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FEASIBILITY STUDY PREPARATION FOR NEW RESEARCH REACTOR PROGRAMMES

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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.

To assist Member States implementing new research reactor programmes, the IAEA published an IAEA Nuclear Energy Series report in 2012 entitled Specific Considerations and Milestones for a Research Reactor Project (also known as the Research Reactor Milestones publication and approach).

This publication is intended to provide guidance for the main supporting organization or team of a new research reactor to enable them to undertake an authoritative and comprehensive feasibility study that could be submitted to decision makers for their review in order to support proposals and endorse an action plan to construct such a facility. It includes considerations of key infrastructure cost–benefit issues and risk issues that would have to be addressed prior to the issuing of authorizations for the establishment of a new research reactor. Addressing these issues will help Member States develop a comprehensive understanding of all the roles, obligations and commitments involved in operating a research reactor and ensure that these are met during all phases of the project life cycle.

The IAEA wishes to thank all contributors to this publication and, in particular, P. Degnan (Australia) who compiled, elaborated and reviewed the first complete version of the text. The IAEA officers responsible for this publication were A. Borio di Tigliole and D. Jinchuk of the Division of Nuclear Fuel Cycle and Waste Technology, D. Ridikas of the Division of Physical and Chemical Sciences and A.M. Shokr of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

In recent years, Member States' interest in initiating new research reactor programmes has grown significantly, and several are at different stages of developing and implementing such projects. The majority of these States are considering building their first research reactor as a key component of their national infrastructure to support the development of nuclear science and technology programmes, including nuclear power.

In addition to multiple uses of research reactors for neutron activation analysis, radioisotope production, silicon doping, neutron imaging, research with neutron beams and so on [1], a great number of these facilities worldwide are used for the education of nuclear scientists and engineers. Some countries also use them for general training or refresher courses for the nuclear utilities workforce. Low power research reactors with flexible operating schedules, especially at a university or institute with teaching facilities and competencies, are well suited for this purpose. Furthermore, high power multipurpose research reactors are indispensable tools that are used to perform advanced fuel and material testing to support the life extension of operating nuclear power plants (NPPs), to validate safety analysis and design methods for new NPPs, to qualify new fuels (including studies on fuel behaviour in incidental and accidental conditions), to validate modelling and calculation tools and so on. Research reactors are also key tools to maintain national nuclear capacity and credibility for public acceptance of nuclear technologies.

To assist Member States in their efforts to build new research reactors, the IAEA published IAEA Nuclear Energy Series No. NP-T-5.1 on Specific Considerations and Milestones for a Research Reactor Project in 2012 [2] (also known as the Research Reactor Milestones publication or approach). It provides guidance on the timely preparation of a research reactor programme through idealized sequential development phases that lead to an end point at which an organization would be ready to commission and operate a research reactor. These phases are listed in Table 1.

Reference [2] includes a detailed description of the range of infrastructure issues that would need to be addressed during each phase and the expected level of achievement (or milestone) to be attained at the end of each of the three phases. More specifically, during Phase 1 of a new research reactor programme (the pre-project phase), the Member State will ideally determine whether there are sufficient needs at a national and/or regional level that justify the construction of a research reactor and, on the basis of this assessment, the Member State needs to have completed a preliminary, but comprehensive, strategic plan [3]. In addition, before embarking on the research reactor programme, the Member State needs to develop a comprehensive understanding of all the obligations and commitments involved in operating a research reactor and maintaining the facility throughout its lifetime as part of a national strategy. As a consequence, it will be essential that the Member State ensures that there would be resources available to carry out the corresponding responsibilities that would arise from constructing, operating and eventually decommissioning a research reactor.

TABLE 1. INFRASTRUCTURE DEVELOPMENT PHASES AND MILESTONES FOR A RESEARCH REACTOR PROGRAMME

Phase	Description	Milestone
1 Pre-project	Justification for the research reactor and considerations before a decision to launch a research reactor project is taken	Ready to make a knowledgeable commitment to a research reactor project
2 Project formulation	Preparatory work for the establishment of a research reactor after a policy decision has been taken	Ready to invite bids for the research reactor
3 Implementation	Activities to design and construct a research reactor	Ready to commission and operate the research reactor

Phase 1 activities would culminate with a comprehensive feasibility study report (FSR) as the achievement of Milestone 1. The report would demonstrate that the Member State is in a position to make an informed decision on whether to proceed with the new research reactor programme or not.

The feasibility study needs to incorporate the results of the earlier developed preliminary strategic plan, including justification for such a facility, and needs to include a comprehensive assessment of the 19 national infrastructure issues described in Ref. [2] that will need to be addressed and developed to support a new research reactor programme. It can be noted separately that the proposed methodology and format of this publication in preparation follows closely the IAEA publication on the Evaluation of the Status of National Nuclear Infrastructure Development for a nuclear power programme [4]. Indeed, in many instances the conditions to achieve the different infrastructure issues are the same or very similar. As part of the feasibility study, gaps in conditions to be met to demonstrate the suitability of national infrastructure components and the means to fill such gaps need to be identified and an estimation of the time, costs and human resources required for the implementation of the new research reactor programme need to be provided.

This publication has been developed on the basis of the feedback from Member States embarking on new research reactor programmes for which assistance was requested from the IAEA to develop guidelines for the preparation of the FSR for a new research reactor programme. As in previous publications in the research reactor capacity building area, for example, Ref. [2] and Strategic Planning for Research Reactors [3], it is emphasized that the methodology for the preparation of a feasibility study, as identified in this publication, is guidance based on good practices from Member States.

1.2. OBJECTIVE

The principal objective of this publication is to ensure that all the key issues related to the preparation of a feasibility study for a new research reactor are recognized and addressed. The aim is that use of the guidance contained in this publication would allow a feasibility study to proceed efficiently and effectively and to meet stakeholder expectations.

The specific objectives of this publication are to:

- Provide practical guidance for the preparation of an FSR to support prospective organizations in countries that are embarking on a new research reactor programme;
- Help to better define and explain to the government and the prospective owner their duties in ensuring that adequate infrastructure and resources will be available for the introduction of a research reactor programme;
- Present an effective model that could be employed to undertake a feasibility study that includes references to methods and approaches that have been developed and successfully adopted in recent years.

Guidance provided here, describing good practices, represents expert opinion but does not constitute recommendations made on the basis of a consensus of Member States.

1.3. SCOPE

This publication describes the various elements to be covered during a feasibility study and included in a comprehensive FSR for a new research reactor programme. It is intended to provide guidance in the preparation of an FSR that would be submitted to decision makers, typically at governmental level, in order to allow them to make an informed decision as to whether to commit to the long term provision of resources and obligations for the proposed research reactor programme. Therefore, the publication covers the issues and influences that would need to be included in an analysis of the feasibility study of a research reactor programme. The analysis would include the justification for a research reactor and an assessment of a State's nuclear infrastructure that would be needed to support such a programme, incorporating the status of human resources, the State's financing capability for both implementation and long term sustainability of the programme, and the potential impact of a research reactor programme on the State's development programmes in nuclear science and technology.

1.4. STRUCTURE

Section 2 provides comments on the prerequisites for a feasibility study for a research reactor programme such as the programme justification and a strategic implementation plan, functional specifications, preparatory steps, identification and needs of key stakeholders, responsibilities for the preparation of the study and the use of a graded approach. Section 3 contains guidance on the process of performing a feasibility study and outlines its general content, including considerations of 19 infrastructure issues that would have to be assessed and, as necessary, improved to support the safe, sustainable, secure and cost effective operation and utilization of a research reactor. This is followed by subsections on infrastructure gaps that might be identified during a feasibility study and how countermeasures might be developed, cost–benefit analysis, budgeting and risk management. Finally, Section 4 contains the conclusions of this publication.

The publication also includes three annexes. Annex I contains a list of suggested headings for an FSR for a research reactor programme. Annex II presents the executive summary of the IAEA Technical Meeting on the Role of Research Reactors in Providing Support to Nuclear Power Programmes, held at IAEA headquarters in Vienna from 21 to 24 June 2016 (the meeting was relevant to research reactor justification, and therefore to feasibility studies). The attached CD-ROM provides some examples and lessons learned from individual Member States in preparing FSRs for new research reactor programmes.

1.5. USERS

This publication has been developed to support in particular organizations and teams in Member States that are considering, or are in the process of embarking on their new research reactor programme. It can also be used by Member States with existing research reactors who are considering building another research reactor and may not have used a comprehensive feasibility study approach in the past, and Member States considering major upgrades, refurbishment or modernization of existing research reactors, as well as revitalization of research reactors under extended shutdown conditions.

The primary users of this publication are intended to be the individuals, teams and organizations involved in, and responsible for, the preparation of an FSR for a new research reactor programme. Other stakeholders that make up the intended audience include the future operating organization; advisers; managers and senior decision makers in government and parent organizations; the nuclear safety, nuclear security and environmental regulatory authorities; emergency response organizations; user community representatives; and other utilization stakeholders (i.e. potential research reactor ‘customers’ such as academic and scientific institutions, health organizations, industry).

An FSR needs to be comprehensive and based on an adequate analysis of all available and relevant information. However, it is recognized that the underpinning feasibility study can only be as reliable as the information used and the competence and diligence of the team or organization carrying out the analysis and providing recommendations.

2. PREREQUISITES OF A FEASIBILITY STUDY

2.1. CONTEXT

A feasibility study needs to be carried out within a framework that provides context and structure for the research reactor programme. The framework and development context in which a feasibility study for a new research reactor programme is undertaken is described in Ref. [2]. In that publication, three distinct phases are identified (see Table 1 and Fig. 1).

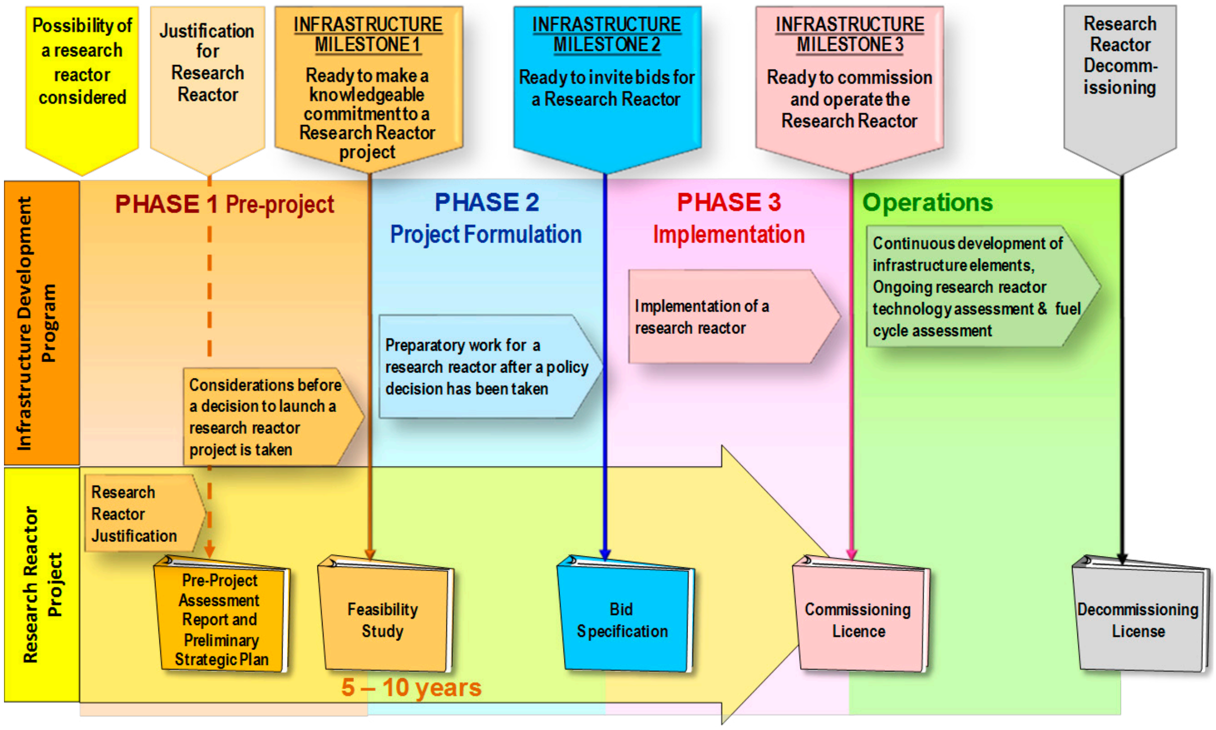

FIG. 1. Milestones for a research reactor programme [2].

Reference [2] provides a discussion of issues to be addressed during each phase and presents the milestones to be achieved in the development of national nuclear infrastructure, so that the Member State can confirm that it has:

(a) A justified need for a research reactor;
(b) Comprehensively recognized and identified all relevant stakeholders;
(c) Comprehensively recognized and identified the national and international commitments and obligations associated with the construction of a research reactor;
(d) Established and adequately prepared the national infrastructure prerequisite to the construction of a research reactor;
(e) Established all the competences and capabilities necessary to regulate and operate a research reactor safely and securely over its lifetime;
(f) Established adequate funding for the research reactor throughout its life cycle from its construction until its decommissioning.

There are three main components that are contributing to the development of an FSR: (i) a comprehensive justification and preliminary strategic plan, (ii) a comprehensive assessment of 19 infrastructure issues that are needed to support a new research reactor programme and a recognition of gaps in meeting the necessary conditions required to be in place at different phases as well as the timescales and resources needed to fill them; and (iii) a detailed financial plan, including a cost–benefit analysis (see Fig. 2).

2.2. RESEARCH REACTOR JUSTIFICATION

An adequate justification for the research reactor is the underpinning foundation upon which the feasibility study is based, and documentation of the justification must be provided early in Phase 1. IAEA guidance [2] indicates that the research reactor justification could be carried out by an assessment, marketing and project team (AMPT) that would include individuals with high personal credibility (i.e. they are both highly knowledgeable and well respected in the field) and that has ready access to key stakeholders. The majority of the team members would

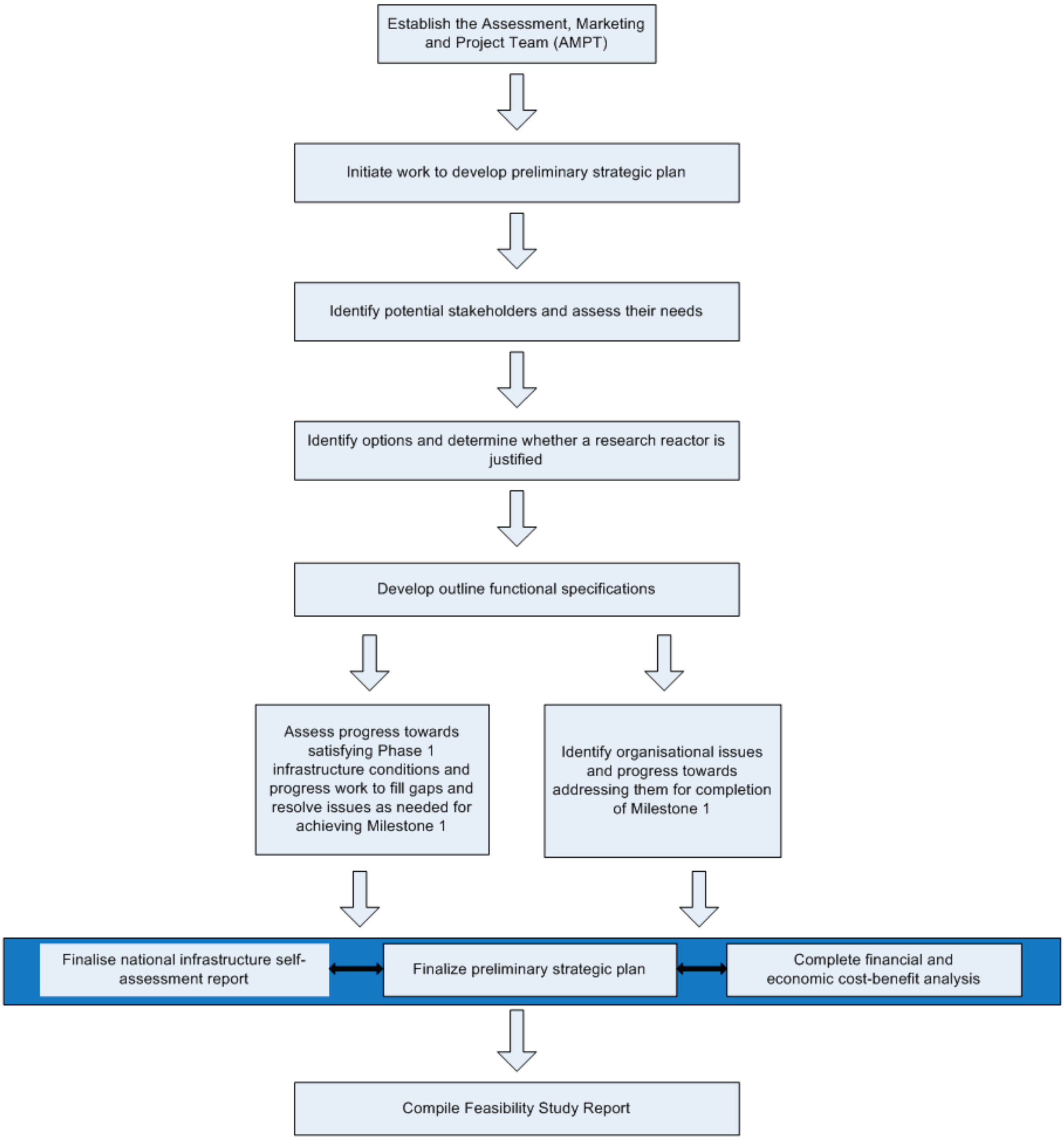

FIG. 2. Major steps during Phase 1 in the production of an FSR.

likely be employees of the main supporting organization of the research reactor programme, but may include other informed representatives from industry, academia, government (local or national) or the regulatory authority.

The starting point for establishing the justification of a research reactor is the identification of stakeholders who have existing or potential interests in the facility and its capabilities [3]. A key stakeholder group will obviously be the potential users of the facility. These stakeholders are interested in the research reactor because it would potentially be able to provide solutions in the form of services not available otherwise (or possibly available elsewhere but at higher cost), or the research reactor could potentially provide products and services that add value to realize an economic or social benefit [1].

The AMPT would be responsible for identifying the stakeholder groups and their needs and for the development of functional requirements that meet these needs. These requirements would in turn result in a draft technical specification for the research reactor and its ancillary facilities and ultimately a conceptual design for the research reactor facility. In undertaking this task, the AMPT needs to rigorously review, to the extent possible, the advantages and disadvantages of using alternative technologies for satisfying stakeholder needs, including the potential use of facilities in other countries. The AMPT needs to be proactive, through engagement with stakeholders, to anticipate the optimization of the utilization of the facility as well as sufficient flexibility in the facility design in order to ensure its maximum utilization in the future.

Finally, facilities and activities that may give rise to radiation risks must yield an overall benefit. Therefore, as part of justification, this benefit needs to be clearly realized compared with other ways to provide the equivalent products and services.

2.3. INFRASTRUCTURE ASSESSMENT

At all stages in the Research Reactor Milestones approach [2], decision makers will want confirmation that the research reactor programme is supported by the infrastructure necessary for safely, securely, sustainably and efficiently managing the project and will want assurance that where there are identified gaps in the infrastructure, progress is being made to fill them. The infrastructure that will be required to support a new research reactor programme varies widely, and includes the physical facilities and equipment associated with the research reactor, the transportation of nuclear materials and supplies, and the handling of spent fuel and radioactive waste materials. It also includes the legislative and regulatory framework and the human and financial resources to ensure the safe, secure, sustainable and efficient construction, operation and utilization of the reactor throughout its life cycle. Table 2 shows 19 infrastructure issues. It is important to recognize that the order of the issues does not indicate a rank of importance or hierarchy. Each issue is significant and requires careful consideration and each of the issues will need to be acknowledged and addressed equally in a feasibility study as they each have a bearing on the success of the project.

TABLE 2. INFRASTRUCTURE ISSUES AND MILESTONES [2]

Issues	Milestone 1	Milestone 2	Milestone 3
(1) National position	CONDITIONS	CONDITIONS	CONDITIONS
(2) Nuclear safety			
(3) Management			
(4) Funding and financing			
(5) Legislative framework			
(6) Regulatory framework			
(7) Safeguards			
(8) Radiation protection			
(9) Utilization			
(10) Human resources development			
(11) Stakeholder involvement			
(12) Site survey, site selection and evaluation			
(13) Environmental protection			
(14) Emergency preparedness and response			
(15) Nuclear security			
(16) Nuclear fuel management			
(17) Radioactive waste			
(18) Industrial involvement			
(19) Procurement			

For each phase and its associated issues, a number of conditions have been defined, which are indicators that the infrastructure is adequate to support a research reactor programme. Conditions are met when it can be demonstrated that there has been sufficient progress on determining national infrastructure development. Reference [4] provides guidance for the self-assessment of the meeting of indicator conditions by providing supporting evidence for each condition. To complete Phase 1, the FSR has to demonstrate that Milestone 1 conditions are met and that, where appropriate, progress is under way in anticipating Phase 2 conditions.

2.4. STRATEGIC PLAN

Another cornerstone of a feasibility study is the preliminary strategic plan that would have been completed earlier in Phase 1 in accordance with the guidance provided in Ref. [3]. The documentation of the strategic plan communicates organizational goals and sets out the actions needed to achieve those goals. It needs to identify key stakeholders, including potential 'customers', and provide confirmation of their needs in terms of expected products and services. This is a key component in the justification of a new research reactor and it can then be used as a basis for the development of the functional specifications of the research reactor and its ancillary facilities.

The strategic plan needs to be periodically reviewed and updated as necessary to reflect new information or changing circumstances. An updated version of the strategic plan needs to be developed iteratively with the feasibility study towards the end of Phase 1 in order to provide decision makers with an understating of the stakeholder analysis, stakeholder needs and how the project would address those needs in terms of action plans with clear indication of responsibilities, dates and required resources [3]. An up to date strategic plan will have to be incorporated in the FSR. A full strategic plan could be added as an annex to the FSR or as a supporting separate document.

2.5. FINANCIAL CONSIDERATIONS

It is noted that the imperatives that underpin the rationale for a research reactor may be education and training, research and development, or commercially driven or, more typically, a combination of all these. In terms of prerequisites for a feasibility study, following a statement of motivation and the identification of stakeholder needs and a description of the services and products to be provided and the technologies that are to be assessed, certain boundary conditions (e.g. financial envelope) for the feasibility study are expected to be discussed in advance with decision makers. Even for a case in which non-financial and subjective decision making criteria dominate the feasibility evaluation, decision makers will nevertheless be reviewing projections of capital costs, operating expenses (and potential revenues) as well as previsions for decommissioning and, therefore, thought needs to be given to the criteria to be used to judge financial implications. Clear decisions need to be established early in the feasibility study, if not before it is begun, regarding boundary conditions and assumptions inherent in it. For example, balancing functional capabilities against investment and operating costs is a complex financial calculation, especially considering the long lifetime involved in research reactor operations. Also, consideration needs to be given early in the feasibility study to the metrics and financial models to be used in any cost–benefit analysis (see Section 3.5).

2.6. DEFINITION OF RESEARCH REACTOR FUNCTIONAL SPECIFICATIONS

As for the justification of a research reactor programme, described in Section 2.5, the production of appropriate functional specifications for the research reactor and its ancillary facilities will be a necessary input for the feasibility study. It has already been mentioned how the functional requirements for a new research reactor are largely derived from an understanding of stakeholder needs, but in this section an outline of guidance is provided on the composition of the functional specifications that need to be considered, while more precise definitions of design characteristics for the various applications can be found in the following IAEA publications and references therein: Applications of Research Reactors [1], Technical Requirements in the Bidding Process for a New Research Reactor [5], and Utilization Related Design Features of Research Reactors [6].

A functional specification is a formal document that accurately and precisely reflects broad requirements derived from an analysis and understanding of current and anticipated stakeholder needs and also from regulatory requirements and guidelines (e.g. safety functions). It describes the expected behaviour and performance of the research reactor and its associated systems, but not necessarily how those functions will be met, which is the subject of a technical specification. Therefore, a functional specification is generally a precursor to a more detailed technical specification that sets out how the functions will be achieved, i.e. the technology to be implemented and the necessary constraints that must be met by the technology.

Functional and preliminary technical specifications will allow approximate estimates of the resources needed. In addition, they have a role to play in communicating how the facility will meet stakeholder expectations. In relation to a feasibility study specifically, the functional specifications must clearly be set out and a high level indication of the technological solutions to be employed also needs to be provided. However, it is not necessary in the pre-project phase (Phase 1) to have defined the detailed technical specifications and the associated research reactor design, as these will generally be developed in Phase 2, when the attainment of Milestone 2 ensures that the main research reactor supporting organization or team will be ready to invite bids. What will be required from the feasibility study is an estimate of resource needs, preliminary analysis of technical and project management risks (see Section 3.7), as well as clear functional specifications and statements of design intent that at a minimum demonstrate consideration of the following aspects [1, 2, 6]:

— Applications and associated functions:
  - Education and training;
  - Neutron activation analysis;
  - Prompt gamma neutron activation analysis;
  - Radioisotope production;
  - Geochronology;
  - Transmutation effects;
  - Neutron imaging;
  - Material structure and dynamics studies with neutron beams;
  - Neutron therapy;
  - Testing of detectors and instruments;
  - Testing of material and fuel;
  - Other possible use and applications of research reactors.

— Safety functions and radiological protection principles:
  - Basic safety functions (reactivity control, removal of decay heat and confinement of radioactive materials);
  - Application of the defence in depth concept;
  - Radiological protection principles;
  - Handling of fresh and spent nuclear fuel;
  - Emergency planning and preparedness;
  - Provisions of decommissioning and management of radioactive waste.

— Reactor technology and operations:
  - Preferred reactor type;
  - Preliminary power level (or neutron flux) required and ability to vary power levels for different purposes;
  - Frequency and duration of reactor use (operating cycle);
  - Measurement capabilities;
  - Number and location of irradiation positions, including neutron energy spectrum requirements;
  - Removal of irradiated targets with the reactor in operation or in shutdown status;
  - Transport logistics of irradiated samples or targets;
  - Fuel type, supply and handling;
  - Instrumentation and control technologies and ancillary systems;
  - Maintenance and ageing management;
  - Spent fuel and waste storage, and end points (e.g. return, recycling, disposal);
  - Dismantling and decommissioning.

Other general design features that need to be incorporated into functional specifications are provided in Refs [5, 6], which also include more detailed design requirements. In relation to the applications and uses of research reactors and how these might influence functional specifications, the IAEA TECDOC on Commercial Products and Services of Research Reactors [7] indicates how research reactors are potentially able to serve three main purposes:

(1) Serving as a tool for education and training;
(2) Providing a source of neutrons for a broad variety of applications for research as well as commercial products and services;
(3) Serving as a prototype facility to demonstrate the maturity of nuclear technology and training before full scale innovative power reactors can be built.

As is noted in Ref. [7], the utilization programme of a research reactor may change during its lifetime and this consideration needs to be built into the functional and technical specifications so as to provide for sufficient flexibility in the facility design and operation plans.

Regarding the role of the feasibility study as a precursor to the development of technical design specifications for the research reactor, functional specifications need to undergo preliminary evaluations of the following issues, in order to be aware of their implications for feasibility assessments:

- Time and cost to design, construct and commission;
- Regulatory requirements (nuclear safety, security, safeguards, environment, etc.);
- Resources required to operate and maintain the facility (including fuel costs);
- Resources to dismantle and decommission;
- Impact on the costs of radioactive waste and spent fuel management.

As noted in Ref. [2], when this evaluation and a preliminary functionality prioritization are complete, initial technical specifications for a facility concept design can be prepared by defining the following:

- Preliminary reactor power level;
- Irradiation and beam facilities requirements (including intensity and energy distribution of neutron fluxes);
- Safety requirements;
- Security requirements;
- Safeguards requirements;
- Core design and performance (nominal operating cycle and fuel design);
- Fuel management requirements (fresh and spent fuel storage, fuel handling equipment and casks, etc.);
- Ancillary facilities (beam hall, office space, hot cells, etc.);
- Integration within a nuclear centre, university or hospital (e.g. in the case of neutron therapy);
- Transport of irradiated samples and targets.

Even though it is provisional, advance information and recommendations on these aspects would be important components of the feasibility study.

2.7. RESPONSIBILITIES FOR FEASIBILITY STUDY PREPARATION

As already discussed above and based on Ref. [2], an AMPT or equivalent needs to be formed to study, develop and promote the research reactor programme. This team may be formed at the institute or organization level or it may be created as a governmental task force. Its role is to build the justification for the reactor, develop functional specifications for it and recommend to the government actions that need to be taken to reinforce or implement the nuclear infrastructure and policy, or intergovernmental issues that need to be addressed. The same AMPT would also be responsible for the feasibility study itself and the preparation of an FSR.

In turn, the government needs to also designate and authorize a research reactor project implementing commission (RRPIC) or equivalent [2] to review and accept or decline, as appropriate, those recommendations from the AMPT and ensure that the necessary infrastructure and policies are in place prior to the establishment of a new research reactor. In other words, the RRPIC has a role in reviewing and decision making, depending on the actual situation in the State. For a newcomer State, this RRPIC can be formed by representatives of the appropriate ministries. For subsequent research reactors, or if a nuclear power programme already exists, the role of the RRPIC may be assumed by a government ministry that is given the task of commissioning the FSR and controlling the project.

Once the research reactor teams have been established as described above and their responsibilities have become clear, early and ongoing communication with different stakeholders is indispensable as it has a two way benefit:

- The research reactor AMPT gathers information and inputs to support the preparation of the FSR (e.g. regarding needs and research reactor applications from future users of the facility and from the nuclear safety regulatory body for the licensing process and specific regulations, etc.).
- The stakeholders are better informed and prepared for implementation measures that are to be put into action in the later phases of the project.

In preparing for a feasibility study, the research reactor AMPT need to have access to adequate human resources with the experience and knowledge to prepare the requirements for a feasibility study and to analyse data and compile the FSR from a technical, socioeconomic and legal perspective. Specific human resource requirements may include:

- Good knowledge of research reactors and their applications;
- The technical expertise to develop functional specifications for a research reactor and to evaluate the assumptions and other considerations that would contribute to the FSR;
- Project and management system expertise to manage the feasibility study and FSR preparation, as well as to ensure that an appropriate risk management strategy is in place;
- Detailed knowledge of the infrastructure in the State;
- Legal and business expertise for FSR preparation and review;
- Financing expertise to develop and analyse financing plans;
- Expertise in stakeholder communication and public information.

Where experience is lacking, the AMPT may need to subcontract specific tasks to a support organization or, indeed, may delegate responsibility for the production of the FSR in its entirety to a third party. In some cases, potential research reactor suppliers have been engaged to accomplish this task, but it should be noted that there is a potential conflict of interest issue should this route be followed.

The knowledge and experiences acquired by individuals during the earlier stages of Phase 1 are of course very useful in the process of FSR preparation and in later phases. Consequently, it would be advantageous if the same key people were to continue in their positions throughout the entire research reactor planning and implementation process.

2.8. PREPARATORY STEPS

There are a number of important preparatory steps that need to be taken during Phase 1 in advance of the production of the FSR. Many of these relate to Phase 1 infrastructure issues, as will be discussed in Section 3. However, as all the relevant infrastructure conditions are unlikely to be in place early in the pre-project phase, the current status has to be assessed and activities initiated to ensure that they are considered and dealt with in a timely manner and certainly by Milestone 1. Accomplishing these would be the responsibility of the future facility owner and/or operator (or AMPT), while the RRPIC or the government would be responsible for review and decision making. Some of the preparatory steps to be undertaken early in Phase 1 include:

— Identification of the legislative framework and demonstration of the capability to develop and promulgate the laws required for the development and safe, secure, sustainable and cost effective operation of the research reactor;
— Identification of regulations already in place and those that will be required to support the site selection, the research reactor design, construction, commissioning, operation and decommissioning;
— Identification of the need for an effective regulatory body and regulatory framework, which may include core regulatory functions in the areas of licensing, review, assessment, inspection, enforcement and public information;
— Identification of the future research reactor owner and operator and engagement with the main stakeholders;
— Identification of the suitable candidate site(s) on the basis of existing data, supported by an initial radiological impact assessment;
— Definition of the tentative facility management model;
— Ensuring that adequate resources — human, technical and financial — are available to complete Phase 1 activities, including the preparation of the FSR.

If the decision is taken to establish a new research reactor, in addition to the above steps, it is advisable that, if not already the case, the government is prepared to commit to adhering to relevant international nuclear conventions concerning, among others, radioactive waste, spent fuel, safety, safeguards, security, nuclear liability and so on, recognizing them as essential to safely operate nuclear facilities and gain membership of international agencies, and in so doing, access active support from the international nuclear community (see Ref. [2] for further details).

2.9. PROGRAMME STAKEHOLDERS

The programme stakeholders are those who have a vested interest in the programme. They can be individuals and organizations involved directly or indirectly in the programme, or those whose interests may be affected during the research reactor programme implementation or its operation. They may also be authorities who would exert influence over the programme's planning, operation and outcomes. As indicated in Section 2.3 and in Refs [2, 3], the feasibility study needs to identify the stakeholders and determine their needs, requirements and expectations. A typical set of stakeholders for a research reactor is shown in Fig. 3.

Involving interested parties in early stages of the research reactor life cycle is beneficial in enhancing mutual trust on issues related to the planning and future operation of the research reactor facility. Beyond the groups

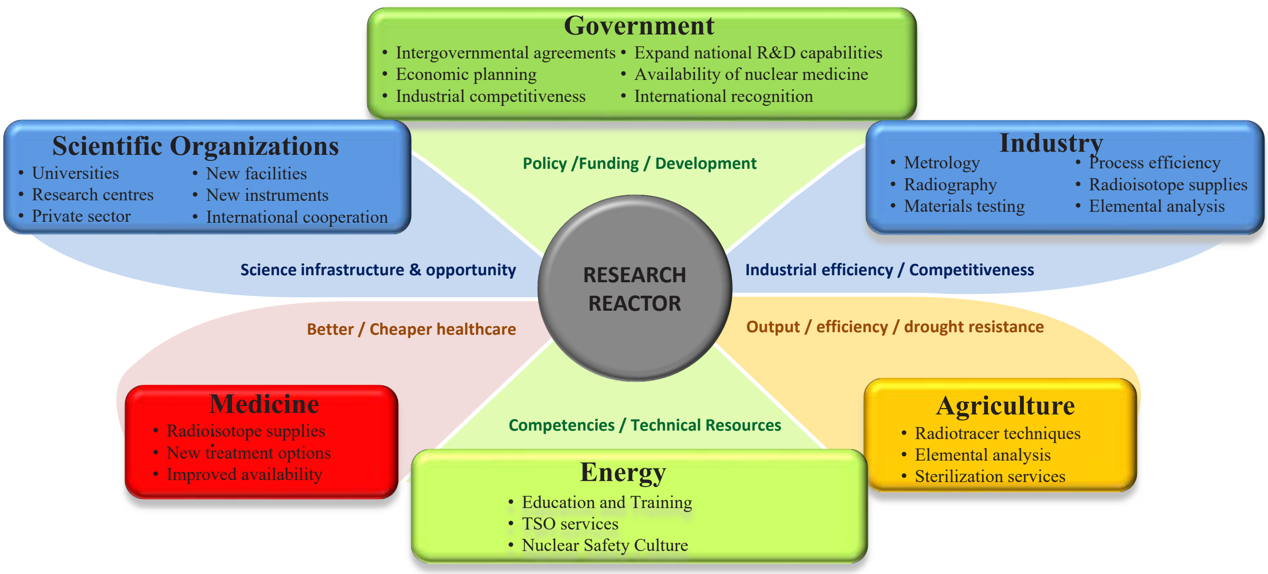

FIG. 3. Possible stakeholders, supporters and users of a research reactor.

traditionally involved in the decision making process, such as the potential customers and relevant national and local governmental institutions, the concept of stakeholders needs to also include the media, the general public and local communities. The IAEA publication Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [8] outlines a route to ensure effective stakeholder involvement during the main phases of the life cycle of nuclear facilities (i.e. construction, operation, decommissioning and waste management) and the use of up to date methods to implement stakeholder involvement programmes.

2.10. USE OF A GRADED APPROACH IN THE PREPARATION OF A FEASIBILITY STUDY

As has already been noted, research reactors are used for special and varied purposes such as research, education and training, radioisotope production, non-destructive testing, materials and fuel research and development (R&D), including nuclear fusion technology [9] as well as a number of other applications (see Fig. 3 and Ref. [1]). Furthermore, research reactors can also be used to support the development of national nuclear power programmes under the following main areas (see Annex II for details): (1) R&D; (2) human resources development; (3) public awareness and confidence building; and (4) development of other elements of the national infrastructure.

All the above mentioned purposes call for different design features and different operational regimes. The design and operating characteristics of research reactors may vary significantly to accommodate the use of different experimental devices that can affect reactor performance.

Owing to this, the way in which the safety requirements are fulfilled may be very different from one research reactor to another. For example, the way in which requirements are demonstrated to have been met for a multipurpose, high power level research reactor might be very different from the way in which the requirements are demonstrated to have been met for a research reactor with very low power and thus a very low associated radiological hazard to facility staff, the public and the environment [10]. References [11, 12], which cover a wide range of research reactors, include information on the application of the safety requirements in accordance with a graded approach.

Similarly, many of the issues involved in the planning, design, operation and decommissioning of a research reactor are similar to those of a nuclear power plant (NPP). While the scope of technical issues to be addressed in an NPP programme compared with a research reactor programme may be similar in many aspects, the level of detail to be considered and the risks involved are not equivalent, and therefore might be significantly different owing to the differences in the size and complexity of the facilities and accordingly their potential radiological hazards.

These considerations highlight the need for use of a graded approach in the preparation of the FSR for a research reactor.

3. CONTENTS OF A FEASIBILITY STUDY FOR A NEW RESEARCH REACTOR

3.1. INTRODUCTION

In this section, guidance is provided on the information that would be expected to be included in a feasibility study for a new research reactor programme. The guidance is necessarily rather generic as it tries to highlight particular issues and considerations that could be applicable to different types of research reactor programme that might, for example, vary in the ownership and management arrangements, scale of activities, the reactor technology employed and its applications and uses. The guidance provided here includes consideration of elements that are either internally controlled by the research reactor AMPT or main supporting organization (e.g. human resources arrangements in the future operating organization) or those external elements that relate especially to national infrastructure requirements and over which the AMPT may have little direct control or influence (e.g. the regulatory framework).

It will be imperative that the AMPT or the main supporting organization of a new research reactor programme address both sets of elements in the FSR, i.e. those amenable to internal control and those subject to externally imposed decisions and actions, in order to demonstrate the viability of proposals and plans. This would likely require the extensive involvement of government (e.g. through the RRPIC or equivalent as described in Section 2.7) and other stakeholders in order that any gaps identified as a result of the analysis of the proposed internal project arrangements and in the existing national infrastructure can be dealt with in an adequate manner to ensure the development and the safe, secure and sustainable operation of a future research reactor facility. Without these issues and conditions being adequately addressed, the feasibility of a research reactor programme cannot be demonstrated.

3.2. GENERAL DESCRIPTION OF THE CONTENTS OF A FEASIBILITY STUDY

The role of a feasibility study is to objectively examine the viability of a proposal. Whether a project proposal for a new research reactor would be considered by a decision maker to be viable or not can be ultimately reduced to an evaluation of the likelihood of successful implementation, based largely on the justification and technical feasibility and an economic assessment of costs and benefits. The feasibility study provides the basis for a long term commitment and investment and supports the detailed design of the facility. It needs to be a comprehensive document aligned with and summarizing conclusions from other Phase 1 technical assessments and reports (e.g. the preliminary strategic plan).

The FSR provides contextual information including a description of the constraints, assumptions and methods employed to evaluate programme viability, with a level of detail provided that is appropriate to support conclusions and recommendations. It also documents the opportunities and risks associated with the implementation of the programme. If not already evaluated and documented at an earlier stage in Phase 1 (e.g. a preliminary strategic plan), the feasibility study needs to also provide information on the investigation of options and scenarios, including the possible use of alternative technologies or solutions that might also be employed to meet stakeholder needs. This is required in order to demonstrate that the most suitable technical solution has been selected to respond to the identified needs.

In essence, a typical FSR for a research reactor programme would include the following major sections:

(i) Background and contextual information, including programme motivation and justification, quantified stakeholder needs and requirements, alternative options that have been considered and a programme description including a definition of the potential customer base, the products and services to be provided and any externally imposed constraints and assumptions. This will also include information about the foreseen utilization of the research reactor and its functional specifications;

(ii) An analysis, considering each of the 19 infrastructure issues and including a description of the assessment methods employed, the data and criteria used and an examination and evaluation of any other factors that need to be considered to evaluate programme viability;

(iii) Results that illustrate how the necessary Phase 1 infrastructure conditions have been met (or not) and an anticipation of understanding how Phase 2 and 3 conditions will be fulfilled that sets out the costs and benefits of the programme, the opportunities that might be exploited and the major risks to be prevented, minimized or mitigated against, as well as an implementation plan;

(iv) A summary, conclusion and recommendations.

An executive summary also needs to be included in the FSR to highlight the main content and recommendations for decision makers. This structure is reflected in the suggested FSR contents list (Annex I). The remainder of Section 3 of this publication sets out in more detail the various factors and issues that have to be evaluated as part of the feasibility study and presented in an FSR.

Broadly speaking, the factors and issues to be considered in a feasibility study can be categorized and structured in several different ways. Such a categorization of factors and issues is useful as it aids analysis and presents information in a logically structured manner to assist decision makers. One way to provide structure is to concentrate on the external and internal factors that could impact or that could be impacted by the research reactor programme and that are important to the viability of the project. External factors can be assessed using the well-known PESTLE[1] analysis approach. Relevant internal (organizational) factors to be considered are typically assessed using, among others, the SWOT[2] approach (see also Ref. [3] on how SWOT is employed for strategic planning) or the McKinsey 7S[3] model. Another perspective is to focus particularly on the requirements for a research reactor feasibility study in terms of market driving forces, with the justification for the research reactor involving an assessment of its potential utility, by identifying stakeholder needs and their motivations (demand side), as well as the availability of critical resources, such as technology, reactor fuel, funding and human resources and their associated costs (supply side).

These methods for structuring issues to support analysis are not mutually exclusive and the approach taken in this publication is to combine both perspectives in an internally consistent manner by considering the fundamental requirements for a feasibility study and by using the 19 infrastructure issues set out in the Research Reactor Milestones publication [2] to provide a more detailed and methodical consideration of the viability of the project. This framework is used for structuring a research reactor programme feasibility study and its associated FSR. It is noted that several of the 19 infrastructure issues include subject matter that will be strongly dependent on government decisions and actions undertaken independently of the programme (e.g. the regulatory framework), while others reflect highly programme specific considerations that will largely depend on decisions and actions by the proponent. For most issues, however, they need to be assessed from a holistic point of view reflecting responsibilities on the part of both the government and the proponent. While generally applicable, the general infrastructure framework presented here and in Ref. [2] is not intended to be exhaustive or necessarily appropriate for all circumstances and as such needs to be adapted to suit national requirements.

3.3. BACKGROUND AND CONTEXTUAL INFORMATION

A research reactor feasibility study will necessarily be preceded by a number of activities and various reports (see Section 2 and Fig. 2 for further details) as part of a phased decision making and development process.

The first component of programme rationale within the FSR would be a needs based justification based on a comprehensive list of potential research reactor users, their needs and requirements, as well as other customers of the products and services arising from reactor operations. This justification for the programme needs to in turn logically lead to information about the foreseen utilization of the research reactor, its functional specifications and related ancillary facilities. To meet the potential user and customer needs, a brief description of the functional specifications of the proposed research reactor and any ancillary facilities needs to be provided, as well as their general features (such as range of power levels, neutron flux values and energy spectra, reactor type, applications, reference design, etc.). The majority of this information will be available in the strategic plan developed as part of the feasibility study [2]. The strategic plan or its summary within the FSR needs to also include reference to an evaluation of the alternative options that were investigated to address user needs. In addition, the FSR needs to summarize the implementation path presented in the strategic plan, which should include the specific actions to be undertaken and who is responsible for them, the metrics to assess progress, the resource requirements and the timescales for implementation and programming. As a result, the FSR needs to include a summary of an up to date strategic plan within a dedicated introductory section of the FSR, or alternatively the reports need to be included within the FSR documentation in their entirety (e.g. as supplementary volumes or annexes).

The second key aspect is motivation. It is acknowledged that interested Member States are seeking to construct and operate a new research reactor for a variety of reasons. The rationale may be fundamentally strategic

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[1] PESTLE (political, economic, social, technological, legal and environmental) analysis describes a framework of macro factors used in the analysis of the external component of strategic planning. It gives an overview of the different external factors to be taken into consideration.

[2] SWOT (strengths-weaknesses-opportunities-threats) is a management tool for the structured assessment of the ability or necessity of an organization to change. It is based upon categorizing functions or tasks as a result of information gathering, e.g. at a users' meeting, as part of a presentation or in a brain-storming session. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favourable and unfavourable to achieving that objective. The details could then be finalized in follow-up discussions with the major stakeholders.

[3] The McKinsey 7S Framework is a management model developed by well-known business consultants Robert H. Waterman, Jr. and Tom Peters in the 1980s. This was a strategic vision for groups, to include businesses, business units, and teams. The 7 S's are 'structure', 'strategy', 'systems', 'skills', 'style', 'staff' and 'shared values'.

in nature, for example, to provide an assured supply of radiopharmaceuticals for domestic use, or to develop the indigenous skills and capabilities needed as a precursor for a nuclear power programme, and so on.

On the other hand, there could be a commercial imperative to provide nuclear reactor services, for example, the provision of irradiation services or research into the production of innovative radiopharmaceuticals and their export. Typically, a research reactor operating organization will seek to optimize reactor usage for both strategic and economic purposes [5] and this may be reflected in the operation of a multipurpose reactor providing a range of services. Nevertheless, with a few exceptions, the vast majority of single and multipurpose reactors are effectively owned and operated by public entities, typically a national atomic or nuclear research institute or a university.

In the future, there could be wider use of public–private partnership arrangements to fund investments in non-power reactors (research reactors). Because of the diversity in motivations and ownership arrangements and because government interest would have to include consideration of intangible externalities that would accrue over relatively long timescales, for example education and health benefits, financial valuations and decisions based on tangible metrics alone may not be sufficient. Consequently, the feasibility of a research reactor programme may not be best assessed purely on the basis of such metrics and projections. Rather, the wider potential social, technological and economic needs and benefits need to be factored in, and these may or may not be conducive to simple quantification.

It should also be recognized that tangible financial metrics based on the development and operating periods alone are not appropriate as the main decision making criteria. In addition to the fact that long term operating costs measured in decades are difficult to determine, a research reactor operating organization without a strongly commercially driven imperative is unlikely to generate sufficient funds over the operational lifetime of the reactor to cover decommissioning and long term radioactive waste liabilities [2].

Clearly, the costs associated with end-of-life aspects must be factored into the cost–benefit analysis for a feasibility study. In these respects, the suggested content for an FSR as provided in this publication may vary from what might typically be expected in a feasibility report undertaken for many other types of significant infrastructure project, as illustrated in Fig. 4.

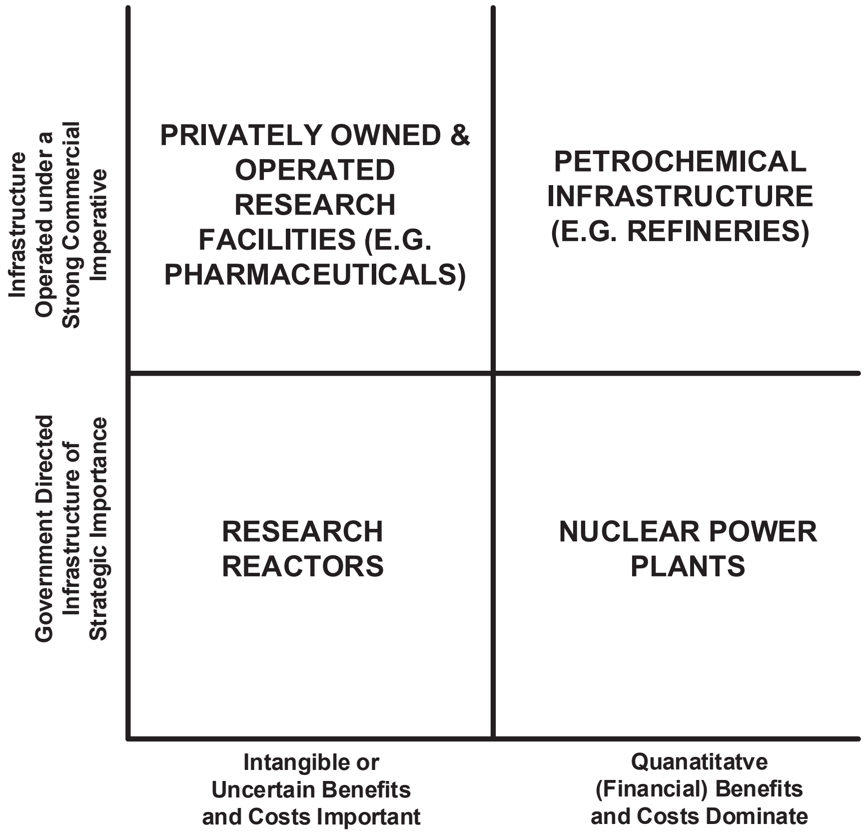

FIG. 4. Illustration of the domain occupied by typical research reactors dominated by wider sociopolitical considerations than economics alone and requiring strong government endorsement and commitment.

As well as the above information, the FSR must explicitly include other contextual information such as a description of the composition and structure of the future operating organization (and its owner, if separate), its mandate, responsibilities, leadership, management systems and its capacity to undertake the project (e.g. financial, technical, human resource assets etc. including established links with international organizations and counterpart organizations). Furthermore, any constraints or assumptions that condition or otherwise influence the planning basis need to be provided.

3.4. ANALYSIS AND ASSESSMENT OF ISSUES IMPACTING ON THE FEASIBILITY STUDY

In order to address the issues and factors that would form part of any feasibility study, there will be a need to gather data and information on a range of topics, to analyse that data and information and then to make judgements concerning their significance for decision making about the viability of the project. The issues and factors include many elements that may be largely within the control of the research reactor AMPT or main supporting organization and that may be readily quantifiable. Where this is the case, key issues may be readily addressed and can be relatively easily evaluated.

Conversely, there are likely to be a number of issues and factors reflecting the status of the national infrastructure [2] that will be required to support a research reactor programme and these may not be easily influenced by the AMPT. Furthermore, they may not be amenable to quantifiable evaluations and so decisions regarding these issues and their impact on the viability of the project will likely require much more subjective evaluations (e.g. through the RRPIC).

The guidance in the remainder of this publication has been organized considering the 19 specific infrastructure issues identified as being of importance in the Research Reactor Milestones approach for a new research reactor project [2]. The AMPT and the government develop a comprehensive understanding of the obligations and commitments involved in designing, constructing, operating and decommissioning a research reactor by ensuring that the infrastructure issues are adequately addressed and there are the resources available to discharge the responsibilities. In addition, it will be necessary for the government to have in place a long term national strategy that reflects and responds to policy decisions within which the research reactor programme would sit in alignment with other components of the strategy.

A key document to assist that Member States demonstrate appropriate national infrastructure conditions is Ref. [4]. This publication sets out a methodology for self-assessment. For each issue it provides examples of conditions to be attained and examples of how the fulfilment of the conditions may be demonstrated. Where omissions and/or deficiencies are identified in the national policy, strategy or relating to the national infrastructure, their resolution would generally require targeted intervention and dedicated efforts by the government or other entities in order to resolve the weaknesses and gaps. As such, a research reactor AMPT needs to be assured at an early stage that the national infrastructure issues can be satisfactorily addressed and that any limitations would not unduly limit the viability of a project, although it is for the decision maker to evaluate the validity of any such assurances.

For the FSR, consideration of Phase 1 conditions for the 19 national infrastructure issues will necessarily be emphasized. However, it is recognized that in order to demonstrate the entire programme feasibility, it will likely be important to anticipate and acknowledge the issues and associated conditions required also for Phases 2 and 3, even though their anticipated status may be uncertain during Phase 1. Because national conditions will be highly variable, this publication does not provide any guidance in relation to addressing the conditions to be met in these later stages. However, Ref. [4] does provide further information of relevance.

The 19 infrastructure issues [2, 4] need to be analysed and assessed, with appropriate use of a graded approach, when considering their applicability to a proposed research reactor programme. If any of these 19 issues and their associated conditions to be met is not considered by the AMPT to be applicable to the envisaged research reactor programme, a clear demonstration as to why this is the case must be provided in the respective section of the FSR.

3.5. SUMMARY OF THE RELEVANT GAPS IN INFRASTRUCTURE AND RECOMMENDED COUNTERMEASURES FOR PHASE 1

A full self-assessment needs to be undertaken in Phase 1, to ensure that a suitable infrastructure is in place to permit a new research reactor programme to proceed and so that all entities are aware of their roles and responsibilities for Phase 1 and for the following phases. The self-assessment report [4] is especially useful in this regard in demonstrating how the issues and conditions have been fulfilled or addressed. Special attention needs to be paid in the FSR to any gaps or deficiencies identified during the analysis undertaken as part of the feasibility study. If it is demonstrated that these gaps and deficiencies will impact the viability of the research reactor project, this needs to be clearly noted in the relevant section of the FSR. As well as providing a clear description of the gap or deficiency identified for each specific national infrastructure issue, it will be useful to document them in relation to the type of gap (internal or external to the AMPT, i.e. can or cannot be internally controlled or influenced, respectively) and to specify the organizations or entities responsible for filling the gap. The necessary countermeasures need also to be provided, i.e. how the gap will be filled or how a deficiency will otherwise be addressed.

The full description of the issues to be addressed, the gaps between the current and expected situation and their significance, as well as countermeasures and resource needs for resolution, would need to be provided for each issue and, for comprehensiveness, would be best presented in the FSR under each infrastructure issue section. It is to be recognized that many of the gaps and deficiencies to be addressed in order to attain a satisfactory condition for an individual infrastructure issue may be related to concerns in other areas. Consequently, an appropriate resolution in one area may satisfy or partially satisfy compliance in another issue area. In order to structure and summarize the results for high level presentation, and to demonstrate interconnections, the construction of a simple matrix approach might be appropriate [4].

Clearly, the understanding of the significance and impact of gaps and deficiencies will improve as the project progresses, and by the time of research reactor operations all national infrastructure requirements must be fulfilled. However, the fulfilment of some issues will be a step-wise process. Therefore, if a gap or deficiency is not totally resolved during the pre-project phase (Phase 1) for inclusion in the FSR, it could be appropriate to simply identify those unresolved limitations and gaps that might exist during Phases 2 and 3, and to also suggest appropriate countermeasures for the future, as well as to identify at which later date the countermeasures might be best initiated. Absolutely essential for completion during the pre-project phase is the identification and description of gaps and the provision of countermeasures that are relevant for attaining Milestone 1 [2, 4].

Some identified infrastructure gaps may relate to more than one of the infrastructure issues and therefore a cross-referencing of the issues and gaps needs to be carried out to ensure that: (i) each gap is appropriately addressed in relation to all issues; and (ii) the resource requirements associated with applying any countermeasures are optimized by ensuring no duplication of effort and taking advantage of potential synergies. In some circumstances, gaps and deficiencies may be recognized, but the requirement for remedial actions and countermeasures may not be pressing or may depend on further analysis, or there may be a need for a break until a more appropriate time when there might be more clarity regarding any implications. It will be appropriate to note these circumstances in the FSR.

Each gap or deficiency identified in Phase 1 for each issue needs to be assessed for its relevance and impact on the global feasibility of the programme. Periodic re-evaluation of the gap analysis status by the team responsible for the FSR needs to be scheduled in order to trigger early warnings of issues that are not being addressed adequately or in a timely manner and consequently are delaying the project timeframe or putting the programme feasibility at high risk.

3.6. COST–BENEFIT ANALYSIS AND BUDGETARY ESTIMATION

In order to evaluate the economic and financial feasibility of the research reactor programme, high level cost estimates associated with the capital investment for the design and construction of a research reactor will need to be provided as part of the FSR. There will also be the need to evaluate the ongoing costs associated with the feasibility study itself and the future operation, maintenance and decommissioning of the research reactor. In order to be comprehensive, the cost estimation exercise must also include the costs associated with the provisions that will be required for establishing an adequate national infrastructure. As well as the costs, the preliminary budgetary analysis requires that expected revenue estimates be established based on the planned utilization of the research reactor. The purpose of this high level financial analysis is simply to indicate the research reactor project's costs and potential revenue as a basis for assessing financial viability at the early stage of project planning.

As was previously noted, because of the diversity in motivations and ownership arrangements and because government interest in investing in a research reactor would have to include the consideration of intangible externalities that would accrue over relatively long timescales, for example education and health benefits, financial evaluations and assessments based only on easily quantified expenditures, income and depreciation of tangible assets may not be appropriate. Consequently, the feasibility of a research reactor programme may not be best assessed purely on the basis of simple financial metrics and projections that do not take into account wider benefits. Rather, the broader potential social, technological and economic benefits need to be factored in, and these intangibles may not be conducive to simple quantification. Despite this apparent complexity, a rigorous cost–benefit analysis needs to be performed as a basis for investment and decisions. In this way, not only would government be assured of the direct costs associated with construction, operation and decommissioning of the research reactor, taking into account a reasonable margin for uncertainty, but the 'income' side of a research reactor project needs to also be assessed. This exercise will rely both on tangible income projections that reflect the anticipated demand for products and services and on converting intangible benefits into suitable quantifiable financial measures. A description of such analysis is beyond the scope of this publication, but it can be readily accomplished using various established techniques, such as comparative and value analysis, together with appropriate assumptions and scenarios. The remainder of this section concentrates on budgetary estimates with a focus on tangible financial measures.

It will be important to ensure that the budgetary considerations provided in the FSR include an estimation of the lifetime costs and income and these need to be presented with appropriate margins for all the project phases. To support budgetary estimates and to structure cost estimates, the costs associated with a research reactor project need to be split into logically ordered categories. One illustrative scheme includes establishing the approximate costs associated, among others, with the following main elements:

- The feasibility study itself [13]: formation of teams and associated training, preparation of a preliminary strategic plan, self-assessment of national nuclear infrastructure, selection of preliminary candidate site(s), consulting services and sub-contracting of external experts.
- Bidding process [6]: preparation of tenders, evaluation, contracting and follow-up activities.
- Human resources [14]: staff costs including administrative, technical and managerial personnel for the future operating organization, regulatory body and other authorities, for project management and review during the planning and development stages and salaries and overhead costs for operational staff during research reactor utilization.
- Site [15]: costs associated with surveys, characterization and procurement, also with ground preparation and maintenance of the facility (e.g. provision of roadways, power, water, drainage, fences).
- External technical support: various technical services will be required during the lifetime of the project and some of these may be outsourced in part or in their entirety.
- Legal counselling and other professional services: lawyers, economists and other professional staff will likely be required on an ad hoc basis.
- Construction work: people, materials and equipment costs for the construction of site buildings and other infrastructure and for the research reactor, as well as ancillary facilities and support. These may also be required for later expansion of the facilities.
- Future operation and maintenance: ongoing costs for the purchase of equipment and consumables need to be established on a yearly basis taking into consideration a reference utilization scheme.
- Nuclear fuel [16]: development, procurement, conditioning of spent fuel, interim and long term storage, return of spent fuel to the supplier and/or disposal.
- Radioactive waste and spent fuel management [17, 18].
- Dismantling and decommissioning [19]: including site remediation as required.
- Safeguards arrangements.
- Security assessments and arrangements [20].
- Safety assessments and licensing [21].

These and other items to be expended over the lifetime of the project may be organized into the limited number of compartments as indicated in Fig. 5.

In addition to the cost estimates that will be required over the lifetime of the project, possible financial income estimates need to be made based on the planned utilization strategy [5]. The services to be provided obviously need to be established taking into account an analysis of current and future service needs. Based on the cost estimates, revenue streams and funding sources, approximate cash flow requirements need to be established for each of the above cost estimate categories. These need to also include statements regarding when expenditures will be required in relation to the project phases (preparation, construction, routine operation, decommissioning, etc.). It will be very important to clearly list the key assumptions upon which any projections are based.

In addition to the direct costs associated with the development and operations of the research reactor and its ancillary facilities over the lifetime of the project, there will also be additional financing requirements on the part of government and possibly other stakeholders, for example, requirements associated with the funding of regulatory bodies, the provision of education and training facilities, additional infrastructure requirements and possibly for radioactive waste management arrangements. It may be very difficult for the research reactor AMPT or the main supporting organization to evaluate these likely costs with any degree of confidence, but they would be required for a universal budgetary analysis. Thus it is of paramount importance to engage relevant governmental organizations and external consultants in the preparation of the FSR.

It can be recognized that even for a basic financial analysis such as would be expected in an FSR, the scope of a cost and income estimation exercise is complex and there are many alternative techniques and tools that could be employed to support the generation of the cost and benefit estimates required for the feasibility study. Evaluating these is beyond the scope of the current report, but, just to mention one example, the benefit–cost ratio methodology can be employed for this purpose [13].

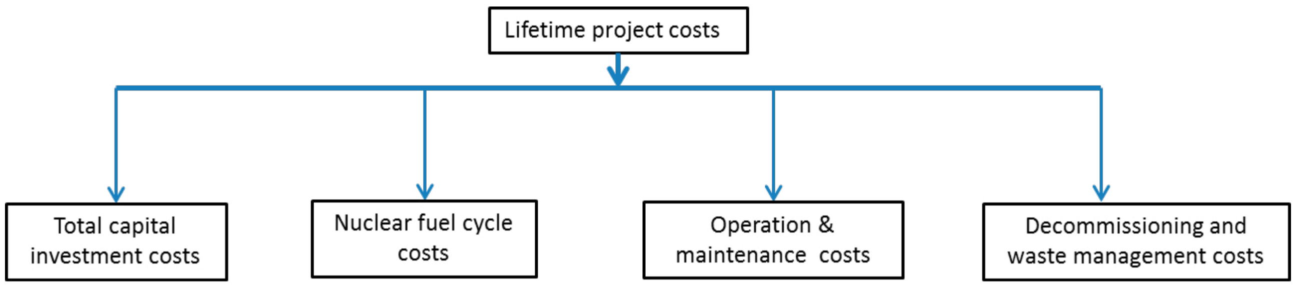

FIG. 5. Compartmentalization of major lifetime costs for a research reactor programme.

3.7. RISK MANAGEMENT

Risk management is a vital component of the good management practices to be undertaken throughout the lifetime of the research reactor project, including during the feasibility study. Although typically viewed as always having a negative outcome, risk can be defined as the effect of uncertainty on an objective, whether that be a positive opportunity or a negative threat. Some amount of risk taking is inevitable if a project is to achieve its objectives, and risks need to be identified and managed as far as possible. Because it cannot be entirely avoided, risk is a major factor to be considered during the management of any project and an appropriate and robust evaluation of risk needs to be an integral part of strategic decision making. Project management must control and contain risks if a research reactor project is to stand a chance of being successful. This is because any project takes place in an uncertain world in which the future cannot be predicted with certainty. Documenting the AMPT's approach to risk management and demonstrating that risks are identified and will be controlled will be an important element of the FSR, enhancing the viability of the project.

The task of risk management is to manage a project's exposure to risk, that is, to assess the probability of specific risks occurring, to reduce it where possible and to mitigate the potential impact on the project if the risk did occur. The aim is to manage that exposure by taking action to keep it at an acceptable level in a cost effective way.

Risk management involves having:

- Access to reliable, up to date information about risks;
- Decision making processes supported by a framework of risk analysis and evaluation;
- Processes in place to monitor risks;
- An appropriate mechanism of control in place to deal with those risks.

A risk management plan and a risk register are widely used as a means of documenting perceived risks and assessing their importance, and for recording actions that are to be, or have been, taken to manage those risks. A risk register can be a very simple document, but it is a powerful means of communication when information is to be shared between all parties with an involvement in the identification and management of risks.

Risks are generally evaluated in terms of their potential severity. It is normal to express the degree of risk as its likelihood multiplied by its impact. The likelihood that a given event will occur is generally judged on a qualitative scale. For each risk identified, the likelihood that the event will occur needs to be determined. As an example, the following five levels of likelihood could be used:

- Remote;
- Unlikely;
- Likely;
- Highly likely;
- Near certainty.

The impact of a risk once the unfavourable event actually occurs (sometimes termed the consequence) is also assessed qualitatively, by using expert opinion within a consistent framework. For each risk identified, the following question must be answered: 'Should the event occur, what is the magnitude of the consequence or impact?' As an example, impact levels can be categorized as:

- Minimal or no impact;
- Some impact;
- Moderate impact;
- Major impact: delays but milestone can be achieved;
- Unacceptable: milestone cannot be achieved.

Risk results from the combination of a hazard and the vulnerability of the project. Even though it is possible to assess the impact, the importance of any given risk depends on the risk tolerance of the person or organization taking the risk. Hence, it is generally necessary to establish a scale of risk for each organization. As an example, in a research reactor organization, impacts could be determined in the following four areas:

- Technical feasibility and resulting performance;
- Schedules;
- Costs;
- Effect on other groups.

The AMPT will need to develop a strategy for responding to risk. The classical risk response strategy takes the following form:

- Avoid;
- If unavoidable, transfer (to whomever is best able to manage the risk);
- If non-transferable, mitigate;
- If unable to mitigate, accept or manage.

Mitigation involves reducing the probability of risk occurrence, minimizing exposure to the risk if it arises, or reducing the adverse consequences resulting from a risk being realized. Mitigation approaches include risk sharing (e.g. through contracts) or having contingency measures in place. Where it is not possible to mitigate a risk, ideally only trivial risks will need to be accepted and managed, but in practice this is not always possible.

A risk register is simply a compact means of recording the information on the risks and any decisions made so that information on risks can be effectively communicated within the project team and to other relevant stakeholders. A typical risk register might contain the following:

— All the hazards related to the research reactor project;
— The risks identified as resulting from those hazards;
— The estimated degree of risk from each (likelihood multiplied by impact);
— The planned response;
— At what stage of the project the response will be given, and by whom;
— The estimated effect of the response;
— Who will carry the consequence of the risk, should it occur.

It would be normal practice for risk owners to be required to review the risks assigned to them on at least a monthly basis and for the senior management of the project to review the top level risks, also on at least a monthly or quarterly basis.

In a research reactor project environment, some of the most difficult risks to manage will be those that relate to the actions of external stakeholders over whom the AMPT may have little or no direct influence, for example, the regulators and local communities affected by the development. These external stakeholders have the power to significantly impact the implementation of a research reactor project and the proponent will need to develop a strategy for seeking to communicate with and influence these and other external stakeholders to reduce the likelihood and impact of these risks as part of a stakeholder engagement strategy. Some of the external risks that could arise for the research reactor AMPT include issues such as:

— Uncertainties regarding government commitment and support;
— Disagreement regarding the assessment of potential user and customer needs and how to respond to them in terms of the nature of the products and services and their volume;
— Uncertainties or significant changes to the reactor and/or ancillary facility functional specifications;
— Delays by external stakeholders in taking decisions that are critical to the implementation of the project;
— Difficulties in obtaining authorizations from the regulators to proceed with key stages of the project;
— Delays or disruption to the preliminary siting process resulting from significant opposition to the project from lobby groups;
— Uncertainties in the details concerning the fuel supply;
— Uncertainties regarding project funding.

The risk assessment needs to cover not only the technical aspects of the research reactor project, but also social and political aspects as well as the risk associated with the funding and financing arrangements. Therefore, it would be advantageous to develop specific categories of risk that need to be considered in relation to projects as this will make the risk manager’s task easier in terms of analysing risks, documenting, presenting and reviewing them.

The identification, evaluation and management of risks are essential parts of all research reactor projects, irrespective of reactor type, power, ownership and so on. As the scale and complexity of the project increases over time, it may become necessary to periodically implement a more detailed process to manage risks. The approach to risk management and an initial risk register needs to be initiated during the pre-project phase and progressively developed and maintained during the lifetime of the project. It will be important to document in the FSR how a risk based approach is being used to manage the potential impacts of uncertain events over the lifetime of the project and hence increase confidence in the viability of the proposals.

The current project implementation status needs to be continuously compared with the schedule and actions defined in the strategic plan, thus identifying possible risks for the project feasibility. In addition, the risks to the project posed by the gaps identified earlier in Section 3 need to be analysed and included in the project risk register together with those arising from the project implementation.

It is very important to recognize that with appropriate effort and using good judgement, identified risks may be successfully controlled and managed during all phases of the project. It may be a challenge for individuals not familiar with a project-risk-based approach to initially develop an appropriate risk management plan and register, but the effort will be highly worthwhile and may indeed be indispensable. There may also be the temptation to see risk management as a 'paper exercise'. This tendency needs to be avoided and the awareness of risks and their implications needs to be of paramount concern. As well as regularly reviewing the risks themselves, and the documented responses to be taken should the risks be realized, the risk management tools employed by the organization need to be periodically assessed for their continued suitability.

More details, including some illustrative examples on the risk analysis, assessment and management associated with the research reactor project can be found in annex II of Ref. [3] and in Ref. [22].

3.8. EXECUTIVE SUMMARY OF THE FEASIBILITY STUDY REPORT

The FSR needs to conclude with an executive summary briefly setting out the feasibility study process, the analyses undertaken and the key results. This summary needs to briefly demonstrate that the project:

- Recognizes specific needs for a research reactor facility and, on the basis of a review of options, is able to meet these needs;
- Could be implemented by an organization (future owner/operator or combined) that possesses both the capability and the capacity to successfully carry out the project;
- Identifies the 19 national infrastructure issues that must be fulfilled to support the implementation of the project, recognizing that this may require commitments from national government and other stakeholders as well as the future owner/operator;
- Is fully costed over the whole life of the project, albeit at a high level, and takes account of both positive and potentially negative externalities;
- Has taken due cognisance of all of the major risks associated with the project over its whole life cycle;
- Has preliminary acceptance by the general public or local community.

This summary also needs to briefly outline all 19 infrastructure issues, together with recommendations for the highest priority actions required to rectify a deficient situation. The recommendations related to each issue need to consist of actions to be taken by the AMPT to overcome the main difficulties identified for the immediate (Phase 1) and future project phases and, furthermore, need to include any actions and resources required from government and other stakeholders in relation to identified gaps and deficiencies in national infrastructure issues.

Subject to a demonstration of a thorough analysis and objective results derived as part of the feasibility study, the main conclusion of the FSR at the end of the report needs to be a recommendation to either:

- Proceed with the research reactor project without delay;
- Undertake additional and/or corrective actions before moving forward;
- Reconsider the opportunity of the project.

Such a bold statement is required to demonstrate that there is a clear and consistent position regarding the feasibility of the project based on a thorough and robust analysis. After careful consideration, this needs to give the decision maker grounds to support the decision on project viability, whether this is positive or negative.

4. CONCLUSION

The role of a feasibility study is to objectively examine the viability of a proposal and provide sufficient and appropriate facts and arguments. It is an essential component of the decision making process for a large scale development project and results in a technical publication, the FSR, that on the basis of analyses and evaluations formally documents the viability and sustainability of a research reactor project by critically assessing the justification for a new facility and examining the various factors that could impact on the successful realization of a safe and cost effective operational research reactor, one that is able to achieve the goals that have been set for it. The feasibility study provides the basis for a long term investment and the identification of infrastructure gaps and supports the detailed design of the facility.

After considering the prerequisites required for a feasibility study, guidance has been provided in this publication on the content of such a study and specifically the need for evaluations regarding the suitability of existing arrangements relating to 19 national infrastructure issues that are important for safely, securely and sustainably designing, constructing, operating and decommissioning a new research reactor. The key obligations and commitments required from government and the research reactor AMPT or the main supporting organization are provided in relation to each infrastructure issue, and emphasis is placed on the need to rectify deficiencies and fill identified gaps between the current situation and the necessary future state. Additional information is provided on the significance of a cost–benefit analysis as part of the FSR as well as the need for high level budgetary estimates. Another important element that needs to be in place at an early stage concerns risk management, as it will be important to demonstrate in the feasibility study that the proponent has carried out an evaluation of project risks and put in place measures to reduce or mitigate against them or otherwise has in place a strategy to manage them.

The work undertaken to evaluate the feasibility of a new research reactor programme will culminate in the production of the FSR, which demonstrates that a Member State is in a position to make an informed decision about whether to proceed with a research reactor programme or not.

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Annex I

LIST OF SUGGESTED HEADINGS FOR A FEASIBILITY STUDY REPORT FOR A NEW RESEARCH REACTOR PROGRAMME

The template provided here may be used in preparing a feasibility study report (FSR) for a new research reactor programme. It is necessarily generic and certainly not exhaustive and consequently it must therefore be adapted to meet the specific needs of Member States. The FSR needs to be underpinned by a comprehensive and robust feasibility study carried out by experienced specialist personnel who are experts in many different areas (research reactor utilization, technology, safety, legal issues, project management, accounting and finance, public relations, etc.). The end results will be an assessment that justifies the presentation of the project to allow government and other major stakeholders to make an informed decision.

It is suggested to use the following divisions and headings in an FSR:

- Part 1: Background and contextual information, including stakeholder requirements, alternative options and a project description including a definition of the potential customer base, the services to be provided and any externally imposed constraints and assumptions:
  - 1.1. Background information;
  - 1.2. Key stakeholders, identification and quantification of their needs (justification);
  - 1.3. Opportunities (including alignment with national objectives if appropriate);
  - 1.4. Executive summary of the preliminary strategic plan;
  - 1.5. Description of the proposed research reactor facility (functional specifications) and scope of anticipated services (including identification of prospective site(s));
  - 1.6. Informative confirmation of the commitment, capability and capacity of the future operating organization to design, construct, operate and decommission the facility.
- Part 2: Analysis, including a description of the assessment methods employed, the data and criteria used and an examination and evaluation of the various factors that need to be considered to evaluate project feasibility:
  - 2.1. Scope of analysis, assumptions and constraints;
  - 2.2. Analysis methods employed;
  - 2.3. Detailed demand studies;
  - 2.4. Technical option studies;
  - 2.5. Assessment of national infrastructure issues and conditions for Phase 1 (19 Issues);
  - 2.6. Understanding of national infrastructure conditions required for Phases 2 and 3;
  - 2.7. Uncertainties, missing information and assumptions;
  - 2.8. Alternatives for procurement and management of suppliers;
  - 2.9. Preliminary design, construction, operation and decommissioning options;
  - 2.10. Economic analysis (including financial cost model, scenarios and sensitivity studies);
  - 2.11. Risk identification, analysis and management strategy options.
- Part 3: Results that set out the costs and benefits of the project, opportunities that might be exploited and the major risks to be prevented, minimized or mitigated against, as well as an implementation plan:
  - 3.1. Results of the service and product demand studies (including nature of products and services, quality issues, volume, etc.);
  - 3.2. Technological solutions;
  - 3.3. Management, governance and staffing models;
  - 3.4. Results of gap analysis against 19 national infrastructure conditions;
  - 3.5. Summary of financial requirements, programme funding and multi-year budget;
  - 3.6. Timeline for implementation, including decision points and other milestones;
  - 3.7. Business model and action plan for implementation;
  - 3.8. Risk management.
- Part 4: Executive summary, including conclusions and recommendations and a succinct statement to demonstrate overall arguments in favour of the viability of the project.

Annex II

EXECUTIVE SUMMARY OF AN IAEA TECHNICAL MEETING

The IAEA Technical Meeting on the Role of Research Reactors in providing support to Nuclear Power Programmes was held from 21 to 24 June 2016 at IAEA headquarters, Vienna. The main purpose of this meeting was to provide a forum that allowed participants to share and discuss experiences, challenges and lessons learned on the role that research reactors have played and are playing in offering support to on-going nuclear power programmes. The meeting was attended by 30 participants from 24 Member States.

Based on the presentations given and the discussions that followed, the meeting participants concluded that research reactors can indeed play an important role to support new and ongoing nuclear power plant (NPP) programmes. The following main areas of contribution have been identified: (1) research and development (R&D); (2) human resources development; (3) public awareness and confidence building; and (4) development of other elements of the national infrastructure.

II–1. RESEARCH AND DEVELOPMENT

The participants recognized that research reactors are indispensable tools for material and fuel testing to ensure the continuous operation, life extension and safety of the existing NPP fleet as well as the development of new NPP technologies and fuel cycles. However, a limited number of material testing reactors can effectively provide such support to the global nuclear industry. Building a domestic research reactor to develop such capabilities is expensive and time consuming, therefore access to international collaborations or consortia built around existing or planned high performance research reactors was recommended by the meeting participants. It was noted that research reactor international cooperation effectively supports the operation of NPPs worldwide and that utilities rely on such international collaborations for fulfilling their R&D needs.

Meeting participants also noted that Member States that are newcomers to NPP programmes are usually looking for NPPs of proven design, licensed in the State of origin, and are not opting for first-of-a-kind NPPs, to reduce the risks in building first-of-a-kind and minimize the uncertainty in associated costs. Thus, it was recognized that building a domestic research reactor with the scope of performing such a kind of front end R&D does not provide any short or medium term valuable contribution to the development of an NPP programme in newcomer Member States.

The participants also highlighted the benefits of low and medium power research reactors in contributing to R&D for the nuclear power industry (including fuel cycle) in various areas such as: nuclear data measurements, code development and validation, and nuclear detectors and instrumentation testing and calibration for NPPs. The participants noted that these activities can sometimes also be conducted within the framework of international cooperation. However, it was also accepted that some Member States operating NPPs utilize their domestic low and medium power research reactors and associated facilities (e.g. hot cells) to ensure a certain level of national autonomy in the management of their NPPs (e.g. as is done by Argentina, India, and Pakistan) as well as for the preservation of national expertise to understand the results and implications of specific tests and of how they satisfy national regulatory requirements. In this regard, the participants recommended that Member States take into due consideration the dimension of their national NPP programme (current and/or planned) and make a cost–benefit analysis before choosing to build a domestic research reactor for this purpose.

II–2. HUMAN RESOURCES DEVELOPMENT

The meeting participants recognized that, nowadays, there are many options to obtain hands-on experience and to train necessary human resources for NPP programmes (e.g. through NPP simulators). However, they also recognized that the development of a national educational system for nuclear capacity building and knowledge preservation can benefit from adding practical hands-on components through access to research reactors. This access can be obtained both through a domestic research reactor and through sustainable access to a research reactor outside the State.

Experiences from research reactor coalitions (e.g. the Eastern European research reactor Initiative, EERRI, in which Austria, the Czech Republic, Hungary and Slovenia take part), from Member States recently engaged in providing hands-on training courses (the first course was proved by Indonesia and Malaysia and the second by Thailand and Viet Nam), the IAEA Internet Reactor Laboratory project (involving Argentina and France as providers of host reactors) and the IAEA International Centres based on Research Reactors (ICERR) scheme (with CEA France as the first designated ICERR) were identified as good examples to ensure access to research reactors for capacity building purposes in a cost effective and time saving manner. In this regard, the meeting participants encouraged Member States, in particular newcomers to nuclear programmes, to take advantage of such opportunities to obtain hands-on experience and training for the development of human resources. The meeting participants appreciated the IAEA's efforts in establishing and supporting the functioning of such coalitions, tools and collaborative schemes which allow also a better understanding of the commitments, challenges and opportunities related to the operation of a nuclear facility.

The meeting participants also appreciated the examples provided by several Member States on the effective use of domestic research reactors to support human resources development for nuclear programmes in general and nuclear education and training in particular.

The meeting participants also discussed the use of research reactors in the personnel training of NPPs and regulatory authorities. Although it was noted that national regulatory authorities usually do not require such hands-on training at research reactor facilities, the experiences of several Member States represented in the meeting showed that the use of research reactors in providing basic and refresher training of such staff (as part of the comprehensive training and retraining programme) is recognized as beneficial by their utilities and regulatory authorities. The meeting noted in this regard the positive experience from Austria (providing training to Slovakia), the Czech Republic, Germany, the Islamic Republic of Iran, and Slovenia (who provided training for their own national needs).

During the meeting, it was also noted that nuclear knowledge and experience developed around a national research reactor had helped some Member States in making a more informed decision on a subsequent NPP programme. Additionally, the participants also recognized that a research reactor can be a point of attraction to build national nuclear competences. In this regard, the experience of many Member States that developed technical support organizations around research reactor facilities or communities to provide support to both regulatory authorities and NPP utilities was presented.

II–3. PUBLIC AWARENESS AND CONFIDENCE BUILDING

The participants concluded that a well managed research reactor can be beneficial to enhance public awareness and confidence in nuclear technologies, including NPPs. This can have a positive impact on local communities and decision makers relevant for an NPP programme. In this regard, the experience of Ghana, India, Poland and Romania was discussed during the meeting, where public access to the records of operating research reactors helped to develop public confidence in nuclear reactor technology and NPP programmes.

The discussions that took place during the meeting showed also that safely and securely operated research reactors are contributing to build a nuclear safety and security culture in States.

II–4. DEVELOPMENT OF OTHER ELEMENTS OF THE NATIONAL INFRASTRUCTURE

Historically, NPP programmes evolved from national programmes to develop nuclear science and technology capabilities, which were structured around research reactors and their supporting infrastructure. Today, different approaches have been observed in NPP newcomer countries: (1) the historical approach (building first a domestic research reactor followed by the construction of NPPs); (2) embarking simultaneously on a research reactor and NPP programme; and (3) embarking on a nuclear power programme without a domestic research reactor programme.

Meeting participants noted that a national infrastructure for an NPP programme can be built around a certain number of different nuclear and ionizing radiation applications and facilities and that, in Member States who are newcomers to NPPs, research reactors are not always the centre of such development. Thus, it was recognized that building a domestic research reactor is not a prerequisite for establishing an NPP programme.

However, meeting participants also recognized that, if the decision is taken to build a research reactor as a first step to embark on an NPP programme, the national infrastructure developed for the research reactor programme, if properly conceived, would be beneficial and could further support the NPP programme. In this regard, the participants highlighted the importance of developing the infrastructure for a research reactor programme in accordance with international standards and good practices (such as the IAEA's safety standards and Research Reactor Milestone Approach), to maximize the benefits to the envisaged NPP programme. The feedback from the IAEA's INIR missions also showed that the development of a national infrastructure for an NPP programme in an embarking Member State is facilitated (particularly in Phase 1 and 2) if this Member State is already operating a research reactor with competent staff, an established regulatory body and active utilization programmes.

However, the participants also recognized that a poorly managed and utilized domestic research reactor or a new research reactor programme not properly conceived and implemented can have a strong adverse impact in a State embarking on an NPP programme.

The meeting participants recommended that, if the decision to embark simultaneously on both a research reactor and NPP programme is taken by a Member State, adequate arrangements need to be made in order to ensure sufficient financial and human resources to implement and maintain both programmes. This will also require effective coordination to ensure the appropriate development of the two programmes, taking into consideration the differences in the timescales, costs, competences needed and other specificities of each programme.

The participants also highlighted the fact that a research reactor operation lifetime is normally longer than the time required for establishing an NPP programme. Thus, justifying the construction of a domestic research reactor only to support the development of the national infrastructure for an NPP programme may jeopardize the sustainability of operation of such a research reactor in later stages of its life cycle. In this regard, the meeting participants highlighted the importance of developing an adequate justification and robust utilization programme for a new research reactor in accordance with IAEA guidance (in particular on applications of research reactors and strategic planning for research reactors) and relevant safety standards.

Annex III

CONTENTS OF THE ATTACHED CD-ROM: COUNTRY REPORTS DESCRIBING FEASIBILITY STUDIES FOR RESEARCH REACTOR PROGRAMMES

Country reports describing feasibility studies for research reactor programmes are available electronically on the CD-ROM attached to this publication. These reports illustrate, through a number of examples provided by the Member States, recent feasibility studies for new research reactor programmes. The IAEA acknowledges contributions from Brazil, Kenya, the Republic of Korea, Morocco, Nigeria, the Philippines, Tanzania and Thailand.

Table A–1 gives the authors and titles of the included papers.

TABLE A–1. CONTENTS OF THE ATTACHED CD-ROM

Author(s)	Affiliation	Paper title
I.J. Obadia, J.A. Perrotta	Brazilian Nuclear Energy Commission (CNEN), Rio de Janeiro, Brazil	Brazil: Multipurpose Research Reactor Project
H. Mpakany, J. Mwangi	Kenya Nuclear Electricity Board (KNEB), Nairobi, Kenya	Kenya: The Justification for a Research Reactor
A. Boufraqech, B. El Bakkari, A. Jraut, B. Nacir	Centre national de l'Energie des Sciences et des Techniques Nucléaire (CNESTEN), Rabat, Morocco	Morocco: Review of the Feasibility Study Undertaken for the Moroccan TRIGA Mark II Research Reactor
F. I. Ibitoye	Nigeria Atomic Energy Commission (NAEC), Abuja, Nigeria	Nigeria: Feasibility Study of a Multipurpose Research Reactor
K.M. Romallosa, A. Astronomo, N. Guillermo, R. Olivares, U. Bautista, M. Ramiro, V. Parami	Philippine Nuclear Research Institute (PNRI), Quezon City, Philippines	Philippines: Conduct of Feasibility Study on the Establishment of a New Research Reactor
I.C. Lim, S.I. Wu	Korea Atomic Energy Research Institute (KAERI), Daejeon, Republic of Korea	Republic of Korea: Feasibility Study for Ki-Jang Research Reactor (KJRR)
S. Mdoe, I. Makundi, J. Ngaile	Tanzania Atomic Energy Commission (TAEC), Arusha, Tanzania	Tanzania: Pre-feasibility Study for a First Research Reactor
K. Tiyapun, S. Wetchagarun, N. Klaysuban, S. Boonmark	Reactor Centre, Thailand Institute of Nuclear Technology (TINT), Bangkok, Thailand	Thailand: A Feasibility Study of the Research Reactor Project for the Ongkharak Nuclear Research Center

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Shokr, A.M.	International Atomic Energy Agency
Zhukova, A.	International Atomic Energy Agency

Consultancy Meetings

Vienna, Austria, 2–6 February 2015

Vienna, Austria, 30 May–3 June 2016

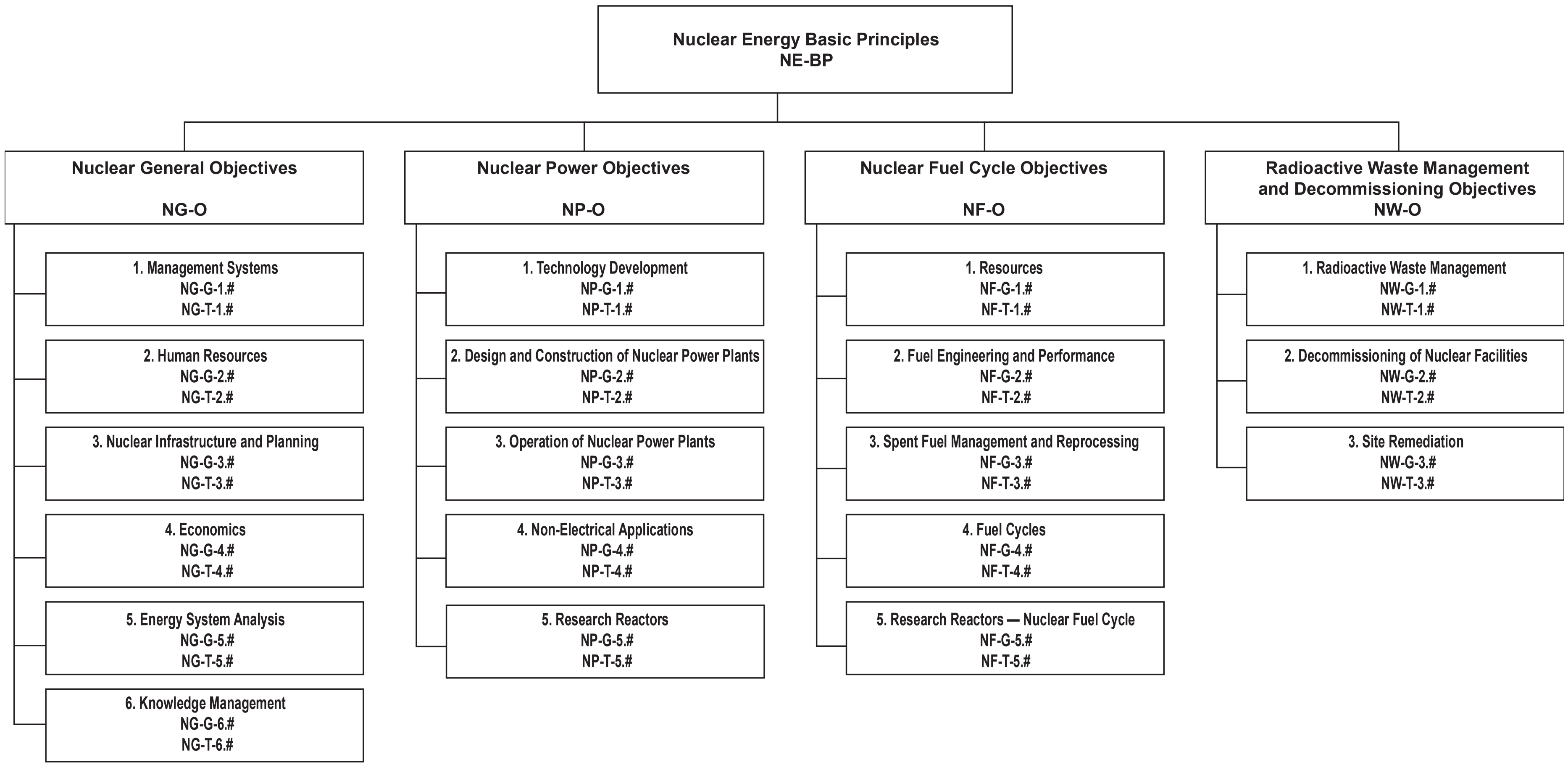
Technical Meeting

Vienna, Austria, 21–24 June 2016

Training Workshop

Vienna, Austria, 9–13 October 2017

Structure of the IAEA Nuclear Energy Series



Key

BP: Basic Principles
O: Objectives
G: Guides
T: Technical Reports
Nos 1-6: Topic designations
#: Guide or Report number (1, 2, 3, 4, etc.)

Examples

NG-G-3.1: Nuclear General (**NG**), Guide, Nuclear Infrastructure and Planning (topic **3**), **#1**
NP-T-5.4: Nuclear Power (**NP**), Report (**T**), Research Reactors (topic **5**), **#4**
NF-T-3.6: Nuclear Fuel (**NF**), Report (**T**), Spent Fuel Management and Reprocessing (topic **3**), **#6**
NW-G-1.1: Radioactive Waste Management and Decommissioning (**NW**), Guide, Radioactive Waste (topic **1**), **#1**

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