IAEA ACTIVITY RELATED TO SAFETY OF NUCLEAR DESALINATION

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Abstract

The nuclear plants for desalination to be built in the future will have to meet the standards of safety required for the best nuclear power plants currently in operation or being designed. The current safety approach, based on the achievement of the fundamental safety functions and defence in depth strategy, has been shown to be a sound foundation for the safety and protection of public health, and gives the plant the capability of dealing with a large variety of sequences, even beyond the design basis. The Department of Nuclear Safety of the IAEA is involved in many activities, the most important of which are to establish safety standards, and to provide various safety services and technical knowledge in many Technical Co-operation assistance projects. The department is also involved in other safety areas, notably in the field of future reactors. The IAEA is carrying out a project on the safety of new generation reactors, including those used for desalination, with the objective of fostering an exchange of information on safety approaches, promoting harmonization among Member States and contributing towards the development and revision of safety standards and guidelines for nuclear power plant design. The safety, regulatory and environmental concerns in nuclear powered desalination are those related directly to nuclear power plants, with due consideration given to the coupling process. The protection of product water against radioactive contamination must be ensured. An effective infrastructure, including appropriate training, a legal framework and regulatory regime, is a prerequisite to considering use of nuclear power for desalination plants, also in those countries with limited industrial infrastructures and little experience in nuclear technology or safety.

1. INTRODUCTION

The general approach to safety of nuclear reactors supplying heat or electrical power to desalination plants is equivalent to the approach used for nuclear power plants producing of electricity. The nuclear plants for desalination to be built in the future will have to meet the standards of safety required for the best nuclear power plants currently in operation or being designed, and for this reason the safety aspects are common with those related to new generation reactors for which a dedicated programme exists at the IAEA. Most of the general safety considerations reported in this paper have been discussed and analysed during the development of this programme. Some specific characteristics of desalination plants such as siting and coupling which require particular consideration from a safety point of view, and further safety studies will be needed when the type and size of the reactor are determined.

2. GENERAL SAFETY ASPECTS OF NUCLEAR POWER PLANTS

There are three safety objectives from which all safety principles and requirements are derived:

General Nuclear Safety Objective: *To protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defences against radiological hazards.*

Radiation Protection Objective: *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 as low as reasonably achievable, and to ensure mitigation of the radiological consequences of any accidents.*

Technical Safety Objective: *To take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate their consequences should they occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including those of very low probability, any radiological consequences would be minor and below prescribed limits; and to ensure that the likelihood of accidents with serious radiological consequences is extremely low.*

The safety objectives shall be achieved through the application of the defence in depth strategy that will continue to be the overriding approach for ensuring the safety of workers and the public, and for protecting the environment. This strategy is effective in compensating for human and equipment failures, both potential and actual. The concept is based on several levels of protection, including successive barriers that prevent the release of radioactive material to the environment. However, its efficacy depends on rigorous implementation.

Levels of Defence in Depth (From INSAG-10)

Levels of defence	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
Level 2	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
Level 3	Control of accidents within the design basis	Engineered safety features and accident procedures
Level 4	Control of severe plant conditions including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures and accident management
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

This implies a determined effort to make the defence effective at each level, particularly for accident prevention and accident mitigation. There is not a unique way to implement defence in depth, since there are different designs, different safety requirements in different countries, different technical solutions and varying management or cultural approaches. Nevertheless, the strategy represents the best general framework to achieve safety for nuclear power plants and, thus, nuclear powered desalination plants. In general, strong implementation of defence in depth requires a determined and constant effort from the design phase, to construction and operation in order to provide graded protection against a wide variety of transients, abnormal occurrences and accidents, including human error and equipment failures within the plant, and events initiated outside the plant.

2.1. Design basis approach and severe accident treatment

Operating nuclear plants are largely designed according to the design basis accidents approach. This means that the plant is deterministically designed against a set of hypothetical accident situations according to well established design criteria in order to meet the radiological targets. The current design basis approach has been shown to be a sound foundation for the safety and protection of public health, in part because of its broad scope of accident sequence considerations, and because of its many conservative assumptions which have the effect of introducing highly conservative margins into the design that, in reality, give the plant the capability of dealing with a large variety of sequences, even beyond the design basis.

The deterministic approach is complemented by probabilistic evaluations with the main purpose of verifying that the design is well balanced and there are not weak areas or systems which could allow for the possibility of risky sequences. Often, probabilistic targets for core damage frequency and for containment performance are established. Experience and analysis have shown, however, that some sequences beyond the design basis (i.e. severe accidents) may need to be considered explicitly in the design, providing it with additional safety features to further prevent and mitigate such severe sequences. In this regard probabilistic safety assessment is recognized as a very efficient tool for identifying those sequences and plant vulnerabilities that require specific design features (elimination by design of the most challenging sequences to the containment). This, together with an effective containment system including good control of potential containment by-pass, ensure minimum radiological impact, with an extremely small chance of any off-site radioactive releases. For a nuclear powered desalination plant, the design basis may need to also include some transients or abnormal occurrences that might originate in the desalination unit itself.

3. SPECIFIC SAFETY ASPECTS OF DESALINATION PLANTS

The total power (electrical and thermal to supply potable water to a medium sized town) varies from a few to several hundred megawatts, and thus any proposed reactor falls into the small or medium sized category. Larger sizes would be required for the combined production of water and electrical power.

The nuclear power plants used for water desalination have several characteristics that are similar to those power plants used for district heating reactors (e.g. siting, power size, possibility of combined production), and the experience gained with these plants should be considered in designing nuclear powered desalination plants.

3.1. Coupling

The overall safety of an integrated complex composed of a nuclear reactor plant coupled to a desalination plant is predominantly dependent on the safety of the nuclear reactor plant and the effect of coupling, or rather the interaction between the desalination plant and the nuclear plant. This interaction should be analysed in various coupling situations to assess its effect on the safety of the reactor and on the overall nuclear desalination system, either in normal operation or in an accident situation.

Coupling will not pose any new safety concern if desalination uses only electrical power.

In thermal processes, the energy to be supplied is mainly low temperature process steam or water. Coupling is accomplished via a heat transfer circuit. Since radioactivity exists in the primary steam or hot water, the risk of contamination of product water exists and must be avoided. This can be done by adding intermediate loops maintained at values of pressure such that any leakage would not produce transfer of contamination to the distributed water. These simple measures, together with appropriate instrumentation and monitoring should be effective in preventing contamination of the distributed water. They do not seem to present any particular technical difficulty.

All the information available from the operating experience accumulated on an existing plant (Aktau, Kazakstan) and from conventional desalination plants will also provide a valuable source of information for design and operation purposes. Operational transients in a desalination plant would have direct feedback into the reactor system. Such transients could have safety implications and need to be assessed.

3.2. Siting

For obvious reasons, the siting of a nuclear powered desalination plant raises some safety concerns, mainly because of the site selection restraints. The plant has to be built on a coastal site and near to populated areas to limit the cost of potable water distribution. The choice of site raises problems related to oceanography (tides, plant elevation) and very often to seismicity (frequent presence of faults on coasts).

The proximity of the nuclear desalination complex to population centres and its implication on the design and to the emergency planning and water supply should be examined.

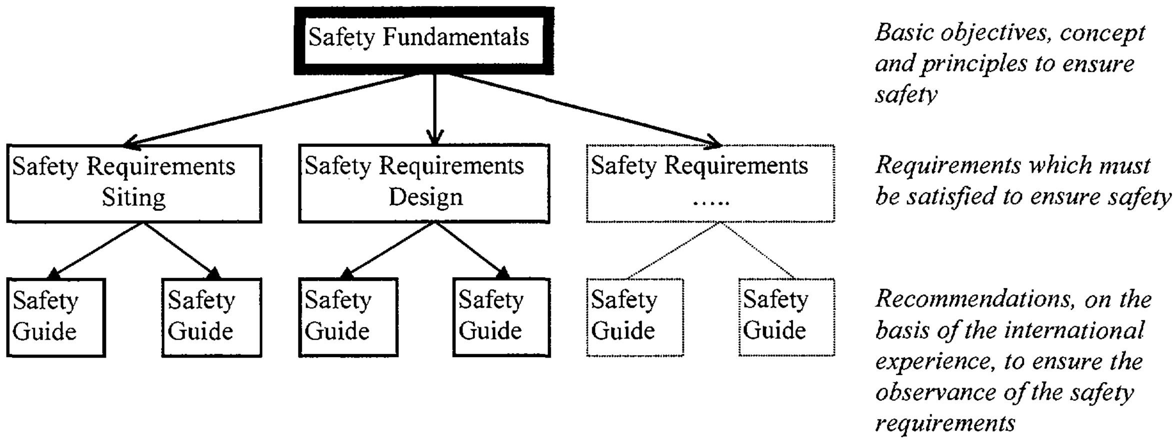
If the site is in a remote area an important aspect to consider is the availability of adequate external electric power grid or supply for safe operation of the nuclear plant.

4. THE ROLE AND ACTIVITIES OF THE IAEA

The Department of Nuclear Safety is involved in many activities, the most important of which are to establish safety standards, and to provide various safety services and technical knowledge in many Technical Co-operation assistance projects. The department is also involved in other safety areas, notably in the field of future reactors. The newly established Convention on Nuclear Safety was developed under the auspices of the IAEA.

The Agency produces many documents related to nuclear safety, the most important of which are those now to be included in the Safety Standards Series (SSS), formerly the Safety Series, which included the NUSS programme. The SSS will comprise three levels: Fundamentals, Requirements and Guides.

Hierarchy of the IAEA Safety Standards Series



4.1. Safety Fundamentals (SFs)

Currently, there are three SF documents, but in the long term aim is to combine these into a single document. These are the first documents in the hierarchy; they present basic objectives, concepts and principles to ensure safety in the development and application of atomic energy or radioactive material for peaceful purposes. The SF documents constitute the reasons why activities must fulfil certain requirements; they do not state what these requirements are, they are self-sufficient and do not include a list of references. In the SF on Safety of Nuclear Installations (SS-110) there are 25 fundamental principles grouped into four main areas, related to the Legislative and Regulatory Framework,the Management of Safety, the Technical Aspects of Safety and the Verification of Safety.

4.2. Safety Requirements (SRs) and Safety Guides (SGs)

Supporting the SFs are Requirements (formerly termed Codes, Standards or Regulations). In the nuclear safety area there will be six main areas: Governmental Organizations, Siting, Design and Operation of thermal neutron nuclear power plants, Quality Assurance and the Research Reactor Series which has two SR documents. All the existing NUSS codes (except QA, which was published in October 1996) are now subject to a comprehensive revision process, which is being overseen by the Nuclear Safety Standard Safety Committee (NUSSAC). This revision will ensure that all the relevant principles in the SF are systematically addressed, thus enabling a coherent set of documents to be produced. The SRs will set out in more detail what is required of Member States to ensure safety in a particular area, and they are governed by the content of the SFs. SRs do not generally present recommendations on or explanations of how to meet the requirements. This more detailed aspect is covered by the third level in the hierarchy, namely, the Safety Guides. The SGs present recommendations on the basis of international experience, of the measures to be followed to meet the requirements set out in the SR documents.

4.3. The IAEA Safety Standards for the Design

Table 1 shows as an example the existing (left side) and the future (right side) structures of part of the Safety Standards for the Design. Some publications will be merged and some, as the Safety Guide on Safety Assessment, will be prepared ex-novo.

The whole process for the revision of the Safety Standards for the Design, comprises the revision of the Code and 15 Safety Guides and the preparation of two additional new Safety Guides. The process will be concluded by the year 2001.

4.4 Specific requirements applicable to nuclear desalination and other heat utilization applications

As previously mentioned all of the current safety standards (NUSS and standards for research reactor) are being subjected to a comprehensive review and revision process. Since the safety requirements applicable to nuclear desalination, district heating and other heat utilization applications will, in general, be those applicable to nuclear power plants, it should be possible during this revision process to incorporate within the revised documents any new or unique requirements specific to these systems. For example the Requirements for the Design which is intended to replace the existing "Code on the Safety of Nuclear Power Plants, Design (50-C-D Rev. 1)" will incorporates the following new requirement:

> **Power plants used for co-generation, heat generation or desalination.**
> *Nuclear power plants coupled with heat utilization units (e.g. district heating) and/or water desalination units shall be designed to prevent transport of radioactivity from the nuclear plant to the desalination or district heating unit during any condition of normal operation including anticipated operational occurrences, design basis accidents and selected severe accidents.*

The above requirement represents the only one that was specifically added for nuclear power plants used for desalination, heat production or desalination. This underlines once more that there are no major differences, from a safety point of view, from these nuclear plants and those used for electricity generation only.

TABLE 1. EXAMPLE OF EXISTING AND FUTURE STRUCTURES OF THE SAFETY STANDARDS FOR THE DESIGN

•50-C-D (Rev. 1) Code on the Safety of Nuclear Power Plants: Design	**•Requirements for the safety of nuclear power plants: Design**
•50-SG-D1 Safety Functions and component classification for BWR, PWR and PTR	
•50-SG-D2 Fire protection in Nuclear power plants	**•Fire protection in Nuclear power plants**
•50-SG-D4 Protection against Internally Generated Missiles and their Secondary Effects in Nuclear Power Plants	**•Protection against Internally Generated Missiles and their Secondary Effects in Nuclear Power Plants**
•50-SG-D5 (Rev. 1) External Man-induced Events in relation to Nuclear Power Plant Design	**•External Man-induced Events in relation to Nuclear Power Plant Design**
•50-SG-D9 Design Aspects of Radiation Protection for Nuclear Power Plants	**•Design Aspects of Radiation Protection for Nuclear Power Plants**
•50-SG-D11 General Design Safety Principles for Nuclear Power Plants	
•50-SG-D15 Sysmic design and qualification for nuclear power plants	**•Sysmic design and qualification for nuclear power plants**
	•Safety Assessment and Verification
CODE + 7 GENERAL SAFETY GUIDES	**REQUIREMENTS + 6 GENERAL SAFETY GUIDES**

Figure 1 shows how the concept of the Safety Assessment has been included in the revised Safety Standards for the Design. The Safety Assessment is a tool for the design and represents a relevant part of the design process since the very initial stage. The same methods (deterministic, probabilistic) for the Safety Assessment can be used by the Designers, Reviewers and Regulatory Bodies.

4.5. Current experience accumulated on research reactors

Nuclear desalination plants have been proposed for various Member States, in particular, those that are located in arid areas of Africa, Asia and elsewhere. Many of these countries have no experience at all with nuclear reactors, while a few have one or more research reactors.

Reviewing the experience gained with research reactors in several developing countries the following points can be made that may be applicable to a desalination project:

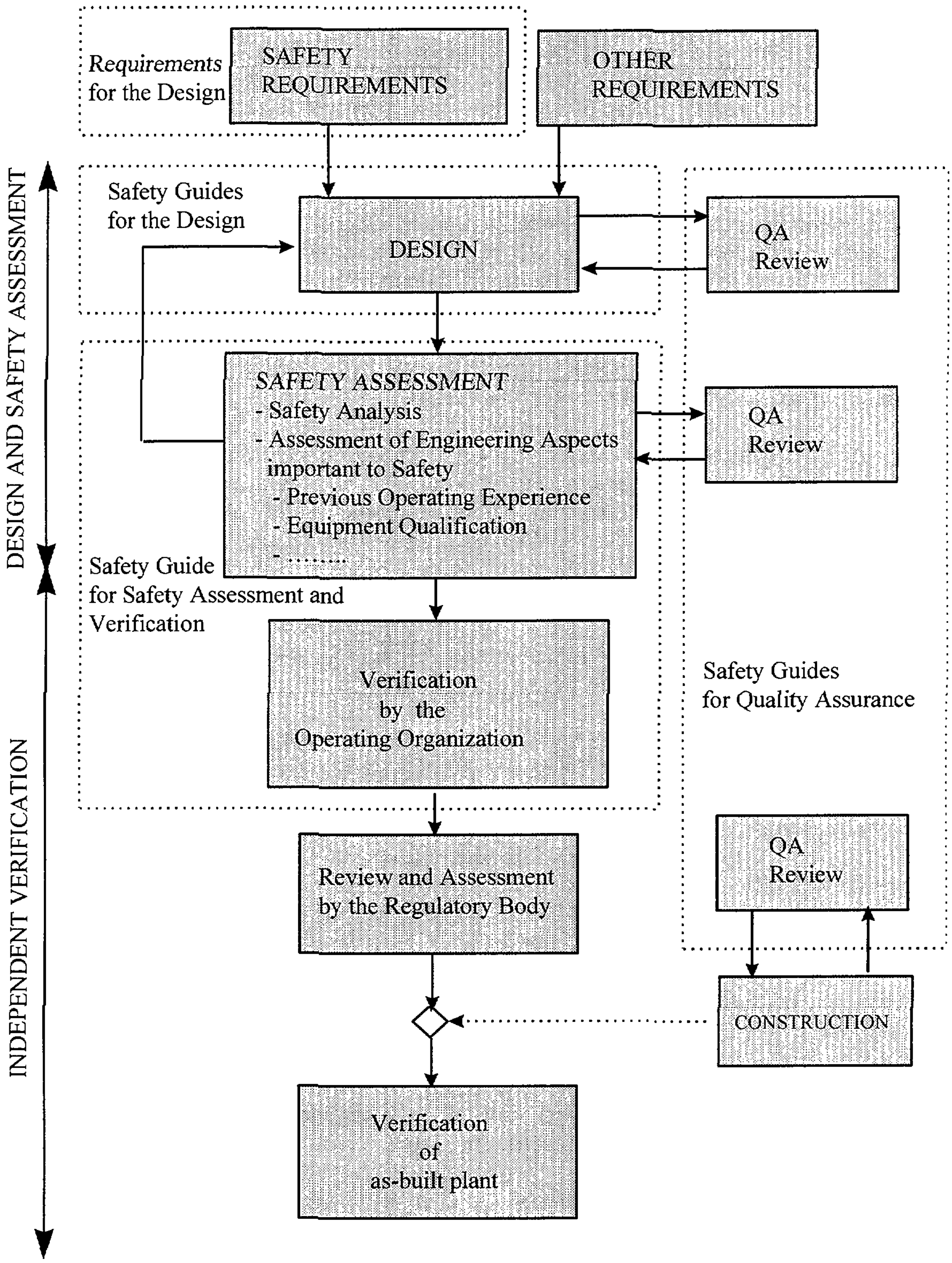


FIG. 1. *Areas covered by the IAEA Safety Standards for the Design of NPPs*

(1) Experience with a research reactor facility may be quite useful as it usually means that the country already has: a nucleus of a regulatory authority; some infrastructure in radiation protection and waste effluent control related to nuclear reactors; group of knowledgeable personnel in the areas of reactor operations and maintenance; programmes for the training of personnel; and experience with Agency sponsored projects.

(2) A research reactor facility (especially a larger reactor) can be used to simulate or experiment with some of the processes associated with a desalination plant, and can also be used as a school for training the new staff needed for the new project.
(3) Developing countries vary greatly in their political stability, economic wealth, technological infrastructure, logistical infrastructure, and general technical and safety related attitudes.

While gaining experience with a research reactor is expected, in general, to be useful as a first step before introducing nuclear power (or desalination), this same experience can shed light on the deficiencies that may undermine the prospects for such a project unless, in particularly serious cases, adequate international support can be provided.

4.6. IAEA activities on new generation nuclear power plants that provided input to the revision of the safety standards for the design

The IAEA activities on the safety of new generation reactors, which were formally initiated after the Conference on the Safety of Nuclear Power: Strategy for the Future held in September 1991, are being carried out under the project Safety Approaches to the New Generation of Nuclear Power Plants. The main objective of this project is to foster an exchange of information on safety approaches to new generation nuclear power plants with a view to promoting harmonization among Member States and contributing to the development and revision of safety standards and guidelines for nuclear power plant design. It is expected that the new standards will have an impact on the design of all nuclear power plants, including those for desalination, constructed in the coming years.

In June 1995, following INSAG's review and comments, the Agency published a technical document, Development of Safety Principles for the Design of Future Nuclear Power Plants (IAEA-TECDOC-801). This documents provided a basis for the development of safety objectives and principles for new generation nuclear power plants and for the revision of safety standards. The key proposal is that severe accidents beyond the existing design basis will be systematically considered and some of them explicitly addressed during the design process for future reactors. The document also emphasizes the need to further lower the risk of any serious radiological consequences and to ensure that the potential need for prompt off-site protective actions can be reduced or even eliminated (good neighbour concept).

Additional effort has been made to prepare a technical document on the implementation of defence in depth for new generation Nuclear Power Plants. The work was based on the report on defence in depth prepared by INSAG, and the main objective was to bring together the relevant aspects of existing publications on both defence in depth and future reactor designs, and then to apply recent defence in depth formulations specifically to ongoing developments in future plant designs.

Particular attention has been focused on identifying and addressing those factors that have the potential to affect multiple levels of defence in depth. This provides high confidence that appropriate actions will be taken to ensure the effectiveness of the defence in depth concept against failures that have the potential to impact multiple levels of defence in depth. (Human failure, internal and external hazards, etc.).

The report provides a good general framework for a safety evaluation and also gives some indication as to how the defence of each level could be enhanced.

4.7. Current activity on safety aspects of nuclear desalination

The activity is being carried out in accordance to the resolution of the General Conference that in the "Plan for producing potable water economically" of September 1998 stated:

The General Conference urges the Director General to continue the Agency's work regarding the safety aspects of desalination using nuclear energy.

The work on safety is being carried out in very tight co-ordination with the work on technological aspects of the Department of Nuclear Energy. The main task consists of preparing a technical document on safety aspects of nuclear power plants coupled with sea water desalination and/or other heat utilization units. In this document, now in draft form, the main safety and licensing aspects and issues are identified and addressed in detail and they are briefly mentioned below.

- Coupling of the reactor with the desalination unit
  - — Single and multi-purpose plants
  - — Various coupling situations
    - - Thermal and/or electrical
  - — Potential of transfer of contamination from the nuclear plant to the potable water
    - - Scenarios to be addressed
    - - Addition of intermediate loop as preventive measure
  - — Sharing of resources between the NPP and the desalination unit (intake and out-fall structures)
  - — Brine discharge (environmental issues)
- Operational transients and accidents
  - — They have to be considered in the safety analysis but do not seem to pose particular safety concerns
- Water quality and monitoring
  - — Radioactivity content shall meet the national and international standards

A continuos monitoring may be difficult because of the very low levels of radioactivity and a batch monitoring will be necessary

- Availability of product water
  - — High availability target will require water storage and energy backup supply
- Siting
  - — Proximity to population centres will result in no need for planned evacuation
- Licensing
  - — Need of an effective legislative framework for the regulation of nuclear facility
  - — Need of independent Regulatory Body
  - — Need of well developed safety culture

5 CONCLUSIONS

The safety, regulatory and environmental concerns in nuclear powered desalination are those related directly to nuclear power plants, with due consideration given to the coupling process.

It is expected that any reactors used for desalination purposes will be designed, constructed and operated in accordance with internationally recognized safety standards.

IAEA missions to operating nuclear power plants coupled to heat production and desalination plants have not revealed any serious specific safety concerns related to the interaction of the nuclear plant with the heat distribution plant or desalination plant, but they have shown that any safety concerns are related to the reactor itself.

Nuclear safety and environmental considerations in nuclear desalination are those arising from the use of nuclear reactors as energy sources.

Nuclear safety and regulatory actions should be based on relevant IAEA safety standards.

The most serious concern, as experience with research reactors has shown, arises from the fact that very often countries that need water are developing countries, with limited industrial infrastructures and little experience in nuclear technology or safety.

An effective infrastructure including appropriate training, a legal framework and a regulatory regime, is a prerequisite to considering use of nuclear power for desalination plants.

Another relevant aspect is the social and political instability of some countries where nuclear facilities could be possible targets of external attack; the plant would require comprehensive physical protection arrangements.

With respect to existing international safety standards and guides, they also seem to be appropriate covering desalination plants. There seems to be no need to prepare any specific guidance for the safety of nuclear powered desalination plants.

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