external market. If the developing country has an existing commodity trade arrangement with the country supplying the SMR components, a countertrade approach can be used. In the barter-assisted approach, the commodities from the developing country are exchanged for equipment and components without involving payment in currency.

The “whole-to-coal” financing model is one in which the purchasing utility and its customers are assured of the same economic and financing situation as would be the case if the utility had constructed a coal plant rather than a nuclear unit. The nuclear unit would be owned by a supplier entity. During the construction and early operating period, the utility's financing requirements would be equal to the coal alternative. Buy-out would be mandatory at a pre-agreed time. On an agreed schedule, the utility would pay back all earlier amounts of financing from the supplier entity, including any losses from selling power on a coal basis, together with interest.

To date, no nuclear plant project has been built using one of the alternative financial approaches. However, such schemes are being used with other energy production technologies (i.e., through independent power producers (IPPs)) and in the future one of these approaches may be employed for a nuclear plant. If the developing country proposes to use one of the alternative financing approaches, this should be stated in the URD.

8. SPECIAL NATIONAL REQUIREMENTS

The special national requirements discussed in this section of the URD are related to the basic factors that determine to a large extent the feasibility and prospects for success of an SMR project in a developing country. These requirements include:

- the development of qualified manpower at all levels (i.e., management, design and engineering, construction, commissioning, operation and maintenance, licensing, etc.),
- the availability of a support infrastructure to assure that the desired level of national participation is achieved (e.g. organizations capable of planning, deciding, constructing, implementing, operating, maintaining and regulating the various project activities during its successive phases, together with local industry),
- active participation in technology transfer,
- the capability to implement a licensing process,
- appropriate contract options and division of scope of supply and responsibilities,
- appropriate guarantees and warranties,
- assurance of nuclear fuel, special materials (e.g. D_2O) and spare parts supply,
- assurance of operational support, and
- opportunities for long term partnerships.

8.1. Manpower development

The safe operation of nuclear reactors is a national responsibility which necessitates early specification of the manpower requirements. Thus, a comprehensive manpower development programme should be an integral part of the national nuclear energy programme. A summary of the manpower development plan should be provided in this section of the URD along with a reference to the full plan. It should also address the training of professional and non-professional staff, however the training of non-professional staff requires special consideration. Safety Culture should be emphasized in all training programmes. The details of how to establish an appropriate manpower programme are given in IAEA-TRS-200 [29].

An important aspect in the manpower development programme, especially in developing countries, is the possibility of a large turnover of qualified manpower (about 10 to 20% per year). The retention of qualified staff could be enhanced through economic incentives and through the creation of a professional and social environment conducive to recognition and career development.

For a developing country, the first nuclear plant would most likely be supplied by foreign vendors with different native languages. In this circumstance, the problem of technical document multi-language translation could arise. Experience shows that the higher the language skills of the professionals and technicians of the developing country, the better it will be able to meet the challenges of collaborating with foreign vendors, absorbing the technology and achieving the national participation goals.

A systematic approach to training plant personnel should be adopted, following the staff structure needed for an SMR and taking into account the successive project phases:

- selection of personnel (technical university graduates, technical high school graduates, engineers and technicians with relevant experience in the construction and operation of fossil power plants, craftsmen, etc.),
- organization of special training courses (both in the host country and for a limited number of personnel in the vendor's country),
- on the job training, encouraging direct participation of all categories of staff in project management, construction supervision, pre-commissioning and commissioning activities, copiloting with the supplier's specialists, and
- taking over plant operation (i.e., special training in similar operating SMRs in the vendor's country). Assurance of the supplier's technical support in training for a given period of time is recommended.

A well founded long term programme should be planned and implemented for the training of control room operators and other key plant personnel (e.g. management level) with the use of the vendor's facilities (e.g. full-scope simulators, copiloting in similar units, etc.). Special attention should be paid to the training of licensed operators, which should follow specific procedures with technical assistance from the supplier and be in accordance with the national regulatory requirements.

In principle, the URD should indicate the extra requirements of the developing country to overcome the above mentioned issues and address additional requirements, such as:

- specify the percentage of extra manpower that needs to be trained, beyond normal practice in developed countries,
- define the role of qualified national professionals in manpower training,
- address the language(s) for the training courses, on the job training, manuals and documents,
- specify the role of the vendor in the training of project, operating and maintenance teams, including the arrangements for training on full-scope simulators and in reference plants,
- define the scope of supply and services of the vendor to establish proper training facilities,

- define the role of the vendor in finalizing the job descriptions and in selecting the project management and O&M teams, and
- specify the role of the vendor in additional training of O&M teams after commissioning.

8.2. Infrastructure and national participation

The initiation of a nuclear programme and the subsequent implementation of an SMR project needs a certain minimum national infrastructure for the management of the required activities at the governmental level, as well as for the utilities, industry, engineering, R&D organizations and educational institutions involved. It is also necessary to set up a national organization to take charge of the planning and co-ordination of the programme including all activities relating to infrastructure. An independent regulatory body responsible for the control of all nuclear activities must be established.

To successfully implement a nuclear project, a minimum level of site infrastructure is needed, whatever the type of contract. The developing country should specify its available facilities, e.g. electrical power and water supply availability, access roads, housing facilities, telecommunication facilities, etc. Any additional infrastructure requirements to be supplied by the vendor during the implementation of the project and/or site development should be specified in the URD.

Even with a turnkey contract there is a possibility for national participation in the implementation of a nuclear project. The URD may identify qualified local firms, factories, contractors and their capabilities or products. The level of participation depends on the qualification of national manpower, the availability of materials and equipment, the capability of local engineering firms (e.g. architect/engineer) and the general industrialisation level.

A detailed description of the activities and issues associated with the development of an appropriate industrial infrastructure to support a nuclear programme is provided in the IAEA’s Technical Reports Series No. 281 [30].

8.3. Technology transfer

One of the most important topics to be considered carefully and addressed clearly in the URD is the degree of technology transfer, which could cover a wide scope. Such transfer refers to the development of indigenous capabilities related to component and system design and manufacture, including nuclear fuel. Smooth and continuous technology transfer from the vendor to the owner will assure successful completion of the construction project, good plant performance and facilitate the accommodation of new developments [30].

8.4. Licensing support

The overall responsibility for co-ordinating the licensing of the entire project will always remain with the utility management (i.e., the owner). A realistic project schedule and the completion of the project can only be assured with good co-ordination and communication between the licensing body and the utility.

The relevant licensing requirements indicating the type of documents needed and expected time periods allocated for review and inspection should be adequately incorporated into the planning for the project. Any necessary information and clarification required for licensing during project implementation, as well as during operation, will be fulfilled by the utility with the support of the partners (e.g. main contractor, architect/engineer, etc.). The roles and responsibilities of each partner in the licensing process, including interfacing with the licensing authority, should be clearly stated in the respective contracts, and corresponding requirements should be included in the URD. The URD should also address the possibility to establish co-operation between the regulatory bodies of the developing country and the vendor's country to facilitate the licensing process.

8.5. Contractual options and responsibilities

The selection of the contractual approach depends upon how the project management and particularly the construction management are to be organized and how the responsibilities are to be shared. However, the final quality and reliability of the plant and its performance should not be affected by the contractual approach.

In general, there are three kinds of contractual options, turnkey contract, split-package contract (i.e., nuclear island and balance of plant) and multiple-package contract, determining the divisions of responsibilities, see for example IAEA's Technical Reports Series No. 279 [31]. From the economic and responsibility points of view, it is important for the plant owner to know the particular advantages and disadvantages connected with each type of contract. These considerations are project specific and/or country specific.

For the turnkey approach there is the least likelihood of cost overruns, as all provisions can be contained in a single, complete contract document, covering all phases up to final plant acceptance. The essential advantage of this approach for the owner is that the main contractor has full responsibility for the project, except for the owner's scope. However, the owner can be expected to pay more as a result of the larger risks and contingencies that the contractor must allow for, particularly for the implementation of the first SMR project in a given developing country.

In the non-turnkey contractual approaches (i.e., split-package and multiple-package) the owner places a number of separate contracts for various portions of the plant. The owner assumes the responsibility for overall project management himself (or through an architect/engineer) and makes all key decisions related to the project.

More detailed descriptions of the various contractual approaches are provided in the relevant IAEA publications [4, 26, 27]. Once the most appropriate contract option has been determined, it should be specified in the URD. In this context, aspects of technology transfer, if so desired, should also be considered.

8.6. Extended guarantees and warranties

It is essential that guarantees on system performance and warranties for the hardware delivered be specified for a certain period of time to assure smooth handover of the SMR facility and reliable operation. Similar assurances apply to the nuclear fuel and its performance. Some developing countries, however, may require additional or extended (both in scope and time) guarantees and warranties. The balance between the increased cost and the benefit of these extensions depends largely upon the technical complexity of the SMR and the capability of the developing country.

The desired warranty and guarantee options for the plant and its nuclear fuel should be specified in the URD.

8.7. Nuclear fuel, special materials and spare parts supply

The availability of nuclear fuel, special nuclear materials (e.g. D_2O), and spare parts, including components, equipment and special consumable, during SMR operation is essential for reliable performance. The developing country should therefore require an adequate inventory of these items as part of the suppliers' contracts and describe this in the URD. This requirement applies if the necessary items cannot be manufactured or obtained in the developing country.

The developing country should require the vendor to provide a list of necessary spare parts including their quantities (foreseen for routine replacement and during an emergency) and related price formulas for a fixed time period. The user could then conclude long term agreements with the suppliers for the noted items at specified prices, particularly for nuclear fuel.

8.8. Technical support

The suppliers usually have the full responsibility for the delivered goods up to commercial operation of the plant with the participation of national staff. Further technical support may be needed from the suppliers during normal operation, including fuel management and maintenance and/or during special situations. This support may be in the form of manpower, equipment or other means.

There are several phases for technical support, with different degrees of involvement of the owner:

- during the execution of the project up to commissioning, usually with participation of the owner's personnel as part of an integrated team,
- during commissioning and initial operation and maintenance,
- during final takeover of the plant operation and maintenance, and
- after final takeover of the plant.

Qualified local design and engineering companies are recommended to be involved in the technical support activities. A certain time period of co-operation with the vendor/contractor for operational and technical support for the owner's team will be necessary after the final takeover of the SMR plant (with a minimum permanent support group from the vendor on site and/or with assistance on demand). Long term vendor assistance on demand is recommended, particularly for abnormal events or special situations.

The developing country should indicate in the URD its intentions regarding the scope of the operational technical support that will be requested, in accordance with the nature of the contract.

8.9. Long term partnerships

The construction and safe operation of a nuclear reactor requires a certain level of technical capabilities. A developing country may need to improve its level of nuclear technology and therefore may seek continuous co-operation to develop its capabilities on a long term basis through partnerships with suppliers and operators of similar plants. The scope of these partnerships may include the upgrading of software, mutual R&D programmes, upgrading of certain equipment especially electronic devices, sharing experience and information, exchange of stockpiles, manpower development programmes, etc.

Up to now, typical arrangements that have been used to facilitate long term partnerships include:

- joint ventures to share the cost of projects to improve the operation and maintenance of the plant,

- long term agreements with selected suppliers to ensure the availability of nuclear fuel, special materials and spare parts, or specialised maintenance equipment and services at reasonable cost and short lead time for delivery,
- inter-station assistance services agreements to promote the sharing of operating experience and expertise by bringing the experts to the requesting site on an as-needed and cost-recovery basis,
- extension of technology licensing agreements to facilitate receiving improvements for systems, components and software, and
- user/owner group activities for a given type of SMR in the field of R&D and the exchange of information on a mutually beneficial basis.

In the future, partnerships with vendor(s) and/or other contractors that last much beyond what has been practised to date may be needed. Such partnerships may be needed for the lifetime of the SMR and may require innovative approaches to co-operation.

The developing country should define in its URD the scope of activities and mechanisms that will be required to reach the long term partnerships that meet its needs. The success of long term partnerships would depend on mutual interest, goodwill and shared benefits, rather than on contracts and legal obligations.

Chapter III

SPECIFIC ASPECTS OF THE PREPARATION OF USER REQUIREMENTS FOR A NUCLEAR DESALINATION PLANT

1. INTRODUCTION

The major role of the nuclear desalination plant (NDP) URD is to provide a technical basis which could be used as a step to the preparation of the NDP owner's bid package. The NDP URD should be compiled by the NDP users based on the country's specific needs and the desires of the water and/or the electric utilities.

2. NUCLEAR DESALINATION PROGRAMME

Increased industrialisation, living standards and human populations have brought fresh (drinking) water resources to the final limits of their extendibility in many countries and in many regions of the countries having large geographical areas. Even the traditionally rain-fed tropical countries experience shortages of dependable sources of freshwater throughout the year.

The world water scenario is demanding an urgent exercise on policy making with respect to water resource augmentation. Seawater desalination offers a realistic alternative to cope with water shortage problems.

Nuclear desalination projects have to be carried out in the context and within the framework of the national water plan, taking into account the national industrial development plan and the national energy plan. The following data should be mentioned in this section of the URD:

- national standards for water distribution and consumption (domestic, agricultural and industrial uses),
- national water resources and the degree of their utilization,
- national water treatment and distribution networks and their performances,
- water demand projections and forecasts including such factors as population growth, industrial and agricultural developments,
- existing and planned water infrastructure, such as dams, wells, drillings, inter-regional water transfers, hill damming (global capacity), desalination plants,
- extent of the nuclear desalination programme within the overall desalination programme, and
- planned implementation schedule for the desalination plant (DP) and NDP programmes and the scope of preparatory work already undertaken.

2.1. Role of nuclear desalination

This section of the URD should present the rationale for choosing seawater desalination relative to other potable water source options. Seawater desalination is an investment and energy intensive technology. Therefore, other steps aimed at the management of potable water consumption through the reduction of water use and the development of existing water resources should be taken before deciding on seawater desalination (nuclear or otherwise).

2.2. Incentives for nuclear desalination

When the need for seawater desalination is established, the rationale for choosing nuclear energy in comparison with other energy options to power the desalination plants should be specified in the URD. Potential reasons include those cited in Chapter II to justify

SMRs, namely:

- most economical energy source option,
- lowest adverse environmental and public health impacts, especially concerning acid rain and greenhouse gas emissions,
- improved energy resource self-sufficiency and long term fuel supply,
- reduced energy supply infrastructure requirements such as fuel transportation,
- conservation of fossil fuels, which are needed as essential raw materials in chemical industries and for which there is no other substitute, unlike the energy supply situation for electricity generation and seawater desalination,
- establishment of another very important peaceful use of atomic energy in alleviating human misery due to water scarcity, and
- promotion of rapid industrialisation of developing countries with limited fossil energy resources.

2.3. Additional considerations

Refer to relevant sections of Chapter II.

3. SITE IMPOSED REQUIREMENTS

3.1. Site conditions

The design of the desalination plant should meet the following site conditions. These data are given for different measurement points located at different distances from shore and/or at different sea depths in order to select the seawater intake, the brine disposal point and to foresee the appropriate chemical treatments. They may include:

Feedwater quality (FWQ)

a)	Total dissolved solids (TDS)	ppm
b)	Total suspended solids	ppm
c)	Calcium ion (Ca^{++})	ppm
d)	Total carbonates	ppm
e)	Dissolved oxygen	ppm
f)	Chemical oxygen demand (COD)	ppm
g)	Total sulphates	ppm
h)	Total nitrates	ppm
i)	Dry residue	ppm
j)	pH	-
k)	Turbidity of seawater	NTU
l)	Electrical conductivity	µS/cm
m)	Organic substances	ppm
n)	Bacteriological composition	N/100 cm^3
o)	Toxicological analysis	µg/l
p)	Ba, Si, Sr, Fluoride	ppm

Sea bottom quality

a)	Appearance (sandy, muddy, rocky, etc.)	-
b)	Smell	-
c)	Color	TCU
d)	pH	-
e)	Water content	%
f)	Fire losses	%
g)	COD	mg/g (dry mud)
h)	Sulphide	mg/g (dry mud)
i)	granular earth composition	
j)	(gravel, sand, mud, clay, colloid)	mg/g
k)	Grains diameter	mm

Oceanographic data

a)	Daily and monthly (weighted average) seawater temperature at different measurement points located at different distances from shore and at different sea depths (°C, min., max.)	
b)	Seasonal (weighted average) seawater temperature	(°C, min., max.)
c)	Annual (for the last five years) seawater temperature	(°C, min., max.)
d)	Tide tables for the proposed site	(tide coefficients)
e)	Seawater salinity	
f)	Seasonal changes	(ppm, min., max.)
g)	Annual changes	(ppm, min., max.)
h)	Seawater pH	
i)	Annual changes	(min., max.)
j)	Seawater turbidity variations	(SDI, min., max.)
k)	Prevailing sea currents	
l)	km around the reference intake point)	-

Topography

The topographical data of the area where the NDP is being sited and of the area where the product water will be distributed should be obtained from the local Geographical Survey Authorities.

3.2. External events

Refer to relevant sections of Chapter II.

3.3. Site infrastructure

Water infrastructure

The NDP URD should specify the following items:

- identification of the institution (authority) which is in charge of the production and distribution of potable water in the city/region;
- definition of the quality and the quantity of the potable water to be supplied to the city/region;
- description of the storage facilities (capacity of the different reservoirs, their location and the characteristics of their equipment);

- the complete data on the distribution system and the characteristics of the pipes used, and
- the complete data concerning:
  i. the storage infrastructure expected to be supplied (topography, materials used, etc.), and
  ii. the projected piping between the nuclear desalination plant and the nearest reservoir expected to be filled (materials used, diameter, topography, etc.).

3.4. Allowable radioactivity release

Refer to relevant sections of Chapter II.

3.5. Emergency preparedness

Refer to relevant sections of Chapter II.

4. LICENSING AND HEALTH PROTECTION REQUIREMENTS

The main objective of this section is to present the key elements necessary to establish the framework of the licensing process for the NDP in accordance with the existing nuclear and health regulations in the user country. These elements are related to the harmonisation of the national regulations with those regulations and norms in the countries of origin, where the nuclear plant (NP) and the DP are designed. The main aim is to ensure that the NDP is licensable in the customer's country and, thus, minimise the changes required in the design.

4.1. National regulations

An effective legal framework and regulatory regime is a prerequisite to the use of nuclear power for desalination plants. The key elements of a regulatory framework specific to nuclear desalination are basically those related to the safety of coupling the DP to the NP. These implications should be assessed by deterministic and probabilistic safety analysis with special emphasis on the possibility of radioactive contamination of product water. The preliminary, the final and any other safety analysis reports should take into consideration the desalination plant. This also applies to the environmental impact report.

The regulations should specify the requirements on the design, operation and performance of the NDP to ensure the protection of product water against radioactive contamination.

4.2. Licensability in the country of origin

Refer to relevant sections of Chapter II.

4.3. International guidelines and technical documents

In addition to those documents mentioned in Chapter II.4.3, reference should be made to other IAEA documents that are specifically relevant to nuclear desalination [32–38].

4.4. National standards for potable water

This section should present the applicable national standards for potable water quality in terms of the recommended and maximum permissible levels of the various constituents as applied to the aesthetic quality and health aspects, including: organic and inorganic constituents, as well as radioactivity levels.

Water quality is an important parameter that influences the final product cost. The quality of the product water, as determined by characteristics such as TDS, chlorine content, pH, hardness, alkalinity, heavy metals, radioactivity, etc., should meet the national standards. If national standards are not available, an existing water quality standard, such as the World Health Organization (WHO) standard, could be applied.

5. TECHNICAL REQUIREMENTS

5.1. Safety requirements

5.1.1. Good neighbour policy

Radioactive contamination of the sea and the coastal area to a level which might impact the use of seawater to feed a desalination plant should be prevented. This may result in more stringent restrictions on the release of radioactive by-products into the environment in the case of severe accidents and corresponding design safety precautions for SMRs used as an energy source for nuclear desalination in comparison with those radioactivity-release regulations applicable to SMRs used for electricity generation only.

5.2. Performance requirements

The performance requirements are very basic, referring to the goals of the NDP project.

Essential requirements that should be specified in the NDP URD include:

- *Quality* of the desalted water;
- *Production rates* at nominal operation per hour and per year;
- *Consumables*, including specific energy and chemical consumption;
- *Availability* in terms of planned and unplanned outages in hours per year (maximum and average annual values). The duration of planned outages should be coordinated between the supplier and the user. Troubleshooting scenarios and corrective actions with time estimates should be submitted to the user;
- *Reliability* in terms of a troubleshooting list with anticipated sequences of occurrence and corrective actions with estimates of the cost and effort needed; and
- *Lifetime* of the plant and the major components. Users may require suppliers to submit a well established assessment of the major components for the whole life of the plant.

Optional requirements that may be specified in the NDP URD include:

- Flexibility to operate at specified load ranges, e.g. 25% to 110% of the nominal capacity, due to changes in demand, minor troubles, maintenance or temporary input-supply shortages (energy, feedwater, etc.); and
- Flexibility to accommodate future increases in the plant capacity.

5.3. Plant design requirements

For design requirements of nuclear reactors, refer to relevant sections of Chapter II.

5.4. Desalination plant design requirements

This section should present the specific design requirements for the desalination plant at a nuclear desalination complex.

A desalination plant must be well managed, operated and maintained without undue impact on the nuclear plant for its lifetime. Therefore, design principles consistent with those used for the nuclear plant should be applied to the desalination plant to prevent the introduction of an additional risk for the nuclear plant by its coupling to the desalination plant. In addition, ample margin should be provided to enhance the reliability of the desalination plant and to prevent unnecessary transients during plant operation. The detailed, country specific desalination plant design requirements should be developed based on the information presented in the following sections of the NDP URD.

5.4.1. Design simplicity

Simplicity should be pursued in every step of the nuclear desalination plant design process, particularly from the viewpoint of plant operation. Simplicity should help the operating and maintenance personnel to understand the NDP and its operation for normal and abnormal conditions of the desalination plant.

5.4.2. Design margins

Sufficient design margin should be provided in the design of the desalination plant to enhance system and component reliability and to prevent the unnecessary occurrence of plant transients which might have an adverse impact on the nuclear system.

5.4.3. Human factors and man–machine interface

Desalination plants should be designed as user friendly systems with adequate consideration of human factors. The layout and structure of the plant should be designed to provide reliable and smooth operation and maintenance, and to minimize the need for operational interaction.

The control room and the instrumentation and control system should be designed with information flow and processing that enable operators to have a clear and complete understanding of the desalination plant's status. Essential information of the desalination plant's status should be provided to the main control room of the reactor system in real time and vice versa.

5.4.4. Standardization

The design, fabrication and installation of structures, systems and components of the desalination plant should comply with applicable national or international standards. The components and equipment required should be standardized in a practical manner to simplify the supply of spare parts and the required qualification tests of major components.

5.4.5. Proven technology

Desalination technology is a proven and established technology, through its use in various industrial applications. New concepts or technologies, which are sufficiently proven, may be incorporated into the nuclear desalination plant to enhance system performance.

5.4.6. Constructability

The desalination plant should be designed to a sufficient level of engineering detail before the placement of structural concrete to assure the successful completion of the plant's construction. Integrated construction planning and scheduling should be provided for effective planning, scheduling and monitoring of construction activities.

5.4.7. Maintainability

The desalination plant should be designed to facilitate easy maintenance without disrupting the operation of the nuclear plant. This may require a modular design of the desalination plant with some excess desalination capacity for maintenance periods.

5.4.8. Quality management

A quality assurance/quality control programme should be established for the desalination plant to ensure high-quality design and construction using well proven techniques and procedures.

5.4.9. Codes and standards

The design, fabrication and installation of structures, systems and components of the desalination plant should comply with applicable national or international standards.

5.4.10. Decommissioning

The desalination plant should be designed and located to take into account the decommissioning plan for the nuclear reactor.

5.4.11. Investment protection

The nuclear desalination plant should include specific measures to protect the product water from radioactive contamination and thereby provide a high degree of investment protection.

Consideration should be given to localize both the physical damage and the spread of radioactive contamination due to internal events of the reactor system. A continuous radioactive monitoring system of the product water should be provided.

Mitigative and corrective measures should be provided to accommodate external events (fire, meteorological storms, earthquake, flooding, etc.).

5.4.12. Environmental protection

The chemical effluents discharged from the chemical preparation room and the analysis laboratory should be neutralized before their disposal to minimize the environmental impact due to the brine.

5.5. Nuclear and desalination plant integration requirements

This section of the NDP URD should present the specific design requirements for the integration of the nuclear and desalination systems at a nuclear desalination complex.

5.5.1. Design integration

The design of the NDP should be managed and executed as an integrated plant in terms of hardware, software and project management. For a dual-purpose plant (i.e., producing electricity and desalted water), common instrumentation and control systems should be used for the turbine island and the desalination island.

5.5.2. Design philosophy

Radioactive contamination of the product water is not allowed under all normal and abnormal conditions. Continuous radiation monitoring of the product water should be carried out.

5.5.3. Impact of the desalination plant on the nuclear island

The performance of the desalination plant should have minimum impact on nuclear reactor performance. Such impact should be included in the safety analysis of the nuclear plant.

5.5.4. Disconnection of the desalination plant

Depending on the grid conditions and the availability of alternative potable water supply, the user may require a dual-purpose plant to continue generating electricity when the desalination section is not operating or an NDP to produce desalted water when the reactor is shut down. In such cases, the design should allow for the disconnection of the DP and NP systems. A backup energy source will be required for the desalination system: a grid connection in the case of the Reverse Osmosis (RO) system and a backup heat source in the case of thermal distillation processes.

5.5.5. Replacement/expansion of the desalination plant

The design life of nuclear reactors is usually much longer than the design life of desalination plants. One of the design goals of advanced reactors is to extend the design life up to 60 years. Therefore, it is essential that the design and layout of the nuclear desalination plant should accommodate the possibility of replacement/expansion of the desalination section with minimal interruption of electricity generation and water production.

5.5.6. Technical aspects of the coupling system

A coupling system connecting an RO plant to the nuclear power system is relatively simple. Even if a feedwater preheating option is taken, it requires only a leak-safe condenser, which is required for single-purpose units as well, including radioactivity monitoring and, possibly, bypass feedwater piping and pumping for situations of power plant shutdown or high seawater temperature. Additionally, an electricity connection to the grid is required for power backup.

The coupling of evaporative-desalination processes to the nuclear plant is more complicated. It calls for much more attention to the requirements.

In general, the fulfilled requirements should ensure:

- safety against radioactivity ingress into the coupling system and the desalination systems, as well as protection against salt ingress to the steam cycle,
- efficiency and optimization of the design,
- easy operation and control, including flexibility of modes of operation (e.g. to operate the DP without the NP or to disconnect it while the NP operates without disturbing the desalination plant), and
- reliable steam supply.

These requirements depend on the type of nuclear system (PWR, gas cooled reactor (GCR), etc.) and the desalting process (RO, multistage flash (MSF) and multi-effect distillation (MED)). The size of the plant may also affect the requirements of the coupling system.

5.5.7. Construction scheduling[1]

A requirement for nuclear desalination is that the two main systems should be commissioned within an optimal time interval, particularly for dual-purpose plants, to minimize financing expenses and interference and, possibly, to optimize construction resources.

5.5.8. Operability in a dual-purpose mode

In addition to the above mentioned requirement for independent operation of the two major balance-of-plant (BOP) systems for a dual-purpose NDP (i.e., the turbine and the DP), two more requirements may be introduced:

- smooth and convenient operation during transients, such as start up, load changes and shut down of one BOP system during operation or outage of the other, and
- steady operation with either one of the two major BOP systems at partial load, independently.

6. FUEL CYCLE AND WASTE MANAGEMENT REQUIREMENTS

Refer to relevant sections of Chapter II.

7. ECONOMIC REQUIREMENTS

An NDP will in most cases be a cogeneration plant, producing both electricity and desalted water. This has to be taken into account in almost all economic considerations, especially in the evaluation methodology applied for comparing different plant options.

For small desalination units (up to a few thousand m^3/d) the owner-operator (i.e., the buyer) of the NP might also own and operate the desalination unit. For larger desalination plants, separate owner-operators might be recommended, one for electricity generation and sale and one for water production and sale. The URD should specify which organizations will own and operate the two plants and how revenues and responsibilities will be distributed among them. A clear definition of the future organizational structure regarding the electricity and water parts is essential.

Similarly, it should be kept in mind that, although the URD explicitly addresses only one “vendor” (main contractor) of the NDP, it will in fact be directed to at least two important subcontractors “behind” the vendor of the NDP, responsible for either the nuclear or the desalination part. The URD should clearly state if and to what extent the vendor should merge the two parts, so that either the vendor is responsible for both parts, or that it remains clearly visible to the buyer that two different subcontractors are involved in the NDP.

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[1] The construction period for the nuclear plant is at least 5-6 years while for desalination systems it is 1½-3 years. Thus, if the user decides, for example, to commission the two units simultaneously (and if the amount of water needed for the construction of the nuclear plant is small relative to desalination plant capacity), the desalination system construction should start, accordingly, 1½ to 3 years before the commissioning date of the nuclear unit. This approach also allows for updating the design of the desalination system.

If the optimal time gap between the commissioning of the two systems is, e.g. 6 or 12 months (desalination later than power, most probably only for RO), the above aspect and the requirement for the two updating activities become even more important.

For a dual-purpose NDP, the capacities of both the electricity-generation and the desalination BOP systems have to fit the national economy. The electricity demand and the water demand stated in the URD should both be a part of an integrated national demand and supply plan. Product water and the desalination plant should not be seen as mere by-products of NPP operation, but rather should be treated with the same effort as the electricity-generation part.

Economic aspects of nuclear desalination are especially dealt with in the IAEA reports TECDOC-666 (1992) [33], TECDOC-898 (1996) [34], TECDOC-942 (1997) [37] and Computer Manual Series No.12 (1997) [38].

7.1. Criteria and evaluation methodology

The economic comparison of different cogeneration plants for electricity and potable water is more difficult than for single-purpose plants, since they have simultaneously two final products, electricity and potable water. The plant with the least overall expenditures is not necessarily the most economic solution, and it is unlikely that two plants offered will have exactly the same net outputs. Hence, the URD should specify in detail which economic data have to be made available for evaluation purposes, and which evaluation method is to be used by the vendors.

Several cost allocation methods suitable for the evaluation of cogeneration plants have been developed. They can be grouped into “cost prorating methods” and “credit methods”. Cost prorating methods divide the overall expenditures of the plant according to a given set of rules entailing, in general, a sharing of the benefit of the cogeneration between the two final products. Credit methods, in turn, attribute a value to one of the products (to electricity in the case of the power credit method), and obtain the cost of the other by difference (thus, in the case of the power credit method, giving all the benefit from cogeneration to the water).

The IAEA offers a computer package, CDEE (cogeneration and desalination economic evaluation programme, see Computer Manual Series No. 12 [38][2]), for the economic comparison of different energy-desalination plant options. CDEE is based on the power credit method. Other computer tools are available, many directly from desalination equipment manufacturers, but are often limited to design aspects and do not include options for economic comparisons.

Apart from methodological difficulties, the following points and criteria are of importance for a URD:

- Water demand and alternative water supplies that form the basis for the URD should be determined in an independent national water plan, involving other national institutions, such as the water authorities and ministries;
- The URD should state information on the existing qualified manpower and ask for costs of training and qualification;
- Construction and licensing times of the nuclear and the desalination plants have to be harmonized to achieve an optimal economic solution. The URD should state when electricity and water will be produced, and it should be kept in mind that these two dates can differ;

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[2] A revised, validated and more user friendly version of CDEE is planned for publication.

- Siting aspects of an NDP might also influence the economics of the plant, as siting distant from densely populated areas might be desirable for the nuclear plant, but water transportation costs will increase with the distance; and
- It is important to ensure in the URD that a consistent set of economic assumptions is used by the vendors for both the nuclear and the desalination plants. A proper economic calculation has to take into account that the technical lifetimes of the nuclear and desalination plants are different.

7.2. Requirements for improving desalination plant economics

Incentives and hurdles for dual-purpose NDPs (producing both electricity and water) compared to NPPs (producing only electricity) include the following:

- The fraction of local participation is likely to be higher for an NDP than for an NPP alone, usually a desirable feature for developing countries;
- Larger nuclear power units can be installed, resulting in economies of scale;
- Economic benefits can be gained from common facilities, common staff, common and coordinated planning, and joint construction; and
- The overall flexibility and availability of an NDP might be lower than for an NPP.

The overall economics of the NDP can be increased by the same measures as for an NPP (see Section7.2.).

Special attention should be given to the coupling of the nuclear and desalination plants. Essentially a technical feature, optimum coupling is also a main condition for optimizing the economics of the cogeneration plant. The URD should ask for an analysis of the economic consequences of different coupling options, especially if more than one desalination technology is chosen (hybrid plants).

7.3. Financing

The URD should state if and to what extent the nuclear and the desalination plants should be treated independently, e.g. if separate financing arrangements are to be made, or if a unified financing concept is preferred. In this context, a clear definition of the future owner-operator(s) is helpful at an early stage. The URD should also emphasize the importance of a detailed analysis of the mutual economic influences between the nuclear and desalination plants, e.g. arising from coupled plant availabilities, joint construction requirements, financial risk in case of delay of start of operation of one plant, etc.

The user should then specify the different financing options to the vendor (as in the case of an NPP), who has to respond by giving the preferred financing option. Options, including the build-own-operate and build-operate-transfer alternative financing approaches are described in Section 7.3.

The vendor should also evaluate the influence of the financing options on the product water cost. The evaluation is similar to that for NPPs, but has to take into account the specific circumstance of possibly having more than one owner-operator of the cogeneration plant. The cost of the desalination plant will in most cases constitute only a minor fraction of the total NDP cost. Financing then remains basically an issue related to the nuclear plant.

8. SPECIAL NATIONAL REQUIREMENTS

A developing country may have additional user requirements relating to its national capabilities and policy goals that may be very important for a successful (from both technical and economic aspects) implementation of a nuclear desalination project. Moreover, the NDP project may represent a relatively large commitment of organizational effort for a developing country and require integration with its other national policies. These additional requirements may include:

- A real and effective technology transfer during project implementation;
- An efficient training of operation and maintenance staff in the framework of a manpower and human resources development programme;
- The involvement of national experts, specialists and institutions that may be concerned, in particular the universities, R&D entities and public or private engineering companies;
- An optimal national participation (private and public) at all project implementation steps;
- The choice of the most adequate contractual approach and sharing of responsibilities;
- The best possible financing options, terms and conditions, with minimum down payment; and
- Extensive guarantees and warranties with long term partnerships in the framework of joint ventures, long term assurance for spare parts, components, consumables and special materials supply.

8.1. Manpower development

8.1.1. General

The main goals of the manpower development programme for nuclear desalination are to develop an adequate number of qualified personnel necessary for the NDP at the proper time and to insure that the program promotes the improvement of the nation's technological and industrial infrastructures.

The manpower development programme for nuclear desalination should be included in the Bid Invitation Specifications (BISs).

Manpower development for nuclear desalination involves planning, implementation and personnel management. To implement the manpower development programme, the industrial techniques and facilities to meet the manpower requirements for the NDP have to be defined and special efforts made within the country's educational, scientific, technical and industrial organizations to fulfill them. This requires close cooperation among the responsible organizations involved.

The manpower development programme should take into account the scope and schedule of national participation in an NDP, the constraints and limitations on the scope and schedule imposed by national industrial, educational and technological infrastructures, manpower resources and the national conditions and characteristics affecting labour.

In addition, technology transfer by local participation and on-the-job training for DP design, manufacturing, operation and maintenance should be included in the manpower development programme to enhance the country's self-sufficiency in nuclear desalination technologies.

8.1.2. Specific manpower development requirements

(i) The supplier should provide the user with a comprehensive, long term manpower development programme to meet the human resource needs of the user for each of the implementation steps of the desalination project, beginning from the design of the desalination units until their full-capacity operation. The purpose of this plan is to maintain and upgrade the knowledge and skills of the DP user's staff.

(ii) The supplier should provide the user with an optimal organization chart of the desalination plant showing the number of employees, their duties, the functions allocated to superintendents and managers in the main work fields of the desalination unit (administration, operation, maintenance and technical support). Lines of authority and communication should be indicated in this chart.

(iii) The staffing proposed by the supplier should be sufficient to accomplish the assigned tasks without unduly increasing personnel expenses in the operation and maintenance costs. However, in evaluating manpower requirements for the desalination plant the supplier should include a reasonable number of reserve and replacement personnel.

(iv) The responsibilities, duties, authority, job description and accountabilities of each employee of the DP user, including management and supervisory staff, should be defined and documented by the supplier.

(v) Basic educational level and degree, professional skills, technical knowledge, applicable experience and qualification requirements should be specified by the supplier for each job position in the organization chart of the desalination plant. Selection criteria should be established for each job proposed by the supplier.

(vi) Technicians, foremen, operators and other personnel should receive on-site training during the construction of the desalination units as well as training in similar demonstration plants that are already operating.

(vii) The training plan should be based on analysis of the various jobs for which training is needed.

(viii) The training programme of DP personnel should include, in particular:
- A general course on water chemistry with topics on drinking water standards;
- A general course on desalination processes and technologies, including chapters on membrane technologies;
- A specific course on the desalination process proposed by the supplier;
- A course on the installations, systems and subsystems that compose the desalination unit;
- A practice period of at least 2 months in a desalination plant;
- A course on operation and maintenance procedures in the desalination plant;
- Special training related to the expected specific job;
- Training on a desalination simulator;
- Supervised “on-the-job” training; and
- An introductory course on nuclear plant operations.

(ix) All personnel of the desalination plant should be qualified for their position and trained for the execution of their assigned tasks before work is assigned. Their competence should be confirmed by testing and by evaluating their experience.

(x) After the completion of the construction project, the supplier should provide the user with specialists who will be in charge of operation assistance and training for a predetermined period.

(xi) The supplier should involve local higher education institutions, universities, R&D entities and engineering companies, especially during the design, commissioning and manpower training phases of the project.

(xii) The supplier should provide the user with complete sets of desalination plant technical documents, including: preliminary and detailed design documentation, plans, drawings, schemes, notices, commissioning, operation and maintenance procedures, equipment notices, computer outputs, validated source computer codes, validated software, benchmarks, weld radiographs, commissioning records and other documents, translated into the user's national language and/or into any other language the user may specify.

8.2. Infrastructure and national participation

8.2.1. General

The purpose of national participation is to perform activities and supply goods and services necessary for the nuclear desalination program that can be obtained most effectively by national means. The nuclear desalination program, therefore, requires adequate national infrastructure and participation for the maximum effective use of national resources.

The development of national infrastructure for nuclear desalination as well as effective implementation of national participation requires extensive efforts of the government and a wide range of the industrial sector. Although both electricity and water supply are necessary in the country interested in nuclear desalination, the nuclear power project should have a leading role because the acquisition, licensing, construction and commissioning of the nuclear reactor plant is more complicated and takes more time than the desalination plant.

The scope and level of national participation will vary according to the specific conditions of each country. The scope of national participation should be determined in the framework of the national policies and infrastructure for nuclear power and water supply. A balance between the benefits, constraints and limitations should be pursued.

The main benefits expected from national participation are:

- Improvement of the overall economy of the country by increasing national production;
- Promotion of the development of national industrial, technological and educational infrastructures;
- Advancement of the general level of industrial qualifications, standards and capabilities;
- Development of qualified manpower;
- Acquisition of new technology and technical know-how;
- Reduction of foreign currency expenditures; and
- Increasing the country's self-sufficiency.

National participation in a nuclear desalination program is limited by economic, financial, and technical constraining factors, such as:

- Cost of national products;
- Financing;
- Achievable quality;
- Market size;
- Availability of qualified manpower; and
- Industrial capability.

Successful technology transfer not only requires a country able and willing to transfer the technology, but also a recipient country capable of absorbing it.

To increase national participation, the national policies and strategies should be established based on the special needs and conditions of the developing country. In addition, a consistent set of governmental actions and incentives promoting national participation should be developed. To achieve the desired national participation goals, the procedures and methods should be defined in realistic terms, taking into account the existing industrial, technological and manpower infrastructure, as well as the overall economic and industrial development plan of the country.

8.2.2. Specific infrastructure and national participation requirements

(i) During the design and construction of the desalination units, the user should provide the data and technical information concerning: the site, local infrastructure, the electrical grid, site access, power supply, the existing water distribution network, existing water reservoirs and related facilities.

(ii) The supplier, in collaboration with the user, should assess and provide a survey of national infrastructure and technological capabilities.

(iii) During the desalination project implementation phase, the user may require local participation that would be as large as possible, mainly in:

  - Project management;
  - Public information and public relations;
  - Supervision of suppliers;
  - Site preparation;
  - Personnel training in local institutions;
  - Preliminary and detailed design engineering;
  - Design reviews and approvals;
  - Procurement and manufacturing of components;
  - Construction of buildings and structures;
  - In-plant assembly acceptance and takeover of main equipment;
  - On-site assembly;
  - On-site non-destructive control and testing of welds;
  - System and subsystem commissioning;
  - Full-capacity commissioning of the desalination plant; and
  - Desalination plant acceptance testing.

(iv) Interest in local participation is not allowed to supersede safety, quality, reliability and, thus, desalination plant availability requirements.

In the course of evaluating the potential for local participation, the risk of disruption of the project schedule and consequent economic loss on a cost/benefit basis should be assessed.

(v) The user may require from the supplier the participation of local R&D institutions with joint user-supplier research projects in areas of common interest concerning desalination processes and related phenomena.

National institutions of higher education in the developing country may also be involved, providing expertise, assessing technical bids, contributing to the academic training of personnel, etc.

8.3. Technology transfer

For implementing the nuclear desalination project, basic industrial, technical manpower and educational infrastructures are essential. In a country without a nuclear industry, technology is usually acquired from a country with nuclear expertise that is able and willing to transfer it. However, for successful transfer of technology, the recipient country must be capable of absorbing the technology, and the key point is the availability of qualified manpower. The available local industrial infrastructure should be closely associated with the NDP programme. Some competent construction and erection companies should be available. They will probably not have all the technology, know-how, level of quality, competence and expertise necessary for nuclear systems, but these capabilities may be acquired through technology transfer.

Each developing country has the overall responsibility for the planning and implementation of its own national nuclear desalination programme. National participation is essential for assuming this responsibility. The extent of such participation will significantly depend on the existing industrial capabilities and on the availability of local resources for the supply of necessary materials, services, equipment and qualified manpower.

8.4. Licensing support

In the framework of the URD for ND, the supplier could be requested for licensing support in two levels/stages:

(i) To the authorities/regulatory body to develop/complete a regulatory (legal) framework, and

(ii) To provide the safety documents (preliminary safety analysis report (PSAR), final safety analysis report (FSAR) and any others) requested by the regulatory body to obtain the licences for construction and operation.

The first (higher) level of support could only take place in the early (preliminary) stage of the project, because the existence of a fixed regulatory framework is a precondition for the bidding process. In this stage, the support could be accomplished either by:

- The proposal of a complete regulatory framework, including the institutional organization, the regulatory structure, etc. and the particular aspects of nuclear desalination. Special attention should be paid to the links and constraints imposed by the existing national legislation and structure of the judiciary power (courts competence, enforcing institutions, etc.); or
- The provision of specific studies requested by the customer to develop the country’s regulatory framework, or to complete particular aspects related to ND of an existing framework.

The licensing support at the (higher) level of item (i) is particularly sensitive to an ND project, because, in principle, it would be reasonable to ask the supplier to provide his knowledge concerning regulatory needs of this particular application of nuclear energy, while the customer keeps the role of finally deciding on the regulatory structure. Therefore, the success of the project needs the mutual acceptance of regulatory and safety criteria (particularly those criteria relevant to design).

For the second (lower) level of item (ii) a regulatory structure already exists and the role of the supplier is limited to the elaboration of the required documents. The user could foresee a previous stage in which the supplier is requested to produce a list of data needed for the safety analysis report(s) (SARs). There is a possibility of having different suppliers for the DP and the NP. A desalination plant should be considered a major modification relative to the NP alone, i.e., the DP design is relevant to the safety analysis for the NP. Therefore, the elaboration of the SARs requires support from both suppliers and, probably, the implementation of joint efforts (user — NP supplier — DP supplier).

8.5. Contractual options and responsibilities

While preparing the specifications and bidding documents, the owner has to make his choice of contractual approach for the acquisition of the nuclear desalination plant. This decision should be taken on the basis of the following considerations:

- How the project management and the construction management will be organized; and
- How the responsibilities during construction and for the final quality and reliability of the plant will be shared.

The main factors for the choice of the contractual approach are the following:

- Financing possibilities (local or foreign financing);
- Experience in project management of desalination plants;
- Local engineering and construction capabilities;
- Local industrial infrastructure;
- Potential contractors; and
- Economic and competitiveness considerations.

The main contractual approaches (and responsibilities) that could be applied to nuclear desalination plants are discussed in the following sections.

8.5.1. Turnkey

A single (main) contractor or a consortium of contractors takes the overall responsibility for the whole work. Only one member is acting as the speaker for the group. The main contractor is fully responsible for:

- NDP design (engineering),
- NDP completion date,
- NDP generating capacity and efficiency,
- NDP quality and functionality, and
- the required desalted water quality.

The owner has to supervise the main contractor during construction and verify that the specified guaranties included in the contract document are fulfilled.

The financing of the nuclear desalination plant is the responsibility of the owner.

The desalted water price is defined by the owner.

8.5.2. Split package

The overall responsibility for the project is divided between a relatively small number of contractors, each in charge of a large section of the work. The owner has to supervise the different contractors and ensure their coordination during construction for the whole duration of the separate contracts. Each contractor has to honour the quality of its work and fulfil the guarantees specified in the contracts.

The owner assumes the responsibility for the overall project management himself.

The financing of the nuclear desalination plant is the responsibility of the owner.

The desalted water price is defined by the owner.

8.5.3. Multiple package

The owner (either within his own organization or assisted by his consultant engineer) assumes the direct responsibility for the design and construction management of the nuclear desalination plant with a large number of contractors. This option requires that the owner is well qualified and experienced in managing similar projects.

Bids are invited for the different works (civil works, electrical equipment, mechanical equipment, etc.), which could lead to a minimum cost plant relative to other contractual options.

The different contractors are not responsible for the quantity and quality of product water, because the design has been performed by the owner

The responsibilities of the contractors are limited only to the quality of their respective supplies.

The financing is the responsibility of the owner.

The desalted water price is defined by the owner.

8.5.4. BOT (build, operate and transfer)

Funding for this kind of contract is provided by the contractor, who takes the overall responsibility for the whole work and for plant operation and maintenance during the contract period.

The nuclear desalination plant design is performed by the contractor.

The owner should specify, in particular, the following parameters:

- Quantity and quality of the desalted water;
- Quality of the materials used;
- Nuclear desalination plant completion date; and
- Contract duration.

The main criteria used for the evaluation of the bids is the lowest desalted-water price offered by the contractors, because the owner has to buy a fixed quantity of water per year at the price which has been set by the contractor and accepted by the owner.

For developing countries with limited experienced manpower resources and industrial infrastructure, turnkey contracts with a high degree of domestic participation and adequate owner influence on design decisions are desirable because these contracts will give the highest degree of integrity and homogeneity in the scope of supply and services under full responsibility of the main contractor. In multiple package contracts, the coordination problems among various contractors may be solved by giving lead responsibility to the supplier who has successfully demonstrated his capability for technical and project management of plant construction and commissioning.

8.6. Extended guarantees and warranties

The supply of NDPs to developing countries requires special consideration concerning process guarantees and equipment warranties from the respective suppliers as given below.

8.6.1. Equipment warranties

Equipment suppliers normally limit the scope of their warranties to the technical aspects applicable to the equipment supplied by them. These include the normal duty conditions, abnormal duty conditions, required availability factors and reliability factors of the equipment.

8.6.2. Process guarantees

The supplier provides a general guarantee on process performance and a specific guarantee on the product. The supplier also furnishes collateral guarantees for the equipment used in the plant, obtained from respective manufacturers. At the end of construction, the process supplier demonstrates the performance of the plant, as per design stipulations under standard operating conditions.

8.7. Nuclear fuel, special materials and spare parts supply

For nuclear fuel and special materials, refer to relevant sections of Chapter II.

The supply and warranty conditions for the required spare parts and consumables should be clearly specified in the supplier's bid for normal operation and maintenance during commissioning and operational testing and guarantee periods. Special attention should be paid to the delivery conditions of non-standard spare parts that could affect the availability of the desalination plant.

8.8. Technical support

The details of operational technical support provided by the supplier to the user and the obligations of the parties should be clearly stated in the contract documents.

Technical support starts when the acceptance performance tests of the nuclear desalination plant are performed and approved by the owner and the plant is officially handed over to the owner.

During the guarantee period stated in the contract, the main contractor, together with the nuclear and desalination plant vendor(s), should maintain an active presence and should provide all the guidance, assistance and technical support that is required to assure satisfactory operation at all times.

Technical support of operational services should be emphasized in the user requirements addressed to the nuclear desalination plant suppliers. These may include:

- Participation of supplier's technical personnel in operational, maintenance and repair activities;
- Training of the user's manpower, including at the supplier's facilities;
- Strong and prompt technical support under any abnormal and emergency conditions at the nuclear desalination plant; and
- Updating of operation and maintenance manuals based on experience gained and technology upgrading.

The permanent presence of the supplier at the nuclear desalination plant might be practical. Reliable communications and procedures providing prompt access to the supplier's technical information and advisory personnel should be established.

Further operational technical support would be facilitated by long term bilateral cooperation agreements between supplier and user countries as well as between owners of similar plants.

8.9. Long term partnerships

Long term cooperation between the user and the plant suppliers should be established to assure the supply of materials, equipment and technical support during normal operation and abnormal conditions. Also, implementation of newly developed advanced technologies could be part of the long term partnership arrangements. In addition, technology transfer should be included.

Chapter IV

CONCLUSIONS

The main conclusion of this work is that a realistic, practical and flexible approach is needed in the preparation of user requirements document(s) for SMRs in developing countries.

This is so because it is rather difficult to modify existing URDs to create a universally applicable URD, since the range of technical approaches and applications for the SMRs currently under development is very wide. In addition, the experience and capabilities of utilities in developing countries vary much more than those in the developed countries.

Therefore, this TECDOC was developed as an interim step to give flexible guidance, in the form of a suggested URD structure and content, to the professionals in a developing country charged with establishing their national URD. It also references other documents that would be useful in the preparation of such a URD.

The URD structure proposed in this TECDOC can be used for various SMR technologies and applications beyond generating electricity. An example of such use is provided in Chapter III of this TECDOC for the specific case of nuclear desalination; this section of the TECDOC indicates the additional requirements that need to be specified in a URD for ND, based on the generic URD structure developed in Chapter II.

When preparing its URD, the developing country should give special attention to drafting Section 8, as its subject matter is not addressed in the published URDs for ALWRs. The required information will depend mainly on the particular conditions and special needs of each developing country.

An example following the suggested structure and content of a national URD for developing countries has been prepared outside the present task and in given in the Annex to further assist users of the TECDOC in establishing their national URDs for various applications of SMRs.

Appendix A[*]

STATUS OF SMRs

The status of SMRs is reviewed periodically by the IAEA [3, 8]. 148 SMRs are in operation and about 14 are under construction as of the beginning of the year 2000. The various types of SMRs that have been considered recently span a large range of technical concepts. The design and development efforts of SMRs have been very active and some new designs have emerged over the last year. These new designs are included in Table A-1.

The overall market is estimated at about 60 to 100 SMR units to be implemented up to the year 2015. It is recognized that forecasts tend to err on the optimistic side. Therefore, an overall market estimate of 70 to 80 units seems reasonable.

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[*] Taken from IAEA Power Reactor Information System.

TABLE A.1. SMR Designs
(based on IAEA-TECDOC-999)

1. Reactors being deployed or in the detailed design stage

Design Name	BWR-90	AP-600	SBWR	QP-300	AST-500	KLT-40	CANDU-6	CANDU -3*	PHWR-500	PHWR-220
Designer/ Supplier	ABB	W	GE	SNERDI	OKBM	OKBM	AECL	AECL	NPC	NPC
Reactor type	BWR	PWR	BWR	PWR	PWR	PWR	PHWR	PHWR	PHWR	PHWR
Gross thermal power MW(th)	2350	1940	2000	999	500	up to 160	2158	1441	1673	743
Net electrical power MW(e)	720–820	600	600	300	not relevant	Up to 35	666	450	500 (gross)	194

* design work was discontinued after publication of TECDOC-999

2. Reactors in the basic design stage

Design Name	PIUS	HR-200	CAREM25	MRX	ABV	GT-MHR	MHTR	PBMR
Designer/ Supplier	ABB	INET	CNEA/ INVAP	JAERI	OKBM	GA	ABB/ Siemens	ESKOM
Reactor type	PWR	Integrated PWR	Integrated PWR	PWR	PWR	HTGR	HTR	HTGR
Gross thermal power MW(th)	2000	200	100	100	38	600	200	220
Net electrical power MW(e)	610–640		27	30	6	286	85.5	100

3. Reactors in the conceptual design stage

Design Name	BWR-600*	VPBER	HSBWR	APWR	SIR	ISIS	ATS-150	MARS	RUTA-20	SAKHA-92	MDPR	4S
Designer/ Supplier	Siemens	OKBM	HITACHI	JAREI	Consortium	ANSALDO	EMBDB	Univ. of Rome ENEA	RDIPE	OKBM	CRIEPI	CRIEPI
Reactor type	BWR	PWR	BWR	PWR	Integrated PWR	PWR	PWR	PWR	pool type	PWR	LMR	LMR
Gross thermal power MW(th)	2200	1800	1800	1800	1000	650	536	600	20	7	840	125
Net electrical power MW(e)	750	630	600	600	320	205	Up to 180	Up to 180	not relevant	Up to 1	325	50

* meanwhile power output was increased to 1000 MW(e)

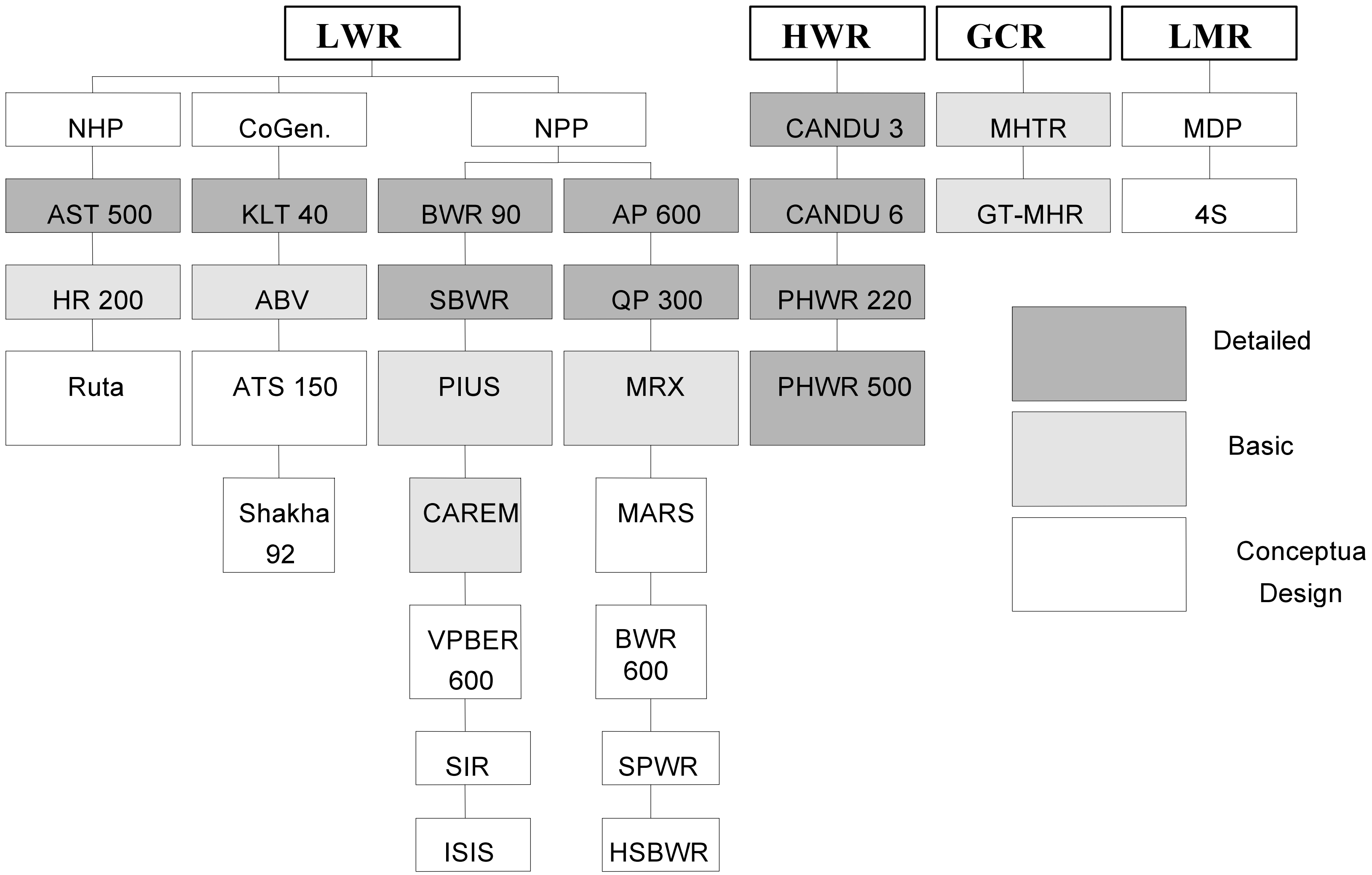

FIG. A-1. SMR development lines and their design status.

Abbreviations

AECL	Atomic Energy of Canada Ltd, Canada
CNEA	Commisión Nacional de Energie Atomica, Argentina
CRIEPI	Central Research Institute of Electric Industry, Japan
EMBDB	Experimental Machine Building Design Bureau, Russian Federation
ESKOM	South Africa
GA	General Atomic, USA
HTR	High Temperature Reactor
INET	Institute of Nuclear Energy Technology Tsinghua University, China
INVAP, SE	Argentina
JAERI	Japan Atomic Energy Research Institute, Japan
NPC	National Power Cooperation, India
OKBM	Special Design Bureau for Mechanical Engineering, Nizhninovgorod, Russian Federation
RDIPE	Research and Development Institute of Power Engineering, Russian Federation
SNERDI	Shanghai Nuclear Engineering Research & Design Institute, China

Appendix B

LIST OF THE IAEA'S SAFETY STANDARDS

Under a new approach to the preparation and publication of IAEA Safety Standards, many documents are being reviewed and revised. The programme's status is presented here under five categories: General Safety; Nuclear Safety; Radiation Safety; Waste Safety; and Transport Safety. Publications listed in ***italic bold*** were issued under the authority of the IAEA Board of Governors. Others were issued under the authority of the IAEA Director General. Many publications are being revised[*] and new Safety Standards are in preparation on various topics.

GENERAL SAFETY

SAFETY FUNDAMENTALS

Δ Safety Series No. 110: ***The Safety of Nuclear Installations*** (1993)

Δ Safety Series No. 111-F: ***The Principles of Radioactive Waste Management*** (1995)

Δ Safety Series No. 120: ***Radiation Protection and the Safety of Radiation Sources*** (1996)

EMERGENCY PREPAREDNESS AND RESPONSE

Δ Safety Series No. 50-SG-G6: Preparedness of Public Authorities for Emergencies at Nuclear Power Plants (1982)

Δ Safety Series No. 50-SG-O6: Preparedness of the Operating Organization (Licensee) for Emergencies at Nuclear Power Plants (1982)

Δ Safety Series No. 109: Intervention Criteria in a Nuclear or Radiation Emergency (1994)

Δ Safety Series No. 98: On-Site Habitability in the Event of an Accident at a Nuclear Facility (1989)

LEGAL AND GOVERNMENTAL INFRASTRUCTURE

Δ Safety Series No. 50-C-G (Rev.1): ***Code on the Safety of Nuclear Power Plants: Governmental Organization*** (1988)

Δ Safety Series No. 50-SG-G1: Qualifications and Training of Staff of the Regulatory Body for Nuclear Power Plants (1979)

Δ Safety Series No. 50-SG-G2: Information to be Submitted in Support of Licensing Applications for Nuclear Power Plants (1979)

Δ Safety Series No. 50-SG-G3: Conduct of Regulatory Review and Assessment during the Licensing Process for Nuclear Power Plants (1979)

Δ Safety Series No. 50-SG-G4 (Rev.1): Inspection and Enforcement by the Regulatory Body for Nuclear Power Plants (1996)

Δ Safety Series No. 50-SG-G8: Licenses for Nuclear Power Plants: Content, Format and Legal Considerations (1982)

Δ Safety Series No. 50-SG-G9: Regulations and Guides for Nuclear Power Plants (1984)

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[*] Revision status as of July 2000 is indicated by the symbol Δ or ?

Δ Includes the preparatory phase of revision schedule to the final phase of waiting for the approval of the Board of Governors and the Publications Committee.

? Includes those revisions approved and waiting for publication.

Δ Safety Series No. 89: Principles for the exemption of Radiation Sources and Practices from Regulatory Control (1988)

QUALITY ASSURANCE

The following code and safety guides have been combined into Safety Series No. 50-C/SG-Q: ***Quality Assurance for Safety in Nuclear Power Plants and other Nuclear Installations: Code and Safety Guides Q1-Q14*** (1996)

- Q1: Establishing and Implementing a Quality Assurance Programme
- Q2: Non-conformance Control and Corrective Actions
- Q3: Document Control and Records
- Q4: Inspection and Testing for Acceptance
- Q5: Assessment of the Implementation of the Quality Assurance Programme
- Q6: Quality Assurance in the Procurement of Items and Services
- Q7: Quality Assurance in Manufacturing
- Q8: Quality Assurance in Research and Development
- Q9: Quality Assurance in Siting
- Q10: Quality Assurance in Design
- Q11: Quality Assurance in Construction
- Q12: Quality Assurance in Commissioning
- Q13: Quality Assurance in Operation
- Q14: Quality Assurance Decommissioning

Nuclear Safety

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Δ Safety Series No. 50-SG-O1 (Rev.1): Staffing of Nuclear Power Plants and the Recruitment, Training and Authorization of Operating Personnel (1991)

Δ Safety Series No. 50-SG-O2: In-service Inspection for Nuclear Power Plants (1980)

Δ Safety Series No. 50-SG-O3: Operational Limits and Conditions for Nuclear Power Plants (1979)

Δ Safety Series No. 50-SG-O4: Commissioning Procedures for Nuclear Power Plants (1980)

Δ Safety Series No. 50-SG-O5: Radiation Protection during Operation of Nuclear Power Plants (1983)

Δ Safety Series No. 50-SG-O7 (Rev.1): Maintenance of Nuclear Power Plants (1990)

Δ Safety Series No. 50-SG-O8 (Rev.1): Surveillance of Items Important to Safety in Nuclear Power Plants (1990)

Δ Safety Series No. 50-SG-O9: Management of Nuclear Power Plants for Safe Operation (1984)

- Safety Series No. 50-SG-O10: Core Management and Fuel Handling for Nuclear Power Plants (1985)

Δ Safety Series No. 50-SG-O11: Operational Management of Radioactive Effluents and Wastes Arising in Nuclear Power Plants (1986)

Δ Safety Series No. 50-SG-O12: Periodic Safety Review of Operational Nuclear Power Plants (1994)

Δ Safety Series No. 93: System Reporting Unusual Events in Nuclear Power Plants (1989)

- Safety Series No. 117: Operation on Spent Fuel Storage Facilities (1994)

DESIGN OF NUCLEAR POWER PLANTS

Δ Safety Series No. 50-C-D (Rev. 1): ***Code on the Safety of Nuclear Power Plants: Design*** (1988)

- Safety Series No. 50-SG-D1: Safety Functions and Component Classification for BWR, PWR, and PTR (1979)

Δ Safety Series No .50-SG-D2 (Rev.1): Fire Protection in Nuclear Power Plants (1992)

Δ Safety Series No. 50-SG-D3: Protection Systems and Related Features in Nuclear Power Plants (1980)

Δ Safety Series No. 50-SG-D4: Protection Against Internally Generated Missiles and their Secondary Effects in Nuclear Power Plants (1980)

Δ Safety Series No. 50-SG-D5 (Rev.1): External Man-Induced Events in Relation to Nuclear Power Plants Design (1996)

Δ Safety Series No. 50-SG-D6: Ultimate Heat Sink and Directly Associated Heat Transport Systems for Nuclear Power Plants (1981)

Δ Safety Series No. 50-SG-D7 (Rev.1): Emergency Power Systems at Nuclear Power Plants (1991)

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- Safety Series No. 50-SG-D9: Design Aspects of Radiation Protection for Nuclear Power Plants (1985)

Δ Safety Series No. 50-SG-D10: Fuel Handling and Storage Systems in Nuclear Power Plants (1984)

Δ Safety Series No. 50-SG-D11: General Design Safety Principles for Nuclear Power Plants (1986)

Δ Safety Series No. 50-SG-D12: Design of the Reactor Containment Systems in Nuclear Power Plants (1985)

Δ Safety Series No. 50-SG-D13: Reactor Coolant and Associated Systems in Nuclear Power Plants (1986)

Δ Safety Series No. 50-SG-D14: Design for Reactor Core Safety in Nuclear Power Plants (1986)

Δ Safety Series No. 50-SG-D15: Seismic Design and Qualification for Nuclear Power Plants (1992)

- Safety Series No. 118: Safety Assessment for Spent Fuel Storage Facilities (1994)
- Safety Series No. 116: Design of Spent Fuel Storage Facilities (1994)

SITE EVALUATION FOR NUCLEAR POWER PLANTS

Δ Safety Series No. 50-C-S (Rev.1): ***Code on the Safety of Nuclear Power Plants: Siting*** (1988)

Δ Safety Series No. 50-SG-S1 (Rev.1): Earthquakes and Associated Topics in Relation to Nuclear Power Plant Siting (1991)

Δ Safety Series No. 50-SG-S3: Atmospheric Dispersion in Nuclear Power Plant Siting (1980)

Δ Safety Series No. 50-SG-S4: Site Selection and Evaluation for Nuclear Power Plants with Respect to Population Distribution (1980)

Δ Safety Series No. 50-SG-S5: External Man-induced Events in Relation to Nuclear Power Plant Siting (1981)

Δ Safety Series No. 50-SG-S6: Hydrological Dispersion of Radioactive Material in Relation to Nuclear Power Plant Siting (1985)

Δ Safety Series No. 50-SG-S7: Nuclear Power Plant Siting: Hydrogeological Aspects (1984)

Δ Safety Series No. 50-SG-S8: Safety Aspects of the Foundations of Nuclear Power Plants (1986)

- Safety Series No. 50-SG-S9: Site Survey for Nuclear Power Plants (1984)

Δ Safety Series No. 50-SG-S10A: Design Basis Flood for Nuclear Power Plants on River Sites (1983)

Δ Safety Series No. 50-SG-S10B: Design Basis Flood for Nuclear Power Plants on Coastal Sites (1983)

Δ Safety Series No. 50-SG-S11A: Extreme Meteorological Events in Nuclear Power Plant Siting, excluding Tropical Cyclones (1981)

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Δ Safety Series No. 35-S2: ***Code on the Safety of Nuclear Research Reactors: Operation*** (1992)

- Safety Series No. 35-G1: Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report (1994)
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- Safety Series No. 78: ***Definition and Recommendations for the Convention on the Prevention of Marine Pollution by Dumping Wastes and other Matter, 1972–1986 Edition*** (1986)
- Safety Series No. 79: Design of Radioactive Waste Management Systems at Nuclear Power Plants (1986)

• Safety Series No. 108: Design and Operation of Radioactive Waste Incineration Facilities (1992)

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? Safety Series No. 111-S-1: ***Establishing a National System for Radioactive Waste Management*** (1995)
• Safety Series No. 111-G-1.1: Classification of Radioactive Waste (1994)

DISCHARGES

? Safety Series No. 77: Principles for Limiting Releases of Radioactive Effluents into the Environment (1986)

PRE-DISPOSAL

• Safety Series No. WS-G-2.1: Decommissioning of Nuclear Power Plants and Research Reactors (1999)
• Safety Series No. WS-G-2.2: Decommissioning of Medical, Industrial and Research Facilities (1999)

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• Safety Series No. WS-R-1: ***Near Surface Disposal of Radioactive Waste*** (1999)
• Safety Series No. WS-G-1.1: Safety Assessment for Near Surface Disposal of Radioactive Waste (1999)
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Annex

SMALL AND MEDIUM REACTOR USER REQUIREMENTS DOCUMENT: INDONESIA

This annex reproduces an interim formulation of the User Requirements Document on Small and Medium Power Reactors (SMRs) for Indonesia, which was prepared collectively by a specially assigned group of scientists and engineers of the National Atomic Energy Agency, while its format and skeleton conform as closely as possible to the ones recommended in Chapter II of the main report.

The SMRs cover a broad range of reactor power, up to the equivalent of 300 MW(e) which are called small and very small power reactors (SVSRs) and from 300 to 700 MW(e) which are called medium power reactors (MRs).

In its current form, this report contains the Indonesian requirements on MRs and SVSRs. Whereas sentences typed in *italic font* are meant additionally for SVSRs. This July 1998 version is the result of revisions following the IAEA Advisory Group Meeting and Consultancy Meeting on the "SMR User Requirements for Developing Countries", conducted in Vienna, June, 1998.

EXECUTIVE SUMMARY

The requirements of the SMRs shall be based on evolutionary improvements in the safety and technology of the system in order to reach wider acceptance by the public, better performance, better economics and better protection for investors.

The main requirements from technology aspects for a country embarking on first NPPs are constructibility, operability and maintainability. These points are closely linked with the reliability and economy of the SMRs. Appropriate design measures, advanced construction methods, comprehensive schedules and improved construction management methods should be implemented. Construction time starting from the first concrete until commercial operation should be limited to 60 months.

Designs should feature engineering advancement, simplification and new improved materials which are more durable, non-corrosive, non-erosive with minimal system radioactive contamination. The MR plant shall be designed for 60 year lifetime, and the SVSRs for at least 40 year lifetime, and 30 years in case of the SVSR's deployment is less than 20 years. Fuel elements shall be designed with increased thermal margin and strength with high burnup capability.

In the safety, implementation of defense in depth principle for systems and procedures and application of quality assurance program in all steps of the activities shall be enforced and enhanced consistently and effectively with special attention on pressure retaining boundaries. From probabilistic point of view, beyond design basis accidents shall be evaluated and taken into account in the design. The core safety margin shall be increased significantly. The core damage frequency without release to the environment should be less than 1×10^{-5} per reactor year and it should be less than 1×10^{-6} per reactor year with minor release to the environment. The dose at site boundary should be less than 0.25 Sv for accidents with more than 1×10^{-6} per year cumulative frequency. Various design approaches should enable simplification of off-site emergency plan.

Specifically, improved, reliable long term residual heat removal system and strengthened containment structure to mitigate further the consequences of severe accident and to eliminate the apprehension of the public on the safety of the SMRs are required. Lastly it is absolutely requisite that SMRs to be imported should be licensable in the vendor's country.

In radiological and environmental safety, the main objectives are to reduce further the collective radiation dose to the plant personnel and minimise chemical and radioactive releases to below ICRP-60 guidelines during operational as well as accident conditions. The objectives point to the applications of improved radiation protection technology, advanced materials and enhanced compliance of personnel to radiation safety rule. The production of radioactive wastes shall be minimised and the emission to the environment should be further reduced. These would suggest to the implementation of advanced materials, process technology and water chemistry in the process system and radioactive waste management plus the function of the final bulwark that is the improved containment.

The radiological and environmental performance targets are formulated as: occupational radiation exposure should be less than 1 man Sv per reactor year and whole body dose of 0.25 Sv at the site boundary for severe accidents with cumulative frequency greater than $1 \mathrm{x} 10^{-6}$ per year.

Operability of the plant means an operation with less burden on operators and better manoeuvrability. This suggests an advanced I&C which is ergonomic and with more automation, is forgiving and forms an operational aid to the operators. Maintainability means that the plant should provide easier means to perform preventive and operational maintenance, with available space and devices to carry out replacement of main components and possible overhaul for life extension purposes.

In the performance, high plant availability and capacity factors are required. Both are primarily linked with plant economy and related to the maturity of the technology discussed earlier. Availability means reliability and absence of operational problems with attendant possible safety implications.

The performance targets are:

– Availability factor	➢ more than 90%
– Capacity factor	➢ more than 80% (lifetime)
– Refuelling cycle	➢ 18–24 months, or more (SVSRs)
– Unplanned automatic scrams	➢ less than 1 per year (lifetime)

The targets set for the technology and plant performance requirements discussed above have direct influence on the NPP's economy. The economic target can be simply stated as: the levelled cost of electricity from nuclear plants should be lower than from coal plant with cleanup system based on prevailing national regulation. Factors that have strong influence on the economy, notably: capital costs, construction time, capacity factor, and O&M costs should be well managed in order to achieve the economic target.

For the deployment at remote areas or at the less developed regions the economic criteria for the nuclear alternative are expected to be :

- the largest social gain,
- the least government subsidy;
- smaller than the cost to upgrade the infrastructure; and
- transportation means in order to remove the "remoteness" qualification.

Human resource development for the design, construction, installation and safe operation of the NPPs should be inseparable from the package in the procurement of the NPPs. Education and training for sufficient number of personnel should be given until they are qualified. They should be specialised in operational safety and regulatory aspects of the SMRs, project engineering and management, operations and operation management. In short, it is not only technical skills but also managerial skills should be specially taught to the plant personnel.

1. INTRODUCTION

The purpose of the user requirement document is to present a clear statement of the upcoming user desires for their small and medium reactors (SMRs). The anticipated uses of the document are the following:

- Establish a regulatory basis for upcoming SMRs which includes the regulatory body's agreement on licensing issues and severe accident issues, and which provides high assurance of licensibility,
- Provide a set of design requirements for a standardized plant which are reflected in individual reactor and plant supplier certification designs, and
- Provide a set of technical requirements which are suitable for use in a SMR 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 SMR are minimal.

The user requirement document concisely covers the entire plant up to the grid *(or distribution)* interface. It therefore is the basis for an integrated plant design, i.e. nuclear steam supply system and balance of plant, and it emphasises those areas which are most important to the objective of achieving a SMR which shall be excellent with respect to safety, performance, constructibility, maintainability and economics. The document applies to pressurised water reactors, boiling water reactors and pressurised heavy water reactors, *and high temperature gas cooled reactor.*

2. NUCLEAR ENERGY PROGRAM

2.1. Role of nuclear energy

In the second long term development plan (PJP-II, 1993–2018), energy demand was projected to increase very rapidly. In order to meet rapid increase of the domestic energy demand, it is becoming more difficult to depend on the existing resources which are now getting more limited. The selection of alternatives of energy supply shall be deliberated from various aspects including ones of energy availability and security, technology, safety, social economic and environmental aspects.

The feasibility study for the first nuclear power plant in Indonesia shows that the generation cost of the 600 and 900 MW(e) class nuclear units are competitive to the coal units of similar capacities using de-SOx and de-NOx equipment. The electric system analyses on the Jawa-Bali electric system shows that the introduction of nuclear power units in the early 2000s represents optimal solutions. Into the year 2019 the role of nuclear power in the Jawa-Bali system could provide 10 % of the installed capacity.

Other applications of nuclear power are also foreseen, e.g. to solve fresh water and power demand in remote and isolated areas, by small or very small-size reactors, on possible cogeneration mode, land based or floating. But site related requirements for each deployment could differ from one case to another, since candidate remote areas in Indonesia are so dissimilar that it can hardly be generalised.

2.2. Role of SMR in the national industrial development plan

At the time Indonesia entered the long term development plan (PJP-II), most parts of the world are preparing themselves toward free market economy in a globalisation era. By involving in the free market activities, international market is open for Indonesian product commodities. On the other hand domestic market is also more and more exposed to foreign products as well. The competitiveness of marketable domestic products, therefore, and the increase of non-oil/gas export are becoming more and more important, which is what the national industrial development is being aimed for.

These objectives in the industrial plan cannot be achieved without reliably increased supply of energy component, in particular, electricity. Therefore the government has adopted the policy of promoting development of energy sources and production in a way which maximises economic efficiency, and provides regional development and employment opportunities.

Entering the second phase of the PJP-II an approach was taken based on the fact that most of Indonesian energy resources are non-renewable and reserves are limited. Thereby the three policy measures adopted are diversification along with intensification and conservation. The introduction of NPP in Indonesia is not only to reach an optimal energy mix (for Jawa-Bali electricity grid) based on costs and environmental protection, but also to relieve the pressure arising from increasing domestic demand for oil and gas.

In the national industrial plan, several of industrial centres are being developed throughout Indonesia. The industrial centres located on the Jawa island are able to rely on the available infrastructure for energy supply by the Jawa-Bali electricity grid, and those on the big islands, such as Kalimantan and Sumatra are able to rely on the primary energy sources (oil, gas, or coal), which are indigenous on their island. *But those industrial centres, located more distantly from the energy sources would have to rely on the energy transported and delivered reliably to their remote locations.*

A medium-size reactor power plant which requires huge amount of initial capital, in fact, turns out to create more jobs during construction and operation, as well as giving beneficial industrial spin-offs due to the sophisticated technology it is based on. These MRs would be very much suitable for contributing to the supply of electricity to the industrial centres on the Jawa island which has large logistics ports as well as large integrated electricity grid.

Whereas smaller size nuclear plants could be deployed in the remote industrial centres where reliable transportation means for energy supply are expensive. This includes possible application for providing high temperature heat for methanol plants on the Natuna island and/or cogeneration for providing electricity and potable water in remote areas, or other process heat for industries.

2.3. Additional considerations

Certain prerequisites on a national basis concerning adherence to specific international treaties, legal obligations and conventions have been met, e.g.:

- Treaty on the Non-Proliferation of Nuclear Weapons (NPT) of July 1, 1968 ratified by the Act no. 8/1978 on December 18, 1978,

- Convention on Early Notification of a Nuclear Accident, September 26, 1986, ratified by the President Decree no. 81/1993 on September 1, 1993,
- Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency, September 26, 1986, ratified by the President Degree no. 82/1993 on September 1, 1993,
- Convention on Physical Protection of Nuclear Material, July 3, 1986, ratified by the President Decree no. 49/1986 on September 24, 1986,
- Treaty on the Southeast Asia Nuclear Free Zone, December 15, 1995, ratified by the Act no. 9/1997 on April 2, 1997,
- Convention on Nuclear Safety, signed on September 24, 1994,
- Convention on Supplementary Compensation for Nuclear Damage, signed on October 6, 1997,
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, signed on October 6, 1997,
- Protocol to Amend Vienna Convention, signed on October 6, 1999, and
- Agreement between the Republic of Indonesia and IAEA on the Application of Safeguards in the Republic of Indonesia of July 14, 1980. INFCIRC/283.

3. SITE IMPOSED REQUIREMENTS

3.1. Site condition

The SMR plant shall be designed and optimised taking into account the main site and environment data. The plant shall be constructed at a selected site having technical characteristics fall within the requirements stipulated, at a minimum, in IAEA technical documents for NPP siting. Hazards from any single external event or combination of selected external events which might occur in the region should not go beyond the manageable level, threaten the structural integrity, and hamper the normal operation of the plant.

One of the best candidate site selected for the medium reactors (MRs), based on the assessment study up to the writing of this document, is on the North coast of the Muria peninsula, tentatively at Ujung Lemahabang. The size of this tentatively preferred site is approximately 3 Km length in East–West direction and 2 Km wide in North–South direction. Elevated land in a height of about 10 m is well developed at the coast continued by gentle hilly slope behind it. The depth of moderately harder layer lies about 12 m below Mean Sea Level. Ultimately the site is intended to host eight to twelve units with total capacity of 7000 MW(e).

The design basis parameters of the plant shall fall within the parameter envelope listed in the table below.

Bearing capacity	kg/cm^2	≥ 7.5
Shear wave velocity	m/sec	≥ 300
Flood level	m	≥ 0.3 below finish grade
Peak ground acceleration	gal	≤ 400
Volcanic ash	cm	≤ 20
Max. ambient temperature	^{o}C	36

The site for stationary SMRs shall be selected so that it is free from surface faulting, pyroclastic flow and lava flow.

3.1.1. Seismic/hydrology/meteorology

Ujung Lemahabang site lies on volcanic and sedimentary rocks of Pleistocene. Site geology mainly consists of four zones: soil zone, upper tuff zone, middle sandstone zone and lower tuff zone. The mean value of unconfined compressive strength of each rock type/class of the bedrock varies between 16 kgf/cm^2 and 62 kgf/cm^2. There exist some possible faults around the site including offshore area. Among the historical earthquakes, Pati earthquake, which occurred in 1890 and with estimated magnitude of 6.8, had the most severe effect to the site.

Remote areas in the Eastern part of Indonesia are located in the potentially high levels of seismic intensities since this part of Indonesia represents the junctions of the Indian-Australian, Eurasian, Philippine Sea and Caroline plates. Troughs and trenches as well as series of volcanoes are located. Therefore specific seismic occurrences (tectonic, volcanic and tsunami) out of these areas shall be thoroughly investigated and requirements specifically determined.

3.1.2. Cooling water availability and temperature

The seawater temperature (at Muria Peninsula *and presumably for remote areas*) in both dry and rainy seasons ranges approximately from 28^{o}C to 30^{o}C. The vertical distribution of the temperature is almost uniform in both seasons. The design seawater temperature for main condenser shall be 29.5^{o}C. The design ambient air temperature for ventilation and air conditioning system shall be 33^{o}C.

The seawater (at Muria peninsula) is muddy, the seabed is so flat that 9m depth is located about 1500 m off the shoreline. The maximum wave height observed in the period from May 1992 to July 1995 is 4.85 m.

3.2. External events

3.2.1. Natural disasters

The plant design shall consider the probability of natural disasters in the region such as earthquakes, flooding (river and coastal flood), tsunami and typhoon. Since the site of the plant is on the seashore, it is necessary to estimate the largest tidal wave, tsunami or hurricane driven waves that may be incident on the site.

Reactor structures shall be designed not only against direct forces of the wind associated pressure drop, but also to withstand the impact of objects carried by and hurled against them.

Among the historical earthquakes at the Muria Peninsula, Pati earthquake is supposed to have affected the site most. Its maximum acceleration was estimated to be 143 gal according to the magnitude method, and 127 gal according to the intensity method. Possible river flood: none. Coastal flooding by tsunami: effect is small (0.42 m wave on the coast), with magnitude of -1, inferring no damage.

Special attention shall be given to the assurance of the availability of ultimate heat sink in the case of volcano eruption and sabotage.

3.2.2. Man-made hazards

The plant integrity must be assured for any man-induced events that might occur due to activities (including sabotage) near the site.

3.3. Site infrastructure

The planning for site preparation and construction activities shall consider the development of infrastructure:

- considerably long connection to existing 500 kV transmission line,
- improvement and widening of access roads and local port, and
- no large fresh water source and very distant from potable water distribution.

3.4. Allowable radioactivity release

The allowable limits for the radioactive release of gas and liquid shall comply with the current recommendation of ICRP and the related regulation of the government of the Republic of Indonesia.

The plant, *including the nuclear desalination plant,* shall comply with the technical requirements, especially safety design requirements (5.1) and plant design requirement (5.3), so that its impacts to its surrounding environment and the general public can be minimised. The radiological release from the plant shall be lower, complying with the ALARA (as low as reasonably achievable) principle. The radioactive release of gas and liquid shall meet the allowable limits as those recommended by the ICRP (such as ICRP Recommendation no. 26/1977, ICRP Recommendation no. 60/1990, etc.). It shall also meet the act of the Republic of Indonesia, Act no. 23/1997 concerning the environment management, the government regulation of the Republic of Indonesia no. 19/1994 concerning the management of dangerous and toxic material.

3.5. Emergency preparedness

The tentative site (for MRs) is a cacao and coconut plantation area, belonging to a government plantation enterprise. The nearest village is Balong which is located 3 Km South-East of the site. Within 5 Km radius, however, the area is densely populated (473 people per km^2).

The selected site (for MRs) shall be large enough to accommodate an exclusion area of 1 Km radius from the reactor building as part of design measures for emergency preparedness plan. For the first total capacity of up to 7000 MW(e), the exact site permitting the inclusion of the above requirements for the SMR construction shall be determined in the Muria peninsular region.

The location of the SVSRs may be in-land near the coast or floating on the sea near the coast. Beyond 800 meters distance from the reactor building no emergency planning for evacuation is needed. For high temperature gas cooled reactors the 800 meter distance shall be reduced to 425 m.

4. LICENSING REQUIREMENTS

The plant shall be licensed by the national regulatory authority before being established and applied in Indonesia. To meet such requirement, the licensee should submit the application for licensing to the regulatory authority of Indonesia. The application should be supported by documents, such as safety analysis documents, environmental monitoring reports and other related documents. This procedure is meant to ensure the health and safety of the general public, nuclear workers and the environment against possible adverse effects arising from the activities associated with nuclear power.

The licensee shall assure that the public health and the surrounding environment will not be negatively affected during the construction, the operation and the decommissioning of the plant.

To ensure the health of general public and to protect the environment against the possible effects arising from the application of nuclear power to the desalination process, the nuclear desalination plant should comply with the national regulations concerning the nuclear licensing procedures. The plant should be licensed before being established and applied in Indonesia. To obtain the license for establishing the plant, the licensee shall submit the application to the national regulatory authority, supported by documents such as safety analysis reports, environmental monitoring reports and any other related documents. The licensee shall assure that the public health and the surrounding environment will not be negatively affected during the construction, the operation and the decommissioning of the plant.

4.1. National regulations

Indonesia is applying primarily its own national rules and regulations. In the absence of any specific regulations, the relevant IAEA guidelines and technical documents as well as those compatible with codes and standards from vendor's country of origin shall be applied.

The highest rule in the nuclear field is the Act No. 10 of 1997 on Nuclear Energy, which will be ensured by government regulations, president decrees and more detailed regulations in the form of decrees of the Director General of BATAN. These regulations will cover site permit, construction permit, commissioning and operating license, and also the assurance of the plant decommissioning.

The design certification and the combined license, the so called one step licensing which is promoted in the US for advanced light water reactor, may be implemented in Indonesian licensing procedures. In this case, the regulatory body will carry out confirmation or re-evaluation of the certified plant design.

The establishment of the SMRs shall conform to the rules and regulations on nuclear energy application such as the Act no. 10/1997, the rules and regulations on environment protection such as the Act no. 23/1997 concerning the environment management, the government regulation of the Republic of Indonesia no. 19/1994 concerning the management of dangerous and toxic material.

Coupling the nuclear power in the desalination plant may induce a possibility of contamination of product water. Therefore, the implications should be assessed by deterministic and probabilistic safety analysis with special emphasis on the possibility of contamination. The assessment should be incorporated into the preliminary, the final and other safety analysis reports of the desalination plant. The environmental impacts shall also be taken into consideration in designing the plant. The assessment documents/reports should embrace all safety and environmental aspects for all planning stages (design, siting, construction, operation and decommissioning stages). To ensure the protection of the product water against radioactive contamination, all technical requirements mentioned later in section 5 should be met.

4.2. Licensability in the country of origin

In the Atomic Energy Act mentioned above, there is no specific difference in the licensing steps for large, medium, small and very small-sized nuclear power plants. The adoption of passive safety concept, non-active components, and other improvement of engineered safety features will be taken into consideration in making possible simplification of the licensing process.

The SMRs *including the nuclear desalination plant* shall be licensable in the country of origin. Furthermore, to simplify the licensing process in Indonesia, adoption of passive safety concept, non-active components, and other improvement of engineered safety features should be taken into consideration as much as possible in designing the plant.

4.3. International guidelines and technical documents

As a basis for formulating national regulations, policies and procedures, IAEA Safety Guides and related technical documents may be used. The planned plants should, therefore, be designed consistent with the IAEA documents including the NUSS Series No. 50-SG collection, as well as "Basic Safety Principles for Nuclear Power Plants, Safety Series No. 75-INSAG-12, such as:

(a) The Safety of Nuclear Installations: A Safety Fundamental, Safety Series No. 110, IAEA, Vienna (1993),
(b) Basic Safety Principles for Nuclear Power Plants, Safety Series No. 75-INSAG-12, IAEA, Vienna (1999),
(c) Safety Culture: A Safety Report, Safety Series No. 75-INSAG-4, IAEA, Vienna (1991),
(d) The Safety of Nuclear Power, Safety Series No. 75-INSAG-5, IAEA, Vienna (1992),
(e) Probabilistic Safety Assessment: A Safety Report, Safety Series No. 75-INSAG-6, IAEA, Vienna (1992).

5. TECHNICAL REQUIREMENTS

5.1. Safety requirements

Some considerations in the reactor safety are:

- Application of defense-in-depth concept,
- Enhancement of inherent reactor safety,
- Accident resistance:
  - (i) assuring the stability of the reactor core;
  - (ii) assuring the core coolability; and
  - (iii) assuring the confinement of radioactive products,
- Mitigation systems, and
- Consideration to determine the sequences for which reasonably practicable preventive or mitigative measures shall be given to the severe accidents.

The safety system design shall be aimed to simplify and maximise the use of passive systems in order to increase the reliability and availability. The safety targets are:

- severe core damage frequency: $< 1 \times 10^{-5}$ /r.y,
- the dose at site boundary shall be less than 25 rem (0.25 Sv) for accident with more than 1×10^{-6} per year cumulative frequency, and
- grace period: 72 hours for DBA and several hours for beyond DBA (only for passive SMRs).

5.1.1 Accident resistance

Design safety features shall prevent core degradation by keeping the core submerged in water at all time and assure that the heat production in the core shall not exceed the cooling capability, and shall prevent initiating event from progressing to the point of core damage and severe core damage.

Accident management augments design features to prevent degradation of an accident to severe accident conditions, and to mitigate accidents if they occur. Emergency planning shall be simplified and effective to prevent the radioactive release to the environment. The design shall aim at reduction of exclusion areas, and of built-in counter measures.

Accident resistance qualifies that design features minimise the occurrence and severity of initiating events, such as:

- Fuel thermal margin equal or higher than 15 %,
- Slower plant response to upset conditions through features such as increased coolant inventory, and
- Use of best available materials.

5.1.2. Core damage prevention and mitigation

In preventing the core damage the design shall assure that initiating events do not progress to the point of core damage. By probabilistic risk assessment (PRA) core damage frequency of less than 1×10^{-5} event per reactor year shall be demonstrated. During a LOCA of a small diameter pipe break, no fuel melting shall occur. The corium shall be retained in the pressure vessel, in case of fuel melting.

The containment design and its contribution to accident mitigation shall be carefully considered and evaluated in the design process, with particular attention to those severe accidents addressed in the design. For severe accident addressed in the design, the containment shall be sufficient to meet safety and radiological objectives. This includes both preservation of containment integrity function and leak tightness. Containment design shall be sufficient to maintain containment integrity and low leakage during severe accident, and withstand mechanical and thermal loads arising from internal accidents.

Severe accident phenomena and challenges to be considered and addressed (prevented and mitigated) in the design of water reactors are:

- high pressure melt ejection and direct containment heating,
- hydrogen production and combustion in the reactor pressure vessel,
- steam explosions in the reactor pressure vessel and the containment,
- core-concrete interaction in the containment, and
- containment bypass and loss of long term heat removal.

In gas cooled reactors should be addressed:

- water ingress into the core,
- air ingress accident of the primary pipe, and
- the stand pipe rupture accidents.

Depending on the design, phenomena related to such processes as reactivity transients, recriticality events, or missile generation may also be addressed.

Provisions to mitigate such accidents shall be furnished in accordance with the latest requirements for operating plants in the Vendor's home country. Accident management manuals shall be provided as part of the plant documentation. However, the mean annual core damage frequency of the plant, evaluated using PRA, shall be less than 1×10^{-5} events/reactor year. The whole body dose at the site boundary shall be less than 0.25 Sv for releases from severe accidents, the cumulative frequency of which exceeds 1×10^{-6} /year. Containment systems shall be designed so that above exposure limits can be met.

In order to have a reactor shutdown system with high reliability and to have a sufficient capacity of pressure control components to mitigate the pressure transient, ATWS mitigation system is required. All station blackout duration for 8 hours shall be considered. Grace time for operator intervention following accidents shall be determined in accordance with either IAEA requirements or the requirements of the Vendor's home country. It is highly desirable the grace period is of at least 30 minutes.

Design basis external events shall be decided from the site data information. Potential Vendors shall submit supporting data including assumption used for decision of proposed design conditions.

5.1.3. Passive safety

Station blackout coping time for core cooling shall be 8 hours minimum, but indefinite for passive MRs. The limits on no core protection in passive MRs shall exceed 72 hours, assuming no operator action for licensing design basis events including loss of all ac power.

5.1.4. Radiation protection

The plant shall be designed and constructed so that occupational radiation exposure is less than 1 man Sv/reactor year. The objectives are to reduce further the collective radiation dose to the plant personnel and minimise chemical and radioactive releases to below ICRP-60 guidelines during operational as well as accident conditions. The objectives point to the applications of improved radiation protection technology, advanced materials and enhanced compliance of personnel to radiation safety rule. Results in the reference plant and measures to achieve this objective shall be provided.

5.1.5. Good neighbour policy

The plant shall be designed to be a good neighbour to its surrounding environment and population by minimising radioactive and chemical releases to acceptable levels.

Release rates for normal operation and incidents, "utility limits and targets" are judged to be appropriate to take into account national and international requirements and should be aimed for as part of implementing the ALARA concept. Release targets for severe accidents are referred to as "limiting release". The limiting release value is intended to be so low that the societal consequences resulting from public health effects and contamination of soil and water will be limited. It is anticipated that realization of this target imply:

- no emergency protection action beyond 1 km from the reactor during early releases from the containment,
- no delayed action (temporary transfer of people) at any time beyond about 3 km from the reactor, and
- no long term actions, involving permanent (longer than 1 year) resettlement of the public, at any distance beyond 1 km from the reactor.

Technical basis for simplification of off-site emergency plan shall be provided. Essentially no evacuation outside 1 km-radius (for MRs) shall be required.

In addition, it is stipulated that restriction on the consumption of foodstuff and crops shall be limited in terms of time scale and ground area.

5.1.6. Protection against sabotage

The plant shall be designed to have a good sabotage protection using the principle of physical protection by considering the effects of fires, chemical explosions, aircraft crashes and missiles. The building and site layout shall assure isolation from the surroundings with rigorous controlled access, and supervision to guard against unauthorised persons and goods.

5.2. Performance requirements

5.2.1. Applications

The first medium reactor units shall be conceived and mainly operated as base load units continuously supplying power to the grid at, or close to, its rated power. Minimum number of cycling and transient over the design life for which the plant shall be designed is specified as follows:

– Start up and shutdown cycles between cold condition and rated output	-180
– Unit loading and unloading between technical minimum output and rate output	-18,000
– Step load increase and decrease of 10% of rated output	-600
– Step load decrease of 50% of rated output	-60

As for operating capability following failures of an auxiliary equipment, basically the loss of an auxiliary equipment shall not affect the operation of the plant at rated power. Reduced power operation at 65% of rated output is acceptable after a loss of certain equipment item such as the following:

- Loss of a train of LP or HP feedwater heaters,
- Loss of a feedwater pump,
- Loss of circulating water pump, and
- Loss of a recirculation pump (BWR).

The consecutive MR units, however, shall be designed for a 24 hour cycle with the following cycle profile: starting at 100% power, power ramps down to 50% in 2 hours, power remains at 50% level for 2–10 hours, and then up to 100% in 2 hours. The plant design shall permit this cyclic load for 90% of the days of each fuel cycle during the plant life.

Dual purpose SVSR plant for electricity and process heat will be preferred. Requirements for electricity production capability shall comply the above mentioned load following and cyclic daily load conditions.

Heat output from the reactor shall be appropriate for the high temperature process, such as: metal industries, coal gasification, coal liquefaction, hydrogen production, CO_2 + CH_4 *conversion, and other related process, or for low temperature processes, such as : sea water desalination and other low-enthalpy process industries.*

5.2.2. Interface

Specially for dual purpose SVSRs, the interface shall have sufficient flexibility to accommodate local/domestic modification of the non-nuclear (industrial production) part of the plant. The design features shall show both improvement in safety and economic aspects.

5.2.3. Availability and reliability

The plant shall be designed so that a refuelling outage free from major problems can be conducted in 17 days or less (breaker to breaker) assuming 24-hour productive days.

The plant shall be designed to limit the number of unplanned automatic trips to be less than one per year. In response to this requirement, the plant shall utilize a minimum number of plant variables for reactor trips signals consistent with plant safety variables so that the number of plant trips resulting from normal operation activities is minimised.

The plant shall be designed to achieve a high availability during its operational lifetime. The main requirements are:

- high overall availability of the plant capacity factor, greater than 90%,
- short planned outage duration (for one-year up to two-year core cycles: average refuelling and maintenance outage shorter than 25 days per year, refuelling only outage possible in less than 17 days, major plant outage shorter than 180 days per 10 years),
- a low level of unplanned outages (unplanned automatic scrams less than 1 per 7000 hours critical, unplanned capability loss factor less than 1.4),
- capacity factor shall achieve not less than 80% (lifetime), not less than 24-month capability, and
- forced outages: less than 5 days/year.

The plant shall be able to operate and to be maintained such that occupational radiation exposure of less than 1 person Sv per year is observed.

5.2.4. Design lifetime

In recognition of the large investment, the plant shall be designed for as long a life as technically and economically feasible. Attention shall be given in the design to the choice of materials and operating conditions for the intended service. Where necessary, provisions shall be made for component inspection, component replacement and possible upgrading in order to assure the long life capability. Operation of the plant shall include a well documented plant history so that fatigue and neutron embrittlement effects can be assessed.

The design life of plant structures and non-replaceable components such as the RPV shall be 60 years. In case of shorter designed operating life (less than 30 years) of the SVSRs, structures and non-replaceable components shall be designed more than 40 years.

5.2.5. Manoeuvrability

The plant shall have the following capabilities:

- The plant shall have automatic power control capability with an output of 15% or more of rated output,
- The plant and in particular the control circuit shall be designed in such a way that normal load changes of the grid can be followed,

- Generator load rejection and isolation from the grid, with reduction of the generator load to the output required to power only the unit auxiliaries, shall be possible from any power level. This shall apply in particular for load rejection from rated output,
- Operation of the plant providing house load (only to the unit auxiliaries) shall be possible for a period of several days. Subsequent increase in power up to rated output shall be possible with the maximum rate of load change,
- The plant shall be able to provide a minimum load change response of ± 5 % of rated output per minute at 65% or more of the rated output and a step load change of ± 10% of the output to the grid for at least 90% of the duration of the cycle, and
- The fast closure of turbine stop valves shall initiate the operation of the turbine bypass system and the subsequent controlled reduction of the reactor power.

5.2.6. Assessment methodology

Methodology of performance assessment which has been implemented in the design process of the plant shall be presented by the Vendor.

5.3. Plant design requirements

Proven technology shall be employed throughout the design in order to minimise investment risk to the plant owner, control costs, take advantage of existing operating experience, and assure that a plant prototype is not required; proven technology is that which has been successfully and clearly demonstrated in SMRs or other applicable industries such as fossil power and process industries.

The design philosophy is to implement simple, rugged, high design margin, based on proven technology; no power plant prototype required.

Design integration requirements call for the management and execution of design as a single, integrated process. Configuration management requirements call for comprehensive system to control plant design basis and installed equipment and structures. Whereas information management require computerised system to generate and utilize an integrated plant information management system during design, construction and operation.

5.3.1. Design simplicity

Simplification shall be assessed primarily from the standpoint of minimising the amount of equipment and the plant operator, e.g. reducing the demands on the operating staff during normal operation and under off-normal conditions, providing simple logic and unambiguous indications at all times to perform particular functions. Design margins which go beyond regulatory requirements are not to be traded off or eroded for regulatory purposes.

5.3.2. Design margins

The plant shall be capable of operating on a fuel cycle with a refuelling interval of 24 months. BWR peak bundle average burnup should reach 50 000 MWd/TU, for PWR the value should be 60 000 MWd/TU and for HTR the value in average should be 80 000 MWd/TU.

For the CANDU first core loading, the guaranteed fuel assembly burnup is 7000 MWd/TU, for the reload batches 7000 MWd/TU.

For the SVSRs deployed on the remote areas the burnup shall be sufficiently high to support the length of production cycles which are at least 24 months, preferably more than 36 months.

The premature failure rate due to manufacturing defects for ALWR fuels shall be less than one in 50 000 fuel rods.

5.3.3. Human factors and man–machine interface

The plant shall be designed with increased consideration given to human factors so as to enable easy operation of the plant from the control room(s). The goal shall be to minimise both the opportunity and potential for human error by providing a high degree of automation adapted for each situation and by providing well organized displays, controls and operator manuals.

Operability of the plant means an operation with less burden on operators and better manoeuvrability. This suggests an advanced instrumentation and control (I&C) which is ergonomic and with more automation, is forgiving and forms an operational aid to the operators.

The instrumentation and control system and the reactor protection system shall be designed so as to minimise the need for operator intervention. Advantage shall be taken of advances in electronic and information processing technology such as microprocessors, video displays, multiplexing, fiber optics, etc. and in the use of artificial intelligence techniques.

Improved diagnostics systems incorporating self-testing and automatic failure indication are available technology and shall be given proper consideration. The man–machine interfaces throughout the plant shall serve to minimise operation and maintenance errors that could influence safety.

Operation simplicity requires that a single operator be able to control a power unit during normal power operation. The control stations shall be human-engineered to enhance operator effectiveness, utilising mockups, dynamic simulation, and operator input to design.

The man–machine interface (MMI) shall be designed according to accepted ergonomic and ergometric principles and be adaptable to the anthropometry of Indonesian operators.

5.3.4. Standardization

The SMR requirements shall form the technical foundation which leads the way to standardized, certified plant designs.

A well defined standardization concept shall ensure that the components can be interchanged and that the number of different types of components is reasonably limited. The requirements for standardization of equipment shall be taken into account during planning, manufacture, construction, erection and commissioning of the plant. The standardization requirement will not apply where diverse components are necessary due to safety reasons (common mode failure).

5.3.5. Proven technology

The plant shall be designed using materials, components and systems whose required capability for services intended are based, as much as possible, on proven performance under closely similar conditions in presently operating plants. If other than such conditions are intended in the advanced nuclear plant, the capability shall be shown to be satisfactory, if possible, by being within a range of conditions that can be interpolated from the proven technology.

If materials, components or systems are intended for service under conditions which are beyond the range of proven capability or are new in terms of intended application, then such materials, components and systems shall be subjected to thorough testing under conditions that permit interpolation or minor extrapolation to those of intended service prior to their use in the plant.

Only plants of proven design are required for the first Indonesian NPP units. A reference plant shall be identified, which is already in satisfactory operation, and have the same basic design characteristics as the proposed plant on the following items important for safety and reliability:

- nuclear and thermal-hydraulic design of the reactor core,
- primary circuit components design, and
- system design of the NSSS (safety and I&C of safety systems).

The reference plant shall have operated for a period of four years after taking over of the plant. The cumulative availability factor of the plant shall be 75 % or more. And the average number of reactor trips of the plant shall be less than 2 times per calendar year.

5.3.6. Constructibility

The SMR construction schedule shall be substantially improved over existing plants and must provide a basis for investor confidence through use of design-for-construction approach, and completed engineering prior to initiation of construction.

Total time from owner commitment to construct to commercial operation: plant shall be designed for less than or equal to 60 months. Construction time from first structural concrete to commercial operation: plant shall be designed for less than or equal to 42 months.

Design status at time of initiation of construction: 90 % complete. Design and plan for construction: design for simplicity, modularization, and adequate space to facilitate construction plan through plant owner acceptance.

In order to reduce construction time, pre-assembled manufactured units or modularization shall be considered. It shall not, however, preclude entirely the local participation.

5.3.7. Maintainability

Maintainability points that the plant shall provide easier means to perform preventive and operational maintenance, the available space, ready access, and devices to carry out replacement of main components and possible overhaul for life extension purposes. Maintainability features designed into plant shall include standardization of components, equipment design for minimal maintenance needs, provision of adequate access, and improved working conditions.

The plant shall be designed for ease of maintenance, reduction of occupational exposure, and facilitation of repair and replacement of equipment, including the replacement of steam generators.

5.3.8. Quality management

The responsibility for high quality design and construction work rests with the line management and personnel of the plant designer and plant constructor organizations.

The quality assurance and quality control requirements related to safety and related to operational reliability should follow the IAEA recommendations, particularly the NUSS Series No. 50-C-QA and 50-SG-QA documents.

5.3.9. Codes and standards

Codes and standards which are used for the design, manufacture and testing of all equipment are those pertinent in the vendor's country or those of internationally accepted ones. In case pertinent Indonesian codes and standards are available, the Indonesian ones prevail. Parallel use of different codes for one particular item or component is not acceptable.

5.3.10. Decommissioning

Decommissioning of the plant shall be taken into account in the design, so that decommissioning and removal of contaminated or activated plant parts can be carried out in such a manner that the radiation exposure of the personnel and radioactive releases to the environment can be kept at an acceptable level. A decommissioning plan shall be developed as part of preliminary design, addressing all elements to enable estimation of the expected methods and procedures for this phase of the plant and associated costs.

5.3.11. Investment protection

The design shall provide inherent resistance to sabotage protection through plant security and through plant integration of plant arrangements and system configuration with plant security design.

Severe accident frequency and consequence: demonstrate by PRA that the whole body dose is less than 0.25 Sv at the site boundary for severe accidents with cumulative frequency greater than 1×10^{-6} per year.

Severe accident risks shall be evaluated in a PRA and the cumulative frequency shall be less than 1×10^{-6} per year.

Containment shall be based on large, rugged containment design being sufficient to maintain containment integrity and low leakage during a severe accident.

With respect to the potential consequences of hydrogen accumulation in the primary containment following a severe accident, it is required that the effect of global adiabatic deflagration of 10% dry concentration of H_2 shall be considered. The assumed total amount of H_2 shall be equivalent to that generated by oxidation of 100% of active fuel cladding.

The containment system shall comprise a primary containment designed to withstand the mechanical and thermal loads arising from internal accidents, including severe accidents involving core damage, and to confine the radioactivity released during accidents as a leak tight structure (including also the penetrations), and a secondary containment designed to collect part or all of any releases from the primary containment.

High pressure melt ejection events (and consequently direct heating of containment) shall be eliminated by reactor coolant depressurization system, and containment shall include measures to decrease pressure to 50% of peak value in 24 hours after accident.

Licensing source term shall be of similar in concept to existing US Regulatory Guide, TID 14844 approach, but with more technically correct release fractions, release timing, and chemical form.

6. FUEL CYCLE AND WASTE MANAGEMENT REQUIREMENTS

6.1. Fuel design

The fuel should be qualified for the intended service. Qualification of the fuel should be based on proven performance under closely similar conditions as for the intended service in presently operating plants. If other than such conditions are intended, the fuel should be subjected to thorough testing under the conditions intended prior to insertion into the core.

In considerations related to fuel cycle flexibility for plants using off-power refuelling, the refuelling scheme, the refuelling interval and the length of time for refuelling shall be optimal on both a technical and economical basis. To enhance the capability of achieving a high availability factor, consideration shall also be given, when optimising the refuelling interval, to inspection and maintenance interval for major equipment which could coincide with the refuelling interval.

For both off-power and on-power refuelling, and particularly for the latter, thoroughly tested and reliable refuelling equipment shall be assured.

Fuel assembly operating requirements:

- Power cycling between rated output (Pn) and 15% Pn or less,
- Load changes ± 5 % Pn per minute in the range 65%–100 % Pn,
- Step load change of ± 10 % Pn for at least 90% of the cycle length, and
- Cycle length requirements is up to 2 years.

The reactor core and its safeguard systems shall be designed such that fuel damage is not expected in normal operation and in incidents of moderate frequency. In the event of an infrequent fault, the reactor can be brought to safe shutdown state with only a small fraction of the fuel rods damaged. Following a limiting fault, the reactor can be brought to safe shutdown state and the core configuration can be kept subcritical with acceptable heat transfer characteristics.

A reactivity shutdown margin is required under hot and cold shutdown conditions of at least 1 % with the most effective control rod out of the core.

There shall be at least 95 % probability that critical heat flux conditions (DNB/CPR) will not occur on the limiting fuel rods during normal operation and operational transient condition arising from faults of moderate frequency at 95 % confidence level. The maximum fuel temperature in the core shall be less than the melting temperature of UO_2. The thermal design limits shall be complied with margin in the order of 15 %.

6.2. Fuel supply

First core loading, two reload batches plus spare fuel assemblies belong to the scope of supply of the initial fuel procurement. All materials except UF_6 for the LWR type fuels are provided by the MR vendor. The fuel assemblies and core components shall be of recent design with the assurance of licensibility. Technical requirements of the Plant shall also apply to the nuclear fuel, wherever appropriate.

For SVSRs implementing the BOO scheme, in which any transfer of fuel ownership is not needed, special arrangement (e.g. leasing) can be devised.

6.3. Spent fuel management

The spent fuel storage shall guarantee for the sub-critical condition and sufficiency of cooling capability.

The plant design shall provide for adequate spent fuel storage. The plant design, site arrangement and licensing activities shall take into account the possibility of providing expansion to the on-site facilities sufficient to store the spent fuel resulting from the lifetime operation of the plant, unless assurance of the availability of an off-site spent fuel storage facility exists.

Site spent fuel wet storage capability (for water reactors) : 10 years of operation plus one core off load.

6.4. Radioactive waste management

The radwaste systems shall be designed to have sufficient capacity to collect, segregate, process, control, store and dispose of all radioactive solid, liquid and gaseous waste produced by the plant under all anticipated operating conditions. Infrequent but possible conditions and large waste volumes must be accommodated. The waste processed by the systems shall be temporarily stored in the plant.

To meet the specified limits, the plant shall be provided with a system (stationary or mobile) for transforming liquid waste into solid waste that can be immobilised and affluent that can be released to the environment or recycled.

The plant shall have provisions for a system (stationary or mobile) for the volume reduction and immobilisation of low and medium level solid waste, unless such capability is assured by the existence of a central facility.

The total volume of the final solidified radwaste produced by one plant should be less than 30m^3 per 600 MW(e) per year of normal operation.

The plant shall be designed and constructed so that the amount of radioactive gases, liquid and solid waste generated in the plant shall be minimised as much as practicable.

- the amount of gaseous and liquid wastes which are generated and released to the environment shall be so small that radiation doses of the public at the site boundary are less than those regulated by the licensing authorities.
- The amount of solid wastes generated in the plant shall be less than the following:
- Solidified product of liquid waste evaporator concentrate (including acid drains) and miscellaneous solid waste is 700 × 200 liter drums/year for 600 MW(e) class unit. Spent resins about 8 m3/year for 600 MW(e) class unit.

6.4.1. Storage

The plant shall be designed to provide for the on-site storage of solid radioactive waste (low/medium level) and all chemically toxic waste for a period of time consistent with the expected schedule of shipments from the plant to disposal sites, which is 10 years. If off-site storage of such wastes is not assured, provisions shall be made for a later enlargement of on-site storage, if necessary, to provide sufficient capacity to store these wastes for the life of the plant.

6.4.2. Disposal

National policy on the disposal of radioactive waste from nuclear plants will be announced at later years. The options of low-intermediate level radioactive waste disposal are shallow ground disposal or near surface disposal.

7. ECONOMIC REQUIREMENTS

7.1. Criteria and evaluation methodology

The targets set for the technology and plant performance requirements discussed above have direct influence on the plant economy. The economic target can be simply stated as: the levelled cost of electricity from nuclear plants should be lower than from coal plant with cleanup system based on prevailing national regulation. Factors that have strong influence on the economy, notably: capital costs, construction time, capacity factor, and O&M costs should be well managed in order to achieve the economic target.

The MR plant is to be designed to have a significant economic advantage over other (coal) central station alternatives on both a near-term (10 year) and life cycle basis.

While for the deployment at remote areas or at the less developed regions the economic criteria for the Small and Very Small Reactor alternatives are expected to be:

- the largest social gain,
- the least government subsidy, and
- smaller than the cost to upgrade the infrastructure and transportation means in order to remove the "remoteness" qualification.

Economic evaluation of any proposal for introducing the MR plant in a conventional financing scheme (by equity, loan on sovereign guarantees) shall be performed on the basis of the two following factors:

- total present worth of the proposed project calculated by the discounted cash flow method at discount rate of 10 %/a (nominal), and
- generation cost per net kWh which will be estimated (using levelled method) with the capital recovery cost, the fuel cost, and the operation & maintenance cost.

Replacement of main components (foreseen during the lifetime of the plant), radwaste and spent fuel storage costs, as well as the decommissioning cost are included in the calculation.

In addition to the above method, for BOO and other non-conventional financing schemes an evaluation based on "profit and risk sharing" can be considered.

7.2. Measures for improved economics

It has been understood that to reach the criteria mentioned above the vendor shall clearly submit the estimated capital cost, operation and maintenance cost and the fuel cost. Furthermore the vendor shall declare and commit themselves on how to achieve longer plant life, how to achieve design stability as well as to assure the construction schedule. Efforts shall be made to develop techniques and procedures which not only can shorten the construction schedule but also prevent delays once construction has started. On the other hand, the User shall be assisted with necessary information in arranging with the Regulatory Body to assure the regulatory licensing stability.

Preliminary decommissioning plans shall be part of the design effort so as to optimise, where possible, the capability to decommission the plant and minimise the associated costs.

7.3. Financing

7.3.1.Conventional financing approaches

In case of conventional financing (with export credits and commercial loans on sovereign guarantees) it is intended that foreign and local currency costs of the work shall be financed by the vendor. The amount shall cover price, financial and incidental charges and loan interest incurred up to the taking over of the plant. Repayment shall extend over at least 15 years, except 5 years for nuclear fuel.

7.3.2. Alternative financing approaches

A potential SMR vendor shall seek the possibility to offer the following three financing schemes: conventional, build-own-operate, and/or conventional with barter.

A turnkey contract with project financing of equity and conventional loan (i.e. export credits and commercial borrowing) on sovereign guarantee basis has been considered the best way, as clearly stated in the feasibility study report. The present Government financing policy, however, has been encouraging private sector enterprises and cooperatives to finance the development to meet increasing demand for electric power.

Specific problems of nuclear IPP which need some form of government encouragement are foreseen, such as public acceptance, third party liabilities, back-end fuel cycles, decommissioning, and long term waste management. The need to share risks at the side of foreign investors can require government participation in the form of partial equity.

Another financial arrangement that alleviates the problems of external borrowings, but still keeps the NPP within the government ownership is complemented by some barter scheme. Some amount of bartered commodity is delivered to the NPP main contractor country as having equivalent value to partial payment of periodic disbursements during construction. Such barter arrangement will then decrease monetary loans, and therefore, avoid or reduce the interest during construction.

8. SPECIAL REQUIREMENTS

8.1. Manpower development

Manpower development for the design, construction, installation and safe operation of the MR shall be inseparable from the package in the procurement. Education and training for sufficient number of personnel should be given until they are qualified. They shall be specialised in operational safety and regulatory aspects of the SMRs, project engineering and management, operations and operation management. Not only technical skills but also managerial skills that shall be specially taught to the plant personnel.

Services relating to the proper training and education of the owner’s personnel shall include:

- special training courses and on-the-job training of owner’s personnel,
- courses for operating and maintenance personnel on the overall concept and functioning of the contractor’s plant design,
- specific courses and demonstration of the detailed functioning and responsibilities of the operating and maintenance personnel,
- specialist courses aimed at training specific operating and maintenance personnel of the owner to fulfill properly their individual responsibilities,

- on-the-job training of operating and maintenance personnel for operating and maintaining the plant, and
- training using the computer and full-scope simulators.

8.2. Infrastructure and national participation

Maximum utilization of locally available materials, manufacturing capabilities and readily made products, as well as Indonesian nationals for labour, skilled workers and supervisory services, are encouraged for the construction, operation and maintenance works, as far as they meet the specified quality. Preference in the hiring of local labour shall be given to residents within the immediate vicinity of the project site.

Local products mean all kinds of goods which are manufactured or produced by industrial companies locally. In the process of creating of goods as well as performing services, the use of non-domestic (imported) input or elements is allowed.

Local contractors to be subcontracted (by the main supplier) shall be companies with the status of Indonesian statutory bodies. Included in this category are:

- industrial companies which have the status of foreign capital investment according to the prevailing regulation and have already invested the capital in Indonesia (established factory in Indonesia), and
- services companies (such as consultant) which represent joint venture company with Indonesian services company and using as much as possible Indonesian personnel.

8.3. Technology transfer

Potential vendors shall state in their offer the plan to execute certain technology transfer through their various activities: e.g. training, on-the-job training, design participation, construction and erection subcontracts with domestic companies, supervisions, QA & QC inspections, and fabrication of components. The user and domestic subcontractors shall be advised on the incremental costs in case certain items of technology transfer do not belong to the vendor’s scope of supply.

8.4. Licensing support

The SMR vendor shall provide necessary information documents on the design, performance and safety of their supplied hardware & software in support to the user in the licensing application and evaluation process as well as for public relation.

8.5. Contractual options and responsibilities

For the construction of the first MR or SVSR plant, a turnkey contract is the preference. A certain local content shall be opted in the offer, which become one of the parameters to be considered in the bid evaluation process. Increasing local content for subsequent plants shall be anticipated. Potential national companies are encouraged to become local partners in the construction, and the supply of materials and services.

8.6. Extended guarantees and warranties

8.6.1. Guarantees

It is required, that performance of the plant as described in the design, e.g. on gross and net power, availability factor, safety factor, be guaranteed for specified period. The performances being guaranteed (within extended period, where appropriate) and assurance of immediate response shall be delineated clearly in advance.

8.6.2. Warranties

It is required, that hardware of the plant be warranted for specified period. The items being warranted (within extended period, where appropriate) and assurance of immediate response, time delivery and related supports shall be delineated clearly in advance.

8.6.3. Long term assurance of fuel supply

Possible long term assurance of external fuel supply, including various fuel cycle materials and services shall be made clear in advance by the initial fuel supplier.

Complete specification of the fuel assemblies and core components shall also be delivered by the supplier of initial fuel batches, so that fuel / core components for future reloads can be procured to other suppliers including possible domestic one.

Guarantee that each fuel assembly will be mechanically capable of achieving the fuel assembly burnup as specified prior to mechanical failure, shall be given. In the event that a fuel assembly is permanently removed from the reactor prior to its scheduled discharge for reasons of mechanical failure without having achieved its guaranteed assembly burnup, the contractor shall, at the owner's option, perform one of the remedies specified.

8.7. Nuclear fuel, special materials and spare parts supply

All required spare parts, including nuclear fuel, special materials, shall be provided and warranted. Two categories of spare parts:

(i) Parts which have to be replaced during the normal operation in first and second fuel cycle periods;
(ii) Parts which are essential to replace immediately in case of damage for achievement of the required plant availability.

Spare parts category 1 shall be made available on the site area before the start of pre-operational testing. The availability of spare parts possibly demanded during the lifetime of the plant (category 2), especially those of obsolete technology, shall be delineated by the vendor.

8.8 Technical support

After the take-over of the plant the vendor/contractor are required to provide engineering, technical and operational supports on demand. The national companies are encouraged to become local partners to these vendors/contractors for the future services through national participation and technology transfer programmes.

8.9. Long term partnership

Long term partnership shall be further developed to other services, such as in-core fuel management, safety verification, or in the R&D co-operation. A worldwide association of users, operating similar type SMRs representing one of the medium for information exchange already available, shall be supported and maintained.

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Meetings on the preparation of URDs for SMRs in developing countries

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