IAEA Nuclear Energy Series

No. NP-T-5.6

Technical Requirements in the Bidding Process for a New Research Reactor

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TECHNICAL REQUIREMENTS IN THE BIDDING PROCESS FOR A NEW RESEARCH REACTOR

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IAEA NUCLEAR ENERGY SERIES No. NP-T-5.6

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2014

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email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
September 2014
STI/PUB/1659

IAEA Library Cataloguing in Publication Data

Technical requirements in the bidding process for a new research reactor. — Vienna : International Atomic Energy Agency, 2014.
p. ; 30 cm. — (IAEA nuclear energy series, ISSN 1995–7807 ; no. NP-T-5.6)
STI/PUB/1659
ISBN ISBN 978–92–0–103414–4
Includes bibliographical references.

1. Nuclear reactors — Design and construction. 2. Nuclear reactors — Safety measures. 3. Nuclear reactors — Economic aspects. I. International Atomic Energy Agency. II. Series.

IAEAL 14–00927

FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." One way this objective is achieved is through the publication of a range of technical series. Two of these are the IAEA Nuclear Energy Series and the IAEA Safety Standards Series.

According to Article III.A.6 of the IAEA Statute, the safety standards establish "standards of safety for protection of health and minimization of danger to life and property". The safety standards include the Safety Fundamentals, Safety Requirements and Safety Guides. These standards are written primarily in a regulatory style, and are binding on the IAEA for its own programmes. The principal users are the regulatory bodies in Member States and other national authorities.

The IAEA Nuclear Energy Series comprises reports designed to encourage and assist R&D on, and application of, nuclear energy for peaceful uses. This includes practical examples to be used by owners and operators of utilities in Member States, implementing organizations, academia, and government officials, among others. This information is presented in guides, reports on technology status and advances, and best practices for peaceful uses of nuclear energy based on inputs from international experts. The IAEA Nuclear Energy Series complements the IAEA Safety Standards Series.

In recent years, the interest of IAEA Member States in developing research reactor programmes has grown significantly. Currently, a large number of Member States are in different stages of new research reactor projects. Several of these States are building their first research reactor as an introduction to developing a nuclear science and technology infrastructure. To support them in such efforts, in 2012 the IAEA published Specific Considerations and Milestones for a Research Reactor Project (IAEA Nuclear Energy Series No. NP-T-5.1). The report provides guidance on the timely preparation of a research reactor project through a sequential development process. It includes a detailed description of the range of infrastructure issues that need to be addressed and the expected level of achievement (or milestone) at the end of each phase of the project. The deliverable of the project phase 2 (project formulation phase) is the bid specification.

In this context, the IAEA perceived the need among Member States considering new research reactors, in particular those building their first such reactor, for guidance on the development of the technical specifications for the bidding process. This publication, which is based on a consensus between research reactor designers, vendors and representative operators, and users, has been developed to provide practical guidance on the development of the bid specifications for the bidding process of a new research reactor. It also addresses the preparation phase of the bidding process and discusses criteria that may be used in the evaluation of the bids. While the guidance provided by this publication is intended mainly to be used by Member States building their first research reactor, it is also considered suitable for Member States building a subsequent research reactor. This publication is to be used in conjunction with other IAEA publications on research reactor safety and utilization, in particular the Code of Conduct on the Safety of Research Reactors and the IAEA Safety Standards.

The IAEA wishes to thank all of the contributors to this publication. Special thanks are due to G. Bignan, who coordinated the compilation, editing and revision of the text. The IAEA officers responsible for this publication were A. Borio di Tigliole, P. Adelfang and Y. Barnea of the Division of Nuclear Fuel Cycle and Waste Technology, and A.M. Shokr, H. Abou Yehia and T. Hargitai of the Division of Nuclear Installation Safety.

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

A significant number of Member States are currently in different stages of building a new research reactor, with several of them establishing their first research reactor. These States are considering their first research reactors for a variety of purposes, including:

(a) Building expertise to support a broader nuclear science and technology infrastructure;
(b) Serving as a major facility for education and training;
(c) Providing services for society;
(d) Promoting science, technology and medical purposes.

In responding to this trend, in 2012 the IAEA published Specific Considerations and Milestones for a Research Reactor Project (IAEA Nuclear Energy Series No. NP-T-5.1) [1]. This publication provides guidance on the implementation of different phases of a new research reactor project, along with the necessary conditions associated with the different infrastructure issues. These conditions should be met at the end of each project phase (milestone).[1] One of the important activities that need to be performed during phase 2 of the project is the development of the bid technical specifications. According to the approach established in NP-T-5.1, milestone 2 is achieved when the Member State is ready to invite bids for the research reactor.

The feedback from IAEA activities, in particular from Member States establishing their first research reactor, indicated the need for further guidance on the development of the technical specifications for the bidding process of a research reactor. The present publication has been developed as a response to these needs. As such, this publication is to be used during phase 2 of a new research reactor project to bridge the gap between the feasibility study (milestone 1) and the bid specification (milestone 2).

This publication should be used in conjunction with other IAEA publications on research reactor safety and utilization, including the Code of Conduct on the Safety of Research Reactors [2] and the IAEA Safety Standards.

1.2. OBJECTIVE

The objective of this publication is to provide practical guidance on the development of the technical specifications for the bidding process of a new research reactor. Guidance on the criteria for bid evaluation and on the performance of the bid evaluation process is also provided. The guidance provided in this publication is oriented primarily toward Member States developing their first research reactor; however, this guidance could also be useful for the bidding process of a subsequent reactor in the country.

1.3. SCOPE

This publication is directed mainly to the turnkey contractual approach, but it may also be useful in other kinds of contractual frameworks. It assumes that the necessary preparatory work has been completed before entering the bidding process [1]. Therefore, detailed financial aspects of the bidding process are beyond the scope of this publication. The guidance is directed mainly to the technical specifications requirement related to safety, operation and effective utilization of the reactor. Technical specifications related to nuclear security and safeguards are not covered.

The scope of this publication covers the bidding process, from the preparation of the technical part of the bid invitation specification (BIS) until the selection of the research reactor design and the signature of the contract with the contractor.

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[1] Guidance provided here in the form of ‘should’ statements, or simply in the present tense indicative, describing good practices, represents expert opinion but does not constitute international consensus recommendations on how to meet the relevant requirements.

The following options for bidding procedures are usually applied for the research reactor bidding process:

(i) Negotiated bid (the contractor has been selected in advance);
(ii) Bids submitted as closed proposals (technical, economic and financial) and negotiated between the owner, which is the operating organization in most of the cases, and each bidder separately, not releasing information to other bidders.

This publication is meant mainly for the second option, but can be utilized, with some adaptations, for other options.

The guidance provided by this publication applies to different reactor types and technologies; therefore, this publication is not recommending a specific reactor type or technology or a specific design. Nevertheless, it is recommended that the design of the first reactor in a Member State possess such general features as being safe, secure, robustly designed and easily maintained.

This publication can be used as general guidance on how to prepare the technical requirements for the BIS of a research reactor and its corresponding evaluation criteria. More detailed information and guidance on specific issues is available in the IAEA publications listed in the References section of this publication. Some of these publications are intended for nuclear power plants (NPPs) (e.g. Refs [3–5]), and therefore should be taken into account in applying a graded approach[2]. It should be emphasized that the responsibility, following the decision to embark on a research reactor project, rests with the Member State concerned. Moreover, specific national authority requirements and conditions have to be met as a priority when organizing and structuring the bidding process. The IAEA does not take responsibility for the completeness of the examples, lists and references offered in this publication.

1.4. STRUCTURE

This publication is structured as follows. Section 2 discusses the general considerations of the bidding process, including a description of the process and its preconditions, the entities involved in the process and their responsibilities, as well as other important aspects such as schedule of the process and pre-qualifications of the bidders.

Section 3 provides a description of the general considerations for developing the BIS, including among others the site selection and specification process, the general design requirements, the main issues regarding fuel supply, and the bid evaluation criteria. These items are presented along with discussions on the relevant information that should be included in the technical specifications of the BIS.

Section 4 addresses reactor utilization related design features. A list of the various applications of research reactors is presented, along with the technical requirements that can shape the owner or operating organization’s request from the vendor during the bidding process.

Section 5 provides a description of the fundamental design requirements for the research reactor that should be included in the technical specifications of the bid. Special emphasis is given to the IAEA safety requirements and to the requirements for demonstration of safety to be included in the BIS [6].

Section 6 provides guidance on the reactor organizational structure during the phases of operation, together with the training requirements as well as the items to be requested from the vendor in this regard.

Section 7 presents guidance on the technical documents to be requested from the reactor vendor as well as the technical documents that should be prepared by the operating organization, for which inputs may be requested from the vendor within the framework of the bidding process.

Section 8 provides a list of infrastructure related facilities (including software) that have to be specified by the operating organization and supplied by the vendor to build, operate and safely utilize the new research reactor facility.

Section 9 discusses the bid evaluation process and provides guidance on performing such an evaluation from the technical and economic points of view. A suggested set of bid technical evaluation criteria is also discussed.

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[2] For guidance in the application of a graded approach, refer to INTERNATIONAL ATOMIC ENERGY AGENCY, Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors, IAEA Safety Standards Series No. SSG-22, IAEA, Vienna (2012).

The Annex provides a graphical representation of the milestones to be achieved in completing a research reactor.

2. GENERAL CONSIDERATIONS FOR THE BIDDING PROCESS

2.1. PRECONDITIONS

The introduction of a nuclear science and technology infrastructure, including the construction of a research reactor, is a major undertaking entailing attention to many complex and interrelated issues over a long period of time. The necessary infrastructure should be developed to the point of complete readiness to invite bids and enter into a delivery contract as described in the IAEA research reactor milestones publication [1] and evaluation publications [7–9].

The following subjects are considered as having been settled, or at least plans for settlement should exist, before entering into the bidding process:

- Strategic plan for utilization;
- General technical requirements of the reactor (reactor flux and power, experimental facilities, etc.);
- Operating organization’s contribution to the project;
- Organization of the operating organization and human resource requirements;
- Experience of potential contractors;
- Overall project schedule;
- Site characteristics (main parameters that affect the reactor design and operation);
- Environmental impact;
- Regulatory requirements and licensing process (stages of licensing);
- Contractual approach and project management;
- Operating organization’s scope of supply;
- Level of national participation (local contractors and suppliers);
- Nuclear fuel supply options;
- Nuclear waste management/disposal;
- Safeguards;
- Security and physical protection;
- Financing and economic options;
- Radiation protection;
- Emergency planning.

The above elements ought to be addressed in a feasibility study and/or technology assessment preceding the bidding process.

Depending on the contract model chosen and the scope envisioned by the operating organization, particular attention has to be paid to the mutual understanding of the roles of the operating organization and the main contractor and subcontractors during project implementation; where necessary, they should be documented along with the relevant scope so that unnecessary future claims and cost estimating risks are avoided. Thus, the structure of the BIS and the criteria and methodology of technical and economic bid evaluation are based on the assumption that the above elements have been considered and defined. The completeness and quality of the above elements have a direct impact on the duration and quality of the whole bidding process.

2.2. BIDDING PROCESS

The ultimate objective of the bidding process is to sign a contract with the selected bidder (contractor) that permits proper construction and commissioning of a research reactor for the operating organization. Therefore, the needs as well as the technical and commercial requirements, and particularly the bid evaluation criteria, contained in the BIS should be recognized and understood.

The bidding process is normally divided into the following main phases:

- Preparation of the BIS (to be performed by the operating organization);
- Preparation of bids (to be performed by the bidders);
- Evaluation of bids (to be performed by operating organization);
- Contract negotiations (to be performed by operating organization and selected bidders);
- Signature of the contract (to be performed by operating organization and contractor).

2.3. RESPONSIBILITIES

The operating organization is directly responsible for preparing the BIS, evaluating bids, negotiating contracts and signing the contracts (contract negotiation and signing is outside the scope of this publication). The operating organization will assume the overall responsibility for conducting the bidding process. Therefore, the operating organization of the research reactors should be established before entering the bidding process.

When initiating the bidding process, the operating organization should have adequate human resources with a basic knowledge to prepare the BIS and to evaluate the bids from a technical and economic perspective. During the pre-project phase [1], it is strongly recommended to develop the following for the human resources:

- Technical expertise to develop specifications for the research reactors and to evaluate the bids, taking into account constructability and commissioning, operability and maintainability, safety and licensing, utilization, fuel cycle, radioactive waste management and decommissioning, safeguards, security and emergency planning;
- Project management expertise to manage the bidding process, to develop specifications and to evaluate the bids;
- Knowledge of the country’s and of the site’s infrastructure (such as geological survey capability, services infrastructure, etc.), as well as international best practices, including the IAEA safety standards and the regulatory requirements that need to be established or upgraded and expedited during the bidding process;
- Legal and financial expertise for BIS preparation, bid evaluation, contract negotiations and fuel procurement;
- Expertise in communication and public information.

The usual criteria for project management should be applied to the operating organization’s basic organizational unit responsible for the bidding process. The structure of the unit may vary along with the phases of the bidding process. However, it is advisable that the same key persons continue through the entire process. The knowledge and experience acquired during the initial phases are very useful in the subsequent phases of the bidding process.

It is advisable for the operating organization to obtain assistance from well qualified consultants with specialized knowledge that may be lacking in the operating organization.

2.4. SCHEDULE OF THE BIDDING PROCESS

It is necessary to set up an overall time frame and description of the stages for the bidding process until the normal operation of the research reactors. The duration of each stage depends on the quality and amount of work to be done before entering into the bidding process [1].

Requirements for the time frame of the research reactor project, including the time between signing of the contract and the start of construction, the desired construction time and the starting date of normal operation should be included in the BIS.

2.5. PRE-QUALIFICATION OF POTENTIAL BIDDERS

It is considered a good practice for the operating organization to conduct a dialogue with the potential bidders before the formal bidding process starts. The basis for this dialogue might be the general outline of a draft BIS, if available. The purpose is to help the operating organization to better understand the properties of the available designs. In parallel, the bidders will obtain a good understanding of the operating organization’s needs and requirements before the final BIS is issued.

To ensure that prospective contractors have the necessary competence and experience to successfully complete a contract, it is recommended that the operating organization request that potential bidders pass a pre-qualification. The pre-qualification may include demonstration of the potential bidders’ financial capability and technical competence, the available resources and the provision of the relevant references from comparable projects.

For this purpose, a questionnaire to solicit the required data could be developed, with the assistance of the IAEA as necessary, and sent to potential bidders. After the pre-qualification of the bidders is completed, the BIS and a request for bids should be distributed to the selected bidders. If the national legislation allows for a so-called pre-tendering negotiation, it would be useful to distribute and discuss the draft BIS with the pre-qualified bidders before the formal bidding process starts.

2.6. CONFIDENTIALITY

Confidentiality aspects deserve special attention during the bidding process. Confidentiality requirements are most stringent during bid preparation and evaluation. Clear confidentiality rules have to be established and communicated. The bidders should be treated in a fair and equal manner. It is a common practice to require a confidentiality undertaking in written form from each person participating in the bidding process. There may be other restrictions arising from confidentiality agreements between the vendor and subcontractors.

3. GENERAL CONSIDERATIONS IN DEVELOPING THE BID INVITATION SPECIFICATION

This section describes the general features and recommended characteristics of future research reactors and the prerequisites that have to be considered before proceeding with an invitation for bids. It is assumed that the conditions discussed in Section 2 have been successfully completed; this section focuses on the main features of research reactors, as well as on the technical requirements and organizational aspects and responsibilities for the preparation of bids for research reactors. The main topics addressed in this section are site selection, the legislative framework, demonstration of the safety and licensing activities, and the scope of fuel supply.

3.1. PREREQUISITES

The decision to build a research reactor, whether it is the first such reactor or a subsequent one, is based on the results of previously performed activities such as feasibility studies showing the justification for the need for the research reactor over its expected lifetime, siting studies, development of a strategic plan and establishment of the regulatory infrastructure. Moreover, it is assumed that Phase 1 allows the future operating organization to obtain a commitment ensuring long term financial support for the safe, secure and effective operation of the research reactor [1]. At the end of the preparatory activities, a bidding process should be initiated, unless only one vendor or contractor has been pre-selected, resulting in direct negotiations. The first stage of the bidding process is the preparation of technical requirements for the BIS.

Within the process, the operating organization has to evaluate its actual and future needs, the reactor utilization programme, and the availability of a suitable site. Such a study has to demonstrate a commitment to establish the national nuclear infrastructure needed to support a new research reactor project. As such, the mechanisms to meet the requirements have to be established. Moreover, the funding resources for regulation and operation should be allocated before the research reactor bid request is issued. A strong commitment to fund radioactive waste and spent fuel management and the decommissioning process should be in place.

The following topics have to be agreed upon prior to the commencement of the bidding process (see also Section 2.1):

- Adherence to international conventions and treaties;
- Regulatory requirements and the licensing process;
- Reactor type and power (or range of power);
- General technical requirements;
- Site characteristics and preliminary environmental impact assessment;
- Integrated management system of the operating organization;
- Financing resources (including the national funding option);
- Utilization plan;
- Nuclear fuel supply options;
- Radioactive waste and spent fuel management strategy;
- Radiation protection and emergency planning;
- Safeguards features;
- Strategy for human resource development, and for training of reactor operating personnel;
- Overall project schedule, contractual approach and project management.

3.2. ORGANIZATIONAL ASPECTS AND RESPONSIBILITIES

Taking into account that the operating organization bears the overall responsibility for conducting the bidding process, the delegation of authority by the owner is assumed to be arranged well before the initiation of the project.

As mentioned in Section 2, the operating organization should establish a basic organizational unit in charge of the preparations. The lines of authority and communication should be well defined. The unit should have direct access to the highest level of decision making authority and capability within the overall organization. It should have easy access to outside expertise for assistance and advice in a wide range of specific topics. The structure of this unit can be simple, consisting of a project manager, an assistant project manager and a team of competent professionals covering the important disciplines needed for the bid preparation.

3.3. SITE SELECTION AND CHARACTERIZATION

Prior to the preparation of the technical requirements for the bid, the operating organization has to select a site for the reactor by conducting an in depth investigation, either using its own professional resources or outsourcing the activity to a qualified contractor. Following the results, the operating organization has to include in the bid all the relevant site information that is needed for the design and safe and secure operation of the reactor. Site information and data need to include at least the following areas:

- Geography and topography;
- Geology, soil mechanics and seismology;
- Hydrology;
- Meteorology;
- Demography, traffic routes, agricultural and industrial use of land, access to the site;
- Potential natural hazards, such as seismic hazards, volcanic hazards, tornadoes, tropical cyclones, lightning, floods, tsunamis;
- Potential external human induced events, such as aircraft crashes, release of hazardous fluids, explosions;

- Particular environmental sensitivities.

IAEA publications [3, 4, 8–10] provide comprehensive guidance on site selection and evaluation.[3]

It is considered to be a good practice to offer the bidders free access to the site so that they can conduct their own studies if they consider it necessary for complementing the information received in the bid. The operating organization has to establish a simple procedure to resolve the questions regarding the interpretation of the site data [8, 9].

3.4. LEGISLATIVE FRAMEWORK

It is the responsibility of the bidder to investigate, consider and refer to laws, acts, decrees, regulations and resolutions valid in the operating organization's country and concerning the project [1]. Nevertheless, it is recommended that the operating organization should include in the bid the available list of the relevant legislation that should include the following topics:

- The commitment to use nuclear energy for peaceful purposes.
- The international conventions, standards and codes accepted by the operating organization's country.
- Legal regulations for the establishment of an independent regulatory authority.
- A description of the existing nuclear licensing process and procedures, regulatory inspections and enforcement measures. Moreover, the legislative framework should be described, including the various areas of nuclear law, i.e. radiation protection, storage of radioactive material and radiation sources, the safety of nuclear installations, emergency preparedness and response, mining and milling, nuclear material transport, radioactive waste and spent fuel, nuclear security, safeguards, export and import controls, nuclear liability and coverage.
- Legislation for foreign investment, including the roles of foreign entities, vendors and contractors, and intellectual property rights.
- Legislation concerning ownership of nuclear material in general and the future nuclear fuel cycle in particular.
- International codes and standards to be used for the design, manufacturing, construction and commissioning of the reactor, including the IAEA safety standards.
- National insurance legislation, particularly that related to nuclear insurance and liability.
- Other relevant legislation (issued or under development), such as industrial safety regulations, fire regulations, local construction regulations, non-radioactive waste, etc.

3.5. LICENSING

The licensing requirements are part of the general legislation in force in the operating organization's country as well as the regulations, rules, guides and procedures established by nuclear and other regulatory authorities of the country. Thus, the operating organization has to present to the bidder a detailed description of the licensing procedure, including the time schedule, indicating the different stages and hold points as well as the documents to be submitted in each stage [11, 12].

The operating organization has to indicate its expectations from the bidder on the preparation of the relevant documents for licensing. As the licensee, the operating organization has primary responsibility on safety and has to obtain the necessary licences for siting, design, construction and operation of the reactor, no matter who assisted the operating organization in the process. The operating organization may seek technical assistance to review the documents to be submitted to the licensing authorities.

In the case of a first nuclear installation in the Member State, the authorities may not have developed a complete set of requirements for a national licensing procedure. In this case, the operating organization has to indicate in the BIS the policy and procedures to be applied for the licensing of the reactor. It is expected that, at the very least, the hierarchy of safety requirements has to be given, for example:

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[3] References [3, 4] are intended for NPPs, and therefore should be taken into account when applying a graded approach.

- National regulatory requirements;
- IAEA safety standards;
- Regulatory requirements of the bidder’s country of origin;
- Regulatory requirements of other countries.

The bidders have to provide information regarding compliance of their proposals with the safety requirements specified above. Furthermore, the bidders have to provide detailed information on the safety approach to be applied in the offered reactor. This information has to refer to the following:

- Safety related codes, standards, regulations and guidelines;
- Protection against malfunctions and accidents as well as external and internal events, indicating the corresponding safety and security systems;
- Radiation protection and emergency preparedness;
- Radioactive waste management.

In the contract, the operating organization has to be committed to providing, at regular intervals, information about any changes or modifications to the licensing requirements in their country during the project execution.

3.6. GENERAL DESIGN REQUIREMENTS

Specific design requirements can be found in Section 5. The basic safety functions designed and expected to be performed at a research reactors are:

(a) Shutting down the reactor;
(b) Cooling the reactor core components continuously;
(c) Confining radioactive material inside the installation.

Research reactors should provide, in a safe manner, the neutron flux necessary for an effective and sustainable utilization programme. The different applications of a research reactor during its lifetime require flexibility in the facility design to enable various applications and introduce different experimental facilities. Such a research reactor is assumed, inter alia, to have the following features:

(a) A robust design that can withstand operator errors without damage;
(b) Ability to withstand design basis accidents without any core damage[4];
(c) Is user (operator/experimentalist) friendly;
(d) Is flexible and easy to operate, inspect and maintain;
(e) Permits access without time limitation to the reactor hall during reactor operation on full power, to facilitate radiation protection;
(f) Has an identified fuel management (back end) strategy.

The design of the research reactor should satisfy the general nuclear safety, radiation protection and technical safety objectives. The main design features include the following:

- Adequacy of the defence in depth concept.
- The overall reactivity feedback coefficient (considering fuel and moderator temperature coefficient, density and void coefficient and coolant temperature) should be proved and verified negative through all operating stages and conditions.
- The reactor design should include inherent safety features as well as passive systems (e.g. natural circulation for residual heat removal).

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[4] This requirement imposes limitations on power and power density.

- Safety systems should be self-actuated and not require operator actions for a given time following a postulated initiating event.
- The safety systems should be fail safe and should have high availability and reliability. They should be based on concepts such as redundancy, diversity, physical separation, protection against single and common mode failures, etc.
- Testing of the safety systems should be possible even when the reactor is functioning at nominal power, without causing a spurious shutdown.
- The reactor design has to withstand, without any prompt intervention, credible combinations of external events, in accordance with site characteristics and regulatory requirements.
- The reactor design has to avoid vulnerabilities of the critical safety functions, following an external or internal fire, and allow enough time for fire fighting staff.
- Radiation levels should be kept as low as reasonably achievable, with social and economic factors being taken into account (the optimization principle).
- The generation of radioactive waste should be minimized through the design and operation procedures.
- Refuelling should be simple. The at-reactor spent fuel storage facility has to be of reasonable size to provide space for at least the volume of two cores. Moreover, the spent fuel storage capacity should be consistent with the fuel back end strategy, as defined previously.
- The human–machine interface should be based on proven, state of the art technology, and proved as being user friendly.
- The availability of the reactor has to be consistent with its intended use.
- The safety features of the reactor have to help in gaining public acceptance, and the simplicity of the design has to aid public understanding of the likelihood of systems failures.

In addition to the above mentioned principles of the design, the designer of the research reactors has to address the requirements of the operating organization and the regulatory body. Typically, the operating organization will seek the best conditions for cost, safety and reliability of the reactor within a simple and short authorization process.

3.7. FUEL SUPPLY

A fundamental part of a research reactor project is the procurement of fuel, its long term management, storage and related services. The nuclear fuel may be offered either as part of the bid for the research reactor or through a separate contract. In all cases, the provision of fuel should be considered in the scope of supply.

The operating organization has to describe in the BIS its programme regarding the fuel cycle activities (back end). This programme should be in compliance with international treaties and obligations on safeguards of nuclear material and agreements with the fuel supplier, considering: the safety and security of supply; safety and security of fuel transport; new and spent fuel storage; and reprocessing (as applicable) and waste management.

The operating organization may like to obtain offers for additional fuel supply through competitive bids from qualified manufacturers. Therefore, it may request the bidders to express their commitment to deliver within their scope of supply all relevant data on the fuel, including information on the physical, thermal-hydraulic, thermodynamic and mechanical properties and calculations, as well as calculations of fuel management and refuelling requirements.

Fuel management activities performed by the operating organization require verification by calculation codes and measurements, which may be a part of the fuel contract or contracted separately to another qualified company. In such a case, it is recommended that the compatibility and interfaces between all project partners be carefully evaluated and contractually well defined, with IAEA assistance as necessary.

3.8. BID INVITATION SPECIFICATION EVALUATION CRITERIA

The purpose of inclusion of the bid evaluation criteria in the BIS is to point out to the bidders the items on which particular emphasis will be placed. The evaluation criteria should include the following items:

- Compliance of the bid with the contents and requirements of the BIS;
- Compliance with the terms and conditions of the draft contract, completeness of supply;
- Experience, reputation, organization, facilities, services and financial resources of the bidder;
- Project structure, project organization and implementation plan of the bidder;
- Safety and security features of the design;
- Compliance of the bid with the IAEA safety standards;
- Technical characteristics of the research reactors, status and reliability of design, standardization, constructability, operability, useability, inspectabilty and maintainability of the facility;
- Project schedule;
- Quality management practices, procedures and measures;
- Assurance of fuel supply and fuel cycle services;
- Assurance of nuclear safety, demonstrated licensability of the facility, environmental effects, waste management;
- Type and contents of documentation provided;
- Flexibility of the operation and ease of maintenance;
- National participation (local contractors and suppliers) and technology transfer, training programme;
- Quality and extent of follow-up services of the bidder during facility operation;
- Prices, price adjustments, foreign and local currency requirements;
- Terms of payment and financing conditions;
- Assurance of supply of the facility and spare parts, including heavy water, if applicable;
- Warranties.

In addition, the operating organization should identify the criteria on the basis of which the operating organization is entitled to eliminate the bid from the evaluation process.

The above items provide the general framework for bid evaluation. The order in which the criteria are listed above should not be interpreted as an order of priorities. The operating organization may select and emphasize some of the above items and evaluation factors, or the operating organization may define and choose others. The operating organization will probably not wish to restrict itself regarding the bid evaluation procedure, nor will it disclose it to the bidders, but it is in the best interest of the operating organization to inform the bidders about what it considers to be essential or of importance.

4. UTILIZATION RELATED DESIGN FEATURES

This section describes the technical specifications demanded by the different reactor utilizations. The technical specifications relevant to reactor utilization that should be included in the bid are discussed in this section. In order to optimize future research reactor applications and utilization, it is recommended to include potential stakeholders (future users) in phase 1 (the pre-project planning phase) [1], to decide on the specific uses of the facility. Considering the fact that the lifetime of the new research reactors is expected to be several decades, it is expected to host different applications that will be changed over the years.

Approaching phase 2 of the project, the experience of experts outside the operating organization may be included in the decision process on the definitions of the design characteristics for the various applications, considering their networking and collaborations for utilization and promotion of capabilities. In this section, various applications and uses of research reactors are presented, along with the basic technical requirements for each application. A number of IAEA publications [13–15] provide additional guidance.

Applications of research reactors fall into five broad categories: education and training; irradiation applications; beam port applications; testing of instruments; and material and fuel testing:

(a) Education and training, as part of human resource development, can be conducted at any reactor. However, in practice, higher power research reactors serving more complex technical missions are less suitable and are not normally utilized for this purpose.

(b) Irradiation applications involve inserting material into the reactor to induce radioactivity for analytical purposes, to produce radioisotopes, or to induce radiation damage or transmutation effects. Almost all reactors can be utilized for some irradiation applications, but as the reactor flux becomes higher the range of potential uses becomes larger.

(c) Beam port applications usually include the use of neutron beams outside the reactor for a variety of analytical purposes. Because of the magnitude of the fluxes needed at some distance from the core, most of the beam port experiments can only be performed by intermediate and higher power research reactors. Utilization of neutron beams includes medical applications as well.

(d) Testing of instruments typically involves neutron or gamma ray detection instruments that need to be tested.

(e) Material and fuel testing, as well as experiments in loops running through the reactor core, are highly specialized activities and are usually only performed by experienced national laboratory level facilities.

4.1. EDUCATION AND TRAINING

Every research reactor facility is capable of being used for education and training purposes. When reviewing the potential uses of the planned reactor, this application should not be dismissed. Education and training should be thoroughly explored and utilized to the benefit of the facility and the public. Therefore, research reactors should be designed to allow safe utilization for education and training. It is recommended to consider in the strategic plan (phase 1) association of the reactor with education and training institutes.

For educational purposes, the planned research reactor can demonstrate reactor physics principles, as well as the generation of radioactive sources for further investigations and research outside the reactor. A reactor designed for education offers an easily accessible core, the ability to display flux maps by several detectors and simple devices to activate and monitor various material probes used to generate radioactive sources.

For training reactor operators, research reactors can demonstrate safe operation as well as operating characteristics, such as: core loading and unloading; increase of neutron multiplication, approach to criticality; control rod calibration; power manoeuvres upwards and downwards; xenon (and samarium) transients; and reactivity control, reactivity changes due to experiment facilities, reactivity feedback coefficients and controlled (slow) and emergency (scram) shutdowns. Provision of a training control room (with a simulator) might be considered as well.

Research reactors used for educational and training purposes have to be designed to overcome, as much as possible, the constraints caused by education and training activities to other applications. For example, the core design should allow safe and easy introduction or removal of test sections or capsules with probes that may generate changes in the neutron flux and reactivity.

4.2. IRRADIATION

4.2.1. Neutron activation analysis

Neutron activation analysis (NAA) is a qualitative and quantitative analytical technique used to identify and quantify a material’s elements with extremely high sensitivity. It can be used in a variety of ways depending on the element and the levels to be measured, as well as on the nature and extent of interference from other elements present in the sample.

Next to education and training, NAA is the most simple and widely used application of research reactors. Almost any reactor of a few tens of kilowatts and above is capable of irradiating samples for some type of NAA. In addition, many of the uses of trace element identification can be linked directly to the potential economic benefits. Therefore, NAA should be looked at as a key component of most research reactor strategic plans.

Considering the neutron flux and the energy spectrum, irradiation positions can be located in the core, in the reflector, adjacent to the core or in beam ports. Although a minimum neutron flux of 10^{10} $cm^{-2}\cdot s^{-1}$ can be used for the determination of some elements in some matrices, a neutron flux greater than 5×10^{11} $cm^{-2}\cdot s^{-1}$ is desirable for the measurement of most elements. Additionally, to obtain an efficient process, the recommended minimum ratio between the thermal flux to the epithermal flux may be in the proximity of two orders of magnitude. Research reactors with higher power levels enable installation in the core of facilities with a high fast neutron flux in addition to high thermal flux for NAA.

Irradiation for NAA is often performed using a pneumatic sample transfer system (rabbit system). Considering the sample travelling time, as NAA is utilized to detect short half-life radionuclides as well, the design of the rabbit has to permit a short travelling time of a few seconds. Systems providing longer irradiation (e.g. manually operated systems) may also be used to detect longer half-life radionuclides or when longer irradiation time is needed.

The design requirements for auxiliary space for further processing the NAA may be summarized as follows:

- Appropriate space for the samples being analysed is required for sample preparation (e.g. drying, weighing and encapsulation). For these activities, standard laboratory equipment is needed such as a rotary mill or pulverizer for sample size reduction and homogenization. To avoid contamination of the samples, the provision of a clean laboratory environment may be necessary. Among other supplies, encapsulation materials (such as vials, plastic bags and quartz ampoules) and solvents for cleaning have to be provided.
- A counting room is required for gamma ray spectrometers, shielded from background radiation, and another room is needed for the storage of irradiated samples. Special attention has to be paid to the floor construction, which is needed to support the weight load of the shielding. The size of the rooms will depend on the extent of activities. Filters may be needed to minimize noise and ground loops in the electricity mains supply. The temperature of the counting room should be controlled and the radiation level should be continuously monitored. This counting room should be placed close to the loading station. It is recommended that the counting room be equipped with the necessary security and safety features.
- Calibrated radionuclide sources (either sets of single radionuclides or mixed sources) are needed for gamma energy calibration and detector efficiency calibration.

At least one gamma ray spectrometry system is needed to perform NAA. If a large number of samples are analysed for medium lived, long lived and very long lived radionuclides, a sample changer can be used to increase the efficiency of operation and to increase the throughput capacity, since samples can also be counted at night and during the weekends. A sample changer can also provide a more reproducible counting geometry.

4.2.2. Radioisotope production

The production of radioisotopes in a reactor involves the irradiation of target materials to create the desired isotopes, either by the transmutation of materials, fission or a combination of both. The specific requirements and irradiation parameters — for example, flux, irradiation periods, temperatures, etc. — are to be predefined for each application. Additional requirements for external equipment, such as handling facilities, transportation devices and hot cells, as well as waste stream evaluations, are significant factors in the overall planning of a production facility.

A radioisotope production programme involves several activities with connected necessary infrastructure such as: target fabrication, irradiation and transportation of irradiated targets to a dedicated laboratory, radiochemical processing or encapsulation in sealed sources, quality control, and transportation to end users. Each step needs experts from the respective disciplines, laboratory facilities equipped for the handling of radioactive material and other supporting infrastructure.

Almost every research reactor facility is capable of irradiating materials to produce certain isotopes in small quantities for research applications. In this way, they can supply the needs of their local users. This is often the practice around the world in university research reactors.

The production of significant quantities of isotopes for commercial utilization typically requires higher reactor power, complex logistics and a major investment in hot cell equipment for processing. Prospective isotope producers are advised to analyse international market prices, assess the market situation in their region and contact potential users to assess the potential customer base before making this a major part of their strategic plan for the facility.

The strong commitment of potential users is very important because commercial isotope production could involve major investments in hot cells equipped for related radiochemical processing. Strategic planning and feasibility evaluations for such facilities are thus essential prior to embarking on such a project.

It also has to be considered that commercial radioisotope production may create constraints for operating the reactor for other purposes, such as basic and applied research, which are usually the cornerstones of research reactor programmes.

As an indication of the required levels of neutron flux for commercial radioisotope production, the following values have to be considered:

(a) In reactors where the unperturbed thermal neutron flux is lower than 10^{13} $cm^{-2}\cdot s^{-1}$, the following radioisotopes can be produced: ^{24}Na, ^{32}P, ^{38}Cl, ^{56}Mn, ^{41}Ar, ^{64}Cu and ^{198}Au.
(b) In reactors with neutron fluxes in the range of 10^{13}–10^{14} $cm^{-2}\cdot s^{-1}$, and which operate in longer (weekly) cycles, the operational schedules may allow commercial production of radioisotopes. In addition to those listed above, the following radioisotopes can be produced: ^{90}Y, ^{99}Mo, ^{125}I, ^{131}I and ^{133}Xe.
(c) Reactors with higher neutron fluxes ($>10^{14}$ $cm^{-2}\cdot s^{-1}$), which usually operate in monthly cycles, are suitable to produce, in addition to the above mentioned radioisotopes, the following: ^{14}C, ^{35}S, ^{51}Cr, ^{60}Co, ^{89}Sr, ^{153}Sm, ^{169}Yb, ^{170}Tm and ^{192}Ir.

4.2.3. Neutron transmutation doping

This category of applications includes all those uses where the neutron and/or gamma radiation is used to cause a change in the material properties. Because transmutation effects usually require significant fluences to be induced within a reasonable time period, intermediate and higher powered reactors are needed. Additionally, to produce commercial quantities, fairly large irradiation positions are required with a highly thermalized uniform neutron flux.

Neutron transmutation doping (NTD) of silicon is the process of irradiating ingots of high purity silicon with thermal neutrons to convert some of the silicon to phosphorus through an (n, p) reaction. The advantage of this technique over non-nuclear techniques is the possibility of greater uniformity. The diameter of the irradiation cavity has to be large enough to accommodate the ingot, the coolant path, the canister containing the ingot and the flux monitor. Since the ingot diameter increases slightly during the irradiation process, this change in diameter has to be considered when designing the irradiation facility and will result in a big core configuration.

The facilities have to be designed to enable the control of the irradiation time and the neutron flux exposure of the ingot very accurately, in order to specify the required resistivity and operate within a very tight tolerance. In the technical specification, the dimensions of the ingots, the thermal to fast flux ratio, the needed resistivity and homogeneity should be defined. Along the radial axis, the required homogeneity can be accomplished by rotating the ingot while the longitudinal homogeneity can be ensured by using shaped shielding or lateral motion, or by a combination of both. The irradiation time of the ingots depends on the fluence and the resistivity demand.

In order to establish an NTD activity, there is a need to construct a dedicated laboratory for handling the radioactive material and supporting infrastructure, such as: measuring room with dosimeters, counting controlled storage room of samples before and after irradiation, waste treatment, quality control and transportation to end users.

4.3. NEUTRON BEAM APPLICATIONS

These applications use reactor produced neutrons that are extracted from the reactor through beam ports. The energy of these extracted neutrons covers a range from below thermal to several MeV. A wide range of experiments from fundamental physics to biological science can be performed using these beams. Medical irradiation also belongs to this group.

Beam tubes and neutron guides provide the connection between the reactor core (being the neutron source) and the experiments. Research reactor design may also include tangential beam tubes and curved neutron guides, avoiding direct view of the core in order to supress gamma radiation. The designer has to demonstrate that the system, consisting of core, reflector and beam tubes, is optimized and validated for the planned uses.

Additional systems and devices should be included in the design for neutron beam applications, such as:

(a) Dedicated platform to carry the additional systems;
(b) Provision of cooling flow circuit and leak detectors as necessary;

(c) Provision of compressed air and He flow circuits as necessary;
(d) Tools for handling the plug and the collimators;
(e) Provision of a vacuum pump and accessories as appropriate;
(f) Crane;
(g) Radiological shielding;
(h) Dedicated radiation monitoring system;
(i) Storage of irradiated plug or collimators and materials for experiments.

The special needs of some uses, such as a room for medical treatment, will be presented together with medical applications. A service room with controlled access to avoid accidental entrance to the high radiation area has to be prepared for handling irradiated material.

If the nominal operating power of the planned research reactors is in the range of several megawatts, the operating organization may consider including a cold neutron source (CNS) in the research reactor project, or installing it after some years of operation. The conceptual design of a research reactor assumes the availability of neutrons produced in a cold source, bearing in mind their decisive impact in basic, technological and industrial applications. To accommodate a CNS, the neutron beam tube diameter has to be designed accordingly (within a range of tens of centimetres).

It should be emphasized that the cost for construction of a CNS is very high, and the maintenance and operating costs are also high. This large investment cannot be possible without expensive, sophisticated instruments in order to obtain good measurement data.

4.3.1. Material structure studies

Material structure studies can be performed using the neutron beams in a research reactor in the low, intermediate and high power level ranges[5]. While it is still possible to perform some studies using low power level reactors, intermediate and high power level reactors are the most efficient for this application. Many high power level research reactors have been constructed primarily for this application.

Using various techniques, neutrons within a small energy band are selected for use in experiments. These neutrons are allowed to interact with samples using a wide variety of instruments. The instruments are referred to as ‘spectrometers’ and the experiments as ‘neutron scattering experiments’.

As a rule, only elastic scattering instruments using crystals are useful in reactors with a thermal power level of a few megawatts. When a CNS is installed with neutron guides at the reactor, the potential utilization is enhanced to the point that some quasi-elastic or inelastic scattering instruments can be installed and used effectively.

A neutron reflectometer utilizes the ‘optical’ phenomenon that neutrons colliding with the material surface undergo refraction and reflection if the refractive indices on each side of the surface interface are different. The reactor based diffractometer uses neutrons of single wavelength and measures the variable scattering angle using a single detector or a position sensitive detector. The accelerator based diffractometer uses a time of flight technique to give a continuous scattered wavelength scan at one scattering angle.

4.3.2. Neutron radiography

Static neutron radiography produces an image on film and/or digital media that has been exposed to the secondary radiation produced when neutrons from the reactor penetrate the specimen and interact with a neutron absorbing screen.

Low power level research reactors with a beam port are well suited for static neutron radiography. The thermal neutron beam intensity at the specimen position should be greater than 10^5 $cm^{-2}\cdot s^{-1}$ in order to avoid unacceptably long exposure times. Fast neutrons cause a loss of contrast in the film image due to specimen and shielding scattering. The use of a radial beam port requires filters and a collimator to produce a highly thermalized beam. Therefore, the use of a tangential beam port is preferable. Proper shielding design is very important for this application.

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[5] Low power < 1 MW, medium power 1–10 MW, high power >10 MW.

4.3.3. Prompt gamma neutron activation analysis

Prompt gamma neutron activation analysis (PGNAA) is an analytical method based on measuring prompt gammas by placing the sample in the reactor beam port along with the necessary counting equipment located adjacent to the port. The analysis is performed in real time with the irradiation and is limited only by the scarcity of suitable neutron beams at currently operating reactors. Typical applications include the analysis of gram sized or smaller samples in geological, atmospheric and materials sciences.

The design requirements for research reactors intended to be used for PGNAA may be summarized as follows:

- A beam port is needed to perform the analysis. A tangential beam tube is preferred for a better thermal to fast neutron ratio.
- PGNAA systems are operated with neutrons provided by a neutron guide, specifically bent guides, providing better signal to noise ratio. A guided beam, especially a beam of cold neutrons, will provide the highest intensity with the lowest background at the sample position. Guides also facilitate physical separation of the PGNAA spectrometer from the reactor and from other instruments that contribute to the low gamma background.
- PGNAA requires a well thermalized neutron beam with a flux greater than 10^7 $cm^{-2} \cdot s^{-1}$ over an area of several cm^2, although controlling a low background, some systems have been operated with fluxes as low as 10^6 $cm^{-2} \cdot s^{-1}$ at the sample irradiation position.

With regard to instrumentation, a high resolution gamma ray spectrometer is required. For data acquisition and for analysing the spectra, the working station has to consist of a computer based multichannel analyser, with commercial software to control data acquisition.

4.3.4. Medical applications

In most cases, a multipurpose research reactor limits the therapeutic application. As research reactors are usually located away from hospitals, there are certain limitations in providing a therapeutic environment, and so it is recommended that when medical applications are considered, there should be cooperation initially with another experienced research reactor centre. It is also advisable to obtain the commitment of the authorities responsible for public health care before the investment. It also should be noted that the reactor facility, while obviously very important, is only one component of a larger infrastructure necessary for the application.

To incorporate medical therapy facilities in a research reactor project, it is necessary to ensure an extremely pure therapeutic neutron beam and operating modes of short irradiation times. The main utilization of research reactors in medicine, other than isotope production, is an application using neutron beams for boron neutron capture therapy treatment (BNCT).

When ^{10}B absorbs a neutron it emits an alpha particle that is highly ionizing and has a range in tissue about equal to the diameter of a tumour cell. Therefore, the methodology in BNCT is to load a tumour with a borated compound and irradiate it with neutrons. Under proper conditions, the dose delivered to the tumour is much higher than that to the rest of the surrounding tissue, resulting in subsequent preferential killing of tumour cells.

Thermal neutrons are desired at the tumour location because the ^{10}B interaction probability is much higher with slower neutrons. Therefore, surface or shallow tumours can be irradiated with thermal neutrons, while those at a depth of a few centimetres can be irradiated with epithermal neutrons, which then become thermalized by the overlying tissue. A proper filtering system is needed to reach the highest capture probability.

Although this use requires low power level (≤ 500 kW) dedicated research reactors, the following recommendations for the design will permit the activity in a more powerful multipurpose reactor:

- A relative large diameter beam port to accommodate the filter system and the beam shutter;
- A shielded and radiation monitored treatment room to ensure patient safety;
- A room for medical facilities, e.g. for patient preparation before treatment;
- A quick access to the hospital and medical staff.

4.4. TESTING OF INSTRUMENTS

One of the uses of research reactors, whether low, medium or high powered, is for various methods of testing. Typically, the work involves neutron or gamma ray detection instruments that need to be tested.

The only facility requirement is accessibility to a well defined field of neutron or gamma radiation. Such a feature has to facilitate the process of inserting and removing the measured instrument in and out of the radiation field and adjusted as necessary. The tested system has to be installed outside of (behind) the reactor biological shielding. A fixed, well calibrated radiation field monitor is necessary as a reference to monitor the actual dose received.

The minimum power rating requirements from the research reactors for this use vary depending on the type of testing being performed. Nevertheless, as the application is assumed to be related to radiation protection instruments, the actual neutron flux and gamma radiation level requirements are assumed to be in the range of from several $\mu Sv \cdot h^{-1}$ to several $mSv \cdot h^{-1}$. These levels of radiation can be achieved by operating a reactor without limitation due the nominal power.

4.5. MATERIALS TESTING

Testing nuclear fuel and conducting experiments in closed loops running through the reactor core are highly specialized and sophisticated activities, and are usually only performed by experienced national laboratory level facilities[6]. These material irradiation programmes usually are closely linked to the support and development of national and, to a lesser extent, international nuclear power generation industries. The main advantage in the use of these research reactors lies in their typical high flux characteristics, which yields early results for ageing management, well controlled and instrumented in-pile test conditions and the potential for pre-commercial irradiations to support the licensing of new fuel. Such facilities should have specific safety features and detailed safety analysis [7, 13]. The minimum flux requirement for this type of work depends on the types of irradiation programmes, but generally thermal neutron fluxes above 10^{14} $cm^{-2} \cdot s^{-1}$ will be necessary.

Reactor facility requirements, including the construction and safe operation of fuel test loops simulating thermal-hydraulic core conditions in power reactors, should be developed. The hot cell facilities for irradiation and post-irradiation examination at the same location should be available, as appropriate. The testing equipment usually employed includes:

(a) Non-destructive testing (NDT) facilities (e.g. dimensional measuring equipment);
(b) Destructive testing equipment.

To carry the specimens into and out of the pool to NDT stations or to hot cells, transferring devices should be provided. The management of devices subjected to irradiation has to be as flexible as possible, allowing, in particular, the installation or removal of devices located at the periphery of the reactor while the reactor is operating.

An in-core loop will occupy space in the core or in the reflector region close to the core. The minimum reactor facility requirements are to equip a loop with:

(a) Temperature and pressure control and monitoring equipment;
(b) Equipment for fission product monitoring of the test loop coolant;
(c) Equipment for fluence monitoring of the specimen;
(d) Cooling facilities;
(e) Fuel performance monitoring equipment;
(f) Radioactive waste management programme.

All of these should be analysed as part of a comprehensive safety analysis.

Compared with previously mentioned uses, dedicated material testing reactors need high neutron fluxes in both the thermal and fast neutron energy domains, and an up to date experimental capacity using loops capable of

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[6] And require a high neutron flux level.

reproducing the power reactor environment. Therefore, it is most unlikely that a research reactor that is the first nuclear installation in a Member State will be used for materials testing other than basic research in a small scale experimental loop.

5. DESIGN REQUIREMENTS

This section provides the operating organization with guidance on design features that should be requested from the designer/manufacturer of the research reactor, with emphasis on the safety features of the design. This section should be read in conjunction with section 6 of NS-R-4 [6]. It also presents the requirements to be included in the BIS for the conceptual safety assessment of the design.

The reactor designer should consider not only the reactor itself but also any associated facilities that may affect safety. The achievement of the best possible design requires that a close liaison be maintained between the reactor designer and the operating organization. The mode of operation (e.g. operation on demand rather than continuous operation, operation at different power levels, operation with different core configurations, operation with different nuclear fuels) should be given due consideration in the design of the safety systems.

The BIS should require the vendor to provide the following information on the design in order to present the main characteristics of the research reactors:

- The definition of operational states, i.e.: start up, power operation, shutdown, refuelling, maintenance, etc.
- A list of structures, systems and components (SSCs), their design basis, and the methodology for the safety classification of SSCs based on their importance to safety.
- A description of design features that respond to usage and application requirements.
- A list and description of the safety functions that are required for the reactor.
- Accessibility to reactor premises during reactor operation.
- The possibility of testing safety systems during reactor operation.
- Availability and reliability requirements.
- Design provisions for radiation protection, radioactive waste management and fuel handling.
- Design provisions for commissioning, utilization, maintenance, ageing management, emergency planning and decommissioning.

5.1. MAIN SAFETY FEATURES OF THE DESIGN

The BIS should require the vendor to demonstrate that the design satisfies the requirements of defence in depth levels, including the following:

(a) According to the first level of the defence in depth concept, the research reactors should be conservatively designed, constructed, maintained and operated in accordance with appropriate quality levels and engineering practices, such as the application of redundancy, independence and diversity. As many initiating events as possible should be considered to test the design.

(b) To prevent anticipated operational occurrences from escalating to accident conditions, the design basis of operation has to be set conservatively, considering uncertainties in measuring systems. The departure of monitored parameters from nominal values to operational limits should be prevented by normal operating systems as the second level of defence in depth.

(c) Inherent safety features, fail-safe design, additional equipment and procedures to control the consequences of a design basis accident (DBA) and to achieve a stable and acceptable state of the research reactor following such events. According to this requirement, engineered safety features should be provided that are capable of transferring the research reactor first to a controlled state and subsequently to a safe shutdown state (third level of defence in depth).

(d) The fourth and fifth levels of the defence in depth concept require inclusion of provisions in the design for mitigation of the consequences of a beyond design basis accident (BDBA) and to ensure that radioactive releases are kept as low as practicable.

Regarding the safety requirements for the reactor core design, the BIS should refer to the following:

- The overall reactivity feedback coefficient should be negative through all operational stages and conditions. It should be measurable and the verification should be included in the commissioning programme.
- An adequate shutdown margin should be ensured in all operational states, including the case of a single failure of the highest reactivity worth control rod.
- Limitation of the maximum excess reactivity of the core.
- Limitation of the reactivity worth that might be inserted by a single action, e.g. experiments, operator action or single failure.
- Limitation of the rate of positive reactivity addition allowed by the reactivity control system.
- Limitation of the reactivity worth of experiments (fixed and non-fixed).

The design limits of the reactor have to be established on variables that can be directly measured in all operational states or on variables that can be readily related to a measurable quantity. These variables may include: neutron flux, neutron flux rate (reactor period), thermal power, fuel temperature, pressure drop across the core, inlet and outlet core coolant temperature, coolant level in the reactor pool, coolant flow rate in the reactor core, control rod position, etc.

Design limits for core cooling should be defined in order to prevent the occurrence of thermal-hydraulic critical phenomena, such as departure from nucleate boiling and flow instability, during steady state and transient operating conditions. These phenomena can lead to coolant boiling on the surface of cladding in the fuel assembly of the highest power density, which may cause cladding failure, leading to radioactivity release into the coolant and to its further escape outside the cooling circuit.

Passive decay heat removal from the fuel should be sufficient to prevent fuel damage, i.e. no fuel melting and no significant degradation of fuel containment capability. In case of a pool type research reactor, the water inventory of the pool should be enough to accommodate the decay energy without external cooling.[7]

It should be demonstrated in the design that the reactivity control system will function properly under all operational states of the reactor and will maintain its reactor shutdown capability under all DBA conditions as well, including failures of the control system itself.

At least one automatic shutdown system should be incorporated into the design (see section 6.90 of Ref. [6]).

No single failure in the shutdown system should prevent the system from fulfilling its safety function when required (e.g. with the most reactive shutdown rod stuck in the out position).

The reactor protection system should be capable of automatically initiating the required protective actions for the full range of design basis occurrences to terminate the sequence of events safely. This capability has to take into account the possible malfunction of parts of the system, i.e. single failures. Other design concepts such as fail safe, protection against common mode failures, physical separation and reliability should be considered in the design.

The reactor protection system should be designed in such a way that:

- Protective actions are initiated automatically.
- Once initiated, the protective actions proceed to completion and cannot be interrupted or prevented by manual actions.
- Manual actions will not be necessary within a certain period of time following an incident.
- Manual reactor trip signals should be provided as an input of the system and consideration should be given to the provision of the capability to initiate reactor shutdown from a remote location.

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[7] This requirement limits power and power density.

The safety system settings should be established with such a margin between the initiation point and the safety limits that the action initiated by the protection system will be able to control the process before the safety limit is reached, in compliance with the safety analysis results. Some of the factors in establishing this margin are:

- Inaccuracy of the instrumentation;
- Uncertainty in calibration;
- Instrument drift;
- Instrument and system response time.

All components of the protection system should be capable of being functionally tested.

Engineered safety features (ESFs) are mainly provided to limit or mitigate the consequences of anticipated operational occurrences and accidents. Examples of ESFs are: emergency core cooling system, confinement systems (particularly the emergency ventilation system), and others. The necessity for ESFs should be determined by the vendor in the safety analysis. The accidents which these systems have to cope with have to be identified and analyses provided which demonstrate that the systems fulfil the requirements. The systems and subsystems which are essential for the proper operation of the ESFs, have to be included in the design and should be provided.

The design basis and various modes of operation of an ESF should be determined and consideration should be given by the designer to:

(a) Component reliability, system independence, redundancy and the single failure principle, common mode failure, fail safe characteristics, diversity and physical separation of redundant systems.
(b) Selection of material able to withstand the postulated DBAs (radiation levels, radiolysis, etc.).
(c) Provisions for tests, inspections and surveillance should be implemented to ensure that the ESF will be reliable and effective upon demand.
(d) The ESF should meet all requirements for normal operation and overcoming the DBA, including external events and their combinations.

The radiation protection objectives need to be specified in accordance with local regulations and should comply with the values recommended by the IAEA and international safety standards in terms of dose limits for workers and the public [16, 17].

For radiation protection, the means for shielding; ventilation; filtration; decay systems for radioactive material such as delay tanks; decontamination and monitoring instrumentation for radiation and airborne radioactive material inside and outside the controlled area should be incorporated in the design. The means of monitoring and controlling the access to the reactor and to its experimental devices and facilities for inspection, testing and maintenance should be part of the design as well. When equipment for radiation protection such as devices for counting, decontamination, monitoring and controlling access are provided by the vendor, the manuals for operation, maintenance and calibration have to be provided to the operating organization.

The requirements presented in NS-R-4, paras 6.50–6.51 [6], are relevant to the safe design. To facilitate decommissioning, consideration should be given to the design of the reactor and its experimental devices. In this respect, attention should be paid to the application of methods keeping the exposure of personnel and the public during decommissioning as low as reasonably achievable and ensuring adequate protection of the environment from undue radioactive contamination. In addition, all design requirements and information relating to final design and construction have to be retained as part of the input information needed to assist in decommissioning.

It is essential that the operating organization provide data related to national regulation and local practices on buildings and structures for the waste treatment and temporary storage facility. If the operating organization is planning to use an existing building for the reactor or auxiliary utilization facilities, the relevant information has to be provided to the vendor. The following seismic national requirements have to be supplied by the operating organization, to allow the vendor to evaluate the integrity of the buildings and structures, and to generate floor response spectra:

- Safe shutdown earthquake (SSE) values in the vertical and horizontal directions;
- Ground motion response spectra (GRMS);
- Hard rock uniform hazard response spectra (UHRS).

International, national and local requirements that should be met in physical protection and security need to be provided by the operating organization. Considering the design of physical protection, the operating organization has to provide information on site security strategy, security rules and the accessible routes to the reactor site.

5.2. FLEXIBILITY IN OPERATION AND MAINTENANCE

The ‘easy care’ features of the design refer mainly to the following (additional detailed requirements and guidance are provided in Refs [6, 18]):

- User friendly, flexible and easy to maintain.
- Provision of an extended period of time between physical inspections or maintenance of reactor systems.
- Reduction of the need for local human actions through the use of automated systems.
- Refuelling the core is not frequently required and can be easily carried out.
- Radiation levels during operation are minimized, and the radiation level in the reactor hall is low enough to allow workers and users to access the hall during reactor operation.
- The human–machine interface is based on proven, state of the art technology and is demonstrated to be user friendly.
- Design features to ease maintenance are included, such as the provision to store coolant during pool maintenance activities.

The design should provide easy access to the reactor core and to the experiments. The demands on the operator should be minimized by the design so as to reduce the burden on the operator and minimize human error by using clear displays, audible signals and automated safety actions.

The operating organization should request from the vendor provision of a spare parts list and maintenance manuals. When appropriate, the operating organization may request the standardization of components used throughout the facility to provide a high level of spare parts availability with a minimal spares inventory. The vendor has to provide the special equipment or facilities required to carry out the necessary maintenance activities. The vendor has to indicate the number of maintenance personnel as well as the level of training required for their qualification.

5.3. RESPONSIBILITIES OF THE OPERATING ORGANIZATION

Input should be provided by the vendor for the information required from the operating organization in the following paragraphs.

Considering the design for emergency planning, the operating organization is responsible for emergency planning. The design requirements related to emergency response should include the requirements on the alarm system, communication system, response centre and environmental sample laboratories, as appropriate.

Considering the management of the radioactive waste of the facility, when the reactor is to be built on a site where the facilities for treatment and temporary storage are available, the operating organization needs to inform the vendor of the boundary conditions or the limitations on transport, storage and treatment. When the facilities for radioactive waste treatment and temporary storage are to be built together with the reactor, the operating organization has to ask the vendor to provide the facilities to accommodate the requirements posed by the radioactive waste from the reactor operation and utilization [16, 17].

As for the airborne releases from the facility, the operating organization should require from the vendor confirmation that the doses due to the releases satisfy the safety criteria. Atmospheric condition data have to be provided by the operating organization, as agreed upon in the contract.

5.4. ADDITIONAL REQUIREMENTS FOR THE VENDOR

The vendor has to provide information on the implementation of measures in each of the five levels of defence in depth [19]. For the first level, special attention has to be paid to the strategy of reactor use and of the users' expected demands in order to propose a design suitable for newcomers. For the fourth level of defence in depth, the aim is to maintain subcriticality of the core under water. For the fifth level of defence in depth, the foreseen emergency planning management strategy has to be indicated, and the requirements for information exchange with the emergency planning management centre have to be specified.

The vendor has to identify and implement prevention and mitigation measures for all PIEs in the design of the facility. The mitigation measures should be actuated by engineered safety features or on-site procedures established by the operating organization, eventually assisted by the vendor.

The vendor has to present a description of the methodology used for the safety classification of SSCs. This information has to include:

(a) The number and description of safety categories or classes adopted;
(b) The requirements on the design, quality assurance (QA), time of performance, and time between maintenance requirements for SSCs in each safety category.

Acceptance criteria have to be established for all SSCs performing a safety function. Moreover, the vendor should provide a preliminary list of acceptance criteria, such as actuation time, acceptable delays and negativity reactivity worth inserted by the shutdown system, and the means used to demonstrate that the acceptance criteria are met by the design. The vendor has to describe the design of all SSCs in each operational and accident state.

The vendor should provide a list of all the codes and standards that will be used in the design and construction of the reactor. This list should include mandatory national standards and international standards, including the IAEA safety standards. This list should remain contingent on the acceptance of the operating organization and the regulatory authority. In the absence of such codes and standards, the results of experience, tests, analyses or a combination of these may be applied, and this results based approach has to be justified. Therefore, the vendor should provide a clear explanation of how this approach will be implemented in the design process.

Computational tools are used extensively in the safety analysis of research reactors. The operating organization of the research reactors should require from the vendor all necessary information on the computational tools that are used in the safety analyses of the facility. The types of information that should be presented include: name and description of software, supplier, range of application and previous experience.

Codes used for the design and safety analysis of the reactor should have a record of validation and verification for their use in these applications. The vendor has to provide information on previous experience with the code and the work done previously to demonstrate that the software is applicable to calculate the conditions of the reactor. This information may help in the evaluation.

The applicability of all correlations, equations, approximations and models to the range of conditions analysed with the software has to be demonstrated, and the information for this demonstration has to be provided by the vendor.

The vendor has to provide all information pertinent to the verification of the code, clarifying whether the verification has been carried out by the author or vendor of the code, or by an independent reviewer. The correctness of the verification and validation process should be checked.

5.5. FUEL DESIGN

The applicable requirements for quality assurance, acceptance tests, etc., should be as recommended in the IAEA safety standards [6, 20, 21]. The fuel elements should use low enriched uranium (LEU).

The fuel assembly design has to take into account the neutronic, thermal-hydraulic, mechanical, material, chemical and irradiation constraints associated with the reactor as a whole.

The proposed fuel should be fully qualified by the vendor or fuel supplier and its performance specified regarding power, power density, irradiation period in the core, burnup, dimensional change and hydraulic stability.

Other parameters have to be demonstrated for a similar period of operation in an operating reactor with similar operating conditions.

Considering neutronic data, an assessment should be provided by the vendor to prove that the reactivity characteristics of the core and the core control systems and experiments are such that reactivity addition capacity and shutdown capability comply with applicable safety criteria.

With regard to the thermal-hydraulic data, all necessary information should be provided to prove that, under normal operating conditions, adequate core cooling capacity will be available to keep the reactor fuel in a safe condition, and that an adequate thermal safety margin will be available to prevent fuel damage in case of anticipated operational occurrences and DBAs[8].

Basic information on thermal-hydraulic core design should comprise all thermal-hydraulic characteristics of individual core components and of the core as a whole for the anticipated operational occurrences of the primary coolant and emergency cooling systems. Uncertainties have to be included in the thermal-hydraulic calculations.

An assessment should be provided proving that the maximum thermal load to which any fuel assembly in the reactor core is subjected during any operational states does not exceed the available cooling capacity. The power distribution in all core components is derived from the neutronic calculations. The assessment has to lead to the determination of a thermal safety margin for the core, e.g. passive core cooling capacity in case of loss of primary coolant pumps.

Required fuel data:

- U mass and enrichment;
- Fuel material data and properties;
- Cladding material data and properties;
- Dimensions of the fuel assemblies/element and the associated components (e.g. fuel meat and wall thickness, plate length, width, rod diameter, active length).

Required core data:

- Core configuration and composition such as the type and anticipated loading pattern of fuel assemblies, control elements and other components which affect the nuclear properties of the core;
- Three-dimensional distribution of neutron flux within the core and irradiation positions;
- Reactivity characteristics of the core for the different operational states;
- Power peaking factors.

Fuel management:

- Description of the fuel management strategy, including strategy for achieving the equilibrium core;
- Refuelling interval based on flux demand and burnup calculations [21].

On-site spent fuel storage and transport requirements have to be defined by the operating organization. The organization should provide the design input arising from nuclear material safeguards requirements.

At least enough fuel assembly for the first core (in certain cases for the first equilibrium core) should be provided by the vendor. The operating organization should specify the provision of fuel elements during further periods of operation.

In phase 1 of the project to build a new research reactor, it is emphasized that the operating organization is responsible for the fuel back end strategy [1], independent of the future technical solution such as reprocessing, long term storage or any other. This may have an important impact on the project and reflects the IAEA recommendation to minimize long term on-site fuel storage.

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[8] This requirement limits power and power density.

5.6. CONCEPTUAL SAFETY ASSESSMENT

The main deliverable related to safety during the design phase will be the preliminary safety analysis report (PSAR) prepared by the vendor based on the safety oriented description and safety assessment of the facility [22]. The PSAR is not part of the bid. Nevertheless, at the bid stage, a conceptual safety assessment should be prepared by the vendor to demonstrate compliance with safety acceptance criteria and objectives. The generic process for the safety analysis is described in IAEA publications [7, 22].

The main approach for the safety demonstration has to follow deterministic methods, though probabilistic methods can be used as a complementary tool. For deterministic methods, the approach dealing with accident sequences and emergency planning should be defined. For probabilistic methods, the risk integrates the likelihood and severity of each of the consequences. The vendor has to describe the approach to safety in the design.

A safety assessment is an integral component of the design process and has to be carried out following standard practices [7]. It provides a feedback mechanism to the designers for verification that the proposed design solutions comply with safety acceptance criteria. Therefore, some preliminary assessment of the safety of the facility has to be part of the documentation required from the vendor during the bidding process. Figure 1 summarizes the safety assessment process.

The safety assessment should meet all the national regulatory requirements for the licensing of a facility. This will influence all the steps of the safety assessment such as:

- Selection and identification of initiating events;
- Establishment of the accident sequences;
- Evaluation of the consequences;
- Comparison with the acceptance criteria.

The contents of the conceptual safety assessment should include the following [7]:

- Selection of PIEs;
- Definition of rules and conventions;
- Identification of acceptance criteria;
- Demonstrating assessment of bounding accident sequences;
- High level system analysis.

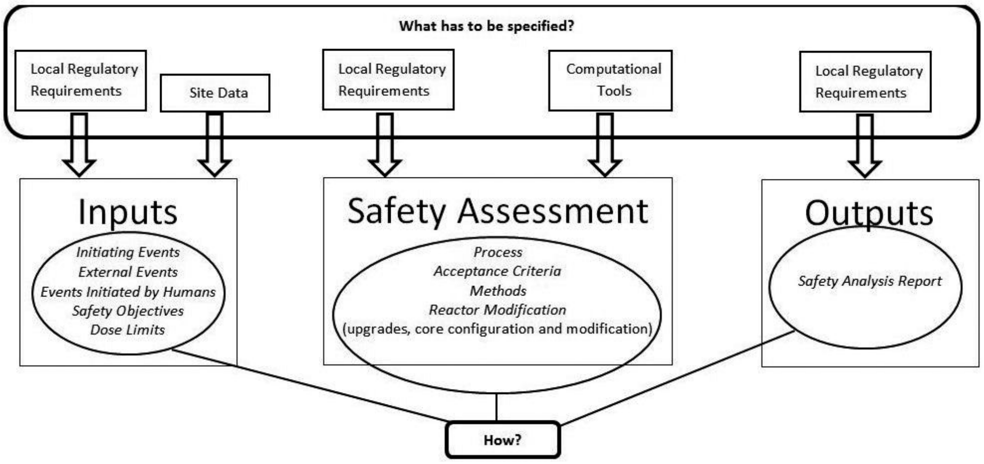

FIG. 1. Diagram of the safety assessment process.

A PIE refers to an unintended event, including an operating error, equipment failure or external event influence, which directly or indirectly challenges the basic safety functions. These events necessitate protective actions (automatic or manual) to prevent or mitigate undesired consequences to reactor equipment, reactor personnel, the public or the environment [6, 7, 22]. Initiating events related to utilization should be identified and included in the list of PIEs [7, 22]. The list of PIEs has to be provided by the vendor and be independently evaluated by the operating organization. The proper set of PIEs provides the basis of the safety analysis, therefore the list of PIEs should be comprehensive and the selection of the bounding events (if any) should be correct. Checking the set of PIEs is a fundamental part of the technical evaluation.

For the evaluation of the PIEs, the operating experience from similar facilities, including examination of event reports and the database of the IAEA's Incident Reporting System for Research Reactors (IRSRR), might be used. A generic list of PIEs is presented in appendices to IAEA Safety Standards Series publications [7, 22], including examples for different reactor designs.

Incidents or accidents may occur whenever a failure, malfunction or incorrect operation of a system or device component challenges the fulfilment of one of the three basic safety functions. Once a release of radioactive material is foreseen, either during normal operation or as the consequence of an accident sequence, this release should be controlled in the case of normal operation and limited or delayed in an accident condition occurrence.

Acceptance criteria may be categorized as basic and specific. Basic acceptance criteria are usually defined as limits set by a regulatory authority and have to be provided to the vendor. Examples of basic criteria are the maximum allowable occupational doses to the nuclear workers and doses to the public, used in the design for prevention of fuel failures. To prevent fuel failure, the analyst may choose to use specific acceptance criteria such as maximum heat flux not exceeding the critical heat flux (CHF) during a transient.

6. PERSONNEL MANAGEMENT

This section provides guidance on the reactor organizational structure, together with the training requirements for operating organization personnel. The operation of research reactors requires an appropriate organizational structure that is clearly defined and staffed with competent managers and qualified personnel possessing a proper awareness of the technical and administrative requirements for reactor operation, utilization and safety [23].

The organizational structure may change during the lifetime of the reactor, from the beginning of the project for site evaluation, design and construction, through the time of commissioning, operation and utilization, modification and decommissioning.

It is the responsibility of the operating organization to require the vendor to recommend within the bid specifications an appropriate management structure of the proposed research reactor. The vendor has to specify the staffing requirements for the various disciplines within the operating organization structure, along with the required qualifications and training programmes, and identify the key personnel.

The operating organization should also require the vendor to recommend and provide information related to the educational level for various reactor positions, in addition to the content and duration of initial and ongoing training and subsequent assessments. The description of the responsibilities and competences needed for each position have to form the basis for the required qualifications and for recruiting, education and training of personnel [23].

The operating organization should require the vendor to provide a description of the training programme for operating personnel and a commitment to provide material for future training. This programme should target training for reactor managers, reactor supervisors, reactor operators, maintenance technicians and radiation protection personnel. The topics have to cover different areas of technology, maintenance, theoretical and practical knowledge of reactor systems, their function, layout and operation. The requirements for qualification have to be defined by the national authorities in Member States [2, 23].

6.1. NECESSARY OPERATING PERSONNEL

The operating organization has to be aware that long term safe operation of research reactors requires qualified personnel such as: reactor manager, nuclear safety officer, reactor shift supervisors, reactor operators, experiment technicians, radiation protection staff, maintenance staff and QA officers. In addition, staff for technical services and technical support to the reactor operation (such as staff for neutronic and thermal-hydraulic calculations, safety analysis, training, security staff, etc.) could be included within the operating organization. The number of reactor operating personnel depends largely on the number of operating shifts and on the national rules and regulations.

The number of operating personnel depends on factors such as operating time, number of shifts, complexity of the facility and maintenance demands. As an example, the functions of a typical low or medium power research reactor[9] with one shift are listed in Table 1.

TABLE 1. TYPICAL LOW OR MEDIUM POWER RESEARCH REACTOR WITH ONE SHIFT

	Function	Remark
1	Reactor manager	Morning shift only (could be a licensed position based on national regulatory requirements)
2	Shift supervisor	Licensed position
3	Reactor operator	Licensed position
4	Experiment operator	Not necessarily a licensed operator — number and requirements based on the existing experimental facilities and the national regulations
5	Radiation protection manager	Morning shift only (specific permission may be required by the regulatory body — could be a licensed position)
6	Radiation protection officer	Licensed position
7	Maintenance engineer	Morning shift only (specific permission may be required by the regulatory body)
8	Maintenance staff (electro-mechanical, instrumentation and control, etc.)	Other maintenance staff may be on-call
9	Nuclear safety officer	Morning shift only
10	Quality assurance officer	Morning shift only

7. DOCUMENTATION

This section provides guidance to the operating organization on which documents, information and services should be requested from the vendor in the bid technical specifications. Based on the information provided by the vendor, the operating organization should implement a management system [20, 24] for reactor operation. It is important to mention also that the management system of the vendor should be described in the offer and should cover the different stages of the research reactor project (design, procurement, fabrication, construction, and commissioning). Such a programme should be subjected to audits by the operating organization. The requirements for such audits (number, steps, contents, etc.) may be included in the technical specifications of the bid. It is expected that the regulatory body will require a defined set of documents at project hold points to approve further actions.

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[9] Low power < 1 MW, medium power 1–10 MW, high power >10 MW.

7.1. LICENSING DOCUMENTS

The operating organization has to ensure that the vendor is obligated to provide the information necessary to successfully achieve project milestones as well as during the reactor operating phase [1]. These documents include:

- Safety analysis report, preliminary and final (which includes the commissioning results);
- Reference documents of the design;
- Reference documents to support the safety analysis;
- Operational limits and conditions;
- Commissioning programme with its associated procedures, and commissioning test results;
- Operation manuals and procedures;
- Quality assurance manual and procedures;
- Emergency plan;
- Specific documentation required by national or local authorities (e.g. environmental impact report).

7.2. DESIGN CODES AND STANDARDS

The vendor has to supply a complete list of the industrial codes and standards used in the design process of the structural, mechanical (piping and vessels), electrical, instrumentation and controls, and any other non-nuclear standards.

7.3. DESIGN BASIS DOCUMENTATION

The vendor has to provide the design documentation at various stages of the project:

(a) Conceptual design;
(b) Basic engineering design;
(c) Detailed engineering design, based on a standard previously agreed upon.

Moreover, at the completion of the project, the vendor should provide a complete set of as-built design documentation.

The list of drawings and documentation to be supplied by the vendor includes, but is not limited to, the following:

- Site (including the surrounding area) plans;
- Reactor building and facilities;
- Reactor structures and internals;
- Cooling systems, including piping line diagrams;
- Instrumentation and control system;
- Process and instrumentation diagrams;
- Electrical line diagrams;
- Electrical component layout;
- Ventilation systems;
- Mechanical component detailed fabrication.

The contents of this list may vary according to national regulations and should be specified by the operating organization.

With regard to the procurement, fabrication and construction packages, the following should be provided by the vendor:

(a) A list of SSCs with their classification with respect to safety;
(b) Fabrication and construction packages, including QA documents of fabrication and factory acceptance tests results.

The operating manual for all SSCs should be handed over, including those purchased from third parties. The vendor should provide a spare parts list for all SSCs.

The list of design and calculation documents to be supplied by the vendor includes, but is not limited to, the following:

(1) Core (neutronic and thermal-hydraulic) and core component design;
(2) Fuel design;
(3) Design of primary and secondary cooling systems;
(4) Seismic and structural calculations;
(5) Piping stress analysis;
(6) Design of ventilation systems;
(7) Electrical loading, fault protection and grounding analysis;
(8) Radiation shielding;
(9) Environmental impact calculations;
(10) Radiological releases assessment;
(11) Waste management.

The content of this list may vary according to national regulations and should be specified by the operating organization.

7.4. TECHNICAL SPECIFICATIONS OF STRUCTURES, SYSTEMS AND COMPONENTS

The operating organization should request the vendor to supply the technical specifications of all SSCs. The specifications have to be associated with individual systems that perform well defined functions included in the design documents of the facility. The information should illustrate in detail the:

- Intended function of the system;
- Design requirements of the system which ensure that the design function will be met;
- Codes and standards used;
- Equipment qualification.

7.5. OPERATING PROGRAMMES AND PROCEDURES

The operating organization of the reactor should require the vendor to provide the operating procedures needed to operate the reactor safely and efficiently. These procedures have to be fully verified during the commissioning. The format and standard of the content of the procedures should be agreed upon between the operating organization and vendor, and should be in line with IAEA safety standards on operational limits and conditions (OLCs) [25]. The procedures should cover the following topics:

- Normal operating procedures. The vendor should provide procedures for the startup, shutdown, and continuous operation of the facility.
- Alarm response procedures. A procedure should be provided for each control room alarm. These procedures should detail the instrument that actuates the alarm, the set point of the alarm, automatic reactor responses to the alarm and the actions taken in response by the operators.
- Abnormal and emergency operating procedures. Procedures in response to analysed reactor transients.

Surveillance test procedures for safety systems and technical surveillance requirements should be written and tested by the vendor in cooperation with the operating organization to ensure the required performance of safety systems.

7.6. MAINTENANCE, PERIODIC TESTING AND INSPECTION PROGRAMME PROCEDURES

The vendor should provide maintenance manuals and procedures related to the supplied equipment to enable the operator responsible for maintaining the reactor's SSCs to keep them in such condition as to perform their tasks as designed throughout the lifetime of the facility. Being responsible for the design of the facility, the vendor should assist the operating organization in developing adequate maintenance, periodic testing and self-inspection programmes. It is recommended that maintenance procedures be verified before they are formally approved, in a similar manner as the operating procedures. A preventive maintenance programme specifically defines the components requiring, periodic testing, inspection and maintenance [18].

The procedures supporting the maintenance programme define the work to be done, the parts needed to be maintained and the tests that should be performed upon reactor shutdown. As the SSCs in research reactors might be subjected to harsh environments such as high temperature and/or high radiation, the programme should also include a monitoring programme. Hence, the vendor should define which SSCs have to be subjected to monitoring according to the environment qualification (EQ) programme, what requirements are in the EQ programme and how to carry on the programme.

Considering that even new facilities can suffer the effects of components ageing in a relatively short time, the vendor should prepare a reliability and ageing management programme for the facility and should provide the calculations or estimates for the expected lifetime of individual components within systems, assuming correct operation and maintenance in the expected environment. Based on these assumptions, the reliability and ageing management programme established by the operating organization should ensure that SSCs are not degrading before their expected end of life, thereby affecting sustainable, reliable, safe and secure operation.

A preventive maintenance programme should be proposed by the vendor, including regularly scheduled inspections, testing, servicing, overhauls and replacement activities. The purpose of the programme is to enhance the reliability of equipment, to detect and prevent incipient failures, and to ensure the continuing capability of the reactor's SSCs to perform their intended functions.

Some components require periodic testing and surveillance in order to satisfy the requirements of the operating manuals. The vendor should provide the operating organization with an in-service inspection and testing programme that includes a list of all components requiring periodic inspection or testing. The vendor should recommend which components of the facility should be monitored continuously or periodically and the time interval of monitoring.

Additional requirements may be imposed by local regulations. These requirements have to be clearly specified by the operating organization.

7.7. WASTE MANAGEMENT

The vendor should provide to the operating organization the calculated values of the gaseous, liquid and solid wastes produced by the reactor and by the experiments (provided by the vendor together with the reactor facility) during routine operation.

With the assistance of the vendor the operating organization should develop an operational waste management programme. This should include procedures for handling and treating the waste and determine the final disposal methods and pathways of the waste [17].

7.8. CONFIGURATION MANAGEMENT PROGRAMME

The vendor should assist in the development of an information management system to help the operating organization control the documentation of all SSCs. An active configuration management system is an absolute requirement for nuclear reactor management to ensure that any changes made to SSCs do not have a negative impact on facility safety and security. This system has to include a systematically organized item list tracking all SSCs [20].

7.9. MANAGEMENT SYSTEM

The vendor should assist the operating organization in establishing a management system for operation and maintenance, including a QA programme [20].

7.10. TRAINING PROGRAMME

Training programme documents for every position in the reactor operation chart have to be provided by the vendor. The programme should include syllabuses, schedules, prerequisites, etc. Training materials should also be provided. It is recommended that the training obligations of the vendor be included explicitly in the contract.

7.11. OTHER DOCUMENTS THAT MAY NOT BE PROVIDED BY THE VENDOR BUT REQUIRE ITS INPUT

The following subjects should be documented by the operating organization, based on the input of data received from the vendor:

(a) Security. A vulnerability assessment should be prepared to ensure that nuclear material is controlled in a secure manner. The vendor should document which provisions have been taken in the design for the security of nuclear material.
(b) Emergency response and preparedness. As the environment around the reactor may be subject to potential releases of radioactivity during accident conditions, emergency planning zones should be defined by the operating organization in agreement with national regulations, based on the inputs provided by the vendor. Having the inputs, the operating organization should prepare an appropriate emergency response plan to ensure public safety.
(c) Environmental, safety and health programme. The operating organization should adopt standards on how to protect workers from industrial hazards such as fire, rotating machines and chemical products. However, the vendor should consider worker safety and health measures as well during design and construction. For example, for the lockout or tag-out of hazardous energy sources, the facility should be designed in such a manner that workers can easily isolate hazardous energy sources in order to perform routine maintenance, inspection and testing. The vendor should provide a list of suggested isolation points for routine operations and maintenance activities.
(d) Radiation protection. Based on the data provided by the vendor, an operational radiation protection programme should be developed by the operating organization to ensure for reactor personnel and the public that the dose is as low as reasonably achievable, based on the Member State’s legislation.
(e) Safety review process. The operating organization may seek the assistance of the vendor in developing a programme to review proposals for modifications and experiments. During the review process their impact on safety (e.g. reactivity, thermal-hydraulic and mechanical effects) that could have an influence on safe reactor operation should be investigated.

8. INFRASTRUCTURE DEMANDS

This section deals with the infrastructure demands that have to be specified by the operating organization to the vendor in order to enable the vendor to consider them in the design and implementation activities of a research reactor facility [6]. The information on the infrastructure needed to be supplied by the operating organization of the research reactor should enable the following design and implementation activities:

- Construction;
- Technical support of facility operation;
- Utilization.

If the reactor is built on an existing site, some of the necessary infrastructure may already be available from the operating organization. In this case, the existing infrastructure might be expanded or further developed in order to accommodate the new facility requirements, taking into account the new construction, future operation and utilization.

If the research reactor will be the first nuclear facility of the Member State or operating organization, the vendor should prepare a list of specific requirements regarding the infrastructure.

8.1. INFRASTRUCTURE FOR THE CONSTRUCTION

For the construction, the specifications provided by the operating organization to the vendor have to define the following:

- The main characteristics of a new or existing infrastructure suitable for construction — such as electrical supply, road access, water supply, communication means, sewage removal, accommodation for personnel, storage areas and buffer zones around the construction site — should be outlined.
- The constraints resulting from existing infrastructure and practices and their corresponding requirements should be expressed. The typical concerns are: firefighting; site security; local regulations of the State pertaining to construction; and site rules.
- Commissioning is an important part of the project, during which the operating organization should study the characteristics of the facility supplied by the vendor. Moreover, commissioning is a good opportunity for the operating organization to accrue experience with the facility. Thus, it is strongly recommended for the operating organization and the vendor to establish a joint safety committee [6], where the major issues and experience during commissioning are discussed and considered. The requirements on this safety committee should be specified by the operating organization in the BIS, while the vendor should propose a plan to meet the requirements.

8.2. INFRASTRUCTURE NEEDED TO SUPPORT THE OPERATION

For facility management, technical support is required ranging from the training of staff to the guiding of visitors. The operating organization should have a plan for technical support of facility operation. Based on this plan, the operating organization has to provide requirements to the vendor such as:

- Training facilities for the staff;
- Thermal-hydraulic test laboratories[10] for the reactor, as appropriate;
- Machine shops supporting the reactor operation, maintenance and experiments;
- Facility for calibration of instruments;

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[10] These tests may include pressure drop tests, vibration tests, leak tests and heat transfer tests for the reactor and experimental facilities.

- Laboratories governed by national regulations for the assessment of external and internal exposure;
- Laboratory for environmental monitoring;
- Infrastructure for security[11];
- Exhibition facility for general visitors.

8.3. INFRASTRUCTURE FOR UTILIZATION

The infrastructure for utilization includes both software and hardware support for users. ‘Hardware’ infrastructure includes: a guest house for researchers and visitors, as appropriate; sample preparation rooms; and offices and meeting rooms for the users.

The software infrastructure system encompasses the mechanisms for communication between users and between operators and users for the exchange of information, submission of user requests, archiving of achievements and results, etc. A web based system is recommended.

The operating organization should have a plan on how to prepare the needed infrastructure for utlization and should specify the role of the vendor. The provisions for communication may be a part of the supply or could be prepared separately.

The degree of infrastructure for utlization depends highly on the applications. If the reactor will be used for material structure studies, the operating organization may need sample preparation laboratories. If the reactor will be used for materials testing or radioisotope production, dedicated laboratories and hot cells should be required. If they are not already available at the site, or not suitable for the new applications, they should be supplied together with the reactor. These will depend on the strategy defining the reactor’s intended use. For more details, see Section 4.

9. BID EVALUATION PROCESS

This section seeks to assist the Member State in evaluating the bids offered for the establishment of its research reactor facility. The evaluation of the bids is a major task, and thus several months are generally needed to complete it. During the bid evaluation process, all aspects of the technical, economic, financial and contractual approaches should be considered [23]. The basis of the evaluation should be the criteria that have been included in the BIS (see Section 3.8).

The evaluation of bids is often divided into two parts: technical evaluation and economic evaluation. Those parts are very closely linked together. This publication deals with the evaluation of bids as a single process that consists of several parallel and sequential activities. However, due to different methods, the technical evaluation and economic evaluation are described separately.

The main references for the bid evaluation are:

- BIS prepared by the operating organization and/or its consultant organizations;
- Bid documents prepared and submitted by the bidders;
- The conceptual safety assessment prepared by the bidders;
- Results from the survey of the bidders, as applicable;
- Results of previous studies carried out regarding the project such as feasibility study, technology assessment, etc.;
- IAEA safety standards and the research reactor milestones publication [1].

In applying the above references for bid evaluation purposes, it is necessary to distinguish between the nature of the various types of information available. Whereas BIS and bid documents in most cases contain binding provisions which will later become part of the contract, the other provisions included in this publication serve

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[11] Guard office, turn gate facility, inspection machine, barrier for threats, etc.

merely as backup provisions unless they might also become part of the contract. This has to be taken into account in evaluating the bids and in using the information provided by a particular bid.

A great help in evaluating bids is the possibility to refer to similar projects already under construction or in operation. Preferably, these projects should be of the same size and design; moreover, the sites should also be similar to the one under consideration.

It is important for the preparation and organization of the bid evaluation that sufficient time is available and that one can start with the evaluation as soon as the bids have been received. The time required for this preparation depends on the available experience and may last several months. Therefore, it is advisable to make preparations for the bid evaluation immediately after issuing the BIS.

9.1. TECHNICAL EVALUATION

The basis for the bid evaluation should be the information provided by the vendor in the technical documents of the bid and in the conceptual safety assessment. Fulfilment of the safety functions should be one of the cornerstones of the bid evaluation. Other aspects to consider in the bid evaluation include operability, maintainability, application and utilization.

During the evaluation, the operating organization has to confirm that the safety requirements set out for the design process and the design itself meet the condition of the BIS. To assess whether the safety objectives have been met, different methods can be developed.

The bid evaluation process should include the analysis of the conceptual safety assessment, demonstrating that the reactor can be operated safely, and control the accuracy of the results of the source terms and radiological release calculations used for purposes of operation and emergency planning.

The probability and consequences of radioactive releases resulting from PIEs and accident sequences should be evaluated and compared with the BIS requirements.

The adequacy of the design for the characteristics of the selected site, including the requirements and acceptance criteria, should be an important part of the evaluation process.

The adequacy of the set of acceptance criteria should be controlled and evaluated. Acceptance criteria are usually applied by the designer (vendor) to judge the acceptability of the results of safety analyses [6, 7, 22].

Specific acceptance criteria may be defined by the vendor if found acceptable by the operating organization. Examples of specific acceptance criteria are the values to be used in order to include additional margins that are more conservative than the basic acceptance criteria. These values should allow for uncertainties and provide additional defence in depth.

The adequacy of the information provided by the vendor about computational tools applied during the design and safety assessment should be considered and checked in the evaluation.

The evaluation should include the control of input data to the codes used or the conceptual safety assessment, with a description of the applicability and the cases to which the data correspond. The technology transfer agreement between the operating organization and vendor has to define the amount and extent of code documentation supply. If appropriate within the technology transfer agreement, the vendor should specify the extent and type of training that will be provided on the use of safety analysis computational tools.

9.2. ECONOMIC EVALUATION

The objective of making an economic evaluation of bids is to rank the bids according to costs and evaluate the resulting cost differences. In addition to ranking the bids by using a selected criterion, the economic evaluation usually provides additional information for the selection, as required. In this publication, the subject of economic evaluation is not presented in detail, only the most important issues are touched.

The cost evaluation is based on the following data and information:

- — Bid prices, as adjusted to reflect differences in the scope of supply through the scope equalization process (negotiation);
- — Bids for first full core and several reloads of fuel, depending on the requirements of the BIS;

- Fuel cycle back end options and cost estimates;
- Operation and maintenance cost estimates;
- Waste management and decomissioning cost estimates (operational waste and decommissioning).

Part of the information for the cost evaluation comes directly from the vendor, while some of the information should be derived by the vendor from the information presented in the bid. For example, waste management, fuel back end, operation and maintenance cost estimates will be obtained by the operating organization from the design information provided by the vendor.

Other important factors that should be considered in the bid evaluation are:

- Results of the technical bid evaluation and corresponding interfaces;
- Deviations from required commercial and contractual terms and conditions;
- Deviations from required financing terms and conditions;
- Options for further fuel supply, if required;
- Legal considerations, if applicable;
- Domestic participation and technology transfer;
- Consideration of uncertainties which cannot be foreseen in the bidding stage (risk management).

Deviations from the BIS should be carefully assessed and can be expressed in actual or reasonably estimated values. These would include differences in:

- Project duration and completion date;
- Payment schedules;
- Warranties and duration of warranties;
- Delays, excusable delays and grace periods (due to unforeseen circumstances);
- Penalties;
- Changes (responsibility for the alterations);
- Transportation of goods and persons;
- Limits of liability;
- Performance guarantees;
- Other deviations in risk distribution.

For the above contract provisions, the deviations from the BIS can be quantified and included in the evaluation result. Deviations from some of the above provisions can be also be evaluated from a qualitative viewpoint.

Furthermore, numerous other deviations in risk distribution between the draft contract from the BIS and the one offered by the bidders will be possible to evaluate only qualitatively (difference in applicable laws, arbitration rules, etc.). For this, an overall project risk assessment and the results of the review of the bidders before and during the bidding process will be required for proper qualification of these deviations. Each bidder will have its own reasons for deviating from the BIS requirements. For the operating organization, it is important to identify those reasons and qualify their potential impact on the project.

Safety system settings should be effective and allow adequate operating margins. The OLCs should be defined to ensure that no design basis accident could lead to unacceptable radiological consequences to the public or the environment. The correctness of the OLCs should be checked as well.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Specific Considerations and Milestones for a Research Reactor Project, IAEA Nuclear Energy Series No. NP-T-5.1, IAEA, Vienna (2012).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Code of Conduct on the Safety of Research Reactors, IAEA, Vienna (2006).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, External Human Induced Events in Site Evaluation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.1, IAEA, Vienna (2002).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Geotechnical Aspects of Site Evaluation and Foundation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.6, IAEA, Vienna (2004).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Invitation and Evaluation of Bids for Nuclear Power Plants, IAEA Nuclear Energy Series No. NG-T-3.9, IAEA, Vienna (2011).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series No. NS-R-4, IAEA, Vienna (2005).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Analysis for Research Reactors, Safety Reports Series No. 55, IAEA, Vienna (2008).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. NS-R-3, IAEA, Vienna (2003).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9, IAEA, Vienna (2010).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18, IAEA, Vienna (2011).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2010).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization and Staffing of the Regulatory Body for Nuclear Facilities, IAEA Safety Standards Series No. GS-G-1.1, IAEA, Vienna (2002).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety in the Utilization and Modification of Research Reactors, IAEA Safety Standards Series No. SSG-24, IAEA, Vienna (2012).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Utilization Related Design Features of Research Reactors: A Compendium, Technical Reports Series No. 455, IAEA, Vienna (2007).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, The Applications of Research Reactors, IAEA Nuclear Energy Series NP-T-5.3, IAEA, Vienna (2001).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Radioactive Waste Management in the Design and Operation of Research Reactors, IAEA Safety Standards Series No. NS-G-4.6, IAEA, Vienna (2008).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Periodic Testing and Inspection of Research Reactors, IAEA Safety Standards Series No. NS-G-4.2, IAEA, Vienna (2007).

[19] INTERNATIONAL NUCLEAR SAFETY ADVISORY GROUP, Defence in Depth in Nuclear Safety, INSAG-10, IAEA, Vienna (1996).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA,Vienna (2006).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Core Management and Fuel Handling for Research Reactors, IAEA Safety Standards Series No. NS-G-4.3, IAEA, Vienna (2008).

[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report, IAEA Safety Standards Series No. SSG-20, IAEA,Vienna (2012).

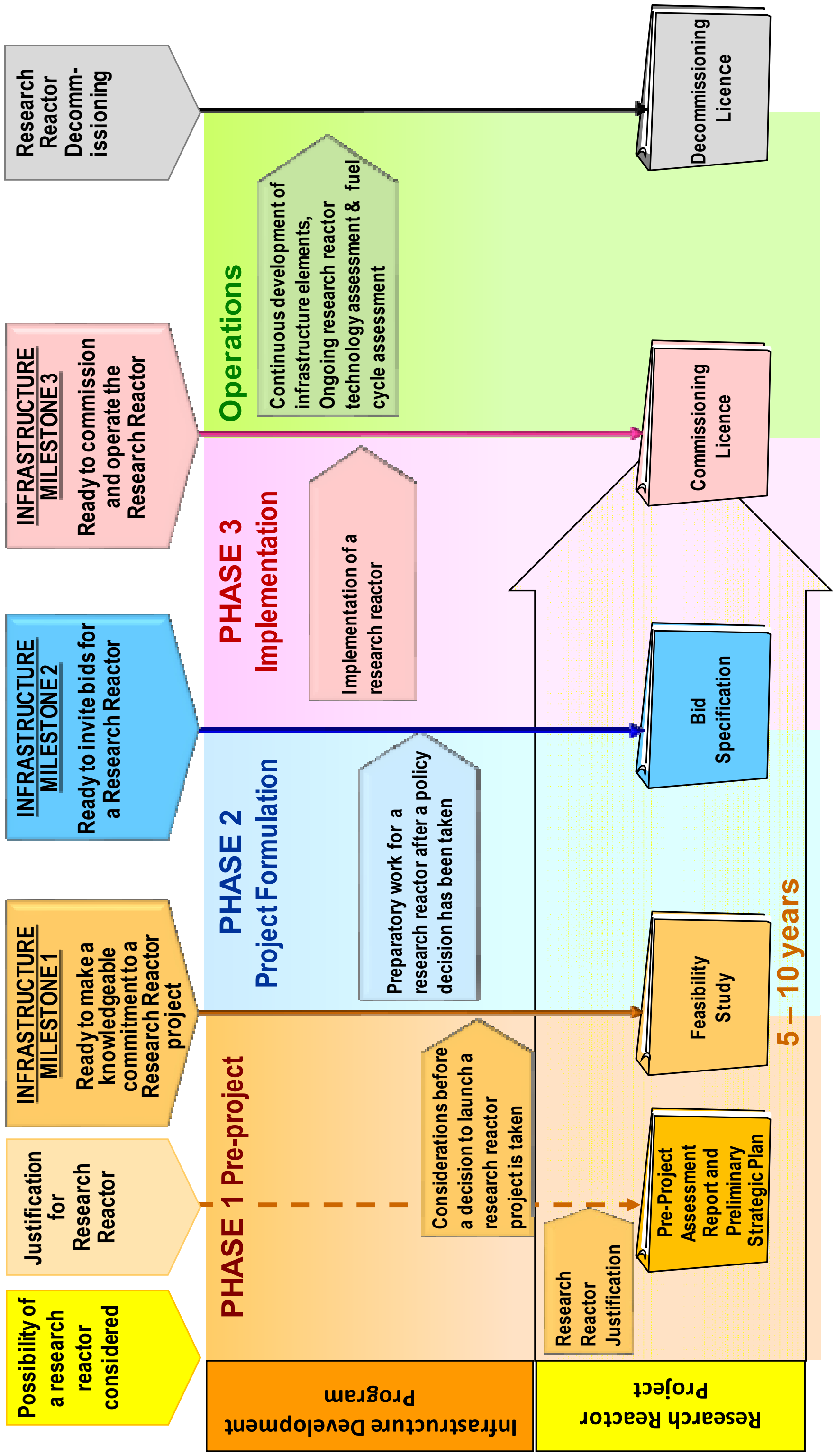
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors, IAEA Safety Standards Series No. NS-G-4.5, IAEA,Vienna (2008).

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Implementation of a Management System for Operating Organizations of Research Reactors, Safety Reports Series No. 75, IAEA, Vienna (2013).

[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Limits and Conditions and Operating Procedures for Research Reactors, IAEA Safety Standards Series No. NS-G-4.4, IAEA,Vienna (2008).

Annex

MILESTONES FOR A RESEARCH REACTOR PROJECT[1]



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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Specific Considerations and Milestones for a Research Reactor Project, IAEA Nuclear Energy Series No. NP-T-5.1, IAEA, Vienna (2012).

ABBREVIATIONS

BDBA	beyond design basis accident
BIS	bid invitation specification
BNCT	boron neutron capture therapy
CHF	critical heat flux
CNS	cold neutron source
DBA	design basis accident
EQ	environmental qualification
ESF	engineered safety feature
GRMS	ground motion response spectra
IRSRR	Incident Reporting System for Research Reactors (IAEA)
LEU	low enriched uranium
NAA	neutron activation analysis
NDT	non-destructive testing
NPP	nuclear power plant
NTD	neutron transmutation doping
OLCs	operational limits and conditions
PGNAA	prompt gamma neutron activation analysis
PIE	postulated initiating event
PSAR	preliminary safety analysis report
QA	quality assurance
SSCs	structures, systems and components
SSE	safe shutdown earthquake
UHRS	hard rock uniform hazard response spectra

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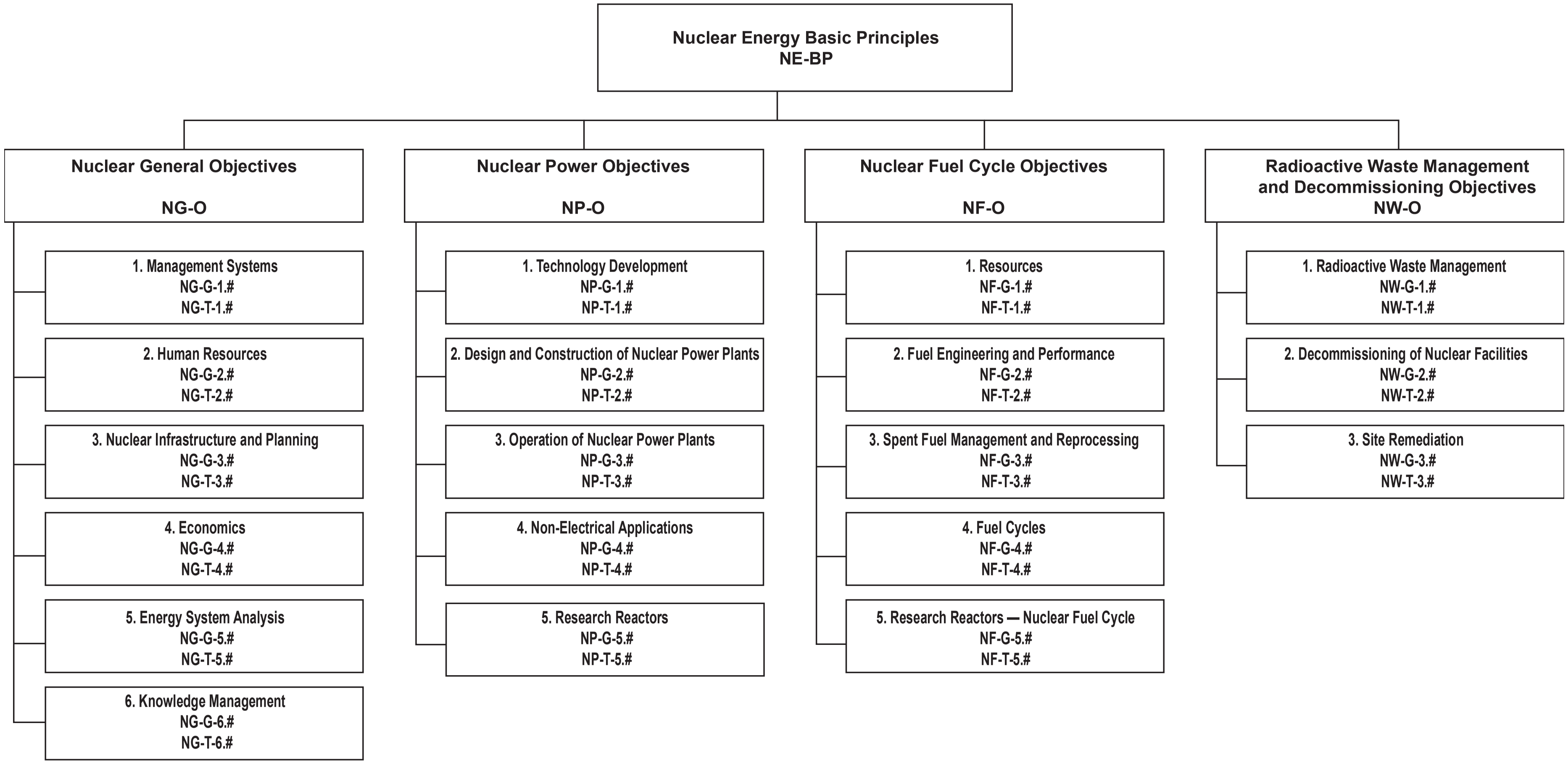

Key

BP: Basic Principles
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T: Technical Reports
Nos 1-6: Topic designations
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ISSN 1995–7807