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PREPARATION OF A FEASIBILITY STUDY FOR NEW NUCLEAR POWER PROJECTS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA NUCLEAR ENERGY SERIES No. NG-T-3.3

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
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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.

One of the steps towards establishing a new nuclear power programme or in planning the expansion of an existing nuclear power plant (NPP) fleet is to commission a feasibility study. Such a study assesses, from an overall and comprehensive perspective, all aspects of the energy demand in a specific country or geographical area, in order to place the nuclear power project in its rightful context. To achieve this goal, a feasibility study will have to analyse the country's industrial infrastructure to take into consideration the prerequisites of a nuclear option, such as the availability and competence of its human resources, its cost impact, its financing prospects, and its social, economic and environmental conditions. These aspects are intrinsically linked, especially in the energy domain. Each energy option, or even each technology within each energy option, in addition to technical and cost aspects, has varying degrees of social and environmental implications that must be included in the analysis.

The feasibility study covers both the preparation work and the scope of the feasibility report itself. An investigation of the energy conditions in the country at the pre-project stage and the planning of the energy sector development needs to be established after conducting an analysis of the structure of the national energy market and of the supply and demand for energy in the country. An important input would be a fresh independent survey of the energy resources, which should be conducted during the preparation phase.

This publication was developed to provide the important technical, economic, financial, regulatory, social and environmental aspects of an NPP programme to Member State authorities contemplating a nuclear power development programme, to allow them to make informed decisions regarding the possible implementation of the project under consideration. The report also attempts to provide guidance to users who are asked to perform a feasibility study in both the technical and process areas. It condenses the experience of individuals involved in previous feasibility study efforts and provides industry best practices in order to maximize the usefulness of the material presented. This report contains guidelines to help plan a correct approach and deliver a competent feasibility study to support the initial implementation of a nuclear power programme; essential details of the conduct of a feasibility study for an NPP; and the elements necessary to build capabilities to both oversee the preparation and correctly develop a sufficiently detailed and defensible feasibility study report in support of the initial implementation of a nuclear power programme.

This publication should assist in obtaining a comprehensive analysis of the introduction of a new nuclear power programme. The work of all contributors to the drafting and the review of this publication is greatly appreciated, and the IAEA wishes to thank the participants for their contributions. The IAEA officers responsible for this publication were K.S. Kang and F. Nuzzo of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

In the context of growing energy demands to fuel economic growth and development, of climate change concerns and price volatility of fossil fuels, and in consideration of substantially improved safety and performance records of nuclear power plants (NPPs), some 60 countries have expressed interest in considering, actively planning or expanding nuclear power.

As of December 2013, there were 436 nuclear power reactors in operation worldwide, with a total capacity of approximately 370 GW(e), and 72 reactors were under construction (Fig. 1), the largest number since 1992. In 2009, construction on 11 new nuclear power reactors began, the largest number since 1985, when construction began on 19 reactors, and, as a result, projections of future nuclear power growth were once again revised upwards. Currently, expansion and near and long term growth prospects remain centred in Asia. Worldwide, in the last 5 years, construction on 58 new nuclear power reactors has begun. Of these, 45 were in Asia, 8 in Europe, 4 in North America and 1 in Latin America [1].

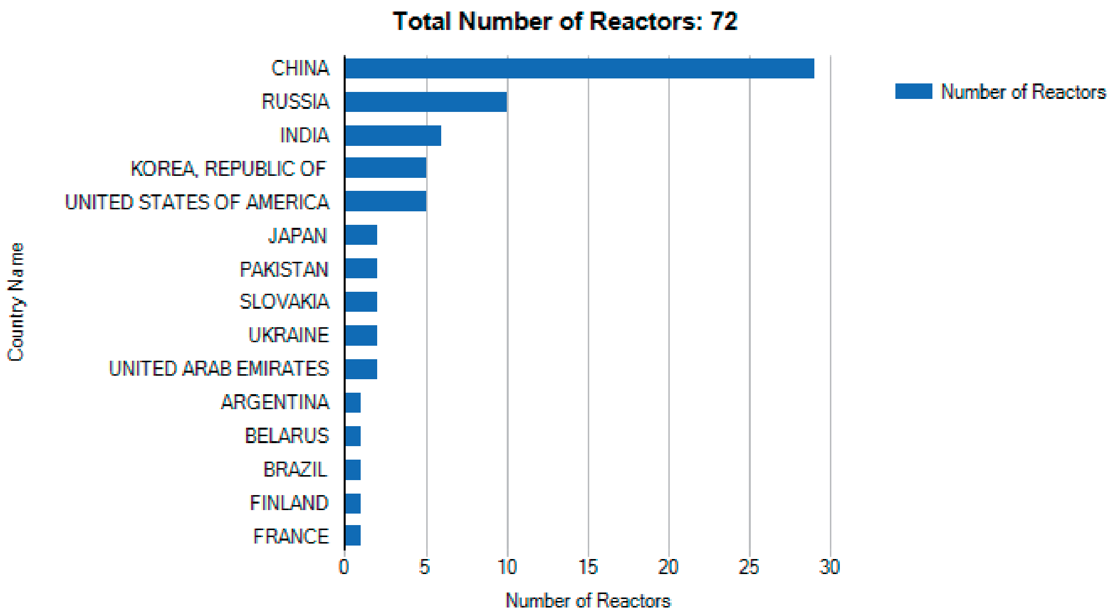

FIG. 1. Number of reactors under construction worldwide (as of December 2013) [1].

In meeting its objective of assisting developing Member States in the peaceful use of nuclear energy, the IAEA conducts an extensive and comprehensive programme of work in nuclear power planning and implementation, including economic assessments to determine the appropriate role of nuclear energy within the national energy plan of developing Member States. These assessments include three major types of interdependent and closely related activities:

- Developing appropriate methodologies specifically adapted to developing countries;
- Conducting training courses on energy and nuclear power planning techniques, including use of methodologies developed by the IAEA;
- Conducting energy and nuclear power planning studies in cooperation with the Member States requesting them.

New initiatives on the development of these guidelines on the preparation of a feasibility study (FS) are framed within the broader IAEA mandate to support Member States in their activities and requirements as they evolve.

Close cooperation has been established with other international organizations, for example, with the International Bank for Reconstruction and Development (IBRD) in the joint IAEA/IBRD electric power sector assessment missions to developing countries. Electrical assessments are a pivotal part of any FS.

1.2. OBJECTIVE

This publication addresses all relevant issues related to the preparation of an FS for a new NPP, and suggests good practices drawn from international experience that will allow the study to proceed promptly, safely and to high quality standards. The main aims of this guide are to:

— Provide an effective guideline for the preparation of an FS in support of prospective organizations of countries that are embarking on their first nuclear power project under either a turnkey contractual approach or a split package approach;
— Define and explain government and prospective owner duties in the preparation of an FS for the introduction of a nuclear programme with particular emphasis on the country’s infrastructures, electrical grid, budget and financing, and interrelated issues;
— Present effective FS models, methods and approaches that have been developed and successfully adopted in the past 25 years, including the growing use of computerized tools.

1.3. SCOPE

This publication describes the various steps generally undertaken to prepare an FS report in relation to the prerequisites of a nuclear project. It covers an analysis of the country’s industrial infrastructure, of the condition of its human resources in terms of availability, competence and trainability, of its financing capability, of its social and environmental conditions, of its economy and financing, and of the potential impact of a nuclear project on the country’s economy.

1.4. GENERAL DESCRIPTION OF THE CONTENTS OF A FEASIBILITY STUDY

One of the steps towards establishing a new nuclear power programme or in planning an expansion of an existing NPP fleet is to commission an FS for an NPP. Such a study assesses, from an overall and comprehensive perspective, all aspects of the energy demand in a specific country or geographical area, in order to place the nuclear project in its rightful context. To achieve this goal, an FS will include the analysis described in Section 1.3. These aspects are intrinsically linked, especially in the energy domain. Each energy option or even each technology within each energy option, in addition to technical and cost aspects, has varying degrees of social and environmental implications that must be included in the analysis. The FS will cover both the preparation work as well as the scope of the feasibility report itself. A comprehensive FS is a complex, but necessary, step when nuclear power is being considered in the mix of energy sources serving a particular country or geographical area. Introduction of the nuclear power option may require energy market restructuring, especially if the gap between supply and demand for energy is at a deficit. Financially, the level of investment funds required may, in some cases, considerably affect government budgets and priorities.

1.5. USERS

The following organizations are foreseen as users of this guide:

— Government appointed nuclear energy programme implementing organizations (NEPIOs);
— Government ministries of industry and commerce;
— Owners and/or operators of NPPs;
— Regulatory bodies and staff;
— Technical support organizations;
— Construction contractors;
— Architect–engineering firms acting as main contractors.

1.6. STRUCTURE OF THIS PUBLICATION

Following the introduction in Section 1, Section 2 presents the broader objectives of a site specific FS for an NPP, its time location within the programme schedule, its main assumptions and pre-conditions, the project stakeholders, the goals and the objectives. Section 3 contains guidelines for the preparation of a site specific FS. It consists of technical guidance on each topical area followed by suggestions as to the process and content of performing the study. It contains 18 topics dealing with the major areas of investigation normally found in a site specific FS. The introduction is followed by subsections, among others, providing information on investigating the electrical system and the demand forecast on which to base the justification for the expansion programme. This is followed by a subsection dealing with unit capacity, its determination and its integration into the existing grid, a subsection on site characterization, the NPP technologies, the fuel cycle, the environmental impact of the project, licensing and authorization, prerequisites and their implications, the project implementation approach, national participation, human resources and training, the project cost estimate followed by economic analysis, financial planning, public information activities, emergency preparedness of the site and a summary and evaluation of the project risks. A subsection on the invitation to bid specification and guidance related to the first NPP commercial contract are also included.

Section 4 ends with conclusions and recommendations. Four appendices are also included. Appendix I contains examples of the environmental impact on water resources, available mitigation options and processes to reach an acceptable solution. Appendix II contains examples of constructability and modularization studies to accelerate construction as well as the drawbacks associated with their use. Appendix III contains the experience of Member States that have recently engaged in the preparation of a feasibility study for an NPP project. Appendix IV contains a table summarizing the type of findings arising from various recently conducted feasibility studies.

2. PREREQUISITES OF A FEASIBILITY STUDY

2.1. BACKGROUND

An FS for an NPP is usually undertaken in the context of nuclear programme development or expansion. It usually requires several preparatory steps to provide the inputs necessary, and may be preceded by a reduced study to facilitate decisions as the development programme proceeds. The context in which an FS is undertaken is described in the IAEA publication Milestones in the Development of a National Infrastructure for Nuclear Power [2], in which three distinct programme phases are identified and separated by three important milestones.

It is assumed that phase 1 begins when a government first expresses an interest in nuclear power. Usually, one of the first actions the government takes is the appointment of an NEPIO made up of representatives of potential future stakeholders with the mandate to manage, regulate and oversee the first steps of a national nuclear programme. The make-up and functions of this working group are described in the IAEA publication Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators [3].

The basic functions of an NEPIO are to inform the government policy makers of the issues related to embarking on a nuclear power programme. As such, a number of investigations and studies are developed to compile a national energy strategy document that contains the necessary information to allow the government policy makers to make a knowledgeable decision on whether to proceed with a national energy development programme that may include nuclear energy.

One of the key sections of the national energy strategy document may include conducting a pre-FS concerning the overall nuclear power programme. This study can also be a standalone document, in which case, the overall strategy document will include the main conclusions of the pre-FS so as to allow an analysis of the overall national energy programme and reference to the pre-FS text for details.

When a decision is taken to start an NPP construction project, a project specific FS should be undertaken before substantial funds are made available and the authorization to proceed (ATP) with the first NPP construction is actually granted. This would be the ideal window of time in which to detect any underlying issue(s) that may pose a threat to the construction project, and therefore significant effort should be made to address any and all potential risks. The pre-FSs, and other work that the NEPIO or others may have performed or commissioned during phase 1, are just as valid as any money, resources and effort invested in them, which, however, might may not have been very significant during that early phase. Before the ATP, and the purchase of long lead procurement items and the pouring of first concrete, the stakeholders, particularly the owner and the financing institutions, usually require a detailed project specific FS and interrelated studies. Every item in the pre-FS (or studies) is reviewed in light of the latest information. Breaking points can be, for example, any design changes to critical systems, structures and components (SSCs) that may affect the size of the reactor building or cause the redesign of large portions of safety systems and components, large increases in the ground level motion resulting from more accurate seismic studies, or a large increase in the number and type(s) of contractors and imported skilled workers that would not be within budget limits. In addition, changes to the critical path, and therefore to the construction schedule and related budget issues, can occur because of new obstacles, i.e. inadequate types of ground, larger cooling towers, larger or increased numbers of diesel generators and/or new licensing requirements, etc.

A site specific FS will focus on known fundamental changes, and all new information and risks that may not have been considered by the NEPIO's pre-FSs. It will also focus on safety implications that may arise from design changes. Both the licensing authority and the stakeholders, particularly the financial partners, would want to have a record of any changes made to the feasibility parameters.

Failure to review the work completed by the NEPIO prior to authorization being given, and the unsuccessful processing of all new critical information, would mean a high risk of project failure, and possibly also negative safety implications, delays and cost increases.

The work carried out during the pre-FS will normally be the starting point for the full FS, should the decision be to move forwards with nuclear energy. The key difference stems from the different focus that exists between a nuclear power programme and a nuclear power project. A programme is part of the strategic plan for the overall development of the nuclear sector in a country. It is focused on the overall energy and economic requirements of a country, and results in policy decisions and legislation. An NPP project is focused on a specific NPP and its associated economic, technical and social issues. It is focused on the realization of a specific project and it results in the actual construction of an NPP.

Phase 1 ends when a knowledgeable decision is taken to proceed to phase 2, see Ref. [2]. If the decision is either not to proceed or to delay the project, then the country will not progress to phase 2. If the decision taken is to proceed with nuclear power, then the country can progress to the next phase.

Phase 2 begins with preparatory work for the NPP construction. A comprehensive and detailed site specific FS is prepared based on the NEPIO's documentation. By that time, detailed vendor information and site specific data may be available. This publication describes the various parts of a site detailed specific FS prepared to support stakeholder decisions and to obtain approvals and budgets to proceed with the detailed programme. Once the FS is published and decisions on how to proceed are made, phase 2 usually concludes with the publication of the bid invitation specification (BIS). The FS that precedes the BIS could include rules and information that assist with the drafting of the BIS, as described in the IAEA publication Invitation and Evaluation of Bids for Nuclear Power Plants [4].

During phase 3, activities to construct the plant are undertaken. During this phase, an update to the FS is normally carried out for the benefit of financial institutions, which, in this phase, are required to approve loans and begin large disbursements. This update will naturally include information especially geared towards the financing of the project and towards loan evaluations.

‘Newcomer’ countries may not have all the inputs necessary to undertake the FS, nor may all the necessary conditions be present for a first NPP [5]. However, the study can still be conducted with particular attention paid to documenting the assumptions made and the existing gaps.

2.2. ORGANIZATION AND RESPONSIBILITIES FOR FEASIBILITY STUDY PREPARATION

When starting the FS preparation phase, the owner should have adequate human resources with basic knowledge to prepare the requirements for an FS and to evaluate the FS report from a technical, economic and legal perspective [6]. Specific human resource requirements may include:

- Technical expertise to develop specifications for an NPP and to evaluate the FS;
- Project and management system expertise to manage the FS preparation process;
- Detailed knowledge of the infrastructure in the country and at the future NPP site, as well as the regulatory environment;
- Legal and business expertise for FS preparation and review;
- Financing expertise to develop and analyse financing plans;
- Expertise in stakeholder communication and public information.

The knowledge and experiences acquired during phase 1 of the nuclear power programme are very useful in the process of FS preparation. However, it is advisable that the same key people continue in their positions through the entire process of the NPP implementation (FS, BIS, contracting, construction, commissioning and operation).

Depending on the country’s constitutional organization and legal framework, the owners of the plant could be, for example, a private utility managing all work with contributions of specialized organizations, or it could be the central or local government through designated agencies or partnerships with the reactor vendor or experienced steward operators of similar plants. In other cases, a government ministry may be given the task to control the project budgets and hence also the task of commissioning the FS. In such a case, the operator and the vendor provide external technical support, but the government controls and bears all responsibilities. No matter what the management model is, the owner of the future NPP should be designated before embarking on phase 2 of the nuclear power programme [2].

The owner’s area of responsibility also includes necessary contacts with all related stakeholders prior to and during the FS preparation process. Communication with stakeholders has a two way benefit:

- The NPP owner receives the information and guidance that it needs in preparing the FS (e.g. from the nuclear safety regulatory body for the licensing process and specific regulations, the national electricity utility for the NPP integration into the national grid, the environmental agency for the licensing process and specific regulations, the ministry of education for human resources development, etc.);
- The stakeholder is better prepared for measures that it may put into action in the later phases of the NPP project.

It is generally advisable for the owner to obtain assistance from well qualified consultants who have experience with FS preparation processes and specialized knowledge that may be lacking in the NPP owner’s organization. However, consultants should always have an advisory function only. A consultant for the FS preparation could be necessary for the following reasons:

- Preparation of the FS requires a strong background in both the technical and the financial aspects of the NPP project;
- The perceived objectivity of the evaluation is an important factor in the credibility placed on the FS by potential financial lenders and other interested parties;
- It is important to hire a consultant with no formal ties to the project, equipment manufacturers or marketers, so that an unbiased evaluation of the NPP project operating potential and efficiency can be made.

The FS consultant should be selected through a competitive process. To this end, a BIS for consultancy services may be issued by the NPP owner. Qualifications should be objectively proven. Qualifications should not be graded in such a way that deficiencies in one skill could be compensated for by above average qualification in another skill in a blind point system. The method used to qualify a consultant for an FS should be based on minimum requirements for each subject (i.e. 80%). If the consultant scores less than the set minimum in even one of the fields, he or she should be automatically disqualified. An example of qualification criteria by skill area for the selection of an FS consultant is presented in Table 1.

The candidate represented in the table would be rejected because one result is below the minimum acceptable (80%, as shown in cell No. 1), even though the candidate consultant scored above 80% in all other fields. In certain cases, a consultant may use a specialized agency to cover specific fields of competency. In those cases, the qualification check shifts to that agency for the specific competencies. Each criterion could be further divided into a checklist of subcriteria or subareas of competency (i.e. ten subareas) to facilitate the scoring. If more than one candidate passes the verification table, then the candidate with the highest total score would be selected.

TABLE 1. COMPETENCIES AND QUALIFICATION EXAMPLE ASSESSMENT OF A POTENTIAL FS CONSULTANT

No.	Criteria	Minimum acceptable requirement is 80% (any score below 80% in any of the seven categories automatically disqualifies the candidate consultant; no total averaging allowed)		
		Knowledge	Skill	Ability
1	Previous experience in creating similar FSs	78	80	90
2	Knowledge of the industry to be studied (nuclear power)	91	81	80
3	Qualifications of key members of the team in which the consultant is working	84	82	92
4	Understanding of the project owner structure	90	99	92
5	Proposed interaction/interfaces with the project owner’s designated representatives	100	90	90
6	Verbal presentation and communication skills	88	82	90
7	Costing of FS	98	99	100
	Total	629	613	634
	Overall score	1876 (max. 2100)		

2.3. PREPARATORY STEPS

A number of steps in favour of the nuclear option may have already been taken during phase 1. The documents (if any) illustrating such steps should certainly be considered without prejudice and with independence of opinion in the preparation of the FS for a specific NPP. For example, a national energy strategy document and a pre-FS or equivalent may have already been issued to stakeholders to provide them with a technical basis for proceeding with phase 2 of the programme introduction. Refer to Ref. [2].

Some of the steps that may have been undertaken during phase 1 include:

- Identification of the legislative framework and demonstration of the capability to develop and promulgate required laws for the nuclear power programme;
- Consideration of any regulations already in place and definition of applicable codes and standards to support the initial site selection, the NPP design, its licensing, construction, commissioning and operation;
- 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 NPP owner and operator and engagement with the main stakeholders;
- Definition of the management model;
- Development, within an appropriate timeline, of the essential legal and safety programmes.

In addition, it is advisable that the government already commit to adhering to the international nuclear conventions, safeguards and security, recognizing them as an essential infrastructure to safely operate nuclear facilities and gain membership in international agencies, and in so doing, access active support from the international nuclear industry.

2.4. PROJECT STAKEHOLDERS

The project stakeholders are those who have a vested interest in the project. They can be individuals and organizations actively involved in the project, or whose interests may be affected during project execution or plant operations. They may also be authorities who exert influence over the project's objectives and outcomes. The FS should identify the stakeholders and determine their requirements and expectations. Involving interested parties in every stage of the life cycle of nuclear facilities is essential to enhance mutual trust on issues related to nuclear energy production. Beyond the groups traditionally involved in the decision making process, such as the nuclear industry, scientific bodies and relevant national and local governmental institutions, the concept of stakeholders should also include the media, the public and local communities. The IAEA publication Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [7] outlines a route to effective stakeholder involvement throughout the main phases of the life cycle of nuclear facilities (i.e. construction, operation, radioactive waste management [8], decommissioning) and the use of up to date methods to implement stakeholder involvement programmes [9].

2.5. SETTING GOALS FOR THE NUCLEAR POWER PROJECT

Goals and objectives should be high level statements that describe what the project is intended to accomplish and what business value the project will achieve. They usually serve the purpose of setting the overall direction and targets. A plant specific FS should identify what must be performed at the national and local levels in order to achieve the high level project goals. Objectives are lower level statements describing the products and deliverables that the project intends to complete. Objectives should always be aligned with project goals.

Goals and objectives may have a short or a long term achievement target. Examples of short term goals for a country about to embark on a nuclear power project are to:

- Develop and establish an institutional capacity (e.g. a NEPIO), the supporting framework, the skills and tools necessary to explore the feasibility of a nuclear power generation programme [2];
- Define readiness milestones such as policy and utility readiness;
- Set the parameters for infrastructure readiness and public acceptance;
- Decide the NPP size and timeframe for the decision;
- Define a nuclear technology localization policy;
- Define a national nuclear safety, security and safeguards policy [10–12];
- Set the fuel cycle and waste management goals;
- Select the reactor technology;

— Select the reactor and the fuel supplier;
— Develop the human resources development plan;
— Develop and implement the emergency preparedness and response plan;
— Issue the environmental impact assessment (EIA) associated with the project.

Examples of long term goals for a country embarking on a nuclear power project may be:

— Security and sufficiency of the country's energy supply to support long term economic and social development and environmental sustainability;
— Reaching the target proportion and role of nuclear power in the energy mix;
— Achieving a positive assessment of the long term sustainability of the nuclear option, e.g. by using the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) methodology to assess sustainability [13];
— Ensuring that the contribution of each NPP (including capacity factors) meets the grid requirements as planned.
— Ensuring that long term nuclear waste disposal facilities are in place as planned.

2.6. IMPLICATIONS OF THE ACCIDENT AT THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

This publication was compiled after the accident at the Fukushima Daiichi nuclear power plant in Japan on 11 March 2011, but at a time still too close to it to encompass all lessons learned.

Details of the Fukushima Daiichi accident and lessons learned are being taken into consideration by NPP design and research organizations, by regulators and by operators. The stakeholders of new nuclear power development programmes should refer to these authorities and competences, which may be documented in new regulatory requirements, new site selection rules, and more restrictive procedures and processes in the pre-construction and licensing phases, and in all successive project implementation phases.

At this time, safety reviews, identified issues and solutions to increase resistance of plants to extreme events and cliff-edge effects generally have both general and site specific implications. New plant vendors should already have built into the designs they purchase some generic features to increase robustness to extreme natural events. Countries interested in introducing or adding nuclear power generation to their grid may have to include, in their technology evaluations and in their candidate site evaluations, elements such as vulnerabilities to extreme events and their consequences for design features and provisions with the technology vendors they are considering.

3. CONTENTS OF A FEASIBILITY STUDY FOR A NEW NPP

3.1. GENERAL OBSERVATIONS ON THE CONTENTS

An FS for an NPP is primarily a justification document for the acquisition of one or more nuclear generating plants to be integrated in the overall mix of electrical power generating plants. It is also a summary of the elements necessary to support the authorities and other stakeholders in their key decisions and financial commitments required to launch a new build project. The study provides the required information to various depths and degrees, depending on the specific requirements. Some of the listed items may have been addressed in separate, standalone documents. In such cases, the FS authors need only refer to these documents, and, if necessary, review, amend or update their contents, or simply summarize their findings and recommendations if the information is still up to date.

In the broadest terms, an FS of a specific power plant provides an analysis of the insertion of the plant into the electricity market, resulting in a number of indicators of the market state at startup and its projected growth in terms of volume, annual sales, sales trends and an index benchmarking the local industry growth.

Another element that may be required in an FS for an NPP is the selection or confirmation of the reactor unit capacity and the possible implications related to its integration into the grid, which may lead to decisions such as grid strengthening or grid expansion, if appropriate.

The candidate site selection is normally proposed at an earlier stage during the definition of the overall expansion programme. In a phase 2 FS, the site should have already been selected, but decision makers still need to know the more detailed characterization of the selected site and all items that will have an impact on cost, such as geology and hydrogeology, seismicity, site preparation work (including excavation, internal and external access routes), emergency preparedness, security facilities, construction laydown and storage areas, all utilities and facilities necessary to support construction (power, compressed air and other gases, service and drinking water, administration and technical support buildings) and any other cost related items.

If the reactor technology had been previously selected in a separate study, the information available and the factors that led to the decision should be summarized, together with the interfacing requirements to other sections of the FS. It is important that interfacing parameters be defined correctly in order to ensure that all studies are conducted in harmony with the selected technology.

In parallel to the technology, a fuel cycle market survey needs to be conducted to examine the options in light of the national participation programme goals in areas such as radioactive and conventional waste management, spent fuel management, safety during operation and accident conditions, spent fuel pool facilities and radioactive waste storage and control.

If an EIA is not available, then environmental issues should be addressed in the FS in order to identify issues, possible configuration or operating modifications and/or remediation costs. If an EIA is already available, recommendations from the assessment should be summarized and conclusions drawn in terms of cost and implications for the plant. The FS should, in any case, identify radiological sensitivities, address economic implications, examine any restrictions and determine how these could be addressed, including options to procure or save funds for future restoration of the environment and any other site specific environmental protection considerations. Measures to mitigate or possibly prevent operational events from causing permanent damage should also be described and assessed here. The licensing process should be described in a later section identifying a milestone schedule and the cost of the licensing documentation and safety analyses required.

A number of possible project financing options should be explored, including various partnership models and capital injection potentials. In addition, possible contractual approaches should be examined, together with procurement models and project management models.

The FS should propose a sustainable national participation model in line with the overall national strategy goals. The model should include items such as the localization plan, technology transfers and related costs.

Human resources should be discussed for the various project phases, together with education and training requirements and their related costs. In the context of public relations, a general public information and communication plan should be laid out since it is a cost item that needs to be known.

In an FS, it is also important to describe the accident preparedness and site emergency planning, and the supporting infrastructure and its cost. Decommissioning and its impact on project finances must also be taken into account.

When enough technical information is available, a project risk matrix and its implications, followed by a risk assessment and management plan, should be developed, and a risk management model should be recommended.

An overall project cost estimate built upon the major cost items, namely the cost of construction, financing, operation and maintenance (O&M) and waste management should be undertaken. For heavy water reactors (HWRs), the cost of heavy water would have to be included, although it is compensated by the low natural uranium fuel cost and the reactor fuel's higher burnup.

An important comparison indicator is the levelized unit cost used for the cost assessment of various energy options. A financial plan should also be included in the FS alongside the cost assessment. Finally, guidance for the preparation of the invitation to bid should be given, in which the various requirements in the future BIS should be described.

The contents, the level of detail and the extent of an FS report will obviously vary depending on the complexity of the investigations, on the amount of research and development (R&D) required, on the outcome of the various analyses and of their consequences, on the type of technology and technology evaluation work, on whether the recommended design is the first of its kind or not, and, finally, it will depend on the objectives and expectations of the decision makers. This, and other international guidelines on the subject, should, in any case, be consulted and the decision to exclude certain topics justified.

Not all the contents and the details presented in the guidelines must be included in all cases. Some of the contents described here in the areas of industrial infrastructure, transportation infrastructure, economic and financing assessment work, some of the siting investigations and the possible research required may have been developed previously as inputs to the energy policy document, depending on the individual circumstances of Member States. The scopes of the energy policy document and the FS for new nuclear construction should be decided beforehand considering the competencies of the various organizations involved.

In terms of the volume (length) of an FS, on average and without counting the independent specialized reports feeding into it, such as environmental studies or separate technology and fuel cycle evaluations, and without including the analysis details and computer code printouts, an average FS would fill the pages of two large binders.

In any case, the binders should also be accompanied by a condensed version that discusses only inputs, assumptions, limitations, depth and range of issues covered in the study, results of technical, economic and financial studies and a list of outstanding issues (if any). In principle, the condensed FS report should be comprehensive but succinct. It should contain the information required by the decision makers, and its length should not go beyond 30 pages of ‘straight to the point’ information.

3.2. APPLICABLE LAWS, CODES, STANDARDS AND GUIDES

The country’s nuclear energy act, its laws and decrees should cover all matters related to the national energy policy. The government should formally commit to the use of nuclear energy for peaceful purposes, adhere to international conventions and treaties, enforce environmental protection, codify occupational health and worker safety policies, and establish emergency preparedness and management policies and the role of various government levels, stakeholders and the public and their interrelationships in enacting these policies. Regulation should also cover foreign investments, vendor and contractor relationships and expected ethical behaviour, intellectual property rights, the preservation of national traditions, cultural values, the promotion of economic benefits and technological development, the control of nuclear material, fuel cycle issues and the national insurance coverage policy.

The regulatory authority is normally established in accordance with the nuclear energy act or law that, in turn, confers onto it the necessary authority to develop specialized regulations of its own and to enforce them. In this context, the regulatory authority establishes the standards to be used in the various steps of the nuclear power introduction process, which constitute the basis for the nuclear power programme including infrastructure, pre-project activities, design, construction, commissioning, operations and decommissioning.

The regulator may decide to adopt the IAEA Safety Standards and Safety Guides and the International Organization for Standards ISO 9000 family of standards related to quality management systems or the quality standards of the vendor country covering the NPP design, licensing and project implementation. It may also decide to adopt all regulations, codes and standards of the vendor country. Alternatively, depending on the circumstances, it may decide to adopt them in addition to those of the vendor country. Examples could be the local building code, fire protection regulations, drinking and sanitary water regulations, security rules, etc. As far as the licensing process is concerned, the regulator may decide to sign cooperation agreements with the regulatory body of the vendor country to help establish the required authorizations for siting, design (licensing basis), construction, commissioning and operation, and to define the licensing milestones for each authorization and any related technical documentation.

Codes and standards are important in estimating infrastructure improvements and programme implementation costs. A typical application of local codes and standards is the adoption of those used during the country’s infrastructure and capacity building exercise or during the national participation and division of responsibilities exercise. These may cover the equipment supply and services that are required, and the industrial infrastructure that should be operated under rigorous quality management programme requirements. In addition, application guides may be made available to provide lower level requirements to develop an industry qualification programme. Guides may also serve as a basis for the evaluation of the industry readiness in terms of manufacturing, transportation, delivery, installation, commissioning [14] and operation.

3.3. ELECTRICAL SYSTEM ANALYSIS

A national or even regional cross-boundary electrical system analysis is usually performed during the national electrical system expansion planning study or in a high level pre-FS conducted long before the NPP specific FS is undertaken. However, it should be reviewed and expanded at the time that the FS of the specific NPP is carried out during the NPP implementation phase.

An electrical system analysis encompasses a broad collection of activities aimed at characterizing the existing network and at projecting its future expansion. Consequently, the electrical system analysis activities must naturally span several time horizons. The analysis can be conveniently divided into categories, such as electricity demand (electricity usage expected at the end period under consideration), generation capacity and growth options available, and transmission and distribution models. Each analysis category may be carried out over different time horizons, with timeframes from less than 5 years, to up to 10 years, or with longer terms, beyond 10 years. However, these models are not to be dealt with as operable in self-contained domains. Although it is conceptually convenient to think in terms of categories and use separate analytical techniques at different times for each category, all models should be intimately interconnected since the system will be workable only if verified in its entirety, both in space and time.

The primary objective of an electrical system analysis is to provide a sound technoeconomical background and framework for assessing the electricity production requirements in order to ensure an adequate electricity supply for the duration of the programme. This activity is usually undertaken by consultants under the supervision of a national commission. An electrical system analysis should take into account the financial constraints, resource availability and governmental policies and regulations that are currently in place or expected to be in place in the future. It must make projections for the expected demand for electricity and identify the requirements for new generating capacity to satisfy this demand. Furthermore, it should ascertain the timing of investment disbursement and the appropriate types and mix of generating technologies to supply the electricity required.

It is important to note that electricity is provided by a system consisting of interconnected, interrelated and interdependent technical, environmental and economic elements. In that sense, modelling techniques and analytical tools must always support the overall functionality of the system. An analysis that does not capture source to source, technology to technology comparisons and all development options is not adequate as justification for a decision to introduce a NPP programme. System modelling and technology to technology comparisons should be mutually compatible and complementary parts of the analysis. If separated, each may present vulnerabilities. The basic underpinning of a sound electrical system analysis should be the development of an appropriate technoeconomic model(s) of the system under study with the technologies as variables. A model of this type should include all of the relevant technical, environmental and economic attributes of the system. The model(s) can then form the foundation upon which the analysis is built and upon which appropriate technical directions are given and conclusions drawn.

As stated above, the electrical system expansion programme, developed during the national electrical system expansion planning phase, should be reviewed and updated at the time, and by the group executing the FS of the specific NPP during phase 2 implementation [2]. The new specific analysis should be focused on the period when the NPP is expected to be integrated into the system within the context of long term analysis. For this specific period, the input data should be more detailed and in greater depth than the data used during the national study of the system expansion planning time.

The electrical system analysis should include:

— Electricity demand and electricity demand projections (base scenario);
— Electricity supply system characteristics (current and future system expansions);
— Electricity market structure and organization;
— Electrical system expansion plans, including generation, transmission and distribution (base scenario);
— Nuclear power project impact evaluation on the grid.

3.3.1. Links to other feasibility assessment activities

The electrical system analysis is linked to the overall energy planning primarily through the energy and electricity demand analysis and projections. These should take into account the major driving forces of demand growth (e.g. anticipated economic activity, population growth). In addition to demand levels, the analysis should assess the structure and dynamics of future electricity consumption. Electricity demand projections are required to evaluate the requirements for future generating capacity. Operation and expansion of an electricity system is planned, taking into account different technical and economic aspects of the existing and envisaged assets in the system:

— Technological options and development in electricity generation, transmission and distribution;
— System operation practices, information and communication technologies;
— Supply side technologies and consumer behaviour;
— Use of resources;
— Environmental and social impacts and interactions;
— Investment costs and economies of scale;
— Fuel prices and operational costs;
— Electricity market structure and organization;
— Availability of capital, etc.

The above mentioned parameters and the environment in which they occur must be projected into the future. Sensitivity analyses of important parameters and the time dependent influencing factors are often the most useful tools to project the current state of an electrical system into the future.

3.3.2. Electricity demand

Any electricity demand analysis should begin with historical data. It should include reviews of past trends and of the present state of electricity demand and electricity demand projections. The past evolution of the electricity demand should be analysed as thoroughly as possible using available data and statistical techniques. The objective is to obtain a basis for projections of future trends in energy demand, bearing in mind the long term planning horizon and possible and expected structural changes in demand patterns.

A detailed and comprehensive survey of the consumer market and analysis of its past development is usually the starting point of electricity demand forecasts. Electric companies or electric authorities, or both, should have the most reliable and complete statistical information on their customers. This information should be found in the company archives. Unfortunately, the data they possess is normally limited to the electricity they themselves supplied to their customers. It does not account for local municipal or private production units, which may or may not be connected to the national transmission grid, usually operated by a transmission system operator. Depending on the prevailing market conditions in the country, this may vary from a negligible amount to a substantial portion of the overall demand. Statistical information on a market segment is generally more difficult to obtain. In addition, there might be a component of the overall demand called suppressed or unsatisfied demand. This refers to latent demand that is not met owing to lack of sufficient generation, transmission or distribution capacity. Such situations are common in the developing world. They render the overall demand difficult to estimate, unless the number of consumers not connected to the distribution grid together with voltage and frequency variations beyond permissible limits are known, and all planned or forced load shedding events are recorded. These data can provide indirect indications about the latent demand.

The electricity demand structure should be analysed in detail for each user sector (domestic, commercial, industrial, services, transport, etc.) and for their geographic distribution. The most relevant aspects to be considered are:

— Electrical energy consumption;
— Peak load demand;
— Load duration and variation (daily, monthly, seasonal);
— Transmission and distribution losses.

The data to be compiled regarding past development should cover a period of 10–20 years, and the data for each independent electrical system (if any) must be analysed separately.

3.3.3. Electricity demand projections

The long term projections (25–30 years) of electricity demand, of peak demand and of load shapes are critical determinants of future generation capacity requirements and constitute the reference for any analysis regarding the scope and composition of the electricity supply expansion programme; see also Ref. [13].

As for other subjects treated in the FS report, the long term projection of electricity demand, peak demand and load shape may not have been produced, or may be outdated. If such a document is not available, then it should be produced at this time, and the NPP FS should extract from it the NPP interfacing requirements in the context of the plant integration to the grid. If, on the other hand, a separate document has been produced for the national electricity demand projections, then it only needs to be acknowledged and reviewed against the interfacing requirements of the new NPP. The FS authors may have new information that requires an update and a new approval.

Many approaches have been developed to estimate electricity demand projections in a systematic way, among which include the most widely used econometric and engineering approaches, or a combination of the two.

The econometric approach uses statistical methods and historical data to infer the response of electricity consumers to price variations and variations in the cost of competing fuels and changes in the electricity demand with changes to income levels, demographics and other aggregate variables. While this approach can capture the behavioural patterns of electricity consumers, limits to data availability also limit its application to aggregate variables, making it difficult to determine the weighted average electricity consumption of particular end users and the overall electricity demand projections. Moreover, since econometric models are based on historical data, they may not be appropriate in forecasting the effects of new technologies or of radical departures from historical patterns of behaviour.

In contrast, the engineering approach emphasizes the end user in analysing electrical load patterns and in assessing the impact on load management, efficiency standards and regulatory changes that significantly and directly influence electricity consumption. The end use accounting models are also somewhat data intensive. Their focus on end use scenarios rather than empirical relationships based on historical data or long time series data makes them preferable in the case of developing countries with limited historical data.

Special attention should be paid to the projection of load demand characteristics into the future since the shape and dynamics of the load (load characteristics) have a strong bearing on capacity selection and ultimately on system cost. Unlike most industrial outputs, electricity is not stored, but is produced on demand. Load varies with the time of day and the season. Generators are often required to instantly meet peak demands for electricity. As some generating technologies can better match changing loads, the load shape and dynamics directly affect the choice of technology mix and the management of the generating capacity.

Projecting electrical system demand is a difficult task involving a great deal of uncertainty because of the many system variables that utility planners should take into consideration when making capacity expansion decisions. In order to deal with this uncertainty, a comprehensive forecasting effort is required, in which the analyst should consider not just one, but a whole range of future energy demand projections. Most often, these include a base scenario representing a medium demand growth model accompanied by a low and a high energy growth scenario, allowing for associated uncertainties. These projections coincide at time zero, but deviate as time progresses.

The validity of the projections generally lies not so much with the specific methodology considered, but rather with the knowledge and experience of the energy systems analysts responsible for them, with the extent of the user data available to them and the accuracy of the development forecast for the country concerned.

The analysis should be conducted with relevant and consistent macroeconomic and microeconomic data, so that electricity demand projections can be reliable and consistent with demographic, economic and industrial development projections.

In order to provide assistance to the Member States, the IAEA has developed a special end use model known as the model for analysis of energy demand (MAED) [15]. MAED provides a flexible framework for exploring the influence of social, economic, technological and policy changes in the long term evolution of the energy and electricity demand. Its module MAED-E was developed specifically for electricity load analysis and projections.

3.3.4. Electricity supply systems

Similar to electricity demand analysis, electricity supply analysis should be based on historical data, including reviews of past trends and the present electricity supply, studies of the electricity generation, transmission and distribution systems, of the available resources for electricity generation and of existing and planned interconnections to neighbouring systems.

A survey of the existing supply system is necessary to support the choice of the end state of the energy generation mix and of the decision to introduce a nuclear power programme into the mix. Its purpose is to establish the past and current state of the electricity supply, the basic characteristics and parameters of the existing power plants and transmission grid, together with any committed expansions (under construction or planned).

The electricity supply analysis should include:

— Reviews of the past and current state of the electricity supply systems in terms of generating and transmission system capacity;
— Overviews of the sources of fuel and of their shares in electricity generation;
— Prices of fuels;
— Fuel import dependencies;
— Electricity imports and exports.

The data obtained from the power system survey, for example, technical and economic details, age, fuel type and life expectancy of the existing electrical system (generation and transmission), should be highly reliable, as there are no estimates involved.

The identification of weaknesses, problem areas or constraints is especially relevant because these will affect the planning of future expansion, which will have to be optimized, both for meeting future demand growth and for correcting deficiencies that may exist.

The survey should also include an analysis of past system expansion experience, in particular, regarding the implementation schedules, costs, system availability and load factors, identifying any deviation between original plans and achievements and their reasons. This will provide a useful input in determining realistic assumptions for future expansion alternatives.

3.3.5. Electricity market structure and organization

The electricity market overview should encompass the following issues:

— An electricity industry overview including a history of reforms that have led to its current structure, including the separation of monopoly elements that are regulated and competitive elements that are market based;
— A description of the market participants and commercial arrangements;
— Tariff structure and electricity price components;
— The legal and regulatory environment in which electricity companies would build and operate power plants;
— Barriers to competition;
— Any energy efficiency promotion initiatives and renewable energy sources;
— Environmental issues;
— Climate change policies and international commitments;
— The current investment environment.

3.3.6. Electricity system expansion planning

Given an electricity demand projection, the next task is to specify how this demand is to be met with different generating technologies — i.e. to determine an optimal mix of energy sources (electricity generation programme) and the transmission system configuration to support reliable electricity generation and supply. Options for distributed generation, the influence of intermittent sources, possible short term energy storage and smart grid concepts should also be included in this analysis.

Special attention should be given to the development of an appropriate transmission system, which could be a critical issue for the introduction of large scale generating units (such as nuclear power units) into smaller scale or isolated electrical systems.

This phase of the study has to take into account many aspects — technical, economic, environmental, political and others that would result in specific constraints. Different economic parameters and criteria can be chosen when deciding among different options for electricity production. The parameters used will influence the price competitiveness of the different generating options. In order to analyse their impact on pricing, some of the parameters can be used as input data for sensitivity analyses.

The major aspects to be addressed in the programme expansion are:

- Energy strategy aspects;
- Limiting energy dependency (electricity imports, preferences to use domestic resources or certain types of fuel, etc.);
- Diversifying fuel types for strategic reasons;
- Goals and strategy for the promotion of renewable energy;
- Goals stemming from climate change policy, etc.;
- Environmental constraints;
- Limits on pollutant emission;
- National goals or limits stemming from international obligations;
- Fuel supplies;
- Availability and cost of indigenous fuel supplies to meet the projected demand; all relevant energy resources have to be surveyed: uranium, hydropower, coal, lignite, oil, natural gas, geothermal, wind, biomass, solar, etc.;
- Infrastructure costs associated with indigenous fuels;
- Availability and cost of imported fuels;
- Risks and uncertainties associated with fuel supply;
- Possibility for electricity imports and exports.

Fuel prices are essential for the economics of coal, oil, biomass and natural gas plants; they are less influential for nuclear plants, and are irrelevant to solar, wind, tidal and geothermal power. Fuel price uncertainty is especially important in evaluating the economics of combined cycle natural gas fired plants. Unfortunately, fuel prices have been notoriously difficult to predict. This requires long term projections based on a set of assumptions, the use of criteria and guesswork applied to national resources (if available) and world market trends. Projections from renowned international institutions (e.g. the International Energy Agency (IEA)) can be used as a starting point. Generally, to deal with inherent uncertainties, the forecasts of energy costs and the reliability of supplies often compare different scenarios for the future, such as a high natural gas price case, a low natural gas price case, etc. The scenario considered most probable is usually labelled the ‘base case’ or ‘reference case’. Low and high price scenarios can be used in sensitivity analyses.

3.3.6.1. Technical and economic characteristics of alternative expansion options

Power generation technologies may be classified into existing major options, together with their advanced versions and potential future options. Special attention has to be paid to technologies that will directly compete with the nuclear options. The list of options should include serious candidates to serve large fractions of the new demand. For each potential option, judgement must be passed on the likelihood of their commercial success and for the success of any advanced versions of such options.

The selection of energy supply options should consider constraints such as the availability of fuels, the need to limit environmental emissions, the desire to limit imports and diversify fuel types for strategic reasons, etc. The data requirements are similar to those of the existing systems and of committed expansions, although they may all be just estimates at that point. Reliable technical information on fossil fuelled thermal plants and transmission systems is generally available on the market. However, special attention should be paid to adjusting the available information to the local conditions. Power plants are large construction projects, and costs vary with differences in wage rates, productivity, industrial and labour market structures, regulations, and environment related construction and design requirements. Differences in costs could be quite substantial. Estimates of construction schedules and investment costs should be reasonably reliable when adjusted to local conditions. For prospective renewable technologies, experience and evolution, leading in time to a decrease in investment costs, can be taken into account.

Characteristics of the nuclear power option would, in principle, be defined by the data provided by the potential vendors or suppliers. Limited data are available on actual recent costs of building nuclear power stations. Moreover, construction cost data supplied by vendors may be optimistic, especially ahead of contractual commitments, if not subject to independent evaluation. Accordingly, the future construction cost of an NPP remains uncertain, and should be subject to sensitivity analysis.

The option of expanding national hydroelectric resources requires extensive studies. Reliable investment cost estimates are especially difficult to obtain. Experience shows that these costs, as well as project schedules, tend to be underestimated.

Certain candidate technologies might involve additional infrastructure requirements (e.g. coal transport, new harbours, gas pipelines, liquefied natural gas terminals, etc.) that must be taken into account when choosing the optimal generation mix [16].

A comparison between nuclear power and its main competitors should show the specific benefits of nuclear energy. The strategy adopted regarding importing or using domestic suppliers, political strategies and polices that may favour renewable energy sources or the use of domestic fuels should all be taken into consideration. Environmental policies that may impose constraints on emission limits may induce the inclusion of alternative technologies in the analysis. At any rate, a given technology should never be excluded a priori, without proper justification, from the candidate list.

3.3.6.2. Discount rate

The selection of the discount rate has a great influence on the total cost (cradle to grave) of capital intensive technology options, and consequently on whether nuclear power is estimated to be economic or not. Models of a competitive electricity market use a discount rate of approximately 10% on the assumption that private companies investing in power plants seek a return that equals the interest rate on a safe investment (such as a government bond) plus a premium for the risk of investing in the electricity business. For markets where the company has access to government financing or is government owned and electricity prices are regulated, it is common to employ only 5% ('social discount rate'). A good starting point for the cost of capital is the rate of return that the energy economic regulator allows companies to earn on regulated (low risk) assets:

— The reliability of power supply;
— The reserve margin over system peak load or reserve as a function of the largest machine in operation;
— The acceptable limit for the loss of load probability (LOLP);
— The cost of unsold surplus electricity.

Even though the reliability of the electricity supply is of prime importance, it should also be realized that the achievement of high reliability is expensive. Consequently, the reliability targets should be reasonable, taking into account the country's real needs and constraints.

3.3.6.3. Determining the optimal generation programme

Once the electrical energy requirements have been estimated, the electricity generation and transmission system must be planned to meet these long range requirements. The planner concentrates on the search for the most economical expansion plan, i.e. the programme of yearly capacity additions and transmission system development that leads to an optimum value for the economic criteria selected, while providing system reliability and meeting other quantifiable constraints.

Because of the complexity of attempting a simultaneous optimization of the generation and transmission subsystems, the transmission system can be neglected in a first approximation. This is a simplification which implies that all generation expansion plans will lead to a similar development of the transmission network. Only major differences in transmission requirements (e.g. long transmission lines to connect a new power station to the grid or the introduction of a higher grid voltage) are accounted for in the comparison of alternative system expansion plans.

The best expansion policy for the generation system found by this method is then subject to analysis of the transmission network configuration. These studies evaluate load flows, transmission line requirements, voltage levels, system stability, etc., in order to determine the expansion required in the transmission system, as well as to provide necessary information for definition of the admissible unit size. This expansion should also be determined with the goal of minimizing costs. The results of the transmission expansion studies may also have a feedback effect on the assumptions made for determining the optimum schedule of plant additions. The possibility of interconnecting independent electrical systems should receive particular attention. Analysis of intermittency of some energy sources and their impact on system operation and reliability must be included and complemented with all available operational and development concepts (e.g. distributed generation, smart grids, real time pricing and controllable demand).

The choice of power plants in comparing technologies and variety of sources for a complex electrical system cannot be carried out by a simple analysis or be based on a single criterion, e.g. levelized generation cost, in isolation from others. Such an approach would be misleading, given that a portfolio of generating technologies will form the basis of any national electricity supply system. The most flexible and efficient system is likely to include a number of different technologies, each economically serving the segment of the system load to which it is best suited. In a well functioning system, a diversity of sources can provide greater reliability and security of electricity supply.

For this reason, the optimal generation plan must be developed from a number of portfolios of alternative generating plant candidates. At least one of the candidate portfolios should not contain NPPs. The choice of candidate portfolios should be in line with clear strategies and limited to a manageable number, taking into account goals and imposed boundaries and constraints.

Simulation of the electrical system operation and the evaluation of the optimal generation mix is a complex task which takes into account that each energy option or technology has varying degrees of social and environmental costs and benefits in addition to direct costs. A detailed model, based, for example, on the suite of the IAEA's energy planning tools (WASP, MESSAGE, SIMPACTS), can be used to arrive at such an optimized energy supply mix [17].

WASP is a widely used modelling tool for power system planning (used in over 100 countries). Within constraints defined by the user, WASP determines the optimal long term expansion plan for a power generating system. Constraints may include limited fuel availability, emission restrictions, system reliability requirements and other factors. Optimal expansion is determined by minimizing discounted total costs.

MESSAGE combines technologies and fuels to construct so called 'energy chains', making it possible to map energy flows from supply (resource extraction) to demand (energy services). The model can help design long term strategies by analysing cost optimal energy mixes, investment requirements and other costs for new infrastructure, energy supply security, energy resource utilization, rate of introduction of new technologies (technology learning), environmental constraints, etc.

SIMPACTS is a user friendly simplified approach for estimating the environmental impacts and external costs of different electricity generation chains. Designed for use in developing countries, it requires much less data, but produces results comparable with those produced by more sophisticated data intensive models.

A decision needs to be made with regard to the range of plans that has been developed. Such a decision is usually based on attributes defined as 'measures of goodness' used to compare different expansion programmes. These might include the generation plan cost, electricity generation cost, and maximization of policy and import and export aspirations, of sustainability targets and of fuel diversity, etc.

3.3.6.4. Sensitivity analyses

Performing sensitivity analyses for the selected portfolios is necessary in order to examine the robustness of the optimized generation plan with respect to the uncertainty of the input data used in the optimization study. It is important to carry out sensitivity analyses to study the sensitivity of the optimal solution to variation of the key input parameters, particularly those with the highest degree of uncertainty. Carrying out too many sensitivity analyses and including them as part of the optimization study report will tend to diminish the credibility of the study and lead to confusion with regards to conclusions and recommendations.

The most frequently considered sensitivity analyses are:

- Demand forecast;
- Fuel cost;
- Investment cost of new power plants;
- Discount rate;

— Year in which certain plants can be added to the system;
— Environmental issues and constraints;
— Quality of supply (reserve margin, LOLP limit, cost of unserved energy).

If presented in isolation, the results of sensitivity analyses would have no meaning without an adequate discussion alerting the decision makers to any potential risks associated with each option, in order to facilitate the decisions they will make affecting the near and medium term future.

3.3.6.5. Presentation of results

Communicating and presenting results to stakeholders and decision makers is a critical step. It involves translating technical information into understandable options with their associated consequences. The analysts will have to:

— Present to stakeholders a plan to meet future customer demands for electricity that recognizes key risks and uncertainties;
— Consider and incorporate, where feasible, feedback from the stakeholder engagement process;
— Explain how environmental, social and economic considerations are included in electricity system analysis.

Limitations associated with the proposed optimal generation programme should be clearly communicated to the decision maker. Planners must conduct their analyses without biasing the results towards any particular point of view (e.g. tilting the balance towards one particular technology by expressing personal, non-technical opinions). It is the role of the decision maker, not the analyst, to include non-technical factors in the decision process. The analyst must provide the best technical and economic information available with the associated limitations and stop at that.

3.3.7. Project evaluation

The feasibility message from the technoeconomic analysis must be clear. The conclusive statement should contain brief recaps of the findings in each area of the electrical system analysis either justifying or excluding the development of a nuclear power unit. Among the key factors listed in the conclusions, the following are examples of relevance in favour of the introduction of an NPP:

— The growing requirement for electricity and for additional generating capacity, since the analysis indicates that given the current and projected economic development of the country, a significant gap between supply and demand is expected.
— The requirement for baseload power is increasing, and nuclear generation capacity must be considered as a suitable and major source of energy for filling the supply.
— Based on the current fuel prices, on the estimated pricing projections and range of reactor prices, and after performing simulations with a number of selected portfolios, the study indicates that the generation programme which includes the nuclear option is a more viable choice for a future capacity mix than the alternative plans that exclude it.
— The proposed electricity generation programme is robust, in that, for example, it remains the best option, even when considering the uncertainties related to load forecast, fuel prices, discount rate, etc.
— The combined effect of the current high commodity price environment for oil, gas and coal — coupled with a low interest rate situation — could make the nuclear option particularly attractive.
— Nuclear power will help reduce dependency on imported electricity, and allow a more appropriate use of valuable thermal fuels.
— The new NPP will contribute to security of supply as it uses a fuel from a global market without security of supply concerns and provides greater diversity of electricity supply sources.
— Sizable air quality benefits (SO_2, NO_x and particle emissions reduction) can be expected from introducing nuclear power compared to fossil fuel based alternatives.

— The results show that nuclear power as a low carbon technology can play an important role in the country's effort to comply with climate change policy and help to meet CO_2 emission targets.
— Nuclear technology offers a relatively stable and predictable initial cost base.
— By making a significant contribution to electricity demand in the country, nuclear power will help in stabilizing wholesale electricity prices.

3.4. UNIT CAPACITY AND SYSTEM INTEGRATION

3.4.1. Station capacity

The FS should include a section on the selection of the nuclear unit size among those that the market offers. Considering that the NPP will be integrated into the national electrical power grid, the selection of station capacity should take into account the necessity of strengthening electrical connections to other nodal points of the electrical grid and to neighbouring countries, and of the necessary legal and commercial agreements with those countries. These arrangements and other preparation work need to be completed before the NPP is ready for commissioning.

3.4.2. Unit capacity

The size of a nuclear unit in this context refers to the maximum electrical power that it can deliver to the transmission system. There has been a steady increase in the size of new nuclear units which is partly driven by economies of scale, so the designs of nuclear units that are currently available from international nuclear plant vendors are large. Consequently, a first nuclear unit built today is almost certainly going to be the largest single generating unit in the system to which it is connected. This may introduce additional requirements if the grid system is relatively small:

— The need to control the large and rapid changes in frequency, voltage and power flow that will occur after a trip of the nuclear unit or if a fault in the transmission system disconnects the nuclear unit;
— The need to have sufficient generation to meet electricity demand during periods that the nuclear unit is shut down, whether for planned maintenance or following a fault or unplanned trip.

When determining the capacity of a nuclear unit, the study should take into account the need to ensure that a trip of the unit will not cause a loss of off-site power, and that the voltage and frequency of the off-site supply will remain within the acceptable range. This is significant because there is a practical limit to the generating unit size that can be installed in any given electrical power system, if the grid is to remain stable and safe in the case of an unplanned shutdown of that generating unit [5, 18].

The trip of a nuclear unit should not cause the transmission system voltage and frequency to go outside their acceptable range, so that the grid can continue to provide a reliable electrical supply to the NPP heat removal and restart systems after the trip. From the point of view of the electricity users, the trip of the nuclear unit should not lead to load shedding or to a high risk of system collapse or blackout.

These issues are evaluated in detail in the IAEA publication Electric Grid Reliability and Interface with Nuclear Power Plants [19]. For a new unit, it will be necessary to plan emergency reserve power (perhaps in addition to the existing capacity) to replace the capacity of the largest unit disconnecting from the grid for whatever reason. The available and the yet to be built reserve will also play a role in the nuclear unit capacity selection [19].

The sizing of a new unit should provide a proper balance between many influencing factors, namely the projected yearly load increase, the replacement capacity of ageing power plants and economic aspects.

The selection of a nuclear power generating unit in the range 1000–1600 MW, with a load following capability of 50–100%, should never result in capacity surplus during low load periods. If the grid is too small and this is not achievable, one way to avoid excess capacity could be to build, in parallel, a suitable accumulating power plant, assuming the construction of two plants simultaneously still remains an economically realistic option. It is also important to consider all the pros and cons of the actual offers provided by the vendors involved. From the economy of scale viewpoint, the largest possible unit size may offer a lower cost per kilowatt, but the risks associated with the selection of the larger sizes should not be ignored.

The operating requirements, including the load following requirements, should be determined in the FS and specified in the BIS. They should then be carefully verified in the bid evaluation exercise and, when the selection of the vendor is fully confirmed, these requirements should be clearly spelled out in the contract and checked in the design, licensing, commissioning and operating documentation.

Another important factor to take into consideration in deciding which NPP unit size to purchase is regional cross-border supply and demand. An expansion of the electricity generation capacity in a location where the country grid is integrated with that of neighbouring countries could allow electricity sales abroad. This condition may have a significant effect on the number of units and on the unit size selection.

In summary, the following aspects should be considered in a unit sizing exercise:

— The current and future gap in power demand including regional cross-border supply and demand. An expansion of electricity generation capacity in a location where the country grid is integrated with that of neighbouring countries could allow electricity sales abroad. This condition may have a significant effect on the number of units and on the unit size selection. The integrated regional reserve targets should be clearly set.
— The flexibility of the electrical output and the power controllability and manoeuvrability range of the nuclear unit. (The nuclear power units offered today are capable of a significant load following regulation, and this capability will only increase in the future.)
— The level of risk that may be undertaken when selecting the larger unit sizes must be carefully evaluated before the final recommendation for unit capacity is made [19].

3.4.3. Integration in the grid

The FS conducted prior to the start of a NPP project should succeed in identifying appropriate possible candidate sites with respect to their connection to the grid.

3.4.3.1. Grid capacity and grid connection

Suitable high voltage power lines are required to export electrical power from the NPP to the grid. A large multiunit NPP (1000 MW or more per unit) typically transmits power at a 400 kV voltage level. After selecting the plant location, the grid must be assessed, not only in terms of capacity, but also in terms of stability. To ensure both, it may be necessary to carry out grid extensions.

If the size of the proposed nuclear unit is about 10% of the minimum electrical demand in the country, the FS should show how the electricity demand in the country will be met when a nuclear unit is shut down. It should also outline a plan of upgrades capable of ensuring that grid frequency and voltage will remain within acceptable limits, even in the worst case of a sudden nuclear unit trip.

3.4.3.2. Load following limitations

Flexibility of a generating unit could be achieved by one or more of the following actions:

— Reducing or increasing the generated output in a planned way over a number of hours (e.g. gradually reducing output in the late evening and increasing it again in the early morning).
— Reducing or increasing output either on instruction from the national control centre, or in response to a control signal from the grid control centre.
— Operating in automatic frequency control mode, so that the output changes automatically in response to changes in system frequency. This would require the generated output to change within a few seconds or less.

Nuclear units are generally less flexible than other power plant units; however, the most common nuclear technologies today (pressurized water reactors (PWRs), boiling water reactors and the Canadian rector design CANDU, which uses natural uranium fuel and a heavy water moderator) offer load following capabilities, but their technical specifications may impose restrictions that limit the magnitude or speed of the load variations or the number of allowed load cycles. In addition, since nuclear units entail high upfront capital costs and relatively low fuel and operational costs, it is preferable for commercial reasons to operate them at full capacity. Frequent load following or automatic frequency control cycles inevitably lead to poorer capacity factors and lower plant reliability, less efficient use of nuclear fuel, increased maintenance and possibly to a shorter plant life. These facts must be considered when planning the integration of the new unit into the national grid.

Consequently, the most preferred mode of operation for NPPs is at 100% full power, with load reductions only when required for maintenance and refuelling shutdowns. The second possible mode of operation is steady state load, with occasional power manoeuvring at a controlled rate only when required by grid conditions. The operating requirements should be discussed with the NPP vendor very early in the pre-FS phase, so that they can be fully implemented in the final configuration and safety assessment of the project.

3.5. SITE AND SUPPORTING FACILITIES

NPP siting is normally carried out at an earlier stage of a new nuclear energy introduction or expansion programme, and it is usually implemented in three stages:

— Stage 1: site survey;
— Stage 2: shortlisting and ranking;
— Stage 3: site characterization/assessment.

In stage 1, large areas of the country planning to introduce or expand nuclear power are investigated to determine potential NPP sites. The most suitable areas are identified and candidate sites are selected. In stage 2, referred to as the shortlisting and ranking stage, the identified potential candidate sites from stage 1 are ranked for suitability. At the end of this stage, a shortlist of two or three preferred sites is prepared. In stage 3, called the site characterization stage, the focus is shifted to the most promising site in order to demonstrate its final acceptability and suitability, and to derive the design basis for site related safety aspects.

During stage 3, the preferred sites should be adequately investigated with regard to characteristics that may be significant to safety, such as external and natural events and human induced events [20]. The factors considered should include:

— Population density and current use of the site and its environment;
— Physical characteristics of the site (seismology, meteorology, geology and hydrology);
— Existing infrastructure (e.g. roads, ports and airports);
— Suitable cooling water sources;
— Distances to transmission lines, substations or load centres;
— Topographic features;
— Potential to adversely impact valuable environmental, agriculture, residential or industrial areas;
— Potential to adversely impact dedicated land use areas (e.g. marine protected areas, historical sites);
— Conflict with land use planning programmes or other restrictions.

In the process of determining potential site hazards, site specific data should be obtained while considering the following aspects:

— Effects of external events occurring in the region;
— Characteristics of the site and its environment that could influence the transfer of radioactive material to persons and the environment;
— Population density and distribution and other characteristics in so far as they may affect the possibility of implementing emergency measures.

Siting factors and criteria are important to ensure that radiological doses from normal operation and postulated accidents are acceptably low and that natural phenomena and potential human induced hazards are appropriately accounted for in the design of the plant. Site characteristics should be reviewed to ensure that adequate security measures to protect the plant can be developed, and that physical characteristics unique to the proposed site, which could pose a significant impediment to the development of emergency plans, have been identified. Extensive analysis and data collection should be conducted to ensure site suitability through geological, hydrological and seismological investigations, meteorological monitoring, etc.

The candidate sites should be evaluated via a comprehensive site characterization effort in respect of domestic regulations and international guidance, as found in Refs [19–24]. Site characteristics that may affect the safety of the nuclear facility should be investigated and assessed for potential radiological impacts in operational and accident conditions throughout the service lifetime of the plant.

For the suitable sites, exact coordinates (latitude and longitude) of the location(s) should be provided, including a preliminary layout of the NPP and its associated structures, such as administrative facilities, worker camp facilities, property boundaries, location of intake and discharge cooling water, access roads and grid.

3.5.1. Natural and external events

The proposed sites should be evaluated with regard to external and natural events to determine their possible impact on the safe operation of the nuclear facility. Relevant available information and historical records of the occurrences and severity of external events, together with site data, should be collected and analysed [25].

3.5.1.1. Earthquakes

Hazards associated with earthquakes should be determined using the seismicity data of the region. An evaluation of geological (including tectonic and non-tectonic) features and geotechnical characteristics and seismic conditions should be conducted [24]. Identification and analysis of deformation features caused by vibratory ground motions should be performed, and historical records should be reviewed to provide insight into the seismic response of the area. Geotechnical and geophysical investigations should be designed to obtain the properties and characteristics of subsurface materials and conditions that may affect plant structures under both static and dynamic conditions. Sufficient surface and subsurface information should be provided for the areas in the vicinity of the site area itself to confirm the presence or absence of surface tectonic discontinuities (i.e. faults). Any reported earthquake induced geological feature should be described, including the estimated top motion levels, induced failure and physical properties of the materials. A thorough investigation should be conducted to assess the seismicity and identify seismic sources that could be significant in estimating the seismic hazards of the region through a probabilistic seismic hazard analysis [26]. A comprehensive description of the site subsurface conditions and its adequacy to bear static and dynamic loads imposed by the nuclear facilities should be documented. The following aspects should also be analysed as part of the study of subsurface materials and foundation instability:

— Geological features and soil stratigraphy;
— Static and dynamic engineering properties of soil and rock strata underlying the site;
— The relationship of the foundations for safety related facilities and the engineering properties of underlying materials, as illustrated on plot plans and profiles;
— Results of geophysical surveys;
— Excavation and backfill plans;
— Groundwater conditions and piezometric pressure in all critical strata;
— Responses of site soils or rocks to dynamic load;
— Liquefaction potential;
— Earthquake design basis;
— Foundation material stability, deformation and settlement under static conditions.

3.5.1.2. Meteorological events

A programme of meteorological measurements should be carried out at or near the site with instrumentation capable of measuring and recording key meteorological variables at appropriate elevations, locations and durations. This programme initially provides data for the site evaluation [21, 23], and then for ongoing use in revisions to the design basis documents in response to safety analysis results during the various phases of the NPP life cycle. Meteorological phenomena should be investigated to evaluate the design loads they generate, understand their effects on the degree of diffusion of postulated radiological releases, under normal and accident conditions, and determine the adequacy of the site. The meteorological study includes an evaluation of the off-site regional data and of the on-site data collection.

3.5.1.3. Data analysis

Meteorological measurements are collected to support the estimates of short term diffusion for accidental releases and of long term diffusion for routine releases. Using available historical data, extreme values of meteorological variables in phenomena such as wind, precipitation, temperature, storm surges, dust, lightning, tornadoes, tropical cyclones, sandstorms and other meteorological events should be investigated at each site to evaluate their bounding values and their frequency of occurrence. Meteorological towers should be set up at each site to collect meteorological data. The data should be compiled, validated and used for calculating site specific dispersion factors to confirm that they fall within the bounding values presented in the standard NPP design envelope. Meteorological and air quality conditions should also be identified and described in evaluating the design and operating conditions of the proposed NPP. See also Ref. [23].

3.5.1.4. Flooding

Hazards associated with potential flooding should be identified and evaluated. Possible combinations of these effects, such as wind generated waves, should be evaluated. Historical flooding at the site and in the vicinity of the site should be evaluated to summarize and identify flood types and combinations thereof. If there is potential for flooding, all pertinent data, including historical, meteorological and hydrological data, should be collected and thoroughly examined. Meteorological events that can cause flooding at the site, such as tropical cyclones, seasonal winds and rhythmic oscillations of the water surface as in meteorological seiches, should be evaluated [23].

A methodology to evaluate the design basis flood should be defined taking into account the maximum level of flooding the plant can withstand without severe fuel damage, and adding appropriate margins. Careful consideration should therefore be given to the interpretation of historical events (hurricanes, cyclones, tornadoes, seiche oscillations), their return periods and the data validity in time. All natural and human-made flood sources in the vicinity of the plant with the potential to affect the flood level in the plant need to be carefully evaluated. In addition, it is important to evaluate combinations of hazards (either combinations of causes or combinations of effects) and coincidences of flood hazards of separate origins. Among the factors to consider are:

- Meteorological events (severe weather conditions causing flooding).
- Oceanographic phenomena (if applicable) such as wave direction and height, sea temperatures, current direction and speed, salinity and tidal levels. These data may be used to evaluate the impact of the unit cooling water outfall on the plant and on the environment and select the most appropriate location for both the intake and the outfall canals. The data may also be used as input to the EIA, to the plot plan site specific detail design and to the civil engineering detail design of all impacted buildings and structures [23].
- The maximum level of flooding the plant can withstand without severe fuel damage and evaluation of margins.
- Vulnerabilities of cliff-edge effects and robustness features required.
- Key SSCs (water intake or emergency diesel generators).
- Mitigation measures required, e.g. dikes, platforms, surveillance and alarm systems, and mobile equipment and storage.

Bearing in mind the lessons learned from the Fukushima Daiichi accident, any new NPP construction will have to consider measures to protect the plant against even a beyond design basis flood. Severe accident measures and protective structures will have to be designed and considered at the time of an FS. Measures will have to be adequate to allow the mitigation of the consequences of severe event combinations:

— Coincident effects such as extreme weather combined with loss of external power and plant isolation with severely curtailed access;
— Coincident loss of primary and ultimate heat sinks owing to beyond design basis flood conditions;
— Loss of ultimate heat sink combined with station blackout owing to beyond design basis flooding conditions.

To be able to face up to such adverse event combinations, on-site severe accident equipment should be provided to prevent reactor core damage. To protect such equipment, reinforced storage and protected access routes to delivery points during beyond design basis flood conditions at the site need to be provided. In a multiunit plant, provision of additional interconnects of essential utilities will have to be foreseen, such as alternative reactor cooling water lines, electrical interconnects from the nearby twin unit(s) and their protective features in line with the plant robustness philosophy.

3.5.1.5. Geological hazards

A review of geological and tectonic history, tectonic features, structural geology and seismology should be conducted to provide a framework within which their significance to safety can be evaluated. Slope stability analysis should be conducted for minor dikes and slopes built for retaining ponds. The site and its vicinity should be evaluated to determine the potential for slope instability (such as sand and rock slides) that could affect the safety of the nuclear facility.

Geological maps and other appropriate information should be examined for the existence of geographical features such as caverns, karstic formations and human-made features, such as mines, water wells and oil wells, and plot plans showing the locations of site explorations should be provided. The potential for collapse, subsidence or uplift of the site surface should also be evaluated.

3.5.1.6. Human induced events

A systematic approach to identify all non-malevolent and human induced events should be implemented. Such events include:

— Aircraft crashes;
— Other transportation hazards;
— Fires and explosions;
— Chemical and radiological hazards.

The site and its vicinity should be evaluated for the presence, availability and distance of transportation facilities and utility routes, such as airports and airways, roadways, railways, pipelines and navigable bodies of water. The locations of, and distances to, industrial, military and transportation facilities in the vicinity of the plant should also be reviewed for potential hazards that could affect safe plant operation. Threats and risks associated with private and commercial airports, including flight pathways, should be evaluated, and potential effects on emergency planning and evacuation routes should be considered. The potential for aircraft crashes on the site should be assessed. If the assessment reveals an unacceptable risk of aircraft crashes, then an assessment of the associated hazards should be conducted. The distance from nearby roads should be evaluated to determine whether the plant is within the range of a ‘rocketing’ tank car, and consideration should be given to military aviation, along with its associated risks. Any potentially hazardous activities in close proximity to the plant should be reviewed to ensure the safety of plant workers and of the public. Land and water transportation routes in the region should also be evaluated with respect to potential explosions, chemical and radiological hazards, and fires.

Activities that involve the handling, processing, transport and storage of materials with the potential for explosions, or the production of radioactive fallout, volatile and reactive gases or asphyxiants should be identified and evaluated.

3.5.1.7. Cooling water availability

- Consumption of water should be evaluated for existing and future water use scenarios in the area to ensure water supplies during periods of drought are still adequate for the safe operation of the nuclear facility. The availability and acceptability of alternate water sources during periods of low flow or low water levels in the ultimate heat sink should be considered in the site selection, along with the frequency and duration of the low flow condition and low water levels from historical records.
- Potential natural and human induced events that could cause a loss of safety system function necessary for long term removal of the residual heat should be identified. They may be caused by the blockage or diversion of a river, the depletion of a reservoir, an excessive amount of marine organisms, the blockage of a reservoir or cooling tower by freezing or the formation of ice, ship collisions, oil spills and fires.

3.5.1.8. Electrical grid disturbances and availability

The interaction of the facility with the electrical grid and other generators on the system, including potential load spikes, and the effects of grid expansions should be considered.

3.5.2. Potential effects of the nuclear facility in the region

3.5.2.1. Atmospheric dispersion of radioactive material

Analytical and numerical models and modelling software can be used to perform calculations and assess the atmospheric dispersion of radioactive material releases. Local meteorological and topographical descriptions of the site area, both before construction and during operation of the nuclear facility, should be evaluated. The possible impact of meteorological data on the plant design and on its operation, and, conversely, the impact of the NPP operation under normal and accident conditions on local meteorological parameters should also be evaluated.

3.5.2.2. Dispersion of radioactive material through surface water, including seas and oceans

A description of the surface hydrological characteristics of the region should be provided, including descriptions of the main characteristics of water bodies, both natural and artificial, of the major arrangements for water control, water intake structures and information on water use in the region. The site evaluation should describe surface water hydrology, including delineation of the drainage basins and available historic hydrological data [21]. An assessment of the potential impact of contamination of surface water on the population should also be conducted.

3.5.2.3. Dispersion of radioactive material through groundwater

The ability of the groundwater environment to delay, disperse, dilute or concentrate liquid effluents, as they relate to current and future water users, should be evaluated. A conservative analysis of a postulated, accidental liquid release of effluents to the groundwater system at the site should be conducted to evaluate all potential radionuclide transportation paths with all possible contamination to natural water bodies [22].

3.5.2.4. Ambient radioactivity

Baseline characterization of ambient radioactivity should be completed before the commissioning of the nuclear facility [14]. It should include baseline data for the atmosphere, hydrosphere, lithosphere and biota in the region, as well as sampling for tritium and other appropriate radionuclides in selected groundwater and seawater systems. This should serve as a baseline for monitoring future effects of the facility on its environment.

3.5.3. Population distribution

In this study, the population distribution within the region should be described, including current and future projections. The most recent census data and their extrapolations into the future should be used as a starting point for the evaluation. The current and future projections of transient residents as valid contributions to the total population counts should be considered. The radial sectors for data collection should be selected in accordance with the regulatory radial distance guidance.

A low population zone starting from the centre point of the proposed facility should be projected and shown on a map on which topographic features can be added, such as roads, railways and waterways that may be used for evacuation purposes, together with the locations of all public facilities and institutions. The population within the low population zone should be provided to include estimates of daily and seasonal peaks of permanent and transient populations. The nearest population centres of 25 000 residents or greater from the facility centre point should also be described.

3.5.4. Uses of land and water in the region

For the purpose of preparing emergency plans, the domestic use of land and water should be evaluated in order to assess the potential effects of the nuclear facility on the region. Dominant land uses and metropolitan centres surrounding the sites should be reviewed and evaluated from the viewpoint of water usage safety. The investigation should also include land and water uses that may serve as habitats for plants and living organisms in the food chains of humans and animals.

3.5.5. Preliminary site layout and site preparation

3.5.5.1. Preliminary site layout

A good preliminary site layout should take into account certain general guidelines. There should be a certain harmony between the power plant and its natural surroundings, good proportions among the various buildings to allow:

- Enough space between buildings to meet the site access requirements;
- An efficient and logical horizontal and vertical staff circulation plan;
- An interference free design of the underground structures, facilities and utilities;
- A safe evacuation plan under emergency situations;
- Sufficient space for adequate fire barriers to prevent the spreading of fires;
- A security plan for access control and management of the NPP site;
- Internal and external sabotage prevention features;
- The functionality of all emergency mitigation features.

3.5.5.2. Economic competitiveness and constructability for plant layout alternatives

Several alternative layouts should also be conceived, especially for structures presenting the possibility of a number of solutions, namely preliminary layouts of the intake and outfall canals, of the radioactive waste building, the switchyard and others. They should all be evaluated using quantitative analysis, to determine which layout is the most economically competitive. An overall economic assessment should be performed along with an evaluation of direct costs (equipment and construction costs) and indirect costs related to changes in the direct construction and to the operational costs.

At the preliminary site layout stage, a comprehensive evaluation of the construction process and the construction method should be conducted. The study should include accessibility requirements for the assigned module fabrication area, for the ringer crane to move heavy equipment, a laydown area, the crane type and its location and interference with adjacent facilities, and a site access strategy with entry, exit and check points for equipment and personnel at each building. This preliminary study is intended to evaluate and improve constructability and economic competitiveness of the future NPP. This is especially important considering that the duration of an NPP construction period significantly affects the cost of the overall construction project and the future cost of electricity generation.

3.5.5.3. Access road and heavy equipment transportation routes

The layout study of all access roads to support the NPP construction and operation should be carefully developed. It may be necessary to remove or permanently close pre-existing roads and rail tracks within the site that are no longer required, neither for construction nor later for operation. An abandoned road within the site is a hazard and a security issue.

The layout should feature the shortest possible distance between the equipment delivery wharf and the power plant entry point. The heavy equipment transportation route for components such as steam generators, the turbine generator stator, the nuclear reactor, the main transformer, the emergency diesel generator and condenser modules should be reviewed and safety checked for possible soft interferences and cross-overs of sensitive underground utilities.

3.5.5.4. Site preparation and excavation

Relocating pre-existing housing of any residents within the site perimeter should be among the first site preparation tasks. The relocation process should proceed according to established relocation rules providing for proper compensation for land or buildings within the exclusion zone, but outside the exclusion zone. If necessary, a new town can be constructed prior to proceeding with the actual relocation. Site grading issues should be reviewed when the selected site includes a hill or escarpment. In coastal areas, if the site altitude is lower than sea level, land filling may be required.

Major excavation should be carefully planned, taking into consideration construction efficiency requirements. Excavation activities should never interfere with any parallel construction such as the reactor and turbine buildings, the intake and outfall structures, the fuel building, the radioactive waste building and, in some cases, the buildings of an adjacent sister unit.

3.5.5.5. Construction phase resources

The conceptual layout for the various temporary buildings and facilities required during the NPP construction phase should be established. These include the concrete batch plant, the soil reception area for filling and backfilling, the field manufacturing facility, the bonded and general warehouses and offices, and the tetrapod storage area for breakwater.

3.5.5.6. Physical infrastructure requirements

For the case where the NPP is to be constructed in a coastal area, breakwater defences for protecting the nuclear facility from abnormal sea waves should be considered. The requirement for a harbour or wharf should be established, and the selection of an optimal location for heavy equipment loading and unloading should be evaluated. This can influence the NPP's general arrangement and layout alternatives [16, 27].

3.5.6. Summary of site characteristics and supporting facilities

In summary, the FS report should:

- Confirm the acceptability of the preferred site(s) in terms of minimizing all safety hazards associated with natural phenomena, human induced events, the absence of potential negative effects of the nuclear facility on sensitive biological, artistic and touristic resources in the region, and in consideration of local population characteristics and ease of emergency planning;
- Describe all physical characteristics of the site(s) related to the safety of the NPPs, including seismology, meteorology, geology and hydrology;

— Identify the design basis for natural and human induced external events (e.g. design basis earthquakes, design basis floods, design basis meteorological events, aircraft crashes, explosions, pressure waves, fires, etc.);
— Address the radiological impact on the population and on the territory during normal and accident conditions, including dispersion characteristics in air and water and the feasibility and effectiveness of the necessary emergency preparedness and response plans;
— Describe the exact site location, a preliminary layout of the NPP, administrative facilities, worker camp facilities, property boundaries, etc.;
— Establish and describe a suitable cooling water source (as the ultimate heat sink), include a preliminary layout of the intake and discharge structures and the grid integration plan, and describe the available infrastructures such as roads, ports and airports.

3.6. NPP TECHNOLOGY AND FUEL CYCLES

This section of the FS report should contain and describe the following:

— A general introduction to the approach used for the NPP technology selection process and fuel cycle assessment for the FS;
— The major interfaces between the NPP technology selection and the other evaluations performed within this FS, such as the economic evaluations, siting studies or nationalization programmes, along with the expected results to be achieved;
— The programme policy objectives and the project goals, recognizing that the NPP technology and fuel cycle assessment is to be aligned with them and with the other considerations described in the FS, in full respect of their order of importance;
— The resources available to access information regarding the NPP technologies and perform decision support analysis on the reactor technology types;
— The key areas that form the basis of the recommendations on the reactor type, including the technology market survey, the assessment process to meet the programme policy objectives, the NPP project goal, the fuel cycle evaluation and impact assessment, and final conclusions and recommendations, including qualitative and quantitative indicators that can be used in the detailed reactor technology selection work.

The reactor technology assessment (RTA) process is an evaluation approach that enables the decision maker to choose reactor technology or the NPP type that will fulfil these policy objectives. This process is established with respect to the other major elements of nuclear programme development, and described in detail by the IAEA publication Nuclear Reactor Technology Assessment for Near Term Deployment [18]. There are several applications where Member States will perform and apply the RTA process and, although the detail of the evaluation and the scope of the selection will vary between phases, there should be a common approach, and the issues raised at each phase should be carried through to the next phase. These applications are:

— Technology assessment during the FS (national infrastructure milestones 1 and 2);
— Technology assessment in preparation of the BISs and for the process of evaluation of bids (national infrastructure milestone 2);
— Technology assessment as a decision making tool in preparation for contract negotiations (national infrastructure milestone 2);
— Technology assessment as an ongoing evaluation tool during the NPP construction and operation (national infrastructure milestones 3).

At each subsequent stage of the milestone process, the technology assessment is refined, beginning with only the feasibility of each technology and, at later stages, exploring the detailed differentiations between design options. Although the reactor and fuel cycle technology assessment may be produced as a standalone document, at the minimum a summary of its findings should be reported in the FS. When the FS is produced, at the beginning of phase 2 of the nuclear power generation programme, the main stakeholders have already determined that nuclear power is an appropriate technical and economic option to achieve a given set of policy objectives. The energy development plan usually includes the target electricity production capacity, and it may include the use of nuclear energy for non-electrical applications, within the framework of the national economic and industrial development programme. In some cases, the development plan may even include the ambitious target of total energy independence.

The IAEA has developed a detailed technology assessment approach to evaluate nuclear reactor technology and its sustainability [13]. The process includes preparing for the invitation to bid, and then evaluating those bids before the final selection [4]. The RTA is a comprehensive assessment designed to ensure that the evaluation appropriately considers, and achieves, the policy objectives and project goals of the Member State, of the NEPIO and of the owner/operator. As the programme or project moves forwards through each of these steps, the details associated with the reactor technology are defined in more depth. Technology assessment and economic and financial evaluations are intertwined to demonstrate the capability of the technology to achieve the project goals and objectives within costs and budget limits.

If the RTA document is not independently produced, a sufficiently rigorous assessment should still be included in the FS because it is necessary to describe, categorize and select the winning technology before the reactor construction phase starts. The degree to which the details of the selected NPP technology may be developed at this stage will depend upon the focus and specificity of the policy objectives that have been prescribed for the nuclear programme.

In the FS, the NPP technologies should be sufficiently explored to demonstrate their financial and technical value and their comparative benefits. As discussed in Section 1, the FS is generally designed to identify all conditions under which the NPP project will be successful, given the programme policy objectives and the NPP project goals. Subsequently, these results are used to refine the final RTA, which will establish the acceptable ranges of features and other requirements to be specified in the BIS and ensure that the construction and deployment of the facility satisfy the commitments made by the design and construction organizations.

Each technology evaluation should include:

— How the evaluation is structured;
— What standard features of each technology meet policy objectives and project goals;
— How the constraints from policy objectives and project goals beyond the standard technology features can be accommodated, either by activating design options or by more structural changes.

Given that reactor technology is inextricably coupled with its nuclear fuel cycle, its evaluation and EIA should extend to the fuel cycle in the FS. Policy objectives and project goals related directly to the fuel cycle should be identified, and their specific economic, safety and environmental impacts should then be assessed.

In addition, there should be a section on radioactive and conventional waste management and an evaluation of the types of facilities available for each fuel cycle under consideration. Waste management particularly differentiates nuclear from other types of power production facilities and imparts distinctive connotations to a nuclear facility. The FS evaluations will be used in the final technology assessment stage, with more specific metrics to show how the selected technology meets the project goals and objectives.

3.6.1. Nuclear power technology market surveys

In the FS, the nuclear power RTA section should contain a market and industry survey. The necessary information can be obtained from documentation and evaluations available through the IAEA, augmented by information obtained directly from reactor vendors or from the architect–engineer.

The market survey examines the spectrum of those reactor types that will be capable of attaining the policy objectives that have been established for the nuclear power programme. As a minimum, the survey should include:

— A description of the database resources and references assembled to develop the market survey information sets.
— A summary of the documentation relaying the nuclear programme policy objectives and the specific project goals. A matrix of these objectives and goals should assist in identifying the types of acceptable reactor systems in terms of design features, availability, constructability, performance records, etc.

- An outline of the differentiators used to perform the shortlisting of the technologies for further consideration in terms of design features, availability, constructability, performance records, etc.
- A description of the candidate NPP and fuel cycle technologies selected for detailed evaluation.

The IAEA advanced reactors information system (ARIS) database [28] for reactor technology options is available for building the appropriate sets of reactor types and parameter listings for the first cut evaluations. Numerous additional references are available on the IAEA web site to first examine the possibilities and then refine the approaches to meet the programme objectives and NPP project goals [18, 28].

Typical differentiators in terms of the programme objectives include:

- Reactor safety expectations and considerations;
- Reactor design demonstration and operating experience;
- Localization potential or implications based on reactor design;
- Localization potential or implications based on the nuclear fuel cycle;
- Programmatic and capacity building support for the reactor technology;
- Timeframe of availability for the reactor technology;
- Expected and demonstrated financial performance.

Typical differentiators in terms of project goals may include:

- Grid integration;
- Nuclear plant safety;
- Technical characteristics and performance;
- Nuclear fuel and fuel cycle performance;
- Radiation protection;
- Environmental impact;
- Safeguards;
- Plant and site security;
- Owners;
- Scope of supply;
- Supplier or technology holder issues;
- Project schedule capability;
- Technology transfer and technical support;
- Project contracting options;
- Economics;
- Reactor availability for near term deployment;
- Considerations or limitations with respect to unit capacity depending on grid limitations;
- Current available experience in licensing, construction and O&M of this NPP;
- Project size considerations or limitations with respect to financing capabilities;
- Specific goals for special NPP uses, e.g. for non-electrical applications.

3.6.2. NPP safety and performance assessment

The IAEA approach for assessing nuclear reactor technology [2] begins with safety. The safety review of a technology is based on IAEA Safety Standards, which are a logical and hierarchical framework of objectives and principles for fostering nuclear reactor safety. The IAEA Safety Standards are composed of three categories:

- Safety Fundamentals, which state the basic objectives, concepts and principles involved in ensuring protection. They provide the overall method for safety assessment, allowing for a systematic assessment of features relevant to safety, and with respect to how the vendor addresses defence in depth and safety margins, and safety analysis. They establish the contents of the documentation for the safety assessment and the requirement to carry out an independent verification.

— Safety Requirements, which contain those requirements that must be satisfied in order to ensure safety for particular activities or in certain application areas. These requirements are in harmony with the basic objectives, concepts and principles stated in the Safety Fundamentals.
— Safety Guides, which supplement the safety requirements by offering recommendations, based on international experience, to implement measures to ensure the observance of safety requirements.

The IAEA Safety Standards series [14, 29–54] allows a technology assessor to identify the completeness and comprehensiveness of the safety cases submitted by the prospective vendors. The IAEA Safety Standards represent a consensual agreement on national regulatory guidelines of the various Member States, encompassing their best practices. A convenient application based on the INPRO methodology called nuclear energy systems assessment is available to help carry out these assessments [13]. Table 2 summarizes the IAEA generic reactor safety review process.

TABLE 2. GENERIC REACTOR SAFETY REVIEW OF NEW REACTOR DESIGNS

Standards against which the reviews are conducted	Safety Fundamentals Safety assessment requirements Design requirements
Supporting information	Design guides Assessment guidelines

The main areas of an IAEA new reactor safety review include:

— Assessment of the potential radiation risks, containment design to address leakage control, penetrations, containment isolation, coatings and coverings.
— Assessment of the safety functions.
— Assessment of the site characteristics.
— Assessment of radiological protection provisions.
— Scope of the safety case, selection of initiating events, internal and external hazards, safety classification, design standards, quality assurance programmes, the management approach and the reliance on operational experience and testing.
— Design basis analysis and fault study including station blackout. The review should determine if design basis accidents and severe accidents are adequately addressed, and the principal IAEA Safety Standards are used, i.e. requirements of safety assessment for facilities and activities.
— Assessment of the engineering aspects of the safety systems, defence in depth, diversity and safety margins.
— Safety analysis approach and scope, safety philosophy and safety criteria used.
— Review of the safety analysis claims and conclusions. This should be carried out with particular attention to uncertainty and to sensitivity analysis.
— Probabilistic safety assessment (PSA) methodology: availability of supporting information such as verification and validation of the analytical methods used. Review of the methodology against IAEA Safety Requirements of safety assessment for facilities and activities.
— Shutdown risk assessment and decommissioning facilitations.
— Use of computer codes and model validation for deterministic and PSA studies.
— An emergency control centre separate from the main control room.
— Inherent resistance to sabotage and fire propagation and measures for fire mitigation.
— Use of data from operating experience.
— Lessons learned from the Fukushima Daiichi accident. Mitigation measures for extreme events, including the combination of seismic and flood events, their consequences and cliff-edge effects.

It is to be noted that various parameters being assessed (including maximum personnel radiation exposure, core damage frequency, significant release frequency, etc.) should not be simplistically compared, one design versus another, because the parameters may not be aligned and presented on the same basis. The specific focus areas for the performance investigation are:

(a) Project specific boundary requirements:
   (i) Country specific requirements and conditions.
   (ii) Size and stability of the national electrical grid.
   (iii) Seismicity of the selected site.
   (iv) Availability of water resources for ultimate cooling.
   (v) Accessibility to waterways for the transportation of large components or modules.
   (vi) Establishment of boundary conditions.
   (vii) Performance considerations, including power level, operability, manoeuvrability, inspectability, maintainability, availability (capacity) factor and reliability.
   (viii) Load and load variation, grid capacity issues, interconnections within the region, and all other existing and planned connections.
   (ix) Fuel procurement for long term supply.
(b) Project risks:
   (i) Level of technology maturity or innovation or proof of the reactor design.
   (ii) Testing of new designs and concepts.
   (iii) Technology maturity risk the country is willing to assume.
   (iv) Licensing risk and design certification or its licensability.
   (v) Use of advanced construction techniques and cost–benefit analysis (CBA) [55]
   (vi) Quality assurance leading to high quality design and construction standards.
   (vii) Construction schedule (first concrete to commercial operation) and its credibility. Proposed schedules will probably be quite optimistic. Often, they are based on schedules achieved in past projects. In fact, schedules achieved for the majority of recent evolutionary light water reactor (LWR) and HWR units have been in the range 48–62 months (with the exception of a water cooled water moderated power reactor (WWER) built in China that required 79 months to build, and some HWR projects in India).
   (viii) Three dimensional (3-D) computer aided design (CAD) modelling plus a common network, use of open top construction; modularization and contracting functional blocks, local participation (not exceeding local expertise).
   (ix) Pre-qualification of contractors.
   (x) Degree of engineering completion prior to construction initiation.
   (xi) Design for maintainability to reduce O&M costs, to reduce occupational exposure and facilitate repairs and equipment replacements.
   (xii) Human factor considerations in control room design to minimize human errors.
   (xiii) Adaptability to future uncertainty.
   (xiv) Social acceptability.
(c) Vendor programmes or project relationship considerations:
   (i) Technology transfer arrangements.
   (ii) A simulator should be available approximately 1 year prior to initial fuel loading to allow sufficient time for training and qualification of control room personnel in advance of fuel loading and to provide a very important resource for validation of plant procedures and other documentation before they are used for fuel loading.
   (iii) Regional partnerships.
   (iv) Fuel supply and/or procurement options.
   (v) Vendor fuel supply arrangements/opportunities, including fabrication and enrichment services.
   (vi) Spent fuel management options, including spent fuel takeback.
   (vii) Human resources planning, education and training programmes [56, 57].

The FS analyst reviews these safety assessments against interfacing areas and against the applicable national and international industrial codes and standards, the economic and financial spheres and the overall national objectives.

The evaluation process performed in the FS is expected to define all conditions or features that cause the NPP to be financially and technically viable compared to alternative approaches (e.g. gas, coal, hydro or renewables).

3.6.3. Fuel cycle evaluation and impact assessment

Fuel supply risks are important for any organization deciding on new nuclear power. It is advisable to include in the fuel cycle assessment the extent to which these features have the potential to influence judgement on reactor technologies or reactor types.

For each reactor technology or specific NPP design under consideration in the FS, the corresponding fuel cycle implications should be identified for evaluation. The approach should also be delineated as described below.

In terms of the project goals regarding fuel that the plant owner may want to review, the risks include:

— Considerations related to the design, procurement, fabrication and type of issues in the experience feedback records and operating performance of the nuclear fuel materials;
— Economic expectations and historical support for potential fuel cycle scenarios in terms of national participation;
— Impact of the fuel cycle on plant operation, including refuelling operations;
— Impact of the fuel cycle on the plant economics considering the length of the refuelling cycle and the reactor downtime owing to refuelling, e.g. duration of fuel only replacement outage, if applicable;
— Storage capacity requirements associated with the fuel and fuel cycle (both wet and dry);
— Characteristics of primary and alternate fuel suppliers;
— Long term assurance for fuel supply and for component and replacement part availability;
— Flexibility of plant operation in relation to different fuel or fuel design types, enrichment levels, potential for the use of mixed oxide (MOX) fuel or alternative fuels;
— Availability of competing suppliers of different fuel materials and components.

Spent fuel production estimates can be based on the information given by the suppliers, but all assumptions should be aligned to ensure that comparisons are balanced, and risks of recriticality and loss of cooling inventory are well aligned. The obvious differences should be cautiously considered, and assumptions must be compared. When comparing technologies, the volumes of spent fuel should be equated to the equivalent annual electricity production. A unit reference of tonnes of heavy metal per terawatt-hour (t HM/TW·h) would be more useful for the comparison, and it would more accurately account for the differences in burnup that can be foreseen. It should be noted that the amount of fuel is of more interest during interim storage and reprocessing, while the heat production in the fuel is more significant with regard to the final disposal phase. The latter is an initial approximation proportional to the energy generated by the fuel.

Finally, the fuel cycle evaluation should be examined, together with the general FS technology assessment results and the waste management assessment results, and prior to developing the final NPP technology recommendations.

3.6.4. Radioactive and conventional waste management

When comparing various power generation options, the evaluation should include waste management and be aligned to the alternative power production options under consideration. The FS analysis should determine the extent to which the radioactive and conventional waste management requirements will be a differentiator [58–61], and whether there is a significant difference between the technologies under consideration in light of the project priorities, policy objectives and project goals. These differences may have an impact on a final recommendation. Potential areas for consideration in this evaluation are:

— Spent fuel management, including safety during normal operation and accident conditions, particularly for the away-from-reactor (AFR) spent fuel pool facility, if provided;

— Expectations and opportunities for dry spent fuel storage and project participation;
— Special considerations or opportunities, if any, for each of the waste management options in the various NPPs under consideration;
— Radioactive waste storage, particularly solid waste and control options for candidate reactor types [8];
— Differences in physical equipment, processes for the management of conventional wastes, including waste handling equipment and process efficiency and radiation protection features.

3.6.5. Interim waste storage

3.6.5.1. Spent fuel storage

In an FS, spent fuel storage should be defined to the extent required by costing and technology selection. Types of spent fuel storage are listed in Table 3. Some criteria that may be useful in determining the fuel storage technology and its cost are given below. Once the technology has been identified, its cost is either known, or is simple to extrapolate based on local conditions. Usually, this amount is included in the cost of electricity production. Spent nuclear fuel has, for decades, been safely stored in pools or in dry systems in over 30 countries. A variety of dry storage options have been developed and applied in the international market.

Most of the fuel is in storage either in 'at-reactor' (AR) pools or AFR storage facilities [59–61]. Additional AFR facilities can also be provided. In these storage facilities, consideration must be given to designs in which the storage period can be extended indefinitely until an end point solution becomes available. Most of the AR and AFR pools are of the wet type (water pools). The small capacities of older plants were mostly expanded by reracking. AFR pools have been built on reactor sites in order to provide additional storage of spent fuel.

The FS authors should select fuel storage technology through a tendering process since it is perhaps the most critical step. The technologies currently available for spent fuel storage fall broadly into two categories, wet and dry, according to the cooling medium used.

(a) Wet storage

The main characteristics of wet pools in the selection of a storage solution are:

— Single pool: This is the simplest layout adopted for most AR pools with small capacities. Expansion of a single pool is difficult. Reracking to maximize fuel density is possible.
— Multiple pools: Additional pools may be connected in series, and spent fuel is moved through the pools by a passage. Isolation of one pool is difficult in cases of leaks or other emergencies.
— Parallel pools: Pools may be connected in parallel by water gates on the wall. It is possible to separate any one of the pools (when emptying for repair or in an emergency).
— Reracking: This process involves moving fuel assemblies closer together. Storage capacity increases by 40–100%. The pool must be able to support the additional weight.

(b) Dry storage

There are several dry storage designs available from vendors in the international market that differ in design details:

— Dry storage facilities have been built of the vault type (1971, Wylfa), of the concrete silo type (1977, Whiteshell), of metal casks (1986, Surry), Castor, and out of concrete casks (1992, Surry).

Metal casks have been designed for both storage and transportation. Casks are generally stored in the open and on a concrete pad in an upright vertical position. Concrete casks have concrete shielding enclosures and a steel liner in the canister cavity. Silos are above ground, are made from concrete and have inner steel liner vaults. Each cavity contains one or more spent fuel assemblies in metal tubes. They are modular and expansible. For more information, see Refs [59–61].

TABLE 3. TECHNICAL OPTIONS AND APPLICATIONS FOR SPENT FUEL STORAGE

Type	Option	Heat transfer medium	Containment (medium)	Shielding	Feature	Examples
Wet	Pool	Water (convection)	Water/building	Water	Classic option	Most ARs and many AFRs worldwide
Dry	Metal cask	Conduction through cask wall	Double lid Metal gasket (inert gas)	Metallic wall	Dual purpose	CASTOR, TN, NAC-ST/STC, BGN Solutions
Dry	Concrete cask / silo	Air convection around canister	Cavity lining / seal welding (inert gas)	Concrete and steel overpack	Vertical	CONSTOR, HI-STORM/HI-STAR
Dry	Concrete module	Air convection around canister	Canister sealing (inert gas)	Concrete wall	Horizontal	NUHOMS NAC-MPC/UMS MAGNASTOR
Dry	Vault	Air convection around thimble tube	Thimble tube (inert gas)	Concrete wall	Several cases	MVDS MACSTOR
Dry	Dry well / tunnel	Heat conduction through earth	Canister (inert gas)	Earth	Below ground	Not commercialized

When costing the various options, the FS authors should consider:

- Project management, design engineering and licensing;
- EIA (can be a critical path item);
- Facility construction and equipment;
- For wet storage systems: the pool, building, fuel handling systems, water cleanup, monitoring systems, air filtration and security;
- For dry storage systems: the cost of the pad, land, security, monitoring, casks or modules and canisters and the cost of the building (if the jurisdiction requires it);
- For vault storage: the vault itself, the building housing it, the handling systems, air filtration, monitoring and security.
- O&M costs (including loading and unloading), staff costs, materials and supplies, utilities, annual licence charges, overheads (property taxes, insurance, etc.) and administrative expenses depending on the technology, water pools require operating costs for water cooling.

The cleanup vault or cask storage is cooled by natural convection and incurs no utility costs. Other costs include:

- Decontamination and decommissioning (D&D), including rental of D&D equipment, staff costs, materials and supplies, utilities, subcontractor fees (for expert advice, audits, measurements), waste transport and disposal, licensing, administrative expenses, D&D planning surveillance, decontamination and removal of SSCs, disposal of material and equipment (including casks), and site restoration and monitoring. D&D costs will be incurred over the next 50–100 years and are to be actualized considering inflation, interests, service costs, cost of obsolescence contingencies, etc.
- Costs of spent fuel transportation include transport cask and impact limiters, trailer(s) (for truck shipments), rail car(s) (if rail is used), buffer car(s) (for rail shipments), staff train charges and security equipment (escort vehicles for truck shipments).

3.6.5.2. Interim storage of radioactive waste

The basic steps in radioactive waste management are pretreatment, treatment, conditioning, storage and disposal. The storage of conditioned waste is normally described as interim storage, and this ranges from several years to about 50 years.

Radioactive waste may exist as raw, treated, immobilized and fully conditioned waste. Radioactive waste rejected from radiochemical laboratories may have to be immobilized (i.e. solidified, embedded or encapsulated). These processes may be required for protection and ease of transportation. Waste immobilization reduces the potential for migration or dispersion of radionuclides during handling, transport, storage and disposal.

In terms of design, while keeping exposures as low as reasonably achievable, protection from ionizing radiation must be optimized to maximize the cost–benefit ratio. Waste production should be minimized through recycling or reuse and via careful selection and control of radioactive materials. The safety design aspects address:

- Potential accidents and measures taken to limit their consequences;
- Site selection and design features related to safety;
- Surveillance and periodic safety reassessment of the facility.

3.6.6. NPP and fuel cycle technology recommendations

This section of the FS report should:

- Provide a summary description of the work that has been performed in the assessment of NPP and fuel cycle technology;
- Identify the key drivers affecting the results of this work, and include key elements from the programme policy objectives and the NPP project goals, along with their priorities and normalized significance weightings;
- Summarize the results and recommendations as suggested in the RTA document;
- Provide appropriate guidance to identify those characteristics of the recommended reactor types that will influence other evaluations within this FS.

3.7. ENVIRONMENTAL IMPACT OF THE PROJECT

3.7.1. Environmental impact assessment report

Environmental protection should receive serious attention when a nuclear programme is contemplated, ensuring no harm comes to humans or the environment at the site, within the country, in the region or globally. This should be a high priority goal during all phases, namely, design, construction and normal operation, and under accident conditions and during decommissioning activities. Therefore, environmental studies should be performed at the potential or selected nuclear facility site to ensure that environmental laws and regulations can be met and particular environmental vulnerabilities identified [61]. These should be addressed in the bid specification where unique plant design provisions or construction techniques have to be identified to address these sensitivities.

The study should identify and assess the potential direct and indirect environmental impacts [62–65] of the planned nuclear facilities on the selected site and its surroundings, identify environmental radiological sensitivities [2], and any gaps between the projected environment quality condition during construction and operation and the greenfield environmental conditions. This comparison should then be used to plan the development of capabilities to prevent, mitigate and monitor any significant changes in the environmental footprint. The EIA should be published to provide information to all stakeholders and positively contribute to the open and transparent approach to the launch of a nuclear facility [64, 65]; to optimize its planning and preparation phase, avoid environmentally unfavourable situations, and offer solutions to technical, construction or operational impacts on the environment; to help plan for the creation of the site baseline profile [2]; and to identify critical environmental aspects that may influence the NPP life cycle.

The scope of the study should cover the effects of any potential impacts on key environmental components such as land use, water, meteorology and air quality, ecology, culture, socioeconomics, radiological impact, waste and the impact from accident conditions [2, 65]. It should address the pathways for effluent transport, and any concentration of risks in the surrounding environment, the predominant plant and animal life and the assessment of their particular vulnerabilities. Moreover, it should characterize the local population and describe the demographics and their trends, the predominant land use, water use, the possible need for cooling towers, and the impact of construction activities on the local environment [2].

The environmental study should also address the long term issues of potential contamination, changes to the population density and land usage, and the future ability to restore the affected locations to unrestricted use. In addition, it should tackle the economic implications of environmental restrictions, both in terms of limiting activities, providing funds for future restoration, and for the solution of any possible specific issue. The report should address all environmental issues, not just those associated with the use of nuclear materials, in order to provide the public with all the facts, as they would for any large, conventional, industrial development project.

3.7.2. Cooling water demand

A cooling water technology assessment should be conducted as part of the FS since the selected technology can have a major impact on NPP economics and on the environment.

The study should include a sufficient description of the cooling water technology so as to evaluate the economic impact on the land, namely water use and its impact on the territory.

3.7.3. Environmental protection requirements of the financial institution

Export credit agencies (ECAs) that are members of the Organisation for Economic Cooperation and Development (OECD) require submission of an EIA or comparable environmental documentation to allow their board of directors to evaluate the environmental effects of a proposed transaction in terms of the liability tied to any substantial environmental damage that the construction and operation of a nuclear plant may produce [66–70].

EIAs are usually standalone documents prepared separately to an FS. The FS authors should take into account the main EIA directives regarding environmental protection in order to evaluate costs and risks. It is also important that, among the various requirements and commitments to protect the environment, those expected by the ECAs as prerequisites for the approval of loans, be included. This information will be useful during the loan application process and during negotiations with the ECAs and other financial institutions [71].

ECAs evaluate nuclear projects against host country environmental guidelines, international nuclear environmental guidelines, the World Bank's Pollution Prevention and Abatement Handbook and operational safeguard policies [71]. These evaluations are intended to ensure that nuclear projects are constructed and operated in an environmentally responsible manner, and that the projects include reasonable measures and provisions to address public health and safety.

ECAs may also require an environmental screening document. The information contained in this document enables banks to screen and categorize the project. Without disclosing proprietary information, ECAs require that the borrower be transparent with respect to the environmental effects during normal, abnormal, upset, accident and severe accident conditions. The information usually required by financial institutions includes:

- A description of the geographic, ecological, social and temporal context, including any off-site infrastructure that may be required (e.g. dedicated pipelines, access roads, power plants, water supply, housing, and raw material and product storage facilities).
- A map showing the project site and its impact area.
- Baseline data: all relevant greenfield physical, biological and socioeconomic conditions.
- Any changes anticipated and proposed developments within the project area, but not directly connected to the project. Data should be relevant to siting, design, operation and mitigation measures, indicating accuracy, reliability and sources of data.
- Air quality protection through emission reduction features in accordance with international guidelines.
- Water use and quality protection, including fresh, marine and groundwater resources through the control and treatment of effluent to the limits set in international guidelines.
- A waste management plan covering the management of solid, hazardous and toxic wastes, including recycling, storage, treatment and disposal in accordance with international guidelines.

— An analysis of natural hazards expected in the area, indicating how to minimize environmental risks by adequately selecting the plant location and its elevation and by making use of design features capable of mitigating the impact of seismic and flooding events in accordance with international safety guidelines.
— A protection plan for ecological resources, biodiversity, endangered species, natural habitats and any procedures, instructions, rules, processes and information exchange plans aimed at encouraging conservation.
— The resettlement plan (if any) and the social development plan aiming at avoiding or minimizing the adverse impact of forced resettlements of local people and damage to cultural property.
— Health and safety measures to avoid or minimize impacts on health, safety and security of the local community in accordance with international guidelines.
— A legal and administrative framework within which the EIA is carried out.
— Any residual negative impacts quantified with economic values.
— Any opportunities for environmental enhancement.
— A statement on the methodology used for selecting a particular design justifying emission levels, pollution prevention and abatement measures.
— A disclosure of the extent and quality of the available specifications, and of the assumptions and key data gaps of all uncertainties associated with predictions.
— An environment management plan containing description, prevention and mitigation of adverse effects, the monitoring of sensitive environmental parameters and the administrative measures planned during construction and operation to eliminate, offset or reduce adverse impacts on the environment to acceptable levels.
— A record of all public and institutional consultation meetings held to obtain the views and address the concerns of the affected communities, of the local non-governmental organizations and a record of all public hearings sponsored by the nuclear regulatory agency.

3.7.4. Environmental impact assessment

Normally, an EIA is performed as a standalone study. In this case, only the EIA conclusions and recommendations are included in the FS. If an EIA is not available at the time an NPP FS is being prepared, a succinct assessment of the environmental impact should be conducted within the FS. The environmental section, in this case, should include an introduction, a listing of the regulatory requirements, a description of the environment and the proposed plant, a projection of the environmental impact of the plant during construction, operations and any design basis, as well as severe accident conditions, the proposed management and monitoring plan for the environment, and finally the ultimate consequences of the project on the environment and the overall conclusions [62].

The introduction should describe the project proposal, the state of the review, the licensing and approval process, and the level of expert consultation. In addition, there should be a summary of the international and national legislative and regulatory requirements for the environmental impact statement. The international treaties and conventions and a discussion on national requirements related to the impacts of industrial activity on the environment are given below:

— Biodiversity [72, 73];
— Atmosphere related requirements [74–76];
— Examples of regional agreements [77–79].

The national environmental requirements for all EIAs are included in each country’s national environmental protection act, environmental policies and strategic environment defence plans. Examples of national acts related to environmental protection can be fisheries acts, rivers and canals acts, forestry acts, water management acts, etc. [62]. Some of these requirements may be contained in national standards, procedures and enforcement policies.

The main guiding principles of these policies and legal documents may include conservation of environmental resources, intergenerational equity, integration of environmental concerns with economic and social development, etc. National environmental strategies may cover pollution control, exclusive promotion of clean technologies, the continuing education of the public to disseminate environmental consciousness, conservation of national resources and protection of the local and global environment.

The initial description of the environment captures the conditions pre-existing the project implementation, and constitutes an irreplaceable baseline reference of key environmental data on land, meteorology, air quality, water resources, ecological resources, cultural and historical resources, socioeconomics, geology and seismology. The information will be used to allow environmental impact predictions and to provide a reference point zero for monitoring the plant impact on the environment and to conduct audits during plant commissioning, operation and decommissioning. Any existing environmental issues should be taken into account to avoid any possible deterioration of the condition and to attempt improvements of its environmental impact.

The environmental assessment section in the FS should include a detailed analysis of all the significant contributing stressors on the environment. These are usually major components such as the reactor core, reactor pressure vessel, pressurizer, turbine generator, plant water systems (primarily the cooling systems), radioactive waste management system, non-radioactive waste system and power transmission system.

The gaseous release from the primary coolant system into the containment and possibly into the atmosphere is a mix of noble gases and aerosol species. The noble gases are mainly xenon-133 (^{133}Xe), xenon-135 (^{135}Xe), argon-41 (^{41}Ar) and krypton-88 (^{88}Kr). They have little interaction with their surroundings, and they can be released, attenuated or removed. Since they do not combine with other elements, the human body does not retain them.

The environmental effects of noble gases are substantially smaller than the effects of other radionuclides. This is because noble gases have short half-lives. Therefore, a delayed release would allow the quick radioactive decay processes to greatly reduce the toxic quantities committed to the environment. Two delay techniques are used for this purpose: storage in special sealed tanks or slow once through release via low speed charcoal delay beds.

In the case of decay by storage, the noble gases and their carrier gas are first pumped into delay tanks, which are then sealed. After a storage time of 30–60 d, they are greatly decayed and can be released through the station stack.

In the once through technique, delay beds consist of a number of vessels filled with active charcoal, in which the flow of noble gases in relation to the carrier gas is delayed, allowing radioactive decay to take effect. Once the decay reaches acceptable doses, the gases containing small amounts of radioactivity are released through the stack. The release contains noble gases, iodine isotopes, aerosols, tritium and carbon-14. If the residual level of radioactivity is still not admissible, the storage period is extended as necessary.

Aerosols, on the other hand, can combine with biological species and body tissues, and hence have a significant impact on health through inhalation, skin deposition or ingestion via the food chain. Aerosols also contribute to external radiation exposure.

The potential environmental impact of an NPP during construction, operation and accident conditions can be inferred once the environmental baseline information has been collected and the NPP technology selected.

The NPP design features and operating modes can severely influence the severity of the environmental impact. If warranted, it may be desirable to modify the NPP design or change certain operational modes in order to reduce the impact on the environment. The implications of any proposed modification should be identified, including cost and benefits, so that its feasibility can be environmentally and economically demonstrated.

3.7.5. Comparative environmental analysis

In comparing technologies, it is important to differentiate between the type of services (i.e. baseload versus peak load coverage) to avoid comparing things which are not comparable. Life cycle analysis (LCA) is a technique used to assess environmental impacts associated with all the stages of a product life cycle (electricity generators, in this case). This starts from raw material extraction through to processing, fuel manufacture, distribution, usage, maintenance, decommissioning and disposal or recycling. This cradle to grave review of a NPP life cycle can provide additional insight into the overall benefits that a nuclear power option may bring to the environment. From the environmental standpoint, each technology has its own issues. The environmental footprint and the risks posed by nuclear power are well known and fully quantifiable. Others are less known, for example:

— For gas fired plants, the need to provide and operate a usually very long fuel supply pipeline carries the risk of considerable methane releases into the atmosphere. In addition, large gas accumulators are required upstream of a gas fired power plant to strengthen the otherwise variable supply pressure from the pipeline. Their presence and operation adds to the plant's CO_2 footprint and the risk of large explosions into the bioenvironment, which would threaten human life, both in the plant and in the surrounding areas.

- For wind turbines, the concrete per MW used in their foundations is higher than that in NPP construction. Although counter-intuitive, the carbon footprint of wind farms (from an LCA standpoint) is normally higher than that of NPPs owing to the production of their concrete foundations.
- For solar facilities, in an LCA type comparative analysis, it is evident that the environmental loads inherited from the manufacturing of the very large numbers of solar or photovoltaic cells is similarly taxing.

3.7.6. Environmental monitoring and protection plan

Environmental monitoring devices and operating manuals should be provided with any nuclear plant technology to avoid undetected releases and allow the best preservation of environmental quality. Monitors send an early warning signal as soon as an abnormal environmental condition related to plant operation is detected. Working in harmony with the monitoring devices, the plant mitigation and prevention systems allow an efficient management of the releases, a prompt correction of abnormalities and a reduction of the overall environmental impact of the plant [62].

The environmental monitoring requirements should include thermal, radiological, hydrological, ecological and chemical monitoring. These devices use special parameters capable of indicating the nature and level of negative conditions and their environmental impacts. Monitoring can be automatic or manual and discrete. The environmental monitoring plan should detail how, when and where it is conducted, and should highlight how manual monitoring activities are undertaken, who will carry them out, and who should receive the monitoring report. Therefore, it is important to prepare a proposal to regulate environmental conformity monitoring activities [65].

Following each assessment of the NPP impact on the environment, measures to mitigate and prevent stressors from causing permanent damage should be identified. Mitigation measures include design alternatives that could decrease emissions, including those caused by construction activities. For those segments of the population within the exclusion zone, relocation assistance should be foreseen. Other interventions include possible land use controls and protective measures. Mitigation measures discussed in this FS must cover the range of analysed alternatives, and should include impacts that might not be considered 'significant' [80]. In some cases, unacceptable environmental impacts may be avoided at the design or construction stage, with relatively minor modifications to the original plan. However, specific impacts may demand major changes. Once effective mitigating measures have been defined in the FS, they should be included in the bid specification package.

3.8. LICENSING AND AUTHORIZATION

Legal regimes are required for peaceful uses of nuclear energy, including:

- Regulating international trade in nuclear materials and equipment to deal with issues of liability and compensation for nuclear damage;
- Providing a legal framework to support construction permits and operating licences;
- Regulating compliance and enforcement;
- Dealing with violations, damage mitigation, allegations and employee relations issues.

An effective legal framework establishes the duties and responsibilities of the various national organizations necessary for a successful nuclear power programme. It provides the legal authority to both the regulatory and licensing framework. Legal regimes in countries embarking on their first nuclear power programme should put special emphasis on activities aimed at establishing infrastructure items and government agencies capable of implementing the nuclear act, and provide the legal means necessary to:

- Allow the country to engage internationally in peaceful uses of nuclear energy, including international treaties and trade in nuclear materials and equipment;
- Establish a competent and effective regime of NPP construction permits and operating licences;
- Regulate compliance and enforcement, establish violations and investigate allegations to provide the legal basis for the resolution of employee relations issues;

- Regulate issues of liability and compensation for nuclear damage and to mitigate damage from accidents [66–68].

This section of the FS report should contain and describe the following categories:

- A summary of the key elements of the national legislation such as nuclear safety, security, safeguards and liability for nuclear damage.
- A description (summary) of the nuclear safety regulatory authorities, with particular emphasis on their primary mandates to uphold public safety, to preserve the environment and to do so independently of commercial interests and conflicts. This item should also clearly describe the source of these agencies' authority and their link to the relevant legislation.
- A summary description of the legislative framework adopted by the country for the implementation of its first NPP [6].
- A cross-reference to relevant international legal instruments [8, 10–12, 59, 66–69, 79, 81–83] and the extent of their applicability.

For each category, references should be made in the FS report or in its appendices to specific national laws and applicable decrees. At the very least, these references should include international conventions and codes accepted by the country, legislation under development (if any) and legislation already in force concerning:

- National energy policy, economic and commercial considerations with a clear designation of responsible institutions or bodies, including their relationships with nuclear power;
- Independent regulatory authorities, the system of licensing, inspection and enforcement, and nuclear safety issues, i.e. radiation protection, radioactive material and radiation sources, accident management and mitigation plan, emergency preparedness and response, transport of radioactive waste, spent fuel management nuclear liability and coverage regime, security, safeguards, export and import controls and physical protection;
- Dealing with foreign investments, including the roles of foreign entities, vendors and contractors, and intellectual property rights;
- Dealing with the roles of national government, local government, stakeholders and the public;
- Dealing with fuel cycle issues in general and the ownership of nuclear material;
- Dealing with the commitment to use nuclear power for peaceful purposes;
- Covering national insurance.

If, during the FS report preparation (earlier in phase 2 of the programme), the required national legislation has not been implemented, the FS report should at least include:

- The national nuclear legislation plan approved by the government for the completion of the national nuclear legislation, which should comprise the actions, timescales and resources required to enact the planned legislation and the timescale for government approval;
- A plan approved by the government identifying the relevant international legal instruments to which the State will become party, which should include the actions, timescales and resources required to implement the instruments and the timescale for government approval;
- A plan identifying other laws to be prepared or amended, which should include the actions, timescales and resources required to enact any amended legislation and the timescale for government approval.

It is recommended that this legislation plan also covers:

- Environmental protection (air and water quality and wildlife protection);
- Emergency preparedness and management;
- Occupational health and safety of workers;
- Protection of intellectual property;
- Local land use controls;
- Foreign investment;

— Taxation;
— Roles of national government, local government, stakeholders and the public;
— Financial guarantees.

Nuclear law is a specialized field. Professional input from experts is highly desirable to completely address and correctly formulate the plans and the appropriate legislation. However, the legislation should also take into account the national legal and political traditions, institutions, economic circumstances, the level of technological development and cultural values. Additional information and direct measurements with specific criteria can be found in the INPRO methodology for sustainability assessment [13].

3.8.1. Licensing process and requirements

The overall responsibility for coordinating the licensing of the first NPP project will always remain with the NPP owner. A realistic project schedule and the completion of the project can only be ensured with good coordination and communication between the licensing body or bodies and the NPP owner.

The relevant licensing requirements indicating the type of documents required and the time allocated for review and inspection should be adequately incorporated into the planning for the first NPP project [5]. Any necessary information and clarification required for licensing during project implementation, as well as during operation, will be provided by the NPP owner with the support of its partners (e.g. NPP main contractor, NPP vendor, NPP owner's architect–engineer, etc.). The roles and responsibilities of each partner in the licensing process, including interfacing with the licensing authority, should be clearly stated in the future respective contracts.

The licensing process should cover the following:

(a) A description of the NPP licensing process and associated requirements in all of its phases (siting, design, construction, commissioning and operation, decommissioning and waste disposal). The description should include the type of required authorization and permit, all applicable regulations (regulatory body documents), licensing bases, codes and standards at each step of the process. This description should cover not only the nuclear safety licensing area, but also all other NPP licensing aspects.
(b) A typical (generic) schedule for the licensing of the first NPP, indicating the following:
  (i) Required authorizations, licences, permits and approval;
  (ii) Licensing and authorization milestones (site selection, construction start, commissioning or operation, etc.);
  (iii) Required technical documentation and specific analyses (NPP design bases, postulated accident analyses, probabilistic safety assessment, preliminary and final safety analysis reports, EIA reports, stress reports of the process systems, etc.) to support the first NPP licensing process.

During the preparation of the FS report (earlier in phase 2), it is possible that the regulatory framework and licensing requirements have not yet been completed or totally enforced. In this situation, it is recommended that this section of the FS report be prepared based on the reference information received from the potential NPP vendor countries, including any input from their regulatory bodies. In case more than one NPP vendor country and design are being reviewed in this FS, it is recommended that a comparison of the licensing processes of each of the proposed NPP alternative designs be included in this section.

The FS should also include clear plans on the development of legislation regulating all necessary radiological control activities such as those described in IAEA publications relating to nuclear and radiological safety [14, 29–54]. This legislation should cover the following items:

— Establishment of the authorization process;
— Development of regulations and guides;
— Safety review and assessments;
— Inspection;
— Enforcement;
— Coordination with other national and international bodies;

— Public information;
— Provision of adequate supporting technical resources.

Finally, this section of the FS report should address and evaluate the possibility of establishing a cooperation agreement between the regulatory bodies of the country implementing the NPP project and the NPP vendor country, in order to facilitate the future licensing process. It is recommended that for the first NPP, the country adopts the licensing process and applicable regulations of the selected NPP vendor country.

During the preparation of the FS report, the final NPP vendor and NPP design may not yet have been selected, so it is important to include a detailed design description of all NPP options being considered, together with a detailed evaluation of the basic design requirements, the main safety features and the licensing process of each proposed alternative. Based on this information, the national regulatory body may agree to perform a preliminary licensability assessment of all alternatives being considered. These initiatives may be financed by the vendors or vendor countries.

3.9. PROJECT IMPLEMENTATION APPROACH

3.9.1. Ownership structure

For the implementation of a new build, a project organization is likely to be established. The structure and weight of this company will depend on several factors, the most important of which are the:

— Total investment for construction;
— Size of the plant;
— Impact on the national grid.

In the case of a multiple ownership structure, the effects on the project may influence the:

— Selection of the reactor technology and type;
— Financing model;
— Procurement concept;
— Organizational structure and staffing of the construction and O&M phases;
— Risks connected to the project.

The ownership structure should include only members who:

— Are financially and technically robust;
— Possess the required management experience and resources for such a complex and large scale project;
— Have the ability to off-take or sell either partially or totally their share of the project in order to optimize operations over the long term.

One approach could be that of assigning the nuclear new build ownership and management to a ‘project company’ responsible for the construction and operation of the new NPP. This project management company should be either 100% owned by the founding utility (which is most likely, at least initially) or be one of its own branches. At a later stage, the project management company may consider selling a percentage of its shares to strategic and/or financial investors. These investors could provide expertise, funding and electricity off-take.

Another approach would be to allow partial ownership to large energy consumers looking to hedge their energy bill and secure lower electricity costs in the future. These parties would normally off-take a percentage of the electricity generated (at cost), proportionally to their ownership stake. The involvement of the partners will require an established long term contractual framework for the O&M period.

Several of these strategic investors and consumer owners will have requirements in terms of:

- Minimum ownership stakes;
- Technology selection;
- Contracting strategy.

Therefore, the selection of a potential partner should take into account all of these variables. Possible types of ownership structures are given below.

(a) Utility as a sole owner

Key advantages would be:

- Full control of the nuclear development company;
- Full control of the selection of the technology, of the supplier and of all subcontractors;
- Use of O&M experience (if any) accumulated as founding members (if that is the case);
- No need for complex transactions.

Key disadvantages would be:

- Limited financial capabilities;
- Limited development experience that could result in less favourable financing terms.

(b) Shared ownership model

This option involves partner capital injection at the project company level.
Key advantages would be:

- Partners would provide the capital.
- Partners could bring development experience, which would reduce the project risk.
- Partner support could favour lower financing terms for the loan.

Key disadvantages would be:

- Some partners could have strict requirements for technology and suppliers.
- The founding owner would need to give away certain governance rights.
- Some partners might not be prepared to invest the required amounts of money, while not getting any electricity output or dividends for the first few years.

(c) Finnish business model

In this model, all shareholders will be entitled to a pro rata share in the output at cost during the entire plant lifetime. The essential point of the financing structure in the Finnish business model is that the shareholders are entitled, subject to their proportion of shares, to buy the electrical power generated in the NPP at cost, so their profit comes from the difference between the production cost and the market price. This structure would require a number of regional power consumers.
Key advantages would be:

- Partners would provide required or additional capital;
- The founding owner would most likely retain control of technology, supplier and subcontractor selection;
- Partners have no influence on running the business.

Key disadvantages would be:

- Partners would provide limited or no development or construction experience, which would likely require an extensive engineering, procurement and construction (EPC) contract from debt providers.
- A complex transaction structure will develop with multiple parties.

In the selection of the ownership structure, the following considerations will have to be made:

- Possible preference for ownership models based on majority shares to the founding company;
- Identification of possible financial and strategic partners;
- Possible cooperation in the economic, financial, technical and procurement areas;
- Risks connected to each ownership structure and their management.

In the case of nuclear power extension programmes, strategic investors for the addition of a new NPP could form a joint venture. The member companies should preferably possess one of the following characteristics:

- NPP investment history or operational experience;
- NPP design, manufacturing and installation capabilities;
- Experience in performing electrical power trading or distribution activities;
- Significant on-wire power demand;
- Active presence on the national market.

3.9.1.1. Bidding and contracting phase

Lessons learned from recent experience have shown four successful strategies that can be used to select an organizational structure and process to successfully manage the delicate phase between the technology and vendor selection point and the contract signature milestone. These four basic strategies require different organizational and staffing models depending on the level of internal effort and external support envisaged:

- Full scale effort: This model takes up to 30 calendar months to complete. The bid evaluations alone take about 30 000 to 50 000 person-hours of in-house experienced resources equivalent to a team of ~80–120 experienced staff. In this process, the utility develops a detailed request for a bid (~12 months), sends it out to selected (3–5) vendors, who need about 9–12 months to prepare a detailed response, followed by detailed bid evaluations taking 9–12 months, and contract negotiations taking about 4–6 months. In other words, the requirement is for about 20–30 experts per reactor vendor/technology, plus ~20 experts independent of reactor vendor and technology.
- Semiscale effort: This model takes about 24 calendar months of in-house expert resources (i.e. a team of ~40–60 in-house expert staff). In this case, the utility spends about 6–12 calendar months to preselect (2–3) vendors and technologies, develops a set of requirements and criteria based on its specific needs (6 months), sends the requirements list out to preselected (2–3) vendors, who are given 2–3 months to respond with a 'budget bid' based on an agreed on reference NPP, followed by bid evaluations and commercial negotiations taking up to 6–9 months of several rounds of seeking 'best and final offers'.
- Fast track effort: This model takes about 18 calendar months of in-house client resources (i.e. a team of about 20–30 in-house expert staff). In this case, the utility develops a list of customized requirements (4–6 months), sends it out to (3–5) preselected vendors, entertains a dialogue with the vendors (3–4 months), selects one technology and vendor and initiates contract negotiations, which take 4–6 months. In this model, substantial outside consultant support is usually required.
- Negotiated effort: In this model, the utility requires about 60 expert in-house staff, and makes a preselection of technologies and vendors to select 3 finalists, a process that takes 12–18 calendar months. Then, the utility signs 3 separate FS contracts, which takes about 3–4 months, with the 3 finalists, who get paid for their detailed design work with the utility. Then follows a period of ~5 calendar years during which the utility and the vendors develop the detailed requirements, 3 customized NPP designs and the final contract for all 3 vendors. At the end of this period, the utility asks for the best and final price from the three vendors and

signs the contract with the best bidder (this takes about 3–4 months). After that, contract implementation and construction can start immediately, with no delay, because all details have already been worked out. The design is almost complete and customized to the client's needs. The second best bidder is kept as a backup for 1–2 years. This model will require a significant initial investment; however, this will lead to greater cost savings and time efficiencies in the long term.

A new building project organization is always highly dependent on the type and number of existing and available in-house experts (any lack thereof may require external consultant support). Some observations regarding the implementation of these four organizational models are:

— Ideally, a utility should shortlist three vendors to maintain healthy competition during the negotiations in order to obtain the exact best and final price.
— It takes a minimum of 2 years to properly select a vendor and sign the best possible contract.
— It requires 20–30 in-house experts to pursue each vendor and technology, plus an additional 10–20 experts independently of reactor technology, to adequately cover commercial, legal, administrative, communications, human resources, management and office support functions.
— Should a utility use fewer in-house experts than indicated, it will require outside consultant support or it will have to contract the whole process to an architect–engineer or agent.

The guiding principle is to use a minimum of two seasoned and experienced staff in all key areas (to guard against disruptions), plus junior support for each vendor and technology, for a total of 70–100 staff. Once the contract is signed and construction begins, the team size should increase to about 200–250 individuals, and reach an average of 300 persons during the construction period. Many of these individuals will eventually transition to the operations organization.

In general, utilities prefer to outsource a significant part of the work to experienced professionals in specific areas. This has advantages such as:

— Allowing internal resources to focus on daily operations and key issues;
— Acquiring the 'best in class' team for each stage of the project;
— Avoiding permanent hires that may have to be laid off in the ramping down phase.

3.9.2. Contractual approach

The selection of the type of contract is one of the basic decisions concerning the construction of NPPs. The contract type can greatly influence the cost estimates of the project. Therefore, it should receive great attention and be based on a careful analysis of the following aspects:

— Potential vendors and their particular experiences and attributes;
— Standardization and proven quality;
— Government and industrial relationships;
— Competitive and economic considerations;
— Foreign financing possibilities;
— Guarantee and liability considerations;
— Planning and implementation of the project and subsequent projects;
— Availability of qualified project management, coordinating and engineering workforce;
— Development of national engineering and industry capabilities;
— Owner experience in handling large projects.

A number of approaches can be considered by newcomer countries.

3.9.2.1. Turnkey contract (engineering, procurement and construction contract)

EPC or turnkey contracts traditionally include the complete scope of work required to construct and successfully operate the plant. It is the duty of the EPC contractor to deliver all parts required for operating the power plant, ensure that the plant complies with all permits and licence requirements, and meets all specific performance test requirements, i.e. guaranteed capacity, guaranteed efficiency, etc.

If the project falls short of guaranteed performance levels, the EPC contractor will be liable to restore the performance of the plant. Usually predefined performance related liquidated damages (LDs) apply if the EPC contractor fails to restore full plant performance. Financial institutions and banks require that the amount of LDs agreed upon in the EPC contract covers the potential financial loss caused by any underperformance and licensing non-compliance.

While EPC contractors are very reluctant to accept rejection rights (for obvious reasons), this instrument can turn out to be a very powerful tool to control and achieve contract compliance. Rejection rights should be included in EPC contracts, especially in the case of:

— A history of failure to comply with permit requirements, suggesting a higher than acceptable risk of failure to obtain an operating licence;
— A history of failure of the EPC contractor to achieve minimum acceptance performance levels regarding capacity, efficiency of systems and components at turnover times, etc.

EPC contracts traditionally comprise a fixed price agreement for a predefined scope of work. Therefore, the owner and the financing institutions are covered against cost overruns caused by increases in raw material costs, increases in labour costs, etc., unless:

— The sponsor asks for change orders;
— The predefined scope of the work is not all inclusive, and the parts of the work required to complete the plant are unaccounted for in the budgets.

Some EPC contractors may have incurred losses tied to fixed price guarantees in the past. Therefore, they may try to introduce exceptions to fixed price agreements, i.e. proposing that a percentage of the EPC fixed price be linked to steel price indices, but this approach may prove inconvenient and very difficult to implement. EPC contracts with price adjustment mechanisms have a significant impact on the financing model as banks are typically reluctant to accept unlimited construction price risks [71]. If index related price adjustment cannot be avoided, a cap on index related price adjustment is a mitigating feature that may normally lead to a successful financing model.

If the utility has the leading executive responsibility of the overall contractual and technical aspects of the civil works, it should perform this task through its site management team. If it does not have this experience and capability, the task should be subcontracted to a highly qualified construction company, closely controlled by the utility, and sometimes to an architect–engineer running a construction department or a subsidiary construction branch. A separate construction company may also receive a contract for the civil works, with similar contractual and management responsibilities.

Site work includes a multitude of other activities such as installing equipment, welding, material handling, shipping, storing, cleaning, inspecting, testing, modifying, repairing and maintaining. These activities should be under the control of the key representative (or the resident manager) of each project partner on-site. Many mechanical and electrical erection activities are handled as subcontracts and executed at the contractor's site. They may be supervised by the engineering, purchasing and/or project management departments of the owner/utility from its headquarters.

3.9.2.2. Multiple contracts

In a multicontracting scenario, all the risks usually embedded in individual contracts can be expected to far outweigh the umbrella protection of an EPC. The three key issues that can be observed in this regard are:

— A multicontracting structure does not cover interface risks between different contracts, which can cause significant delays, underperformance, cost overruns, failure to comply with permits, and even potential failure to correctly complete the project.
— Even if interface risks do not materialize, performance risks may remain partially uncovered or fall short of EPC contract coverage, i.e. a rejection right would only apply to each individual contract independently of the others (the owner cannot reject the whole project based on the failure of a single contractor). LDs would be payable only within the scope of the underperforming contract, even if the one failed performance materially impacts the overall project performance. Neither rejection rights nor LDs under the failed contract can be expected to make up for the overall project loss.
— A strong EPC contractor can also cover the risk of default of a weaker subcontractor (counterparty risk).

A contractor responsible for 5% of the project costs, for example, will most likely accept LD levels that are in line with his/her share of the overall construction costs, but certainly not delay LDs covering 100% of the overall project delay costs, even if his or her failure to deliver was the cause of the overall project delay. Compared to an EPC structure, this will make a significant difference to the owner and consequently to the financing institutions in terms of LDs received [84–86].

It is therefore important to consider, at the project planning stage, that contracting a new NPP is a major undertaking (~1000 pages of contract accompanied by up to 15 appendices made up of a further 1000 pages). Whether the selected strategy is a human power effort requiring an agreement with the vendor consortium, or alternatively with the multiple contractors to produce effective contracts, the outcome is roughly the same.

Beyond the construction contracts described above, some broader contract types may be considered, especially by smaller private utilities or by countries embarking on the nuclear industry for the first time. These broader contracts are usually based on country to country agreements. The following are examples of the various models that have been used:

— Build–own–operate (BOO);
— Build–operate–transfer (BOT);
— Design–build–finance (BDF).

To develop an accurate project cost estimate, if the selected technology is not first of a kind, and the cost data of a reference project can be provided by the vendor country, then the cost estimate of the future project can be based on the cost model of the reference plant. Cost adjustments will need to be made to the reference plant model to account for time differences, location parameters, code updates, design changes, obsolescence, different suppliers, different workforce and project management levels of experience and vendor profit requirements. The technology vendor usually provides this customization, and an asking price is set based on the division of responsibilities and on the contract type. The purchaser will normally negotiate the final price based on its own review of the three elements of construction cost plus the cost difference between the reference plant and new plant plus the vendor profit allowance. A consulting firm may be used to carry out this review. If more than one vendor is involved in an international bid, then the future plant owner may conduct an alignment of the various offers that may help influence the final price negotiation with the winning bidder.

The host country may decide to adopt a policy of government subsidies to control the price of electricity to the ultimate consumer customer. To that effect, some of the expenses incurred during the NPP construction may be financed by the government, e.g. the cost of the infrastructure development and regional facilities (i.e. transport, temporary living quarters, services, etc.), so as not to burden the population with excessive electricity tariffs.

3.9.3. Procurement programmes

3.9.3.1. Selection of equipment suppliers

The selection of suppliers is by open competition. The tender announcement is usually split into packages that allow for (i) large bidders, to offer a scope of supply encompassing all packages, and (ii) smaller bidders, to offer to supply individual packages separately. During the course of the evaluation process, the owner/investors may select a model comprising a main contractor responsible for the full supply and who, in turn, directly supervises a number of smaller subcontractors as appropriate.

In the event that procurement responsibilities are borne by the owner and investors, contracts are awarded directly to the suppliers or vendors of systems and components, each within its own scope of deliveries. The vendors are usually required to follow the procurement policies set forth by the owner/investors, including local content requirements, as, in this case, the scope of supply and the different delivery specifications are controlled by the owner/investors.

Furthermore, for the successful application of this model, the owner/investor project team should be knowledgeable in nuclear technology, experienced in project management and organization, and skilled in the drafting and management of international and domestic contracts.

In the deployment of new units, the owner/investor usually distributes the technical scope on the basis of logical modules or skill based delivery packages. By selecting only suppliers with proven manufacturing capabilities, and by placing orders in a timely fashion (even ahead of schedule), the risks associated with the procurement of large quantities of complex equipment, such as high quality nuclear grade components, may be minimized. A typical example of the division of responsibilities for the scope of supply is given below.

(a) Nuclear island

This package may include all systems and components making up the nuclear energy generation systems, supporting and shielding structures and components and all interconnected auxiliary systems, e.g. the reactor building with the primary circuit equipment (the reactor, the steam generators, the pressurizer, the main cooling pumps, the interconnecting primary circuit pipes, etc.), the fresh and spent fuel storage building, the auxiliary system building, the redundant safety system buildings, the safety emergency diesel generators, the emergency electrical distribution systems, the instrumentation and control (I&C) and dosimetry systems, the radioactive waste management system, etc., which are either directly or indirectly connected to the nuclear systems.

(b) Conventional power plant (secondary circuit)

This package includes all those conventional power plant components, such as, for example, the main steam system with its pipelines, the turbine (high pressure and low pressure parts), the separator reheater equipment, the condenser, the feedwater preheaters (low and high pressure), the feedwater pumps, the tanks and pipelines of the feedwater system, its closing and safety armatures, the generator, the electrical auxiliary operations and I&C systems, which ensure the electrical power generation conforms with the nuclear island interfacing requirements.

(c) Balance of plant (BOP)

This package may include all conventional components, systems and structures, such as, for example, the water pump station, the hot and cold legs, the water purification plant, the channel, etc., which are necessary for electricity generation and allow its control.

(d) Network connection

This package includes all electrical network components, such as, for example, transformers, circuit breakers, switches, measurements, information systems, electric power lines, isolators, supporting towers, pylons etc., through which the new units are capable of transferring the generated electrical power to the grid.

In countries with limited technical resources and a limited highly skilled labour force, national participation in the procurement effort should logically be limited, at least initially, to smaller conventional components or lower class nuclear supplies. The degree of utilization of the conventional branches of the industry depends on the industrial infrastructure in the given country.

3.9.4. Project schedule

The construction schedules proposed by vendors today are significantly shorter than those previously achieved. Therefore, the purpose of this particular section is to assess the feasibility of the schedules by determining whether:

— The key assumptions are valid and if all critical assumptions are represented;
— The schedule scope includes all pertinent activities;
— Task durations are realistic relative to historical precedent and current standards;
— The schedule logic is sequenced in a reasonable manner;
— Modularization is used in the design and whether its consequences have been incorporated;
— The critical path scope is complete and the logic is reasonable;
— The vendors have performed a risk assessment and what the significant conclusions were.

As it is difficult to align schedules of different technologies and vendors, the evaluation should focus on expected activities, level of detail, project critical paths and key assumptions.

Once the vendors' assumptions have been verified, the body of this section should review common areas that can be compared between vendors and the domestic capability to support the project and the schedule. Incomplete detail design and gap engineering issues, outstanding issues and insufficiently defined areas are listed, may have a negative impact on the project schedule. This is particularly threatening to the schedules of the initial units pertinent to a first of a kind reactor design. In third generation reactors, vendors have introduced significant changes to improve safety, construction schedule and economics. This may engender engineering difficulties and many incomplete details. Conceptual designs are not the problem. They are usually well conceived and even receive design certification from their regulators, but new designs often have an incomplete complement of details, infringing on the timely delivery of many of their components.

Late supplies of critical structures and components may kill a construction schedule and easily exceed a project budget. In order to take advantage of economies of scale, some of these new concepts include larger and more complex components and the use of multifaceted modules, which are often entire volumes or sections of the plant. They are built in shipyards and factories off-site, and comprise several components, entire piping runs, cable trays and composite structural walls. Given their complexity and size, modules require precise on-time delivery of all their parts and materials, which may come from different corners of the world; if designs are not detailed enough, suppliers cannot deliver on time, and module assembly may suffer delays. In addition, the sheer weight and dimensions of some modules may introduce distortions and alignment issues that are difficult to handle and resolve in the field.

Project preparation for two reactors may last for about 5 years, while construction following and to some extent in parallel with detail design varies between 4 and 6 years. Hence, a total of 9–11 years is required for the completion of a new nuclear power project after the first decision to proceed with the project was taken. The preparatory phase can be divided into two parts: preparation of the strategy and preparation of construction activities.

The detailed time schedule can begin only after the actual supplier of the nuclear technology has been selected; however, in a broad sense, the general construction schedule of a new unit comprises the following milestones.

3.9.4.1. Project preparation

During the pre-project period, the following activities would have to be undertaken:

— Gathering the necessary information to allow strategically pressing and crucial decisions;
— Preparation of the overall implementation plan;
— Establishment of the financial model;

— Tendering activities;
— Selection of the main contractor and subcontractors;
— Licensing activities.

3.9.4.2. Project implementation

The project implementation phase includes the core activities necessary to support construction all the way to the commissioning and reactor startup. These activities include:

— Detail design;
— Procurement and manufacturing;
— Construction and system installation;
— Commissioning and power ramp up [14].

As it is difficult to align schedules of different technologies and vendors, the scheduling activities should focus on completeness, level of detail, critical paths and key assumptions. They should involve a review of the following factors:

— Status of the domestic infrastructure to support the schedule;
— Elements supporting the overall schedule improvements compared with previous experience;
— Impact of project management and organizational structures;
— Influence of modularization and construction planning;
— Interactions with regulators and new regulatory processes;
— Impacts of key vendor assumptions;
— Effects of plant staffing on construction and operations;
— Incomplete detail design and gap engineering issues.

The last item, which comprises outstanding issues and insufficiently defined areas, may play a negative role on the project schedule. This is particularly threatening to the schedules of the initial units of a first of a kind reactor design.

New designs often have an incomplete complement of details, infringing on the timely delivery of many of their components. Late supplies of critical structures and components may kill a construction schedule and easily exceed a project budget.

3.9.5. Project management

3.9.5.1. Project implementation concepts

For the project implementation of new units, two execution concepts might be considered or a combination of both:

(a) A single EPC or turnkey contract, where the design, manufacturing, procurement, construction, installation and commissioning of the new units are assigned to one main contractor or consortium solely responsible for the outcome. The main contractor selects the national and foreign partners (subcontractors). The owner/investor will have only the right of approval. Consequently, the main contractor must ensure that the design is complete, the licensing is conducted according to schedule, the manufacturing, procurement, delivery and installation of the equipment closely follows the integrated schedule, the performance of the civil construction work, of the commissioning and the training of the operational personnel is correctly sequenced in the overall schedule, and that durations are respected. The role of the owner's engineering department is limited to detailed surveillance of the EPC execution.
(b) The owner/utility divides the implementation of the new units into work and service packages (nuclear island, conventional power plant parts, network connections, etc.), and entrusts vendors experienced in project implementations with a project management and coordination role.

The definition of the technical content and conditions for the various construction tasks and services, the determination of the supply boundaries, the conduct of tendering and the selection of the vendors will be the responsibility and risk of the owner.

The designated vendors have the selection right of domestic and foreign partners (subcontractors) in agreement with the owner/utility. This is the contractual concept in which it is possible to ensure the appropriate proportion of domestic industry scope and supplies, and thus to enforce the positive effects of the investment on the development of the domestic economy and employment.

The investor will ensure that the division into packages covers the full scope of the design, licensing, manufacturing, procurement, delivery and installation of the equipment necessary for the new units, the execution of the civil construction works, and the commissioning and training of the operational personnel.

In this case, a project management organization is given the responsibility of project management, contractor coordination to ensure correct execution of the packages, adjustments to the schedule where required, inspection of the implemented contracts, management and organization of commissioning of the new units up to successful completion of the trial operations [14], and performance guarantees, as should be stated in the execution contracts by means of performance parameter measurements.

3.9.5.2. Project management tasks

Project management means the execution of the following tasks: preparation of project planning and execution schedules, establishment of the local infrastructure, preparation of the public information programme, preparation of the basic environmental protection data, progress surveillance, introduction and coordination of the quality assurance programmes and quality management system, continuing project cost control, supervision of manufacturing, contact with the local authorities, review and approval of the safety and technical procedures, as well as of the O&M manuals of the power plant, etc.

The project management activities start with the project work scope definition with certain input data taken from the vendor or from reference projects, milestones and obstacles. The project management responsibility ends with the handover of the completed and functioning system, structure or component to another organization or legal entity. This legal entity will be responsible for the O&M of the completed project.

A number of different organizational structures for the project management function can be used, depending on the owner's practice. The matrix type project management structure is the most commonly used model, especially in the case of multiunit projects. This is due to the extreme complexity and unique character of NPP projects, where the highly specialized practical skills and the high coordination skills must be combined in order to complete the given work scope in accordance with the project schedule, within the allocated budget and with the required quality. Within the matrix type organization, the project manager is entitled to assign tasks to each member of the project team and approve all preliminary plans.

3.9.5.3. Preparation of the site

The execution of the site preparatory activities might take place following reception of the construction licence. These include construction of the road and docking site, of the open air and covered equipment storage areas, of the fence, and the provision of utilities and services (electrical power, water, compressed air, etc.) necessary for construction of the plant and of the auxiliary services and facilities (office buildings, hostels, first aid, hospital, canteen, car park, etc.).

A certain part of the on-site infrastructure is made up of small and medium sized facilities required for certain on the spot manufacturing activities and for the preparation of structural elements before installation. Such facilities should ideally be constructed at the earliest possible project phase to avoid hindering progress during the delicate start of the construction phase.

3.9.5.4. Implementation planning

For the preparation of the construction plan, fewer person-hours are required than for the overall project plan, although it is still necessary to involve the full planning organization. In order to draw maximum benefits from the state of the art reactor construction technologies and achieve the schedules proposed by new reactor vendors, the planning effort will likely require several iterations with significant corrections.

During the planning effort, it should also be assumed that long lead items would have been ordered long before the first concrete milestone at the early ATP milestone, and that a major number of technical specifications, especially for the BOP, would have been prepared by the subcontractors responsible for items such as the nuclear steam supply system, the turbine machine group and other conventional components in the BOP.

3.9.5.5. Procurement of the equipment and materials

For turnkey contracts, the main contractor is, within its scope of supply, responsible for the procurement of every single piece of equipment and bulk material item. In non-turnkey contracts, the responsibility for the organization is borne by the owner/operator and the responsibility divided between the main contractor and subsuppliers of partial systems, each within its actual scope of delivery.

The procurement starts with long lead items with the ATP. By that time, the equipment and system designs and specifications, the procurement packages and the contracts should be ready to be sent out.

The manufacturing of long lead equipment starts 2–3 years prior to the first concrete pour, while the delivery and installation of the last components will likely take place during the commissioning of the power plant.

Procurement ends with inspection of the delivered item, and completion assurance certificates are issued, which may last up to the end of the commissioning phase [14]. The procurement of the services related to the fuel and to the fuel cycle is usually treated as a separate activity, but it might also constitute part of the tasks performed by the procurement organization. Procurement of components normally comprises two principal aspects: one incorporates the actual technical aspects that arise from the nature of the items to be delivered, and the other is the commercial and legal aspect, which depends on the applicable practices, prescriptions, regulations and laws. Other than having an important impact on the financial and economic aspects of the project, procurement directly influences the project schedule, as well as its reliability, performance and safety.

The procurement unit usually establishes the procurement criteria and planning, supplier qualification and selection, execution of the tendering and bid evaluation process, contract awarding and the management of guarantee claims. As a result of its activities, the procurement unit might become a primary tool in promoting the national participation programme, by supporting the gradual insertion of local, qualified suppliers. In some instances, it might even play a mediatory role between new local suppliers and project management, who may be unwilling to substitute an experienced foreign manufacturer.

3.9.5.6. Construction of new units

The construction and equipment installation time is the period immediately following the award of the procurement contracts. It extends through construction of the new units and lasts until the commissioning and beginning of operation of the power plant.

Some of the new plant designs include larger and more complex components and use complex modules, which are often entire volumes or sections of the plant. They are built in shipyards and factories off-site, and comprise several components, entire piping runs, cable trays and composite structural walls. Given their complexity and size, modules require precise on-time delivery of all their parts and materials, which may come from different corners of the world; if designs are not detailed enough, suppliers cannot deliver on time, and module assembly may suffer delays. In addition, the sheer weight and dimensions of some modules may introduce distortions and alignment issues that are difficult to handle and resolve in the field.

Site work includes a multitude of other activities such as installing equipment, welding, material handling, shipping, storing, cleaning, inspecting, testing, modifying, repairing and maintaining. They should be under the control of the key representative (or the resident manager) of each project partner on-site. Many mechanical and electrical erection activities are handled as subcontracts and executed at the contractor’s site. They may be supervised by the engineering, purchasing and project management departments of the owner/utility from its headquarters.

At the peak of the construction period, at least several thousand skilled and experienced workers will be required, and the on-site infrastructure and services will have to match the increased demand. Significant site support structures and systems will be required (site offices and workshops, temporary and final roads, a concrete preparation workshop, a temporary site electrical network, illumination, a water and a pressurized air network, healthcare facilities, a firefighting network, etc.) prior to when the first concrete is poured (usually the foundation of the reactor building).

3.9.5.7. Commissioning

Commissioning means full scope testing and startup of components and systems. Its goal is reliable, trouble free operation of individual components, of partial systems, of auxiliary systems, and of the main power system, as well as compliance with all applicable safety, performance, environmental and other related requirements [14].

The inspection and testing should cover all operational and emergency modes and conditions. All detailed test data, adjustments and test results must be documented in an appropriate controlled manner.

3.9.6. Risk matrix

In the context of an NPP FS, risk analysis can greatly facilitate the decision making process. Nations and the world community are required to make decisions about the best energy mix and the distribution of power producers, particularly nuclear power, in the world. The nuclear power industry has traditionally led the way in the development of quantitative risk assessments because of its intrinsic need to answer questions dealing with the likelihood of accidents. Serious nuclear accidents represent a threat to life expectancy and property damage, as well as to the business model in an NPP project. Beyond nuclear accidents, risks can be of a conventional or natural nature, and yet still threaten the business model of an NPP. Licensing risks are a typical example of this. They do not threaten life and property, but they can render a project instantly non-viable at its initiation or even at any time during the plant's service life [87, 88].

Another major risk is the risk of production failure that can go from a reduction in capacity factors and production levels all the way to a business model collapse, for example, when production fails because of the development or discovery of major component defects. These can interrupt the whole plant operating life since component repairs have the potential to become economically unacceptable.

Business risks due to human factors are also to be dealt with, for example, those associated with mismanagement of the plant leading to the failure to meet the owner's financial obligations, which can, in turn, seriously threaten the whole business model. Risks can exist at all project phases, beginning with the procurement phase that may threaten the schedule and with it even the whole financial model. Risks of injury, of industrial accidents, of poor contractor performance during construction and equipment installation phases, of injury and delays during the commissioning phase and ongoing multifaceted safety and production risks in the various activity groups during the operating phase may also arise.

Even the risk of decommissioning a plant that has undergone a major nuclear accident may represent a substantial cost overrun that can overcome any financing model. The risk matrix should be prepared and analysed to understand whether the overall risk is acceptable.

In order to achieve this, suitable methods of quantitative risk assessment can be employed. The foundation of any risk analysis rests on the definition of each risk item, on the correct quantification of uncertainties and on the ranking of all risk items, which together influence the quality of the results and hence the accuracy of the business decisions.

It is a fact that a nuclear power project is capital intensive. If we add to that the high risk factors of a nuclear power project, especially if the investment is in new technology, we end up with a premium on financing that other technologies do not have to face. This premium can be as high as 3% or more compared to conventional plant financing. This may require the use of innovative solutions such as a financing scheme which involves a stepped approach that seeks risk reduction by eliminating barriers such as complex regulatory processes and engineering uncertainties. This can be accomplished by using a design certification process in terms of licensing and by increasing the rate of detail design completion, two steps that reduce both the complexity of the regulatory process by transferring the design licensing burden and the engineering gap on the technology vendor. This increases the NPP value and lowers the capital cost. If the nuclear power development programme includes several units, the capital cost is further reduced once successful construction and operation of the first plant has been demonstrated.

3.9.7. Risk management plans

Risk is inherent to all projects, and project managers should assess risks continually and develop plans to address them as they arise. The risk management plan contains an analysis of likely risks with both high and low impacts, as well as mitigation strategies and corrective action to avoid multiple occurrences and help the project avoid being derailed should common problems arise. Risk management plans should be periodically reviewed by the project team in order to avoid the analysis becoming stale and not reflective of actual potential project risks.

The main elements of a risk management plan should be developed in this section of the FS. The first element is the review of risk items identified in the risk matrix described above, or, if not yet available, a list of credible risks can be produced by reviewing the risks encountered in previous projects. In this case, they will need to be evaluated in light of the conditions specific to this project. Once the risk items are defined, it is important to postulate their occurrence and assess the consequence of each of them independently and of any credible risk combinations. When this is completed, the ranking of risks and their combinations can be determined and assigned a weighting factor [88, 89].

Following this step, it is necessary to foresee the acquisition of barriers and controls if not capable of preventing the occurrence of the event, at least helpful in the mitigation of its consequences. Other than barriers and controls, it is important to postulate the failure of all controls and barriers and provide the capability to respond to the event with a plan to block or mitigate the consequence of the initiating event. In most cases, an assessment of the risk matrix defined above is also included in the risk management plan.

3.10. NATIONAL PARTICIPATION

National participation is an essential element in the development of an NPP project. The extent of such participation will significantly depend on the local infrastructure and on the capabilities and availability of local resources for the supply of materials, services and equipment, and for the recruitment of a qualified workforce [90].

The construction and operation of an NPP requires supporting systems, commodities, human resources and services. The local supply of such assets and services can be a source of jobs and economic growth for the country introducing its first NPP and for the region in which the NPP is located. However, supplying equipment and services to support a nuclear facility requires an industrial infrastructure [90] that can comply with the applicable codes and standards and operate under rigorous quality management programmes. Before agreeing to yield any scope of supply to the domestic industry, the supplier of an NPP, whether on a turnkey basis or not, would require assurance of the capability of the national industry to deliver the quality requirements of a nuclear supply.

While maximizing the utilization of domestic industrial and manufacturing resources is the common aspiration of all newcomer countries, national involvement in NPP development is a gradual growth process that requires a policy and an action plan with sufficient budget favouring the evolution of national capabilities, for example, through technology transfer agreements, in various areas of nuclear technology development (detailed engineering, mechanical and electrical construction, etc.).

It is assumed that before the FS report is prepared, in phase 1 of the programme, the following actions would be performed:

- General survey of national and local industrial capabilities to satisfy the requirements of a nuclear power programme [90];
- Ability to obtain the investment necessary to upgrade and expand the country’s industrial facilities and programmes.

Short term policies are required before the start of a nuclear power project; others are longer term to support gradual growth. They are both important for the success of the nuclear power development programme.

However, policies cannot be left in a vacuum. They should evolve into firm plans and budgets to develop facilities, programmes and skills to achieve the desired level of national involvement. A number of selected activities should be carefully performed before the project is established. They can be carried out as part of the FS itself, or in separate specific studies, and their results included in the FS report. These activities include:

— A detailed national industry survey;
— Establishment of a strategy for national participation;
— A localization plan;
— A technology transfer plan.

Recommendations for each of the items above are included in Sections 3.10.1 and 3.10.4 of this publication. In subsequent phases of the nuclear power development programme, the NPP owner and its consultants may use the information in this section of the FS report as input for the preparation of the BIS. The consultants for these activities could be those who prepared the FS report or, if different, those who performed the evaluation of local capabilities to supply goods and services for the first NPP. Criteria for the selection of consultants are given in Section 2 of this publication.

3.10.1. National industry survey

A realistic assessment of the national and local capabilities to supply commodities, components and services for the construction of a nuclear facility is an essential input to further economic, financial and commercial studies. It can be either included in the FS report or conducted as a separate study, and its conclusion reported in this section of the FS.

An NPP project places special demands on industrial infrastructure, for example:

— Advanced technology, which usually has to be acquired through technology transfer from foreign suppliers, is required.
— Strict quality standards have to be met owing to nuclear safety and reliability requirements;
— Unfamiliar industrial standards have to be applied.
— Some special materials foreign to conventional industry are used.
— Some supplied items are of unique design.
— Equipment and components of unusually large size and weight with handling and transportation challenges, as well as materials entailing safety and security hazards, are necessary.
— Because of the onerous upfront capital and construction costs, schedules must be rigorously complied with, and the project well controlled, coordinated and managed to maintain the project cost within budget.

Consequently, the national industry survey should particularly focus on the following aspects:

— The ability of local suppliers to meet delivery schedules;
— The ability to meet stringent quality requirements or at least the ability to acquire the qualification and capability within the required timetable;
— The availability of a qualified workforce;
— The availability of relevant technology and know-how or at least the ability to fill any technology gaps within the required timetable.

In this survey, financial and economic limitations must be taken into account, namely:

— The availability of funds for expanding factory facilities and machinery in order to allow the acquisition of new technologies;
— The adequacy of the market size to justify the investments required for the items to be produced domestically;
— The total cost of the items to be domestically produced as compared to their cost on the international market.

An important consideration governing the extent of the national participation is the size, duration and continuity of the nuclear power programme, which must have sufficient breadth to be attractive to local industry and justify the necessary investments and efforts to obtain the required special equipment and qualifications and assume the burden of creating a pool of skilled workers.

There are no firm rules regarding the industrial infrastructure requirements of a country starting an NPP project. If the plant is procured in an absolute turnkey fashion entirely from vendors abroad, including procurement, construction, licensing, commissioning, O&M, the industrial infrastructure required is at its lowest possible level. However, even in this case, a minimum number of competent construction and erection firms and some O&M capabilities are still required. Under these conditions, the industrial infrastructure will not have the technology, know-how, quality level and expertise necessary to independently support the NPP programme. In time, these can eventually be developed.

A detailed survey best starts with an assessment of the present engineering and industrial capability, its participation in conventional power projects and in other types of large projects in the country and abroad. In preparation of an NPP project, it would be advisable to increase local participation in conventional projects. This would be a good means to prepare the local engineering and industrial capability for an upgrade to the level required for participation in an NPP project.

If the national industry detailed survey is conducted independently, it should lead to useful conclusions or recommendations that can then be included in the FS report, together with a list of local companies with capabilities to support the first NPP. This list should also indicate the level and type of quality management in these companies. If the capability is lacking in some aspects, additional information should include, as applicable, requirements for eventually upgrading their quality assurance programme, the acquisition of new technology, the installation of additional equipment, and improvements in methods and procedures. Any upgrade generally implies extra financial demands on these organizations. Investments, interests and service charges associated with the consequent development effort must be evaluated on a cost–benefit basis.

Available opportunities may be explored across the full spectrum of the nuclear cycle, namely at the front end, such as uranium conversion, uranium enrichment, fuel fabrication and, of course, localization during the build programmes, as well as during the O&M phases. Opportunities for localization can also be found at the back end, such as in waste management facilities, in spent fuel reprocessing and even in the decommissioning phase.

In the component manufacturing area, opportunities may arise in specific nuclear island areas and in the BOP, for example, for turbine and generator components. In parallel, opportunities can be found in the nuclear fuel cycle, including spent fuel handling and servicing and in radioactive and conventional waste management. Other opportunities may arise in the following specific fields:

— Research studies and engineering for the first NPP site selection;
— Detail engineering of the first NPP (including support for the licensing process);
— Construction and erection;
— Control of manufacturing and construction quality (non-destructive evaluation, etc.);
— Equipment and systems testing;
— Manufacturing of non-safety related components (materials and equipment);
— Manufacturing of certain safety related components, including specific testing facilities.

Local engineering and research companies should also be explored as potential future technical support organizations (TSOs) for the construction, commissioning and operation of the first NPP and for the further implementation of the national nuclear power programme. Based on this investigation, a specific upgrading programme for the candidate TSO could be developed, including training and support, possibly by the NPP vendor.

The results of the national industry survey, if conducted independently, should be input into the FS report in the form, as a minimum, of a list of potential local suppliers of goods and services, their area of competence and any additional support necessary to upgrade their capabilities, if required. This information will be particularly useful in the preparation of the invitation to bid for the NPP vendor verification and selection.

3.10.2. Establishment of the strategy for national participation

As previously mentioned, when an informed decision for the introduction of a nuclear power programme is made (milestone 1), an overall policy for a short and long term localization strategy, aimed at encouraging national participation, must also be developed based on the results of the national industry survey described in Section 3.10.1.

Development of this strategy should take into account the following advantages for the country, if national participation is to be optimized:

- — Limit the necessity for foreign loans for the first NPP;
- — Improve industrial competitiveness and the country's self-sufficiency;
- — Increase local employment;
- — Raise the national engineering capability;
- — Develop the ability to use new technology and acquire know-how;
- — Strengthen the capability to independently train the local workforce.

The following steps should be taken in the development of this strategy:

- — Establish clear goals and objectives (i.e. engineering, construction and equipment installation, manufacturing, commissioning, TSOs, etc.), based on the state of the national industry and of service suppliers.
- — Determine to what degree local industries with their existing know-how can meet the national participation objectives.
- — Identify what new technology and facilities would be required to achieve the envisaged local participation goals and determine the needs for technology transfer.
- — Ensure that the timeframe required to obtain the necessary local capabilities and skills is consistent with the nuclear power programme schedule, always keeping in mind that national participation must never compromise the quality and safety aspects of the plant. An important consideration governing the extent of national participation is the size of the nuclear power programme, which must be sufficiently large to be attractive to the local participants.

The strategic goals and objectives should be realistic in terms of expectations, budgets and schedules, rather than aimed at achieving immediate economic gratification. In assessing the potential candidate businesses for participation in the local suppliers of goods and services programme, attention should be paid to both their weak and strong points, so that efforts may be focused on eliminating weaknesses and on making effective use of their strengths. The assessment of each prospective supplier's manufacturing capabilities is fundamental in optimizing modifications and additions and avoiding errors and wastes. Such an assessment will generate important information regarding the optimization strategy of the national participation programme.

Localization of large component manufacturing in the country usually requires government intervention. In contrast, manufacturing capacity for medium sized components (e.g. pumps, valves, tanks), and for bulk materials and components for heating, ventilation and air conditioning, control and instrumentation, electrics and piping may be developed, even without government intervention. This section should include a summary of the specific national participation strategy for both the first NPP and the broader nuclear power programme, particularly if it has been conducted as a separate study.

3.10.3. Localization plan

The localization plan represents an action plan within the overall national participation strategy described in Section 3.10.2. It can either be included in this section of the FS report, or be part of a separate study and only the conclusions reported in this section.

If local participation is well framed within a realistic plan and is rigorously monitored, it can be a strong positive stimulant to the economy and industry of the country. On the other hand, if it is poorly implemented, it can cause an unbalanced industrial structure, be a considerable waste of money and time, as well as damage the NPP programme. Construction and quality related delays will greatly increase the cost of a project and negatively affect the confidence of the regulatory body and of the public.

The planned domestic industry involvement should be included in the BIS for the first NPP, as it will have to be negotiated with the NPP vendor and/or with the EPC contractor. However, opportunities may still exist for local industry involvement in the non-nuclear safety related areas of the project. Some power cycle portions of the facility or some supporting buildings and structures can be constructed to typical commercial standards. Government or industry can also put in place plans and programmes to increase participation of national and local suppliers in the nuclear power programme as they develop their capabilities.

During the development of a localization plan, the following important aspect should be taken into consideration:

- The required development and quality management upgrades of the potential local supplier and any associated costs.
- The difficulty of transferring technical knowledge of complex equipment to places where manufacturing know-how is not adequate. This transfer can be accomplished through suitable technical assistance or technology transfer agreements from experienced technology suppliers, accompanied by suitable training.
- The cost of providing support to potential domestic suppliers with the basic capability to manufacture a product, but requiring some additional equipment and technical know-how.
- The cost of creating prototypes and the cost of developing industrial capability whenever precision components of nuclear grade must be produced on a repetitive basis.
- The convenience of adopting a standardized design that makes repetitive manufacture possible, thereby progressively cutting cost and time.

After the first NPP project, the localization plan should become an important tool for the NPP owner to:

- Perform periodic analyses of the local industrial growth potential beyond the contribution level to the first NPP;
- Help issue periodically updated reports with information on product groups and local industries that have newly demonstrated their capabilities.

These analyses should be beneficial after the plant has been connected to the grid and put into commercial operation for the recruitment of local contractors to perform maintenance activities or for the award of continuing maintenance agreements.

The information included in the localization plan section of the FS should also be very useful during negotiations with the NPP vendor on the local contractors and subcontractors to be used and on contract provisions defining the level of vendor support and assistance to the proposed local suppliers of goods and services to the NPP.

3.10.4. Technology transfer and goals

One of the most important topics to be considered carefully and addressed clearly in the FS report is the degree of technology transfer, which refers to the development of indigenous capabilities related to NPP O&M, to component and system design, and the manufacturing of equipment and special materials. A smooth and continuous technology transfer from the first NPP vendor to the NPP owner will ensure successful completion of the first NPP construction, good plant performance and facilitate the accommodation of new NPP developments.

Technology transfer is the agreement between the governments of the vendor country and the receiving country, and between the commercial institutions of both parties, to transfer skill, knowledge, technologies, operation procedures and methods. A technology transfer and training programme comprises several steps, and may be agreed upon between:

- Government agencies and organizations;
- An NPP Vendor and NPP owner/operator;
- Technical expert organizations;
- Research institutes (scientific cooperation in energy sectors);
- Universities and technical schools;
- Industries and utilities in the fields of design, construction, component manufacturing, maintenance and operation;
- Architect–engineering firms.

This process ensures that scientific and technological developments are accessible to the users who can then further develop, exploit and operate the technology.

For a newcomer introducing a nuclear power programme for the first time, it is essential to obtain expertise and technology to participate in the construction and operation of NPPs. National policies and the strategy setting goals, objectives and requirements for the technical transfer should be reported in the FS in terms of:

- Technology: Transfer of manufacturing documentation for safety related equipment and materials, qualification procedures and tests (environmental, seismic, etc.);
- Expertise: Training and support of the NPP operation staff and commissioning procedures and methods, and the capability level for the local TSO to develop the final safety analysis report, to perform accident analyses, to support the owner in safeguarding the NPP design and licensing bases, to develop the engineering and verification procedures for future design changes, to set the requirements for the procurement of spare parts, etc.

A good technology transfer programme includes both the expertise and the technology aspects, and should be included in the BIS as a requirement for the first NPP. Technical transfer of expertise also includes training in the use of specific engineering tools (safety codes, custom made codes for NPP O&M and tools for the engineering of design changes and safety verification, etc.). Technical transfer of more advanced aspects of the technology depends usually on the scale of the nuclear power programme (number of units) and on the intent to develop the capability to manufacture safety related equipment and materials.

For most newcomer countries, it is not possible to develop a highly complex technology in a reasonable time using only domestic resources. Acquisition from abroad is the usual method for obtaining a new technology. Where localization is not yet possible, technology transfer is a first step that should be explored. Normally, this requires governmental involvement so as to secure continuity, typically ensured by a bilateral cooperation agreement sealed in conjunction with commercial contracts for the NPP. The contract itself will usually cover technical and managerial cooperation between the NPP purchaser and the NPP vendor.

The NPP owner can develop the technology transfer plan, either in the context of the FS or in a separate study whose conclusions and recommendations should still be included in the FS. After the FS has been approved, the information on localization and technology transfer should be incorporated into the BIS so that it may be negotiated in detail with the selected NPP vendor and included in the commercial contract.

Detailed recommendations for the preparation of the technology transfer plan are included in Section 5 of the IAEA publication Developing Industrial Infrastructures to Support a Programme of Nuclear Power [90].

3.11. ORGANIZATION, HUMAN RESOURCES AND TRAINING

3.11.1. Construction workforce and logistics

This section should include a study to size the required workforce of the owner/operator organization and its evolution in time. To achieve this, it should address influencing factors such as the plant location with respect to population centres and contractor support services, the regulatory requirements for construction and operation, the number of units at a site, the environmental monitoring requirements, the extra effort required to assimilate and implement construction and advanced construction techniques and modularization (see Appendix II) [55] and labour laws and the effort required for public awareness and education [91].

3.11.2. NPP owner organization during construction, commissioning, operation and maintenance

The project management organization of the owner/operator is usually established at the start of the preparatory phase, and the contractor’s organization is formally established after the ATP or the award of the contract. In the case of turnkey contracts, the main responsibility is delegated to the main contractor. Figure 2 shows a typical organizational structure for the project management team of the owner/operator. The evolution of the workforce in time during the various phases of pre-construction, construction, commissioning and operations should be evaluated, beginning with the civil infrastructure at the proposed project site. Depending on the type

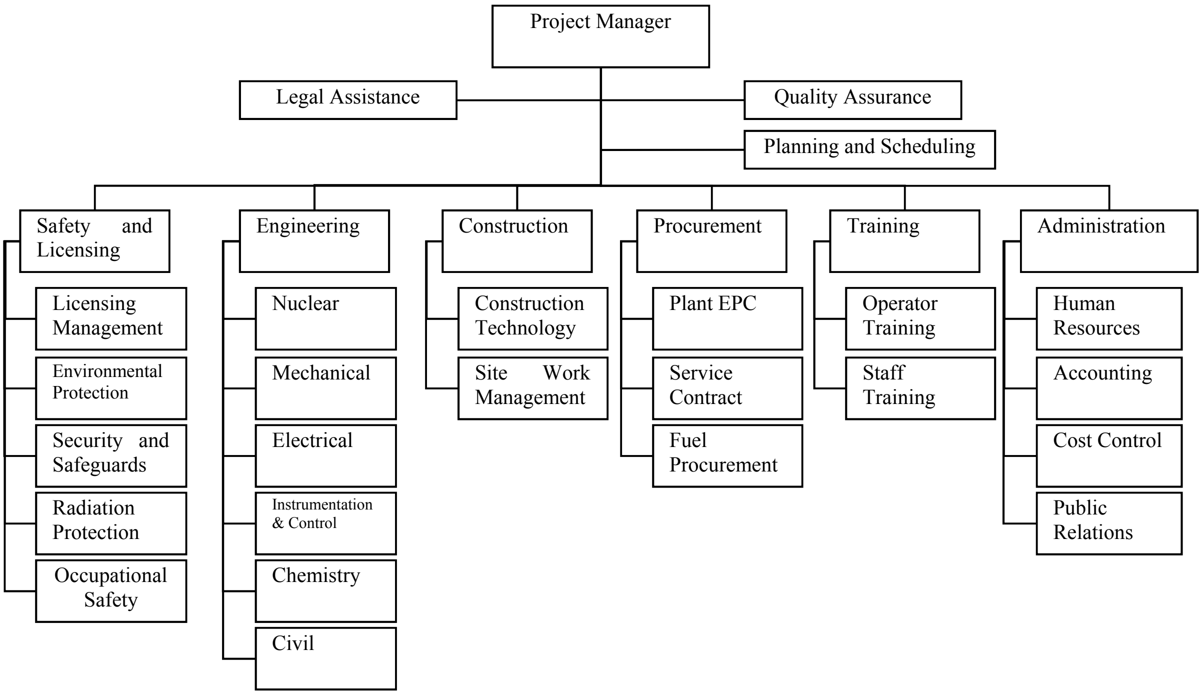

FIG. 2. Sample of a project management team organizational chart of the owner/operator. EPC: engineering, procurement and construction.

of contract (turnkey, split package, multicontract), the workforce requirements for the owner/operator would change [92, 93].

In a turnkey contract, especially for the first nuclear power project, all engineering and construction activities are usually delegated, and the owner/operator remains responsible for the preparation and management of the contracts, for the preparation, review, planning and implementation of the schedule, for interfacing with the regulators, for obtaining the construction and operating licence, and for the management of communications with the public, local authorities and project stakeholders. During construction, if the owner/operator retains the overall site management responsibility, its site staff may be larger than that of the main civil contractor because it must carry out the responsibilities of both the supervising owner (quality functions) and the leading constructor. Its supervising functions should extend to engineering, procurement, construction, manufacturing and installation quality.

3.11.3. Staffing requirements

An effective workforce plan for the owner/operator should cover both the organization and the human resources required to support the operation of the plant at the national level. Once the numbers and qualifications are known, the next and most important element of the plan is the good management of the competency and knowledge of the workforce to carry out its mandate without compromises in quality and efficiency. In addition, the staff should naturally augment their experience by acquiring on the job knowledge. At the same time, their competence requirements may change through the different phases of the life cycle.

For newcomer countries and countries expanding their nuclear fleets, even before the bid specification is issued, the owner/operator should know the training requirement expected of its local staff [92].

Using the IAEA categorization of a nuclear power project into phases and milestones [2], it is essential that the staff required for phase 2 be hired during phase 1 and be given the opportunity to develop their competence during phase 1; similarly, the staff required for phase 3 should be recruited and trained progressively during phase 2.

During phase 1 of a nuclear power development programme, the NEPIO is likely to be the entity responsible for the development and management of the workforce plan. It is important in this case that its members or the members of its advisory group be well aware of the programme workflow to be able to determine the resources and competencies required. At the beginning, the staff involved should be small in number. The local staff may have to be drawn mostly from specific government departments to develop recommendations on national policies, while an external expert advisory group would normally look after specialized detailed analysis work. As stated earlier, Ref. [2] deals in more detail with the NEPIO's responsibilities.

At the onset of phase 2, the regulatory body and the owner/operating organization should be established, if not already in place, and the NEPIO will peak (typically a maximum of 40–50 staff) during this phase before gradually handing over its responsibilities to the aforementioned permanent organizations by the end of phase 2. Some of its oversight responsibilities and resources may very well be transferred to other organizations, especially to the regulatory body and the operating organization, and, depending on their experience, even to senior positions.

During this phase, the owner/operating organization should appoint the core project team; in quick succession, the core team should recruit operations staff with long training lead times. In parallel, the regulatory body should build up its licensing staff. Staffing in the regulatory body should also increase during this phase and continue well into phase 3. To prepare and issue safety regulations, safety guides and industry codes, to develop and implement review and authorization processes and assess designs and design changes, and inspect vendors and manufacturing facilities, a regulatory body would typically require 40–60 competent people initially, in the areas of legislation and regulations, technical disciplines, regulatory experience, and personal and interpersonal skills.

The operating organization staff required during phase 2 is about 25–40 for the preparation of the bid specification and long lead training. In other areas, the operating organization will require skilled staff, either to manage and review the work done by consultants or to carry it out themselves, such as in the areas of the BIS, the EIA report, safeguards, security, physical protection, nuclear fuel cycles and radioactive waste. At this time, it will also have to define the management system, the safety culture, the communication strategy and the emergency planning and prepare procedures.

By the start of phase 3, the NEPIO should largely hand over its mandate or, if the programme includes more than one unit, it may continue to oversee the broader programme. As the NEPIO's mandate is completed, most of its staff would either return to the government departments from which they came, but with new responsibilities (possibly in the area of nuclear activity oversight), or else move to other stakeholder organizations within the nuclear power development programme.

The regulatory body would have to work on the licensing of the site and the plant design, and overseeing manufacturing and construction. The operating organization would recruit and manage the training of its permanent operators.

The operating organization should consolidate its project team that may have been initially established by the NEPIO to oversee, on behalf of the owner, the other project teams established by the vendor, the contractors, the suppliers and the actual construction of the NPP. The staff requirement is much larger than for the other organizations: 500–1000 for one unit and several thousand for multiunit plants. They also require much larger training programmes that can last several years. Training of the staff used for commissioning would naturally have to be accelerated and completed before the turnover from construction to commissioning. More than for any other group, their training may have to be conducted in a hands-on manner in reference plants abroad [56]. The actual numbers will vary depending on the specific technology, the level of automation, maintenance, layout, national laws and regulations, regulatory requirements and level of interfacing. Numbers could be quoted and compared, but each country must analyse its own situation and requirements by preparing a detailed workforce plan.

The initial operating organization can be staffed by vendor trained local staff with vendor expert supervision, or by turnkey contractor staff, by local staff from other plants and local trainees, or by a mixture of experienced and newly trained staff in strategic positions. These models usually include a gradual handover schedule.

In the operating phase, specialist support will be required, including R&D to cover typical operations tasks, e.g. routine and periodic maintenance, in-service inspections, non-destructive testing, replacement of aged components, upgrading and uprating of the plant, and life extension preparatory work.

The resource profile for all project phases is typically in the shape of an 'S' curve at various inclinations, depending on how aggressive the programme is. From an education and qualification viewpoint, in phase 1, the core staff is principally at the university graduate level, while during staffing for the construction and operating organizations, the majority of the workforce is at the technician/technologist level or high school or vocational/apprentice status. In terms of qualification, during construction, the requirement is for less nuclear radiation knowledge, and more attention should be dispensed to quality and safety.

Recruitment sources can be:

— Former expatriate nationals with specific nuclear experience;
— Non-nationals with nuclear experience (working, but also coaching or mentoring);
— Research reactor staff (if applicable);
— Nationals from other appropriate industrial fields, who may not have specific nuclear experience, but who are from various relevant industrial fields and nevertheless possess many of the skills also required in the nuclear field.

In the decommissioning phase, the owner/operator will have to decide the extent of the national involvement in order to plan recruitment and training on time and to effectively manage the work and prepare tender requirements for external specialized contractors, as appropriate.

3.11.4. Education and training requirements

An important element to address is the availability of human resources, the long term sustainability of a skilled workforce, and the retraining of workers from other industries. The adaptability of technical faculties in universities should be investigated. It should be determined whether they can incorporate sufficient formation programmes in nuclear power science or in management and production technology to support the nuclear power project, and determine if synergies can be exploited, such as building specific courses around their existing general energy or physics programmes that would require only limited remedial actions.

The duration of training programmes may range from a few weeks of familiarization for already trained personnel, who will continue to be employed in their specialized field, to several years for a plant operator, a reactor engineer or a trainer in radiological safety radiology who may have had no previously relevant work experience.

Other than nuclear science and technologies, the training programmes should include environmental protection, radiation safety and health physics, handling of radiological and hazardous materials, nuclear and industrial waste, legal and regulatory requirements, safety culture and questioning attitudes, event reporting relevant to safety and quality, industrial safety and specialized labour skills. In all organizations (including contractors), an appropriate systematic approach to training (SAT) model should be applied to ensure that the training provided will actually support development of the necessary competencies.

The resources and facilities required for the training itself and the deployment of nuclear expertise will have to be sized to match the scope of the course, activities and training requirements. For countries either embarking on nuclear power for the first time or expanding their programmes, special attention should be given to the possibility of recruitment, either from conventional industries or directly from educational institutions.

In phase 1, resourcing and training requirements may be initially limited (20–30 people), mostly from within the NEPIO, in areas such as legal, regulatory, commercial, policy consulting, electricity market and generation assessment, fuel cycle assessment, nuclear technology, environmental assessment, sector economics and technology localization assessment. The long term planning of training, education, licensing and qualification in special skills is particularly challenging, especially if key competencies are not available in the country. One recruiting and training model that has been successfully implemented is based on the combined approach of importing international expertise to work side by side with local staff and of simultaneously placing national staff in an operating plant abroad to gain more specialized hands-on experience in an advanced environment.

External expertise can be used, either by awarding turnkey work contracts to experienced consulting organizations with clauses reserving the obligation to accept and train national recruits in work package delivery, or using the managed work concept, in which experienced consultants or consulting teams are incorporated into the local organizations, working side by side with local staff.

When national recruits are sent abroad to build competencies, it is usually carried out through bilateral agreements with governments, regulatory agencies, vendors or other utilities. Training could take the form of first principle, basic training in educational institutions in formal courses and at different levels such as vocational, undergraduate and postgraduate programmes. Relevant international organizations such as the IAEA provide training courses, fellowships and internships. For example, the INPRO methodology may be a useful tool to explore issues of long term sustainability [13]. Another effective method to train large numbers of staff would be to enter into strategic joint ventures or cooperation agreements with vendors or equipment suppliers, in which national organizations acquire licences to design and/or manufacture components in-house, which normally includes staff training, specialized qualifications and sometimes staff swapping to profit both sides. For more information on workforce planning and training, consult Ref. [91].

3.11.5. Project cost estimation

For the purpose of considering lifetime project costs in a systematic and comprehensive way, it is useful to work within the framework provided by the IAEA's account system for NPPs [85]. As shown in Fig. 3, this system breaks down such costs into three current cost components, and a fourth component which is waste management costs treated as deposited funds. The current cost components are:

- Total capital investment costs (TCICs) (accounts 21–72);
- Nuclear fuel cycle costs (accounts 100–171);
- O&M costs (accounts 800–890).

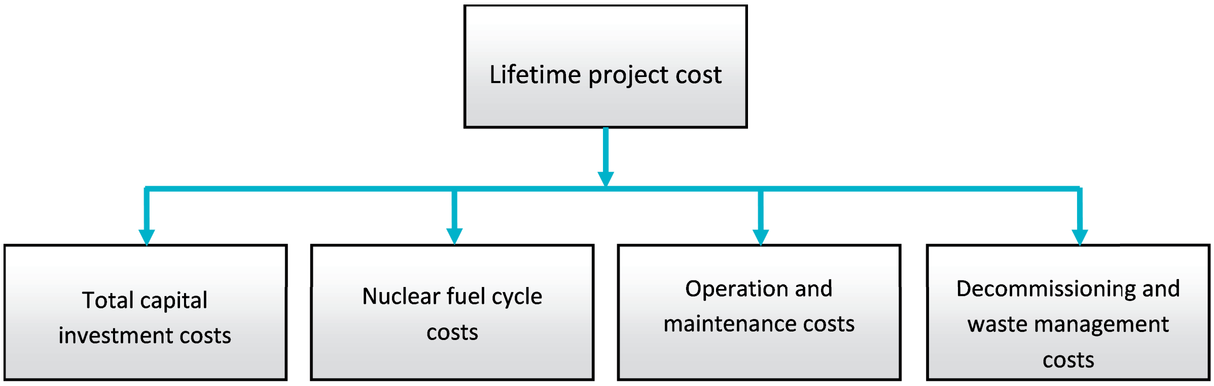

FIG. 3. Lifetime project cost breakdown.

As will be discussed below, decommissioning and waste management costs are to be included within the lifetime project cost. The remainder of Section 3.11 will discuss each of these cost types and will take a 'deeper dive' into some important subcomponents.

3.11.6. Total capital investment costs

The TCICs are the costs of acquiring and building an NPP and bringing it to commercial operation. These costs make up about three quarters of the total cost of generating electricity from nuclear power. The TCICs can be broken down into two broad categories: overnight costs (OCs) — the cost of building an NPP if it were to be literally constructed 'overnight' (no financing and no escalation) — and financial costs. This breakdown is important, as failure to distinguish between estimates that include financial costs versus those excluding them can lead to confusion in the comparison of published capital cost figures.

Within the IAEA account system, OCs comprise accounts 21–54 and 70 [85]. The OC concept is a useful one in that it abstracts from the reality that the construction of an NPP will typically stretch over a number of years during which the price of equipment, labour and materials may very well escalate, and during which interest charges on borrowing undertaken to finance construction will be incurred. A cost estimate that does not make such an abstraction will, by definition, embed forecasts of escalation, construction duration, expenditure profiles and possibly interest rate variation. Since these variations are likely to differ between projects, cost estimates that include them will make it difficult to compare project costs in a useful manner. In contrast, insofar as OC estimates differ between projects, it is likely that such differences reflect accurate differences in variances such as labour costs at different sites, material requirements for the construction of different types of plant, etc.

It should be noted that decommissioning costs may be included under the OC heading (as account 54), although they may alternatively be included in O&M costs (as account 870).

Reported overnight investment costs vary widely, even when presented on a 'per kW(e)' basis. It is likely that these differences are largely due to 'real' factors, in the sense of reflecting differences in local market conditions and technology choices. At the same time, there are factors that are largely 'apparent' in the sense of reflecting differences in accounting approaches and/or deviations in exchange rate values from appropriate 'purchasing power parity' levels.

Furthermore, there is limited data on actual recent costs of building nuclear power stations available. Moreover, construction cost data supplied by vendors may be optimistic, especially ahead of contractual commitments, if not subject to independent evaluation. In this context, it is desirable to maintain good relations with vendors, and it would be prudent of States engaged in nuclear power FSs to undertake or commission their own independent assessments of OCs within the context of their proposed NPP project.

Such assessments could be based on either a top down or a bottom up cost estimation approach. The former approach relies on the application of escalation indices and engineering scaling factors to a 'reference plant' — a plant that is technologically similar to the proposed NPP, but which was constructed in a different time and place (and thus under different market conditions), even though the reference plant may differ in some significant aspects (typically, size). Escalation indices and engineering scaling factors would be designed to adjust for differences in relevant market conditions and plant size, respectively. A bottom up approach to estimating potential NPP costs would rely more heavily on decomposition of a plant into its major components. Some of these components (e.g. turbine generators) may be more transparently priced than others, but with expert advice, it may be possible to gain some understanding of the overall costs of the complete NPP 'package' using this approach.

The financial cost component of TCICs can be broken down into escalation costs (account 60), interest during construction (IDC) (account 61) and fees (account 62). Note that decommissioning costs are included (as account 54) if not included as part of O&M costs (account 870).[1]

Escalation costs result from changes in the price of commodities, wage rates, etc. In arriving at an estimate of TCICs for a potential NPP project, these must be projected or forecast — a challenging task. Similarly, IDC — which comprises the accumulated money disbursed to pay off interest on the capital invested in the plant during construction — must be forecast in the preparation of any cost estimate prepared for the purposes of evaluating project feasibility from an economic perspective. Both escalation costs and IDC will depend, to a large degree, on the duration of construction. As far as escalation costs are concerned, the longer the expected duration of construction, the more uncertainty there will be around projected changes in relevant costs. As far as IDC is concerned, the cost of carrying given debt loads for a longer time results in an unambiguous relationship between construction duration and IDC: the longer it takes to build an NPP, the higher the resultant IDC.

3.11.7. Costing a new build

Nuclear power has a historical tendency to push costs up. Newcomers should be mindful of the fact that national regulations change significantly from one country to another, and that change is opposite to standardization, which is a primary cost abatement measure. National licensing deviations from the rules valid in the vendor country may also bear a price tag. It is also important to be mindful of the fact that licensing is not a static set of rules; the rules tend to evolve, and, more often than not, they tend to drive costs up. Another issue is the first of a kind risk that newcomer countries to nuclear power tend to underestimate. Without a reference plant, the risk of cost escalations as construction proceeds may be staggering. The reality in the field seems to be inevitably breaking the best cost predictions, even in countries that otherwise succeed in keeping repeat projects on time and on budget. This tendency makes nuclear power obviously more subject to giving way to competing energy sources that are becoming greener and driving down their fuel costs. They are succeeding in arriving at a lower levelized cost of energy, which now competes with the levelized cost of nuclear power considering the operating cost of fuel and maintenance added to the cost of financing the large initial capital of nuclear power and its infrastructure.

For a new build in a newcomer country, the least risky scenario in costing the plant is that of selecting a repeat plant. In this case, the cost of the new build can start from the detailed cost of the reference plant that, given its

[1] A 2003 survey based OECD/NEA study [72, 73] suggested that "decommissioning costs of PWRs vary…around 200 to 500 [July 2001] USD/kWe, if the extremes (3 out of 22 data sets reported) are excluded".

accuracy (assuming it is known, which may not be the case given the commercial sensitivities involved), becomes a low risk base element. To this cost, the estimators will have to add the cost of the inevitable detail design changes necessary to adapt the reference design to the new site conditions and the cost of any new licensing conditions. In addition, any profit margins and price escalations of the equipment, construction and incidentals will have to be taken into account.

3.11.8. Nuclear fuel cycle costs

There are two main types of reactor fuel: uranium oxide (UOX) and MOX fuels. UOX fuel is the output of the so called once through fuel cycle whereby spent fuel is stored pending ultimate disposal following its removal from the reactor core. MOX fuel results from reprocessing, whereby fissile plutonium and residual uranium are recovered from the spent fuel after its removal from the reactor core, and can be used to fabricate fresh fuel.

The IAEA account system fuel cycle costs comprise accounts 100–171 [85], and cover the major drivers of fuel costs for both of these once through and reprocessing fuel cycles, including uranium supply, conversion, enrichment and fuel assembly fabrication. Accounts are also defined for the costs of final disposal of the spent fuel in the case where no reprocessing takes place, as well as for the costs of final disposal of radioactive waste from reprocessing.[2]

In estimating the fuel costs likely to arise over the lifetime of an NPP for the purposes of economic evaluation during an FS, it will be necessary to make an assumption as to which of these two fuel cycles will be employed [60]. Another study [84] suggests that fuel cycle costs may be around 20% higher than the once through estimate of $8.28/MW·h, if reprocessing is adopted.

3.11.9. Operation and maintenance costs

Accounts 800–890 [85] cover costs such as wages and salaries for engineering and technical support staff, and for O&M and administration staff, as well as costs of consumables, materials, operating equipment and purchased services. Decommissioning costs are included (as account 870) if not included as part of the TCICs (account 54). Account 880 comprises the costs incurred in the management and disposal of low and medium ('intermediate') level radioactive operating waste.[3]

A 1995 US study [7] quoted analysis suggesting that roughly two thirds of O&M costs were labour related. Work presented by the OECD/IEA and the Nuclear Energy Agency (NEA) in 2011 [94] shows, once again, a considerable variation in estimated O&M costs.

3.12. ECONOMIC ANALYSIS

Economic analysis is a systematic analysis approach to determine the optimal allocation of resources. It involves the comparison of two or more alternatives in achieving a specific objective under a given set of assumptions and constraints. Economic analysis should take into account the opportunity costs of the resources employed and attempt to measure, in monetary terms, the private and social costs and benefits of a project to a society or an economy.

Economic analysis compares project economic costs with project economic benefits; in other words, it performs what has come to be known as CBA. The analysis should evaluate the economic feasibility of the NPP project and compare its economics to other (mutually exclusive) alternatives. Costs and benefits should be accounted for as fully as possible, allowing estimation of the net economic benefit associated with the nuclear plant relative to the alternative case where new investment in electricity generation will flow to its alternatives.

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[2] The cost of the Finnish repository for the disposal of spent fuel from five NPPs has been estimated at €2542 million (December 2003 prices). See Ref. [69] for further details.

[3] A recent OECD study suggests a 1000 MW(e) NPP produces roughly 500 m^3 of low and intermediate level waste per annum, of which around 100 m^3 could be intermediate level waste. Estimated life cycle costs for low level waste (including processing, storage and disposal) are a minimum of $4000/$m^3$. Estimated life cycle costs for intermediate level waste are a minimum of $45 000/$m^3$. It should be noted, however, that some estimates suggest considerably higher life cycle costs.

The methodology of comparing costs and benefits is the same for either an economic or a financial measurement of the project worth, but the definitions of costs and benefits are distinctly different. The key point of the economic feasibility analysis is that it is performed from the point of view of society, i.e. it appraises the project contribution to the economic welfare of the region or the country, while the financial feasibility analysis is made on behalf of the sponsor of the plant, and evaluates the ability of the project to provide debt service from the capital required to construct and operate the project.

These are complicated analytical activities that require specialized skills that may not be available internally. Consequently, it may be necessary to hire external consultants to estimate the private and social costs and benefits of a project to a society or an economy.

The main objective of the economic analysis is to help create and select projects that will contribute to the welfare of a society. The tools of economic analysis can help answer various questions about the project's impact on the entity undertaking the project, on society and on various stakeholders, and about the project's risks and sustainability. The economic analysis provides solutions and recommendations regarding:

(a) Project objectives:
  (i) The objective(s) of the project must be clearly defined. A clear definition of the objective(s) will help reduce the number of alternatives considered, and aid in selecting the appropriate analysis tools and performance indicators. A set of feasible alternatives has to be defined based on the project objectives.
  (ii) The relationship of the project to the broader development objectives of the sector and of the country is an integral part of the economic justification for the project, and analysts should always ascertain that the project fits with the broader country and sector strategies.
  (iii) In terms of the FS of an NPP, the main objective is not the construction of a plant per se, but other outcomes such as a stable and reliable supply of electricity at predictable production costs, reduction of adverse environmental impacts, supply diversification, etc.
(b) Project outcome and alternative outcomes:
  (i) Economic consequences for the owner if the project under consideration is not implemented;
  (ii) Economic consequences for the country if the nuclear power project is not implemented.
(c) The optimal solution to meet the specified objectives:
  (i) Costs and benefits of alternative solutions achieving the same objectives must be examined and estimated.
  (ii) Alternatives could involve different technologies, technical specifications, policy or institutional settings, locations, beneficiaries, financial arrangements, or differences in the scale or timing of the project. Comparison of alternatives will indicate the best path for fulfilment of economic objectives.
(d) Those benefitting from and those bearing the costs of the project:
  (i) Generally, a good project contributes to overall society welfare, but still not everyone benefits, and some parties may even lose out (groups that benefit from a project are not necessarily those that incur the costs of the project).
  (ii) Identifying those who will gain, those who will pay a cost, and those who will face adverse impacts gives the analyst insight into the incentives that various stakeholders will have to obtain, if the project is implemented as designed.
(e) Impact of the project on the fiscal situation:
  (i) Fiscal policy is important for the macroeconomic stability of a country, and the associated impact of the project should always be analysed.
  (ii) In economic analysis, taxes that are part of the total project benefits are remitted to the government, which acts on behalf of society as a whole, and therefore prices of inputs and outputs to be considered for CBA should be net of value added tax and other direct and indirect taxes; this is because taxes are not treated as costs since they are theoretically benefits to society. Conversely, government subsidies to the project are costs to society. In financial analysis, such adjustments are not to be made — taxes are treated as costs and subsidies as a return.
  (iii) How and to what extent will the costs of the project be recovered from final users? What changes in public expenditures and revenues will be attributable to the project? What will be the net effect for the central government and for local governments?

(f) Financial sustainability of the project:
   (i) The financing of a project is often critical for its sustainability. The cash flow profile is often as important as the overall benefits. For these reasons, it is important to know how the project is to be financed and who will provide the funds and on what terms.
(g) Environmental impact of the project:
   (i) There are important differences between the public sector and the private sector points of view concerning costs (or benefits) to society attributable to the project, but not reflected in its cash flows. When these costs and benefits can be measured in monetary terms, they should be integrated into the economic analysis.
(h) Evaluation of whether the project is worthwhile:
   (i) Costs and benefits should be quantified whenever reasonable estimates can be made. It is not always feasible to quantify all benefits and costs, and sometimes various approximations must be used.
   (ii) It is important to take into account all costs and benefits and to make appropriate comparisons of money flows appearing at different times.
(i) Project risks:
   (i) Economic analysis of the project is necessarily based on uncertain future events and involves implicit or explicit risk judgements. The basic elements in the costs and benefit streams are seldom represented by a single value, but more often by a range of values that have different likelihoods of occurrence.
   (ii) It is desirable to take into consideration the range of possible variations in the values of the basic elements and clearly reflect their influence on the project outcomes. Economic analysis should identify the critical variables that determine the outcome of the project.
(j) Evaluation of environmental externalities:
   (i) Consideration of the environmental impact (positives and negatives) leading to social benefits and to social costs is an essential part of the economic analysis of power plants, but they are not to be considered in the financial analysis as they do not generate actual expenditures or income.
(k) Conversion of market prices into accounting prices:
   (i) In financial analysis, market prices, which take into account taxes and subsidies, are normally used. In economic analysis, some market prices may be changed so that they more accurately reflect social or economic values. These adjusted prices are called 'shadow' or 'accounting' prices. In both financial and economic analysis, projected prices are also used, in which case, both make use, to a substantial extent, of hypothetical price components [95].

The main steps in the economic feasibility analysis of a power plant are:

— Establishing the project's economic lifetime.
— Choosing a reference point for computing the present worth (a convenient point is the time when the project comes into operation).
— Determining the appropriate escalation rates if variables such as energy prices or construction costs are escalated at a rate different to the general inflation rate, assembling for the project and its competing alternatives the unescalated annual cost streams, by year, for the economic life of the project. This includes the capital costs by year, O&M costs, replacement costs, quantified non-monetary (externality) and other costs.
— Assembling the unescalated yearly benefit streams for the life of the project. This includes the value of power generation, quantified non-monetary benefits and other benefits.
— Escalating costs and benefits as determined above.
— Establishing the appropriate social discount rate.
— Calculating the chosen economic performance indicators.
— Performing sensitivity and risk analyses.
— Evaluating the economic feasibility of the project and determining if the project is favourable with respect to alternative generation options based on analysis results.

The comparison is properly made using a common value base. The use of monetary units of constant value throughout the study is highly recommended to avoid the disturbing influence of different and varying rates of inflation, which otherwise would have to be estimated and then compensated for.

The timeframe commonly used for CBA begins the first year of the power plant operation and extends through its economic life. It is normal practice that costs and benefits be stated in the constant value terms existing at the time of the FS completion (e.g. stated in constant dollar values of the study year). A more detailed treatment of the subject can be found in Vol. 2 of Ref. [13].

3.12.1. Some important issues in economic analysis

Some issues and typical problems in economic analysis should be faced and resolved in the economic section of the FS, as discussed below.

3.12.1.1. Monetary value of benefits

As markets are never perfect in the real world, actual market prices used in financial analysis may fail to reflect the social value of inputs and outputs in the economic CBA. This may be the case when some prices are regulated by the government so as to compensate for perceived market failures in ways that are consistent with their own policy objectives. This can occur when indirect taxation is used to correct externalities, when a monopoly regime or trade barriers exist, or because of some other legal constraints or market imperfections (e.g. tariffs for inputs such as energy or fuel). Whenever some inputs are affected by strong price distortions, this may be considered in the project appraisal, and, through the use of appropriate conversion factors, a transformation of market prices into accounting prices that may better reflect the social opportunity of the resources should be carried out.

International practice has assumed standardized factors for some input and output classes; others require specific factors to be defined case by case. Nevertheless, there are often good economic arguments for using border prices or marginal costs, or both, as accounting prices, when actual prices are deemed to diverge widely from social opportunity costs. In the case of power projects, benefits are quantified as the revenue from the sale of energy at appropriate accounting prices, which should be determined while accounting for the possible distortions that may exist in the power market.

3.12.1.2. Discounting

The discount rate in the economic analysis of investment projects — the social discount rate — attempts to reflect the social view on how future benefits and cost should be valued against present ones. It may differ from the financial discount rate when the capital market is imperfect (which is always the case in reality). Theoretical literature and international practices show a wide range of approaches in interpreting and choosing the value of the social discount rate to be adopted. The discount rate of 10% adopted by the World Bank and, more recently, by the European Bank for Reconstruction and Development, can be considered as an upper bound. Usually, national governments set the social discount rate for public projects at a lower level than international financial institutions.

The use of a low discount rate is sometimes justified for the estimation of the environmental net benefit of the project by the fact that environmental impacts produce negative effects in the long term. Some people argue in favour of a zero discount rate because of ethical considerations for future generations. In any case, where strong environmental impacts occur, a low discount rate (approx. 3–5%) should be selected in order to include some ethical principles such as the precautionary principle.

Since there is no completely satisfactory way of computing the social discount rate on the basis of general economic data and objectives, its estimation always contains an element of arbitrariness. To compensate for this arbitrariness, ranges can be defined and sensitivity analysis applied.

3.12.1.3. Environmental externalities

The objective of this phase is to evaluate external costs or benefits from environmental impacts on society that are not considered in the financial analysis, and therefore not reflected in its direct cash flows. These might include air pollution impacts on the mortality and morbidity of people, impacts on plants, building materials and biodiversity [72], acoustic and visual pollution, decreased value of land and real estate in the impact zone, etc. The presence of externalities has been one of the major sources of divergence between the private and social benefits of projects. In the context of project analysis, the environmental impact should be properly described and appraised, possibly with recourse to state of the art evaluation methods. For a summary of the relevant literature, and more detailed discussion on methodologies for the monetization of environmental impacts, see Externalities of Energy, Methodology 2005 Update by the European Commission.

IAEA's computer tool SIMPACTS, which has been developed with the primary goal of helping developing countries appraise the external costs of electricity generation, can be helpful in this phase. As a general rule, in addition to its financial costs, any social costs or benefits other than compensation flowing from the project to third parties that can be identified, quantified and given a realistic monetary value should be accounted for in CBA. If this is difficult or impossible to do, these costs and benefits should be taken into account and described at least in physical terms for a qualitative appraisal, in order to give the decision maker more material to facilitate an informed decision. Inclusion of the environmental costs and benefits in the CBA of a nuclear project will likely have a beneficial impact on its appraisal because substantial air pollutants and carbon emission reductions can be gained from adding nuclear energy rather than fossil fuel alternatives.

Other externalities may include:

— The value attributed to a greater or lesser dependence on imported energy, the evaluation of which can be conducted by applying appropriate shadow prices (if there are distortions to energy markets due to duties, internal taxes, prices levied, etc.) to the substituted energy from abroad;
— Estimates of the security of supply benefits of adding new nuclear capacity, which can be modelled as reduced costs of insuring against fuel supply interruption (e.g. costs of adding extra gas storage capacity that would otherwise be added in a scenario where investment flows to gas fired plants rather than nuclear generation).

3.12.2. Project performance indicators

3.12.2.1. Net present value

The net present value (NPV) of a project is defined as the difference between the present value of all project related benefits and the present value of all project related costs.

This is a very concise performance indicator of an investment project. An NPV that is greater than zero indicates that the project generates a net benefit and is generally desirable. It is also useful for ranking mutually exclusive projects since the discounted values of alternative cash flows will show immediately which is the more favourable. However, project appraisal generally looks for an index of economic merit rather than for a numerical difference of costs; a variation of the comparison method, the cost–benefit ratio, is therefore more commonly adopted.

3.12.2.2. Benefit–cost ratio

The ratio of the present value of the lifetime benefit stream to that of the lifetime cost stream is computed. Benefits must exceed costs, i.e. the ratio (present value [benefits]) / (present value [costs]) must be greater than unity by an acceptable margin for the project to be judged economically viable. The method is straightforward and simple — it is a pure number that is independent of the size of the investment. It does not allow conclusions of any economic significance, other than the simple fact that benefits exceed costs by a given percentage.

In that respect, a more useful index of economic merit is the net return on the total capital investment in a given project, defined as the ratio of net benefits to capital investments. It avoids the danger of offsetting costs by spuriously inserting benefit items directly into the cost stream. It allows a comparison of the result, including the opportunity cost of capital and a clear demonstration of the merit of the project in terms of the yield on capital.

3.12.2.3. Internal rate of return

This method overcomes the disadvantage of using relatively arbitrary selected discount rates that may not be appropriate if economic conditions should change. The internal rate of return (IRR), also termed economic rate of return, denotes the discount rate at which the present value of the two cash flows — costs and benefits — are equal, i.e. the net cost of the project is zero.This rate shows the return to be expected on the project that has the highest initial investment costs (generally, in the nuclear versus fossil fuel plant comparison, it is the nuclear based scheme). Under a specific IRR value, the investment should be considered not suitable. The IRR method is transparent, facilitates the inclusion of quantified non-technical features, and can be compared directly with other economic indicators that are helpful for decision making.

3.12.2.4. Levelized unit electricity cost

The economic feasibility analysis of a power project is not complete until the production cost of the energy has been determined and compared to the competing alternative sources. Different power generation technologies have specific characteristics that may vary considerably from one technology to another. Such characteristics, together with construction time, electrical output, project operating life, capital investment, fuel source (price and price volatility), operating costs and maintenance costs, all influence the cost structure of the projects. The levelized cost methodology is a standard methodology that allows the performance of such a comparison.

The amount of energy produced by the plant and its time related operational cost will generally vary from year to year; therefore, the present worth values of annual streams of costs and energy output are employed in the cost evaluation. The calculation can, in principle, be performed either in current monetary terms, with nominal cost escalation and a nominal discount rate, or in constant monetary terms, employing a 'real' (i.e. net of inflation) cost escalation and a 'real' discount rate. Utilities prefer to use current monetary terms to estimate costs as closely as possible to the actual values, inter alia, since tariff rates are based on cash flow requirements. For the purpose of common comparison, the discounting method in constant monetary terms is recommended.

The total plant costs factored into the levelized cost calculation include capital investment, O&M, fuel cycles, waste management, meeting emission regulations (including, possibly, the cost of carbon) and decommissioning. The detailed components of electricity generation costs were discussed in Section 3.11. As the expenditures of a certain cost category (e.g. O&M costs) are uniformly distributed over each year, it can be assumed that they occur mid-year.

The levelized cost can be viewed as the rate that must be charged to each kW·h of electric energy to recover precisely the present value of the total plant costs. The levelized unit electricity cost (LUEC) does not depend on the discounting date. It should be noted that this unit cost is not an average figure. The discounting process tends to weight the results in favour of the earlier part of the time period in question, and consequently in a nuclear fossil fuel plant comparison, the longer periods over which favourable production costs are experienced in the nuclear case tend to be adequately valued.

3.12.3. Sensitivity and risk analyses

Uncertainty and risk are important points to be considered when appraising investment projects. The uncertainty of the forecast carried out in the CBA stems from uncertainty surrounding the variables and parameters entering into the CBA. An outcome unfavourable for the project sponsor is possible. The risk should be analysed to the extent feasible. The recommended procedure is based on:

- A first step, where a sensitivity analysis should determine the impact that assumed changes in the variables determining costs and benefits are seen to have on the financial and economic indices calculated (NPV, IRR or the LUEC);
- A second step involving the study of probability distributions of selected variables and the calculation of the expected value of the project performance indicators.

Discussions on sensitivity, risk and scenarios used in the analysis of risks associated with the project are given below.

3.12.3.1. Sensitivity analysis

Sensitivity analysis and switching values have been traditional tools of risk analysis in the appraisal of investment projects. Sensitivity analysis may be defined as the investigation of the impact on decision criteria (performance indices: NPV, IRR or LUEC) of variations in the important project variables and parameters taken one at a time. Its main step consists of the selection of the 'critical' variables and parameters of the model, that is, those whose variations, positive or negative, with respect to the value used as the best estimate in the base case, have the greatest effect on the performance indices (NPV, IRR or LUEC).

The switching values analysis determines the percentage by which a variable must depart from its posted value in order for the net benefits of the project to disappear. The criteria to be adopted for the choice of the critical variables vary according to the specific project, and must be accurately evaluated on a case by case basis. The sensitivity analysis may include investment costs, discount rates, sale price for electricity produced, cost of fuels, valuation of externalities, etc. Both sensitivity and switching values analysis have two major limitations: they take neither probabilities nor correlations into account. The usual technique of varying one variable at a time is justified only if the variable is uncorrelated with all the other project variables, which most often is not the case.

3.12.3.2. Risk analysis

Risk analysis evaluates the probability that a project will (or will not) achieve a satisfying performance (in terms of NPV, IRR or LUEC), as well as the variance with respect to the best estimate previously made. In contrast to sensitivity analysis, risk analysis allows uncertainty in a number of project parameters to be simultaneously accounted for and the impacts on the decision criteria to be quantified.

The procedure starts with assigning a probability distribution to each of the critical variables identified in the sensitivity analysis, defined over a precise range of values around the best estimate used in the base case. A typical method for doing this is to assign a triangular probability distribution characterized by three values (the best estimate and two deviations, one positive and one negative). Another common approach is to model uncertainty in the parameter as a normal distributed variable with a mean value and standard deviation from the analysed literature, historical data or expert judgement. Having established the probability distribution of the critical variables, it is possible to proceed with the calculation of the probability distribution of the performance indices of the project. The most frequently used method for investment projects is the Monte Carlo method, which can be applied using appropriate commercial software. The method consists of the repeated random extraction of a set of values for the critical variables, taken within the respective defined intervals, and of calculating the performance indices for the project resulting from each group of extracted values. The correlation between certain variables can be taken into account. This procedure is repeated for a large enough number of extractions (generally, more than a few hundred) until a convergence of the calculation is obtained with the probability distribution of the IRR, NPV or LUEC.

From the obtained probability distribution (or cumulated probability distribution), it is possible to assign a degree of risk to the project, for example, verifying whether the cumulated probability is higher or lower than a reference value that is considered to be critical (e.g. there is a probability of approximately 53% that the IRR will be less than 5%). Of course, a risky project is one with a high probability that it will not surpass a certain threshold of the considered performance indicator.

3.12.3.3. Scenario analysis

In the situation when it is not feasible to carry out a meaningful risk analysis, e.g. in the Monte Carlo type case, because of a lack of information on underlying probability distributions (particularly in the area of nuclear costs) or for some other reason, a scenario analysis can be undertaken. However, it should be noted that a scenario analysis is just a procedural shortcut, and cannot be considered an adequate substitute for a risk analysis. The approach is to model uncertainty and show the extent of the economic viability of the project under a range of scenarios. 'Optimistic' and 'pessimistic' values of a group of critical variables could be selected to demonstrate different scenarios, within certain hypotheses. In particular, more pessimistic scenarios for the nuclear option should be carefully analysed. These scenarios include high nuclear construction costs, high discount rates, low gas prices and low carbon prices. Project performance indicators are then calculated for each hypothesis. In a scenario analysis, an exactly specified probability distribution is not required.

3.12.3.4. Other resources in economic analysis

The OECD NEA has published a press kit on the economics of nuclear power in which useful information is made available on the competitiveness of the nuclear option, including the role of carbon pricing [94], cost comparisons of different technologies, regions and discount rates and several sublinks to other useful NEA studies, reports and publications [94–99].

3.13. FUNDING AND FINANCING

The funding and financing requirements for an NPP are significant. In general, the term ‘funding’ refers to items that are the responsibility of a government implementing an NPP (e.g. ensuring the necessary resources for regulation) and the term ‘financing’ refers to items that are the responsibility of the NPP owner/operator (whether it is the government or a private utility).

Financing for a first NPP can be pursued in a number of ways. Total financing and ownership by the government is an option if the nation’s economic situation provides a revenue that can be dedicated to this purpose. This approach is probably not feasible for some countries. Export financing is the most likely vehicle for a nuclear power project. However, export financing will still only cover part of the overall investment. Local or foreign commercial financing will be required for the balance of capital and possibly for the IDC. A more likely approach is obtaining private financing backed by specific government guarantees. Full private funding by a consortium of partners seeking a return on their investment through guaranteed sales of the energy from the NPP is also possible.

Credit worthiness is the first order of consideration for obtaining any NPP project financing. Economic policy, debt management and legal risk sharing mechanisms are important factors in this regard.

It is assumed that in phase 1 of the programme, before the government’s informed decision on the introduction of nuclear power, specific analysis would have been performed in order to determine the funding requirements, as a function of time, for each of the following elements:

- Initial infrastructure;
- Sociopolitical acceptance of the NPP;
- Creation or hiring of required expertise or consultants;
- Creation and maintenance of a competent regulatory body;
- Creation of expertise for competent project management and operating staff;
- Security and safeguards arrangements;
- Long term storage of radioactive waste;
- NPP decommissioning;
- Human resources development.

It is also assumed that an evaluation of financing options for the NPP implementation would have been performed in phase 1 of the programme, based on the government and future NPP owner/operator capabilities and credit worthiness. Options may include total financing and ownership by the government, export financing, local financing, private funding, or a combination of these.

Obtaining financing for a first NPP is a complex undertaking, and developing a successful plan to obtain such financing will require significant expertise. The main task during the FS report is the development of a financial plan for the NPP and a risk analysis of the financing.

The financial plan should define the sources of financing (government, local loans, external loans, etc.) and the levels of equity and borrowed money (loans). This plan will also evaluate the cost of financing (IDC, other specific fees, etc.) that will be taken into account in the economic analyses of the project (see Section 3.12) in order to determine the optimum solution for the financing, including the ratio equity/loan (30/70 or 25/75).

Controlling the cost of financing will require attention to many issues. The sources of financing seek opportunities to earn a fair rate of return on their investment with confidence in their capital recovery over a reasonable period of time. These requirements apply whether the financing is public or private, but public financing may have a higher risk tolerance than private financing. However, the control of risk is common to both approaches.

The risk management plan included in the FS report should identify all the key financial risks, their sources, their probability and consequences, and how they are being controlled and mitigated, including the nature of any risk insurance and guarantees. These plans should cover the impact of any significant event such as delays in NPP construction, prolonged NPP shutdowns, public liabilities, regulatory delays, political interference and public intervention.

A successful financial plan should take into account the nation's susceptibility to these risks and adverse factors, in order to acquire the capability to minimize or mitigate their impact, should they intervene. Issues of interest and capital importance from the viewpoint of financial institutions include the political and economic stability of the nation, degree of sociopolitical involvement, prospects of continued economic development, protection of foreign investment, promulgation of legislation favourable to nuclear power, existence of a competent regulatory body and the capability to manage large capital construction projects.

A sound financial plan is also necessary to attract NPP vendor interest and entice them to bid on the project [7, 58].

3.13.1. Technical, financial and economic viability

A detailed financial analysis is provided to financial institutions to request a loan. Financial institutions seek to satisfy a guarantee that all conditions which may present a risk of insolvency are within their own acceptance parameters. The main parameters considered are:

- The project's technical, financial and economic viability against the background of national, industrial sectors;
- The economic and financial justification for the proposed output(s);
- Sustainability of the project and/or entity;
- The extent of its contribution to human and technological advancement;
- The actual local requirements for the investment;
- Governance aspects of the project.

Financial analysis is included in an FS strictly from the point of view of the owner's interest and to facilitate decisions. It should therefore begin with analysis of the financial resources of the owner/utility. It would then consider all external financing sources, the type of financing available, or a combination of different sources such as owner's equity, supplier's credit, buyer's credit, bonds, leasing, joint ventures, institutional investment vehicles such as those provided by international development banks, etc. [71]. Any financial analysis would also have to take into account the lender's conditions, and their requirements and procedures at both the preparatory and implementation phases. The output of this study should be the formulation of a number of credible scenarios and a proposal for the financing of the project with due consideration to risks and pre-conditions.

There are incentives to nuclear power generation that may be appealing to potential investors. They should be highlighted in this section. It should be underscored that the fuel used and its pricing are totally detached from the price uncertainties and large fluctuations associated with gas and coal. The nuclear fuel price also has a modest effect on the total electrical generation cost of an NPP, while any increase in the price of gas significantly impacts the price of the electricity produced by the gas fired plant. This means that for a utility which operates gas fired plants or cogeneration plants, an investment in nuclear energy would reduce its business risk associated with its dependence on the price of gas.

From the point of view of the plant owner, of associated stakeholders and other decision makers, including the government, it is important that they be provided with the present value of the net economic benefits created by the project and of the economic gain or loss incurred by each stakeholder. Decisions regarding any differences between the distribution of net economic benefits and the net financial benefits must be explained. In the evaluation of project risks, from the owner's viewpoint, it is also important to put in place all necessary mitigating measures and to establish their cost.

Financial analysis should ultimately show whether, with the financing in place, a project is viable and whether the established programmes are capable of bringing the project to fruition on time and within budget.

3.14. STAKEHOLDER COMMUNICATION FOR TRANSPARENCY

3.14.1. Stakeholders

A stakeholder is generally defined as any person, group or organization that is influential in the process of decision making and in its outcome, which usually varies according to the decisions made.

Stakeholders may include customers, owners, operators, employees, suppliers, partners, trade unions, the regulated industry or professionals, scientific bodies, governmental agencies or regulators (local, regional and national) who have a stake in one or more aspects of a nuclear power generation programme. Other groups of indirect stakeholders include the media, the public (individuals, community groups and interest groups), other States, especially neighbouring States that may have entered into agreements committing to an exchange of information concerning possible transboundary impacts, or States involved in the export or import of certain technologies or materials [9].

3.14.2. Transparency

Communication is an essential tool to bridge the gap between the rigour of the mathematical definition (risk = consequence × probability) and the perception formula (risk = hazard × outrage). Through continuing communication, the difference can be progressively reduced.

It is also important for communicators to know that communication does not always mean reaching an agreement. Differences identified through communication activities are not always negative. They may contribute to improving the quality of the decision making process. A high quality decision making process always has transparency as its end point. Transparency is always the product of good communication activities, and does not exist on its own in advance.

The definition of transparency was formulated by Espejo and Wene in 1999 [100] as "In a given policy area, transparency is the outcome of ongoing learning processes that increase all stakeholders' appreciation of relevant issues, and provide them with channels to stretch their operators, implementers and representatives to meet their requirements for technical explanations, proof of authenticity, and legitimacy of actions".

3.14.3. Communication

It is essential that all parties recognize that everything in life intrinsically contains a certain amount of risk and that it is difficult to imagine that all risks can be totally eliminated. Uncertainty and risk cannot be tackled only by science and technology. In this sense, communication is also essential to gaining a sufficient degree of common understanding.

Figure 4 shows the conceptual image of a successful communication activity. The main characteristic of a good communication policy regarding nuclear power is to achieve transparency between communicators and stakeholders via communication that is not patronizing and is definitely not a one way flow of information to the public or local inhabitants who live near a nuclear facility, which could be likened to a teacher who disseminates information and distributes educational material to the classroom, but rather a two way interactive communication channel with the stakeholders.

In order to establish a climate of effective communication, communicators should empathize, not sympathize with stakeholders, and should be honest at all times. They should have a spirit of commitment to their goals, and should never promise what they are not able to deliver. Competence and professionalism is required of communicators in the nuclear power field.

Risk is not always the same as risk perception. Stakeholders may have different understandings of what governmental authorities, including the nuclear safety regulatory body, may have communicated. Communicators should keep in mind that truth, authenticity and legitimacy of the information they provide is of the utmost importance. In order to achieve a balance in Fig. 4, effective communication is critically important. Its goal should be to achieve transparency between communicators and stakeholders, and maintain its quality through a sustained ongoing effort.

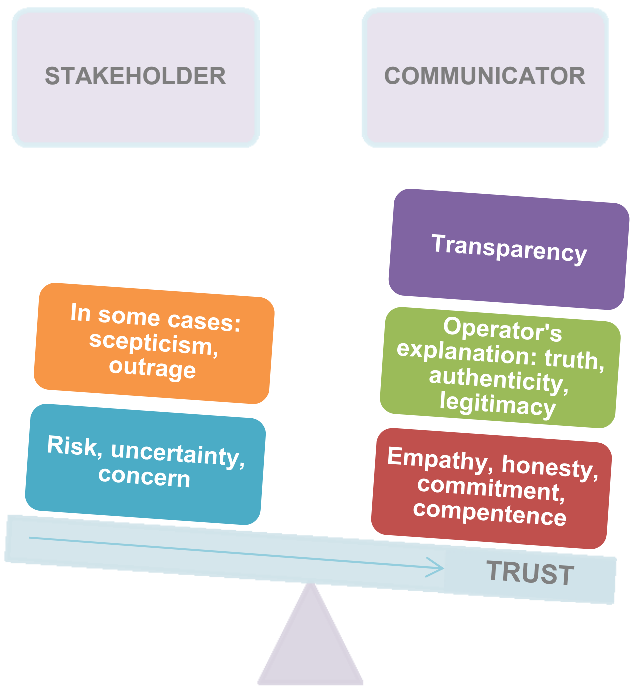


FIG. 4. Communication strategy diagram.

3.14.4. Stakeholder communication strategies

Communication activities vary depending on national and local experience and traditions that have evolved into political and social systems and into a specific culture. However, even taking these aspects into account, it should be noted that it remains quite a challenge to establish a programme of effective communication without a communication strategy that may be multifaceted, to be able to respond to the various needs of every category of stakeholder.

In addition to a good stakeholder communication strategy, there should be a clearcut national policy on nuclear energy, a high awareness among senior managers of a nuclear programme of the importance of stakeholder communication, of the need to recruit a sufficient number of competent communicators, and the human and financial resources required to carry out communication activities necessary to achieve the programme goals. A stakeholder communication strategy should have several recurrent and important elements as described in the following.

3.14.4.1. Identification of stakeholders

Opinion surveys, interviews, spontaneous feedback from the stakeholders themselves and demographic data should all aim at identifying the groups of stakeholders and their concerns and expectations through the information collected. Owing to the limitation of human and financial resources, the groups of stakeholders may have to be ranked in order of the impact that concerns and expectations of each stakeholder group may have for the project.

3.14.4.2. Stakeholder communication planning

A stakeholder communication plan should include communication tools, message content and a delivery schedule. Communication tools should be assessed for effectiveness with each group of stakeholders, and the most effective and efficient tools can then be selected for each group in order to achieve the best results with each group. Messages should be customized for each group. They should be concise and easy to understand, and they should meet the concerns and expectations of each group. The communication plan should be scheduled in line with the national nuclear power generation programme schedule.

3.14.4.3. Implementation of the stakeholder communication strategy

Before a full scale implementation of the stakeholder communication strategy, testing of the customized messages with the specific group of stakeholders for the purpose of fine tuning the messages is suggested to ensure that communicators have a fruitful interaction with the stakeholder groups.

3.14.4.4. Evaluation of the effectiveness of communication activities

An evaluation plan for the effectiveness of communication activities should be developed, identifying the target stakeholder groups, detailing what will be evaluated, and selecting the evaluation techniques and the evaluation questions that will be discussed. Based on the evaluation results, the current stakeholder communication plan should be fine tuned for each group of stakeholders and for each political, social and cultural aspect. Through the evaluation of communication effectiveness, the groups of stakeholders should be reviewed, and perhaps new, more appropriate, groups formed.

Taking into account these elements in stakeholder communication activities, a mechanism of a 'plan do check act' should be developed to preserve their effectiveness. Activities which lead to successful stakeholder communication in one country will not always be a success in another country, and a successful activity in one local area within a country will not always be a success in a different local area of the same country.

In addition to the stakeholder communication strategy described above, a communication strategy for during and after nuclear emergencies or a crisis communication strategy should also be developed and included in communication protocols, particularly with the nuclear safety regulatory body and with government representatives and the media. These communication strategies should be agreed upon with these parties within the framework of the broader national nuclear emergency communication strategy.

3.15. EMERGENCY PREPAREDNESS AND RESPONSE WITHIN THE SITE

3.15.1. Preparedness within the site

The response to mitigate the consequences of a nuclear or radiological emergency must be taken into account in the plant budget in the construction and commissioning schedule preparation; hence, these costs should also be taken into account in the FS, as part of the cost of the infrastructure support. Functional and infrastructure requirements for emergency preparedness should be a prerequisite to an operating licence application and should be taken into account in budget and schedule preparation; hence, they should also be taken into account in the FS. They include the legal framework, authority and organizational roles and responsibilities, response coordination, plans and procedures, communication protocols, logistical support, quality assurance programmes as well as training, drills, simulators and live exercises. Operators must be trained and ready at all times to promptly determine the appropriate emergency class or the level of emergency response and initiate the appropriate on-site actions proportional to the severity class when circumstances require. The operator must also notify and provide updated information to predetermined off-site notification points [81], according to the agreed emergency plan. It should be kept in mind that some rules, sequences and activities may be different, depending on the country circumstances.

In general, the basic principles of preparedness are given in the four list items below. Following this, the IAEA groups of action items on preparedness and emergency response and a brief summary of their contents, with specific references to IAEA requirements and guidelines, are listed:

- All emergency measures must meet both the functional requirements and the necessary infrastructure requirements [101]. In order to ensure that the response capability exists and that it is functional, the concepts of operation and the activation procedures must be developed and tested [102] within the emergency preparedness and response planning activities, well before first fuel loading.
- The system of emergency preparedness arrangements within the site must include directions on the operational actions necessary to manage the accident (establishment of emergency management and operations).

— Arrangements must include emergency plans, operating procedures and guidance for the operator on the mitigation of severe conditions for the full range of postulated emergencies, including nuclear accidents beyond the design basis.
— The plans and procedures need to be compatible with the workload and conditions of the operational staff (particularly in the control rooms, secondary control rooms and emergency control centres). They should include the emergency responder equipment within the facility and the access routes, the protected physical features in the facility for the responder's safety in the worst scenario, the means facilitating the effectiveness of the personnel response and their access to the operative areas, the severe accident I&C systems designed to continue operating under extreme emergency conditions, etc.

The IAEA Safety Standards related to emergency preparedness and response [101, 103–105], refer to steps to building an efficient preparedness and response programme. They are:

— Legislation to allocate responsibilities at the operator level, as found in safety guides [101, 103] dealing with these responsibilities. Requirements of the officers invested with these responsibilities are found in Refs [6, 101, 103–107], while the implementation may follow the guidelines in Refs [107–111]. The national legislation should cover responsibilities and functions of government involved in preparedness and response, and the functions of the coordinating authority in developing and maintaining, through ongoing training and drills, preparedness and response capabilities at the plant level, at the infrastructure level and at the licensing level for the approval and licensing of the preparedness, of the whole infrastructure and of its implementation. On the response side, requirements for emergency facilities, equipment tools and the communication system must all be capable of surviving the worst and extreme threat combinations and cliff-edge effects. Responsibilities must ultimately be defined at all levels and integrated into an incident command and control system.
— Assessment of radiological threats in a State should meet the laws and requirements of the State in harmony with the IAEA requirements found in Ref. [101]. The implementation of the necessary arrangements may follow the guidelines outlined in Refs [103, 105]. The State should implement a radiological assessment plan before embarking on a nuclear programme. The programme should include regulations for radiological assessments, adopt threat assessment methods for which IAEA guidelines are available in Refs [101, 104], and institute periodic reassessment of radiological threats.
— Establish emergency management and operations guidelines by allocating responsibilities and implementing a set of response scenarios and practices for each type of emergency at the nuclear facilities in the State. Guidelines for this response element are found in Refs [6, 105], for first responders in Ref. [106], for research reactors in Ref. [107], for protective actions in Ref. [108], for plant emergency operating procedures in Ref. [109], and for safety infrastructure in Ref. [110]. The involvement of local and national authorities in assigning responsibilities, coordination and resource management tasks should be in accordance with a pre-existing national radiation emergency plan. The plan should ensure on-site and off-site access to information on plant conditions covering source terms, warning of releases, radiological maps in and around the facility, mitigation measures, evacuation planning and coordination, drinking water and food supplies, transportation, weather and protective actions.
— Building capability to identify and assess a radiation emergency; requirements are described in Ref. [101] and implementation in Refs [6, 101, 103–105, 112, 113].
— Mitigatory actions must regulate the development of the capability to implement them by means of procedures for on-call advice to assist first responders, for supporting local authorities and connecting with the IAEA emergency network, to prevent escalation and return the facility to a safe and stable state and smoothly switch from a normal operation set-up to an incident command system, as described in Refs [105, 106], which includes not only the command and control functions, but also the law enforcement functions.
— Taking urgent protective actions [108] by means of arrangements to ensure personnel safety on the premises of the accident as well as off-site and to obtain quick local, national and international support for the operators. This can be carried out through the IAEA under the terms of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency [111]. However, national expertise is required in radiation protection and mitigation within the facility and off-site; specialists must be available on call 24/7

for emergency advice through an incident command system [105, 106]. Arrangements for precautionary and protective action must be in place to provide iodine prophylaxis, shelter, evacuation, decontamination, food and water restrictions, communication, relocation and recovery.

— Provide information and issue instructions and warnings. Development of this capability is subject to the safety requirements listed in Ref. [101]. Arrangements and procedures to regulate coordination, accuracy, consistency of information and timeliness are required. Implementation guidelines are found in Refs [6, 9, 104, 105, 114].
— Protecting emergency workers. Requirements are found in Refs [101, 115], and implementation guidelines are given in Refs [104, 106]. This item also requires regulations on emergency worker protection and protective equipment, and a graded approach to exposure based on task assignments and dose control.
— Initial phase assessment concerning the capability to evaluate human exposure (internal and external) in correct dosimetric quantities and in terms of risks of developing severe effects (deterministic and stochastic) on-site and off-site, and the capability to provide medical treatment to overexposed persons. Capabilities extend to the on-line radiation monitoring of facilities, prediction of transport contamination in soil, air, food and water in facilities to plan food restrictions, and laboratory of analysis of soil, air and other samples. This entire category is subject to the requirements found in Refs [101, 115], and recommendations for implementations can be found in Refs [103, 104, 108, 110, 112–117].
— Managing the medical response. Designation and qualification of hospitals, ambulance teams and training of medical staff to detect symptoms and to decontaminate and treat exposed and contaminated persons. This is required at the local and national levels. This category is subject to the requirements found in Refs [55, 101], and recommendations for their implementation can be found in Refs [103, 104, 106, 112, 114, 116, 118].
— Keeping the public informed concerning the capabilities in terms of infrastructure networks, procedures, processes, protocols and coordination to communicate with the public in an emergency. Some of the requirements include arrangements for continuous reliable communications before any emergency occurs and for responding to information requests from the media and the public. This category is subject to the requirements found in Ref. [101], and recommendations for implementation can be in Refs [103, 105, 106, 114].
— Taking agricultural countermeasures against ingestion and long term protection. This category implies the capability to monitor contamination in soil, air, foodstuffs and water, and protect the public in the nuclear emergency affected zones with countermeasures such as restrictions on food consumption distribution and sale of food from affected areas within the restriction radius. Requirements for this category are found in Ref. [101], and recommendations for implementation can be found in Refs [25, 103–105].
— Mitigation of non-radiological consequences, which concern the capability to get the message of the hazards across to all strata of the population, to prevent and promptly correct possible misinformation or misunderstanding on the part of the media, to explain in plain language the risks associated with inappropriate personal actions and the capability to quickly implement the required countermeasures to prevent or minimize all non-radiological consequences. Requirements for this category are found in Ref. [101], and recommendations for implementation can be found in Refs [103, 105, 106, 114].
— Conducting recovery actions that involve the capability to quickly transition from emergency phase operations to routine long term recovery operations, to identify and establish appropriate new requirements where necessary, the capability to direct the resumption of normal social and economic activity, and in the plant to monitor and control exposure situations for workers undertaking recovery operations. All these actions should be taken in accordance with international guidance. Requirements for this category are found in Ref. [101], and guidance can be found in Refs [103, 105].

Requirements for an effective preparedness and response infrastructure are based on a quality assurance programme. The evaluation of the abilities to carry out all response actions is to be conducted through surveys, reviews of past performance, training, drills and exercises. Capabilities include a national coordinating authority and designated institutions to develop, maintain and regulate arrangements for preparedness and response to nuclear emergencies; on-site and off-site emergency facilities to manage the response; arrangements to receive 24/7 technical advice from nuclear power vendors; adequate tools, computer codes, instruments, supplies, communication systems, facilities, procedures and processes to support all response actions; emergency plans at all levels; and training courses based on the SAT method. These requirements are found in Refs [101, 119, 120], and guidance for their implementation can be found in Refs [57, 102, 103, 121].

3.15.2. Site emergency planning and coordination with off-site emergency response organizations

Arrangements for a nuclear or radiological emergency must be integrated with arrangements at the national and local level for response to emergencies [82, 83]. The implementation of a command and control system for the response to a nuclear or radiological emergency must include arrangements for coordinating activities, for developing strategies and for resolving possible disputes among the various response organizations, concerning functions, responsibilities, authorities, allocation of resources and priorities of mitigating actions. The command structure must work within predetermined clear procedures, regulating the relationship and the coordination among all safety and security authorities.

For external events that can have a major impact over large geographical areas, arrangements must be preorganized for coordinating the response to a nuclear or radiological emergency with the competent authorities identified under the Early Notification and Assistance Conventions [111].

The national preparedness and response organizations must include interfacing protocols with organizations and jurisdictions (at state level) that fall within the precautionary action zone or the urgent protective action planning zone.

Cooperation with international organizations is crucial in the management of the aftermath of a severe accident. These are subject to safety requirements developed by the IAEA in co-sponsorship with the Food and Agriculture Organization, the International Labour Organization, the OECD/NEA, the Pan-American Health Organization, the United Nations Office for the Coordination of Human Affairs and the World Health Organization.

3.15.3. Response function requirements for a coordinated response of the on-site and off-site responders

As feasibility study consultants evaluate the infrastructure and resources needed to support coordinated response functions during an accident, they should consider the following items:

- Identification, notification and activation;
- Mitigation of consequences;
- Urgent protective actions;
- Public communication;
- Instructions to the public;
- Emergency worker protection;
- Medical assistance;
- Longer term protective actions and agricultural countermeasures;
- Personal contamination and overexposure;
- Psychological impact mitigation.

At the international level, the requirements for preparedness and response are based on international instruments and conventions. The thresholds for reporting events, including malicious acts that have radiological consequences on affected Member States and the IAEA, are defined in these requirements.

3.16. COGENERATION

Cogeneration of electricity and steam or hot water for other uses is a possibility in an NPP project. Applications may be varied, for example, district heating, agroindustrial and industrial use in chemical, oil sand recovery and processing, oil refineries, coal and lignite refinement, seawater desalination, etc. For countries either with smaller grids or who are embarking on large capacity NPPs, or both, it may be possible to combine steam production for electrical generation with steam extraction for other uses in the same NPP. This type of cogeneration can be considered during an FS if:

— The electrical output of the reactor selected is too large for the electrical grid.
— The electricity demand undergoes large seasonal variations, e.g. it could be used to produce fresh water in a desalination plant when electricity demand is low, storing the water for later use.
— There is a demand for process or industrial steam near the future NPP site.

Other low energy applications could also be combined with the secondary cycle of an NPP, such as utilizing waste heat from the NPP condenser.

It is also fair to recognize that integration of non-electrical applications with steam or condensate streams of a nuclear plant, if in close proximity, may necessitate safety precautions and integration with the general radiation monitoring requirements and preparedness plan of the nuclear plant. Any potential carryover of radioactivity from the primary to other circuits is to be prevented, and protective barriers should be included in all cogeneration applications, so that, in case of leaks, all contaminants are trapped at the power plant end. This usually affects the economics of the application.

If cogeneration is being planned, the FS should address the economic and environmental drivers of the specific cogeneration applications being contemplated and consider the future requirements for electricity production and cogenerated products (water, heat, process, industrial requirements, etc.); seasonal demand variations and the storability of these products; the business case, including the cost of the cogeneration coupling; the cost of heat transmission; the utilization factor; the cost of producing the required energy; the operating cost and a comparison of the viability of the plant with and without cogeneration; safety and environmental implications; public acceptance; the evaluation of local participation in terms of project management and operating capabilities; the design and development effort; and the financial model and its implications for the business case.

Siting may present challenges. Nuclear plants are normally located far from densely populated areas and close to a source of cooling water to more easily comply with safety, regulatory and design requirements. These siting features may be more challenging when steam is transferred. In the case of industrial cogeneration applications, the requirement to have the nuclear plant in close proximity is less problematic, but still some basic considerations should be made:

— For a given steam delivery pressure, the unit energy cost of steam transmission increases with distance, and decreases with capacity and inlet pressure.
— As the steam delivery pressure is decreased, transmission costs also decrease.
— The use of compressors to reach greater distances makes steam transmission uneconomical.
— If hot water is used instead of steam, greater distances may be achieved, e.g. 100 km with a 2% loss.

3.17. DECOMMISSIONING

Decommissioning is the final stage in the life of an NPP unit, and comprises a whole set of activities aimed at bringing the facilities to a permanent shutdown and decontaminated state, and possibly with its SCCs dismantled and disposed of in a manner that is safe for the personnel, the public and benign to the environment.

Activities are carried out (and paid for) by the operator of the plant; however, in the event of operator default or non-performance, this responsibility likely reverts to the regulating entity. In addition, certain countries have established a special body with long term responsibility for decommissioning.

Decommissioning of the plant is considered in an FS as a cost item. Its cost will depend on the type of capitalization, on the technology options selected and on the environmental impact that the process entails.

International standards now require that a decommissioning plan be prepared at the design stage of all new NPPs, and that it be updated during the facility lifetime. A final decommissioning plan must be developed two years before the planned shutdown [87]. Decommissioning is a necessary but costly step that should be considered in the planning and implementation of a nuclear project.

3.17.1. Cost of decommissioning

Since few NPPs have been fully decommissioned, the exact costs of implementing this last phase in the life of a plant can only be predicted. Estimates vary from 10% to an indefinite multiplier of the construction costs. Data are often not published owing to contractual arrangements and property rights.

Given the significant variation in decommissioning cost estimates, it has become binding to include decommissioning estimates from the project inception, with the intent of carrying out periodic reviews of such estimates throughout the plant service life. Regulators today may request NPP owners to even establish a trust fund during the plant service life to accumulate sufficient money instruments to cover decommissioning, as it is recognized as a particularly complex and time consuming undertaking, whose cost may escalate and last several decades. Funds may be accumulated through a variety of means, including revenues from electricity customers, from taxes and from imposition of fees, and they should be protected from fund subtractions to finance other initiatives during operations.

If we attempt a cost breakdown of decommissioning, we realize that stringent regulations are a primary cost driver for decommissioning and waste disposal. Beginning with the impact on the land, there may be a requirement for temporary expansion of the perimeter to provide for staging and laydown areas for the removal of large components. Similarly, decommissioning activities may require the construction of temporary building and facilities for waste treatment and temporary storage, training, changes to the fence and security arrangements.

Other cost items are driven by the classification and type of waste, the amount of waste produced, the construction of waste repositories for each of the particular types generated, and the special transportation requirements. Adequate long term repository sites are required to store radioactive waste from the decommissioned NPP.

The sheer duration of decommissioning projects will weigh on labour costs, including ongoing site monitoring and surveillance. In estimating the cost of decommissioning of NPPs and of waste disposals, appropriate multiplication factors should be used to account for the risk to public health and safety and to the environment.

Soil contamination is also a possibility, and represents another uncertainty factor that may drive up the cost of decommissioning up considerably. Reporting any leaks during the lifetime of the NPP will enable decommissioning plans to be more precise in this respect. Contaminated flow pathways in the soil below the reactor and auxiliary buildings may form and cause radioactive material to be transported in directions and rates that cannot be estimated. Only direct testing can determine this, but soil testing below buildings cannot be carried out until access has been made safe. Depending on the results of these tests, varying amounts of soil may have to be removed, and these cannot be determined until the decommissioning process is well under way. One of the possible consequences of soil contamination is the contamination of natural groundwater, either through migration of the contaminants through the soil to the water table, or through the variation in water table height to the point of entering into contact with the contaminated vein from the site. Possible soil contamination is one of the main reasons that decommissioning is carried out in steps to avoid such grave disruptions to the overall plans.

3.17.2. Decommissioning phases

Decommissioning usually starts with the plant being placed into a transitional phase, which is a preparatory phase. The second phase is the deactivation phase, which includes the total reactor defuelling, followed by the drainage and flushing of all fluid systems. The third phase has three alternatives, depending on the conditions of the retired plant. Normally, it involves decontamination and dismantlement (DECON), which is the most expensive. This process is normally only used in combination with other methods, but it may also be used independently of other less complex methods in order to leave the facility intact and allow placement in a safe storage mode or encasing/entombing it in a long lived structure. In this case, it must be continually monitored for leaks until the radioactivity decays to acceptable levels.

The most likely case for decommissioning is the use of a combination of different options for different parts of the plant [87].

The final phase is a verification step, in which compliance with all relevant regulations is ensured before the final disposition of the site.

Problems associated with the final disposition of waste, particularly with the selection of a site for the long term disposal of high level waste and spent fuel, have been ongoing for many years; action was still suspended at the time of writing. Countries facing greater economic constraints will have even more serious difficulties dealing with long term radioactive waste disposal. In some cases, no waste management systems exist, and the dismantling will have to be deferred to a later date.

3.17.3. Environmental impact of decommissioning

As a rule, the decommissioning of an NPP unit is carried out after the expiration of its design service time or even beyond it, after a longer term operation beyond its originally assumed service life. Decommissioning can also happen before the completion of an NPP design life if safe operating conditions are impossible to maintain. All decommissioning activities should be conducted in full respect of the requirements and assumptions contained in the plant EIA. A nuclear power generating facility is contaminated, even after permanent shutdown and defuelling because, during operations, SSCs become activated. There are two major vehicles by which contamination occurs:

- First, activation may occur by contact with fission products. Radioactive fission products normally sealed in the fuel may occasionally leak and contaminate the reactor coolant. This contamination inevitably propagates, despite precautions, to other parts of the reactor systems, especially around SSCs near the reactor and around the spent fuel pool.
- Another source of activation is created when stable substances are subject to high neutron fluxes. Examples of such stable substances are the steel surrounding the reactor core such as the reactor pressure vessel, the vessel internals, the bioshield, the steam generator, the pressurizer, the primary coolant piping and other systems interconnected to the reactor coolant system. In addition, contamination is found in the radioactive waste systems.

During system and equipment disassembly, exposure to radiation may occur, as protective safety barriers are dismantled and radioactive substances can migrate outside the units [122]. During cutting up of materials for decommissioning, radioactivity is in a different form (dust and gas) to that in which it was during the running of the NPP. This may cause leaks of radioactivity to the environment [80, 123]. Decommissioning one 1000 MW reactor generates approximately 10 000 m^3 of low and intermediate level waste (LILW), much of which is concrete and other building materials containing small amounts of radioactive materials [124].

LILW is subdivided into two classes: LILW-SL (short lived), which has a half-life of 30 years, and LILW-LL (long lived), which has a half-life longer than 30 years or which produces too much heat to be classified as SL. In addition, some quantities of high level waste (HLW) are also generated. HLW has a much longer half-life, generates heat and requires isolation from the biosphere, for example in deep underground repositories.

The environmental impacts of decommissioning, although normally smaller than those occurring during site construction or operation, are nevertheless present and must be taken into consideration. They begin at the cessation of operations with changes to the thermal footprint of the plant. Warm water ceases to flow, for example, into the plant's ultimate heat sink. This may result in the loss of marine organisms that are dependent on that warm water. Impacts on land and water use, air and water quality and ecology, in addition to impacts due to radiological, socioeconomic and landscape changes, must be considered and may require remediation.

In terms of water use, DECON normally require much less water than operation of the plant. Nevertheless, water must be available, and DECON will require more water than other solutions.

3.18. GUIDANCE FOR THE BID INVITATION SPECIFICATION

This section is meant to be a coordination section in which the prerequisites of the BIS are provided. Before starting the preparation of a BIS, certain prerequisites should be settled or at least plans for their settlement should exist; therefore, they should be listed and discussed in this section. If the information exists in other sections of the FS, a reference should be given to those sections or to other independently conducted studies if it is the case.

Prerequisites to the BIS are:

- Size or size range of the NPP;
- Feasible NPP designs;
- General technical requirements;
- Experience of potential contractors;
- Overall project schedule;
- Site characteristics;
- Adequate legal frameworks governing nuclear activities;
- Environmental impact;
- Radiation protection;
- Regulatory requirements and licensing procedures;
- Grid characteristics;
- Contractual approaches and project management;
- Levels of national participation;
- Nuclear fuel supply options;
- Nuclear waste management and disposal;
- Security and physical protection;
- Safeguards;
- Economics;
- Financing options;
- Owner/operator's scope of supply;
- Owner/operator's organization;
- Emergency planning.

The completeness of the above elements has a direct impact on the duration and quality of the bidding process.

Another element that needs to be estimated and provided in this section is the human resources required to prepare the BIS and then conduct a bid evaluation. Specific human resource needs may include:

- Technical expertise to develop specifications for an NPP and to evaluate the bids;
- Project and management system expertise to manage the bidding process and to develop specifications and evaluate the bids regarding areas of expertise;
- Detailed knowledge of the infrastructure in the country and at the site, as well as the regulatory environment;
- Legal and business expertise for the BIS preparation, bid evaluation, contract negotiations and fuel procurement;
- Financing expertise to negotiate with financing organizations and to develop financing plans;
- Expertise in stakeholder communication and public information.

The owner's responsibility area also includes necessary contacts with all related stakeholders prior to and during the bidding process. The communication with stakeholders has a two way benefit:

- The owner receives necessary information and guidance for preparing the BIS, evaluating bids and negotiating contracts;
- The stakeholder is better prepared for measures that it may put into action in the later phases of the project.

To ensure that the potential bidders have suitable plant designs available and the necessary competence and experience to successfully complete a contract, the potential bidders may be requested to pass a pre-qualification process. Depending on the legislation, this process can be carried out as part of the technology assessment if performed before the bidding process. The pre-qualification process should include demonstration of the potential bidders' financial capability and technical competence, available resources and the provision of the relevant references from comparable projects. For this purpose, a request for information document for pre-qualification to solicit the required data could be developed and sent to potential vendors. After pre-qualification of the vendors is completed, the BIS should be distributed to the vendors who passed the pre-qualification stage.

It is good practice for the owner to establish a dialogue with the potential bidders before the bidding process starts. A good forum for such dialogue could be an FS or technology assessment conducted by the owner in cooperation with the potential bidders. The purpose of this dialogue is to help the owner to better understand the properties of the available NPP designs and the characteristics of the vendor market. In parallel, the bidders will obtain a good understanding of the owner's wishes and requirements before the final BIS is issued.

More information on the invitation and evaluation of bids for NPPs can be found in Ref. [4].

4. CONCLUSIONS AND RECOMMENDATIONS

An FS is an analysis of the various aspects whose primary purpose is that of supporting the owners and other stakeholders to reach the correct business decisions. It should also be written in a way that becomes useful as an authoritative record of the reasoning and the methodologies used to support the decision to build an NPP, including risk analysis and legal and political implications, as well as a reference document that can be used as a basis for further studies, for the preparation of the BIS and for the information package requested by the prospective financial institutions, export banks and private investor groups.

In summary, the key risk elements that need to be addressed in an FS for an NPP are:

- Various contractual approaches should be impartially examined, together with the possible procurement models and the project management styles before recommendations are made.
- Various partnership models with a variety of capital injections should be examined. In addition, various contractual approaches should be examined, together with the procurement models and the project management styles, and recommendations made.
- It is also important to describe the accident preparedness and site emergency planning, the infrastructure required, if any, and its cost. Various options should be compared before a solution is recommended.
- Before a final recommendation for unit capacity is given, the risks that may be undertaken when selecting larger unit sizes should be well assessed, together with the risks associated with grid size, and all other aspects must also be carefully evaluated [18].
- Recommendations on the reactor type and size should be preceded by an accurate technology market survey, and the assessment process should strictly meet the programme policy objectives, the NPP project goal, waste management objectives, the fuel cycle evaluation, a comprehensive safety assessment based on international experience, and the recommendations from the EIA.
- If the regulatory framework and licensing requirements have not been completed or enforced, it is recommended that this section of the FS report be prepared based only on the reference information received from the potential NPP vendor countries, including any input from the regulatory bodies of these countries.
- A detailed national industry detailed survey, the establishment of a strategy for national participation, a localization plan and a technology transfer plan (if required) should be conducted to a degree that allows further, more specific studies and for the BIS.
- In the cost estimate of the project, in addition to financial costs, any social costs or benefits other than compensation flowing from the project to third parties quantified by assigning realistic monetary value should be accounted for.

A project risk matrix and its implications, followed by a risk management plan, should be developed and included in the FS.

Given the complexity and multidisciplinary character of an FS for an NPP project, it is recommended that a consulting firm be used with solid experience in creating successful FSs, with qualified key personnel with proven knowledge of the nuclear industry and of the variety of topics making up the study, with a good knowledge and understanding of the cultural environment and of the owner/operator organization and its interfaces.

Appendix I

ENVIRONMENTAL IMPACT OF WATER RESOURCES AND SELECTION OF SOLUTIONS

I.1. WATER RESOURCE EVALUATION

Cooling requirements for an NPP are primarily a function of its size and thermal efficiency. NPP size is assessed as part of station/unit capacity reviews, while thermal efficiency is a function of reactor design, the related cooling system technology, and the NPP's geographic location and resultant weather and seasonal impacts. Recent trends have shown reactor designs moving from a traditional 33% efficiency to 36–39%, with new designs aiming for even higher efficiencies. This leaves less energy to be discarded as heat, lowering the overall cooling requirements.

The larger the temperature difference between the maximum steady state temperature of the primary reactor coolant close to the heat source and that of the external cooling medium (referred to as the ultimate heat sink), where the surplus heat at the lowest temperature of the cycle is rejected, the more efficient is the thermal dynamic cycle in achieving mechanical work — in this case, turning a generator. It is thus desirable to have the highest possible temperatures compatible with reactor safety near the nuclear heat source and to have the ultimate heat sink outdoors at the lowest possible temperature. This consideration implies that it is desirable to locate power plants alongside coldwater bodies, and design the plant taking into account fluctuations in thermal efficiency due to seasonal temperature excursions of the ultimate heat sink. For a given NPP, design thermal efficiency will be lessened in warmer climates, and also seasonably on peak temperature days.

Quantitatively, the greater demand for cooling water in a nuclear plant is from the low pressure steam condenser that is housed in the turbine hall. In the condenser, water is used to cool and condense the secondary steam after it has expanded through the various stages of the power turbine group. Other than steam cycle cooling, NPPs also require water from various plant components via the component cooling heat exchanger. In addition, water is used for make-up in the steam cycle, to regenerate ion exchange resins, for fire protection, for waste treatment, and for domestic use such as cleaning, showers, toilets, laundry or irrigation. This usually requires local water treatment facilities and a waste or sewage plant, which will both need to be factored into the overall plant FS cost calculations. During accidents, cooling water is required to remove decay heat from the reactor (via the safety class heat exchangers), but during outages and accidents, the large steam condenser user should be isolated. Water of various quantities and qualities (e.g. filtered, demineralized, potable) is normally required, and redundancy of supply should be taken into account as an alternate heat sink in the case that the primary heat sink becomes unavailable. Water consumption in the treatment of radioactive wastewater will also have to be included in the heat/mass balance.

I.2. OPTIONS AVAILABLE

Steam condensing/cooling is typically carried out in one of following ways (see Fig. 5 for a diagram):

— Open cycle cooling, also called direct cooling or once through cooling. If the power plant is next to a sea, large river or large inland water body, cooling may be carried out simply by running a large amount of water through the condensers in a single pass and discharging it back into the water body a few degrees warmer. The water body could provide either salt water or fresh water. This is the simplest and most convenient method. Very little water is lost from the water body in this process. A small amount of evaporation will occur off-site due to the water returning to the water body being a few degrees warmer than its original temperature. In some cases, innovative water streams such as municipal wastewater can be incorporated into the cooling water supply.

If the power plant does not have access to abundant water, cooling may be carried out by passing the steam through a condenser connected on its secondary side to a closed circuit with a cooling tower, where an updraft of air through water droplets cools the water. Sometimes, an on-site pond or canal may be sufficient to cool the water without the need for a tower. There are three classes of cooling towers generally available: the wet tower (also called the evaporative tower), the dry tower and the hybrid wet–dry tower. Within each class, there can be two varieties: the natural draft and the mechanical draft. These systems are:

— Closed cycle natural draft wet cooling tower system.
— Closed cycle dry cooling system without evaporation in which an air cooled condenser is used (direct method), or using a dry cooling condenser and evaporative cooling towers (indirect method). A variation of indirect dry cooling is known as the 'Heller' method, where a direct contact spray condenser is used and some of the condensate is diverted to the cooling towers. The closed cycle dry cooling system is less costly to build and operate than the closed cycle natural draft wet cooling tower system, but it is feasible only if there is an adequate water supply in the vicinity.
— Closed cycle dry plus wet cooling. This is a combination of dry and wet cooling, whereby dry cooling methods are utilized preferentially, supplemented by wet cooling methods during peak demand or hot periods. This may involve, for example, a water deluge system on the heat transfer surface of the dry tube bundles, or by introducing water into the air cooled condenser in order to precool the inlet airstream.
— Pond cooling. A few nuclear plants use cooling ponds (not shown in Fig. 5), which are another type of closed cycle cooling. The advantage is that evaporation in a pond is lower than that occurring in cooling towers. Heat is transferred gradually to the atmosphere as the hot stream from the plant enters the pond. This way, the temperature differentials that govern the heat exchange are also gradually lowered, and both evaporation and convection are lower than in cooling towers, and so is the rate of water loss and hence make-up needed. In addition, the environmental impact is typically much less than that of direct cooling. On the other hand, ponds require a large surface and clear land, which may not be available and is usually more difficult to protect from malevolent acts. A typical nuclear unit of 1000 MW(e) would require an average 1200 acres of land reserved for a cooling pond, and only an average of 150 acres for spray ponds and 15 acres for cooling towers.

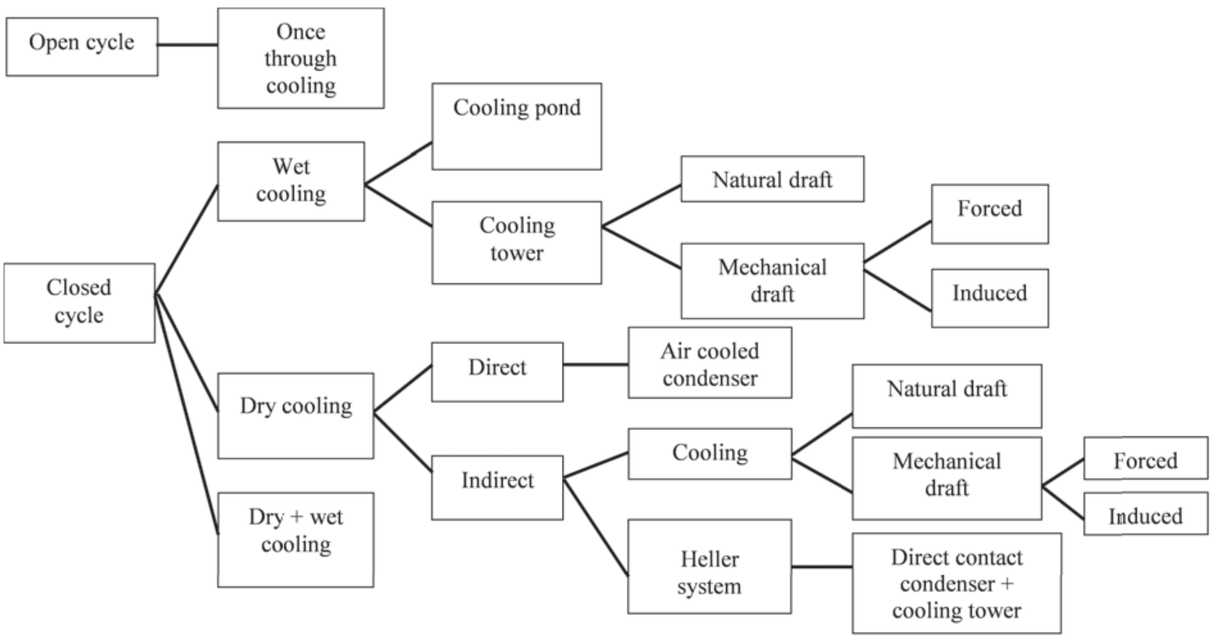


FIG. 5. *Types of cooling systems.*

I.3. ADVANTAGES AND DISADVANTAGES OF THE OPTIONS

Each major cooling system design has its advantages and disadvantages, and the major issues related to each are listed in Table 4. Optimal technology selection involves a trade off between the following issues:

- Capital operating costs (electricity, chemicals, equipment maintenance, etc.);
- Weather patterns (impacts of hot weather on plant output with various technologies);
- Site size and other characteristics (footprint required);
- Water availability and type (salt, fresh or grey/wastewater);
- Environmental regulations on aquatic life (once through systems), drift emissions (wet or hybrid towers) and plant siting;
- Jurisdictional costs associated with costs to take water from the natural environment;
- Aesthetics such as visual plumes (for cooling towers) and visual impacts (plumes and structures);
- Licensing risk surrounding time to address any environmental and/or community concerns.

To reveal the impact on the environment, water usage per MW should be calculated for each of the cooling methods. Water usage is expressed as water withdrawal and water consumption (evaporation to the atmosphere). Once through systems and pond cooling systems have a similar water consumption rate, while cooling towers will evaporate nearly twice the amount. Compared to once through systems, cooling towers generating additional power to meet the energy penalty would cause changes in land use and wildlife habitat. Other impacts include increased evaporation, cooling tower drift, noise, aesthetics, discharge of biocides from cooling towers blowdown, additional solid waste as cooling tower basin sludge, etc.

From the siting viewpoint, once through cooling systems using fresh water and sea water are less costly to build and more energy efficient than systems using wet recirculation through cooling towers or ponds. Thus, the siting of NPPs on coastlines is usually preferable where other considerations allow. Siting along the coastline will have to be balanced with the electricity transmission losses in the system, depending on the locations of the users. It should be balanced against the cost benefit of proximity to electricity consumers. Where there are no large water bodies or large rivers, evaporation can be used to exchange heat with the atmosphere by means of recirculating water systems. For example, tall cooling towers use the natural draft of air, also called the chimney effect, whereby air naturally rises in the tower and meets in counter current the hotwater flow returning from the plant which is finely dispersed into water droplets that more efficiently lose heat to the rising air. Shorter towers instead of natural draft use a fan forced draft, which consumes electricity, as opposed to the tall towers, that use natural circulation.

From the point of view of plant efficiency, once through systems offer the greater advantage because the temperature of the incoming flow is lower than that of ponds and cooling towers. In fact, recirculating water systems reduce the overall efficiency of a power plant by 2–5% (variations due to operating conditions) compared with once through systems. The selection of cooling technology may ultimately depend on the community and regulatory environment. ‘Best available technology economically achievable’ is a recent concept in environmental regulation that may be applied to the decision process.

Countries embarking on or expanding nuclear power programmes are encouraged to establish directions at an early stage regarding the regulatory acceptability, the environmental impacts and the relative importance of the various issues surrounding cooling water technologies. Potential owners can thus perform detailed FSs and conceptual designs for various cooling options that can be evaluated for implementation.

I.4. COST CONSIDERATIONS

From the point of view of cost, it is important to note that cooling towers are about 35–40% more expensive than a direct, once through cooling system, based on life cycle costs, which include O&M costs. In the selection of the optimal cooling system, an economic compromise between capital cost and performance penalties will have to be made. Generally, seawater systems are more expensive than freshwater systems because they have to be designed to resist corrosion from brine. On the other hand, freshwater systems often face regulatory constraints on the temperature of returned water and may therefore require backup systems using recirculation and dry cooling

TABLE 4. TYPICAL COOLING TECHNOLOGY ADVANTAGES AND DISADVANTAGES

Technology	Site flexibility	Visible plume and structure impacts (community concerns replume and size, plus drift emissions (chemical losses from steam plume))	Installation cost	Water withdrawal	Aquatic life impact (entrainment, impingement, thermal plume)	Plant efficiency	Capital costs	Operating costs
Open cycle	Low (requires large water body)	None	Lowest	Highest (however, least loss)	Highest	Highest	Lowest	Lowest
Closed cycle — wet cooling pond	Low (requires very large pond area)	None	Low	Low (5–10% of open cycle)	Low	Lower	Medium	Higher (electricity to run fans, wastewater and chemical treatment)
Closed cycle — wet cooling tower	Medium (needs to be near body of water for make-up water)	Highest (large plume and structure)	High	Low (5–10% of open cycle)	Low	Lower	Medium	Higher (electricity to run fans, wastewater and chemical treatment)
Closed cycle — dry cooling	High (good site flexibility, however, larger footprint and height than wet cooling; good for areas with scarce water resources)	High (no plume but largest structures)	Very high	Lowest	None	Lowest (highest efficiency penalty, load limitations on hot days), approx. 2% lost generation penalty; plant efficiency decrease of up to 25% in hottest weather	High 5–10 × wet cooling	Highest (higher electricity costs (4–6 × wet cooling), higher metric tonnes of carbon equivalent, wastewater and chemical treatment), unit trip/derating potential
Closed cycle — dry + wet cooling	Medium to high	Low (only in hottest weather)	Highest	Low (between wet and dry)	Very low	Better than dry cooling alone	Highest More equipment than dry cooling alone	

technologies. In hot summer conditions, the plant may approach the limit set for discharge and may have to derate or use alternate recirculating cooling, to return within the regulatory constraints.

A comparative analysis between the wet tower solution and a wet–dry combination can be conducted. First, the type of draft, either mechanical or natural, should be decided for the two options, then the common design meteorological conditions such as the plant altitude, the total electrical generation power, the capacity factor, the plant thermal efficiency, its heat loss, the terminal temperature difference, the drift, which is the amount of droplets of liquid water entrained by the airstream (0.03% of the total circulated water), the blowdown and make-up water rates should be determined based on the best compromise desired between fouling and water consumption.

The design parameters of each of the two types should also be decided. For the wet tower, it will be important to determine the wet and dry bulb temperatures based on the annual joint frequency distribution of these two parameters, the relative humidity, the temperature range, the coldwater temperature, the approach temperature (which is the difference between the coldwater stream temperature leaving the tower and the wet bulb temperature (the lowest possible temperature to which the hot water from the condenser can be cooled)), and the turbine backpressure at the condensing temperature.

For the wet–dry system, it will be important to determine the heat load rejected on the dry side at the design ambient temperature, the design coldwater temperature, the design temperature range, and the turbine backpressure at the condensing temperature. The comparison results will yield the make-up water consumption for both systems. The cost of the wet mechanical draft cooling tower will depend on the size and number of the cell blocks, the cost of delivery and installation, the cost of the concrete basins, the power of the fans and the tower operating cost. It has to be kept in mind that an additional thermodynamic penalty is inherent in the use of the wet–dry tower system due to the design conditions, assuming a higher temperature of the condenser condensate. The plant net capacity is reduced by the power required to drive the additional fans to compensate for the higher temperature of the incoming condenser condensate flow. It is also necessary to take into consideration that the lower the initial temperature of the cooling water, the larger the vacuum that can be produced and the greater the efficiency.

For wet–dry towers, the cost will depend on the number of cells and their length, the pumps and size of the distribution header, and the size of the fans.

Appendix II

CONSTRUCTABILITY AND MODULARIZATION

Modularization is the prefabrication of sections of a plant executed either off-site in specialized factories or within the site perimeter in specially reserved and protected areas. Modularization allows the application of parallel construction techniques whereby civil, mechanical and electrical work can proceed for the most part in parallel. Without modularization, in conventional construction, the mechanical, electrical and I&C installations are carried out exclusively in situ inside the buildings where they will be permanently located. Installation in such cases must wait until the civil work is complete.

Modularization may not always be desirable. However, it should be noted that, depending on the technology selected, modularization may be a mandatory pathway. Some new generation designs have been developed around an inherent modularization technology, which may not be compatible with conventional stick type construction. In an FS, it is important to be aware of all the possible pros and cons tied to the implementation of a modularized NPP project.

Often, modularization implies that a substantial amount of work is outsourced to off-site locations. This should reduce labour costs for the owner/operator in terms of salary disbursements, per diems, accommodation and overheads, by as much as 40%. Corollary to a smaller labour force on-site is the benefit of substantially reducing congestion, which should reduce work interferences, the risks of cost overruns associated with on-site congestion, increased training and the inevitable sequencing of activities. Other reductions may come from simpler material management and more advanced construction support systems. In multiunit sites, modular construction allows savings in terms of replication. Environmental advantages are also drawn from modularization, although they may be less easily quantifiable. They can nevertheless be identified in lower disturbances to the local environment, and in reductions to material waste, dust and noise.

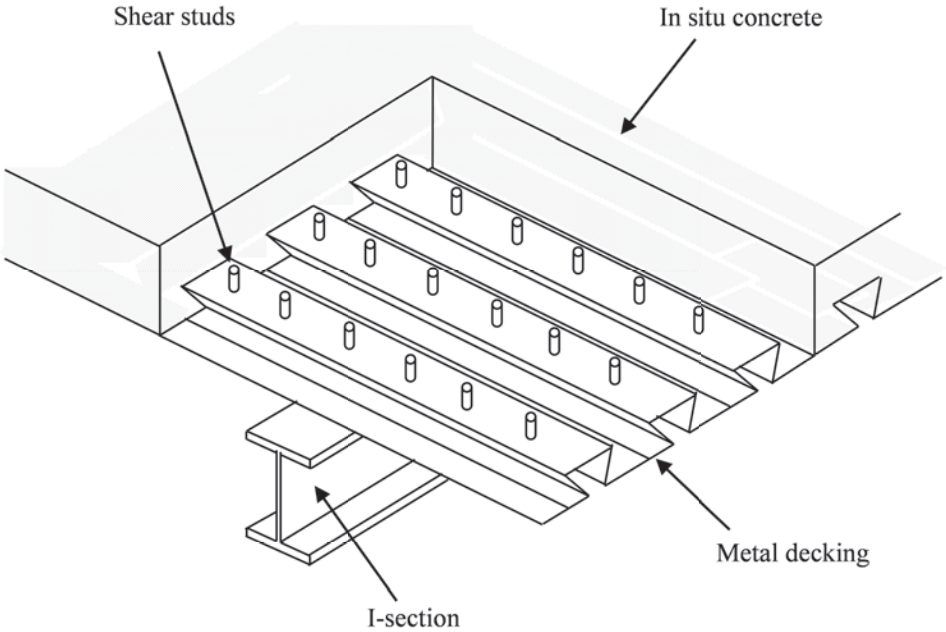
Certain modules are mainly structural in nature, others mostly mechanical, or a combination of both. Structural modules are prefabricated assemblies, mainly made of steel beams and steel sheets. A particularly advanced type of structural modules is those constituted of composite structures that are still made of steel elements but also receive a concrete pour once installed at their final destination.

As shown in Fig. 6, a composite wall has its steel frame sandwiched between two metal sheets that, once the module is installed, will act as a holding formwork. The steel sheets on both sides of the wall are interconnected by structural elements to increase the overall stiffness of the composite structure and to act as reinforcing steel once embedded in the concrete. The end sheets remain as permanent elements of the composite structure, unlike a traditional wooden formwork that must be removed once the concrete has cured. The steel sheets participate in the structural strength of the assembly, they protect the concrete inside and may help facilitate room sealing properties in nuclear applications if necessary.

Similar to a composite wall module, a composite floor module consists of a web of steel sections and steel plates strengthened by stiffeners. As in composite walls, the concrete is poured in between the steel elements after the module has been installed. The steel plates contain the concrete, acting as a formwork. In some cases, composite walls and floors may be prefabricated as one single larger module.

Other modular structures can be stairwells complete with steel platforms, gratings and landings. Structural modules may contain anchor points or embedded parts to support smaller mechanical modules within them and peripheral attachments to allow their own restraining to adjacent modules or to embedded parts protruding from the building walls.

Mechanical modules usually contain a number of process components, a selection of any equipment combinations of pumps, compressors, motors and control centres, heat exchangers, fans, air ducts, valves, interconnecting piping, instruments, cables, cable trays, wiring, etc. The assembly is mounted on a frame made of permanent steel and of temporary steel stiffeners that are removed after the module is installed. Mechanical modules can be fabricated and assembled in situ within the construction site perimeter, or in a factory environment off-site. They may contain tie-in points to adjacent modules, as well as lifting hooks and positioning guides. Modules destined for the reactor building are lifted into place in a predetermined sequence. They possibly enter the building through a weather protected open top to facilitate installation. The maximum size of a mechanical module depends on the specific design, and is usually set as a requirement during the design phase. Size limits could be



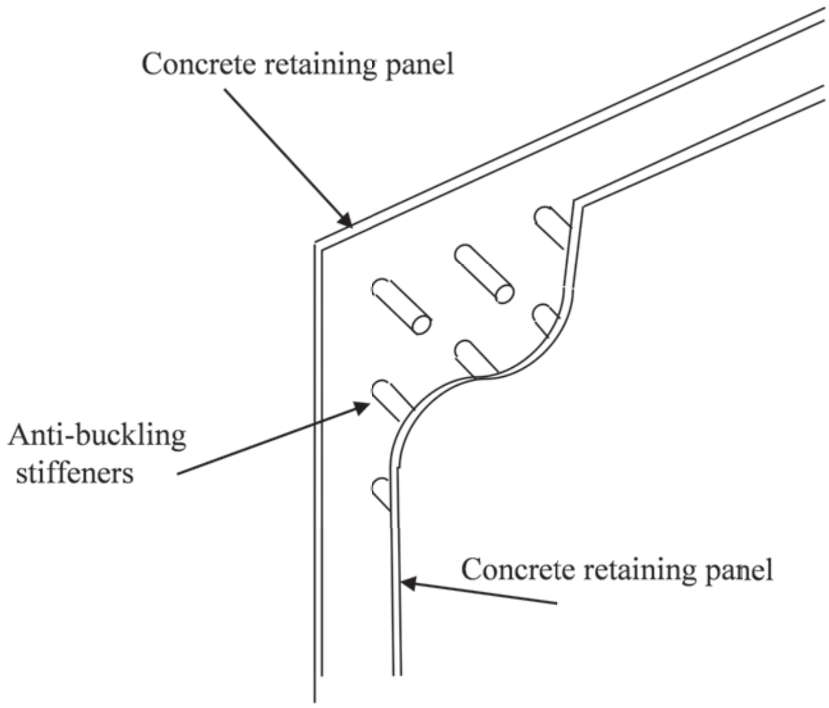


FIG. 6. Example of composite walls and floor in a structural module.

dictated by the need to allow land transportation (e.g. rail), in which case, the maximum allowable dimensions would be 3.7 m × 3.7 m × 27 m, and the maximum weight below 100 t. Structural and mixed structural mechanical modules are usually larger and less numerous than mechanical modules. Their size and weight limits are set higher, and they are designed for transportation through waterways, either by ship or by barge.

From the quality perspective, being able to work on large modules in a controlled factory environment should result in higher quality and safety performance. In particular, the detailed work, for example, I&C installations, is carried out more efficiently in a factory or in a specialized shipyard environment. Another example can be prefabricated large bore induction bent piping with martensitic coating and complex spool welding, which can be carried out under controlled quality conditions and at lower costs. When modules are fabricated off-site, specialized labour and specialized techniques are more readily available. For example, advanced material management tools allowing radiofrequency tagging and bar coding integrated with material tracking databases, advanced 3-D CAD visualization tools may be used. On the working floor of a factory, precision fabrication equipment and tracking technologies are also elements that favour quality and performance. Usually, modules are not assembled on a system basis, but rather on a construction volume completion basis, which means they may not be delivered as tested functional units. Nevertheless, as much testing and commissioning as possible should be conducted at the off-site location to alleviate the overall commissioning schedule in the plant. In countries where there is a lack of specialized workforce, modularization may reduce the burden of hiring, training and overseeing a large multidisciplinary workforce for the owner/operator.

Modularization also has its challenges. Experience has shown that schedule and duration reductions attributed to modularization may not be achievable for the first unit. To reduce risks, a cost–benefit study and a constructability review should be commissioned for the site specific conditions. The constructability review would allow the development of an accurate site specific NPP implementation plan, in which module fabrication is totally integrated within the overall construction schedule. The review must take into account all enhancements necessary to accommodate modularization, including infrastructure and larger access roads, and heavy lift equipment and module laydown areas. In addition, a constructability review involves assessing local capabilities, the degree of experience of all stakeholders, the implications of the lessons learned from the reference project or other construction projects, and the specific conditions of the site and its surroundings. Constructability reviews are best developed in cooperation with the vendor and the architect–engineer or main contractor. Usually, the standard design of the modules is provided by the reactor vendor. The detail design must be completed before the ATP is issued and months before the main contract is signed. Long lead modules are usually tendered and contracted at the general ATP, together with the large components such as the reactor vessel or the steam generators (which may be considered modules on their own) in order to achieve any sort of gains on the critical path.

A qualitative schedule comparison between conventional stick type installation and a modularized project is shown in Fig. 7. Durations are intentionally not shown, as they must be estimated by the site specific constructability study.

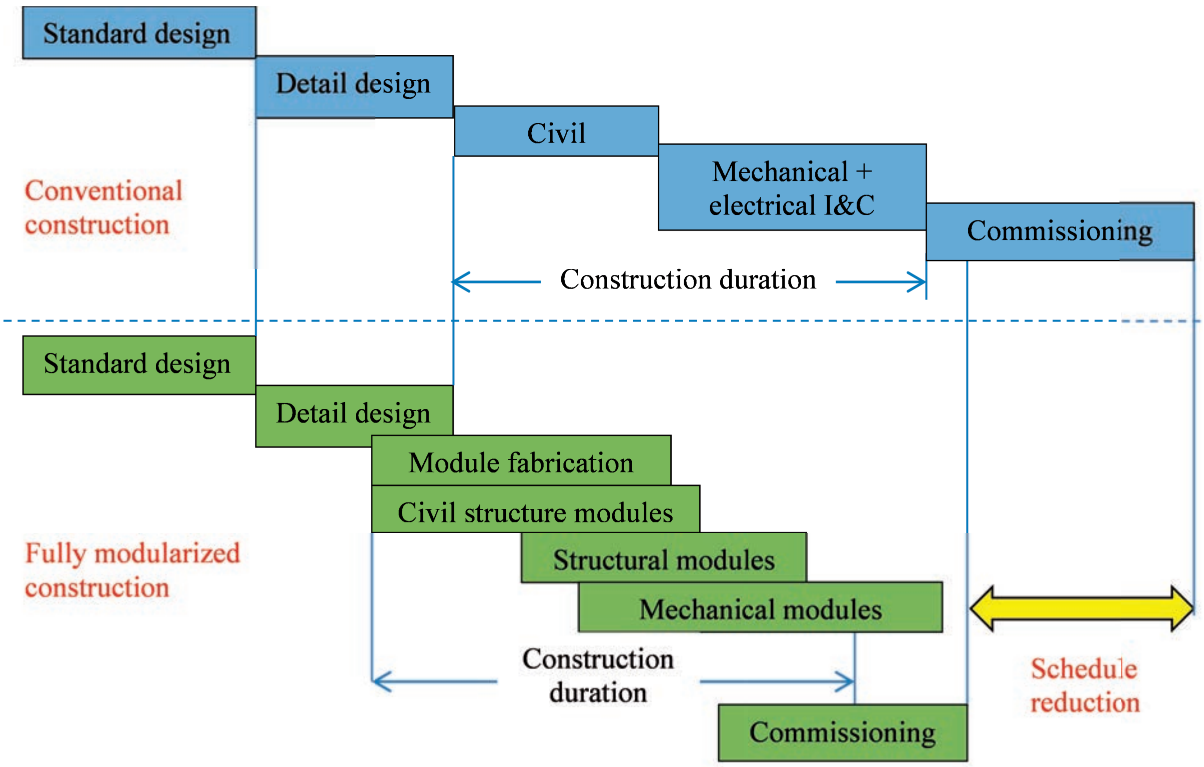


FIG. 7. Possible gains in a fully modularized parallel construction plan. (I&C = instrumentation and control.)

As discussed above, a different approach to procurement, scheduling and module installation would have to be adopted for modularization. The key elements of this approach are:

- — Early procurement of equipment for module fabrication;
- — Advanced accessibility and transportation plans;
- — Extra ground surfaces allocated for heavy lifts and long lift radii;
- — Extra laydown space for module handling;
- — An integral module/construction management approach.

To handle large modules, a very heavy lift (VHL) crane would have to be rented, and an open top construction model would have to be implemented. Depending on the size and weight of the lifts, the VHL crane can be selected with the appropriate capacity, maximum lifts, boom lengths and reach radius.

Some of the lessons learned from modularized or partially modularized construction projects are reported below:

- — Engineering complexity. Detail design of the modules requires a multidisciplinary effort very early in the project, when vendor details may not be totally available and the complexity of interfaces and shipping envelopes must be detailed up front. Structural member sizes and bracing requirements in modules to accommodate incremental loads during shipping and installation lifts will often reduce accessibility to the equipment. A different drawing list, drawing types and numbers may be required, since detail module interface drawings are usually required in addition to traditional plans. Changes in terminology, referencing and progress measurement techniques will have to be implemented. Extended coordination with multiple module fabrication sites, upfront shop detailing and special transportation requirements substantially increase engineering costs by 5–15 %. During module fabrication, tolerances tend to accumulate, and must be carefully estimated and highlighted at the design stage and on the tendering drawings; otherwise, the overall module dimensions may not be compatible with the slot allocated within the reactor building, the turbine and other auxiliary buildings. Tolerance accumulation should be checked on the assembly drawings and monitored during fabrication at the module factory. Modules tend to have an uneven and highly irregular weight distribution, which makes the overall centre of gravity harder to calculate, hence added risks of lifting accidents may induce serious hazards to workers and possible costly schedule implications.
- — Procurement and delivery become particularly critical with parallel construction. Much closer coordination is required between civil construction and module fabrication since they must happen in parallel, and both must accommodate and respect the module lift schedule.
- — Although factory module fabrication tends to be faster than individual component installation in situ, module transportation, lifting and alignment are complex manoeuvers that require longer allotted durations on the integrated schedule.
- — Increased coordination of the movement of workers and materials at the site caused by parallel construction and more demanding contractor oversight increase the complexity of construction management. Project managers should have previous experience with modularization to implement the coordination processes required to get the right material in the right place at the right time. Closer oversight of module fabricators becomes necessary. Influence and centralized power may shift from the general contractor to speciality module fabricators. As a result, the project manager will have to deal with substantial adjustments to the work breakdown structure.
- — Turnover activities will also have to change since modularization is usually carried out by volume rather than by system to allow clean room set-up and system commissioning to occur in parallel with continued installation. Open communication of information, drawings, data, critical path, schedule milestones, transportation and delivery requirements, as well as project decisions, must be delivered in real time among the several headquarter sites, including the owner's own organization, the main technology vendor, the detail design support organizations, suppliers and contractors.
- — Modularization presents great benefits for subcontractors and interfacing stakeholders; however, it must be noted that even with the implementation of best practice mechanisms, a keen awareness of its inherent risks must be acknowledged.

— Durations of the integrated schedule must be carefully estimated to correctly predict module transportation and installation activities. These durations tend to be underestimated, and they usually increase proportionally to the size and weight of the modules.

Modularization may require a compressed financing plan, since concentrated workforce peaks and costs will be incurred, as shown in Fig. 8.

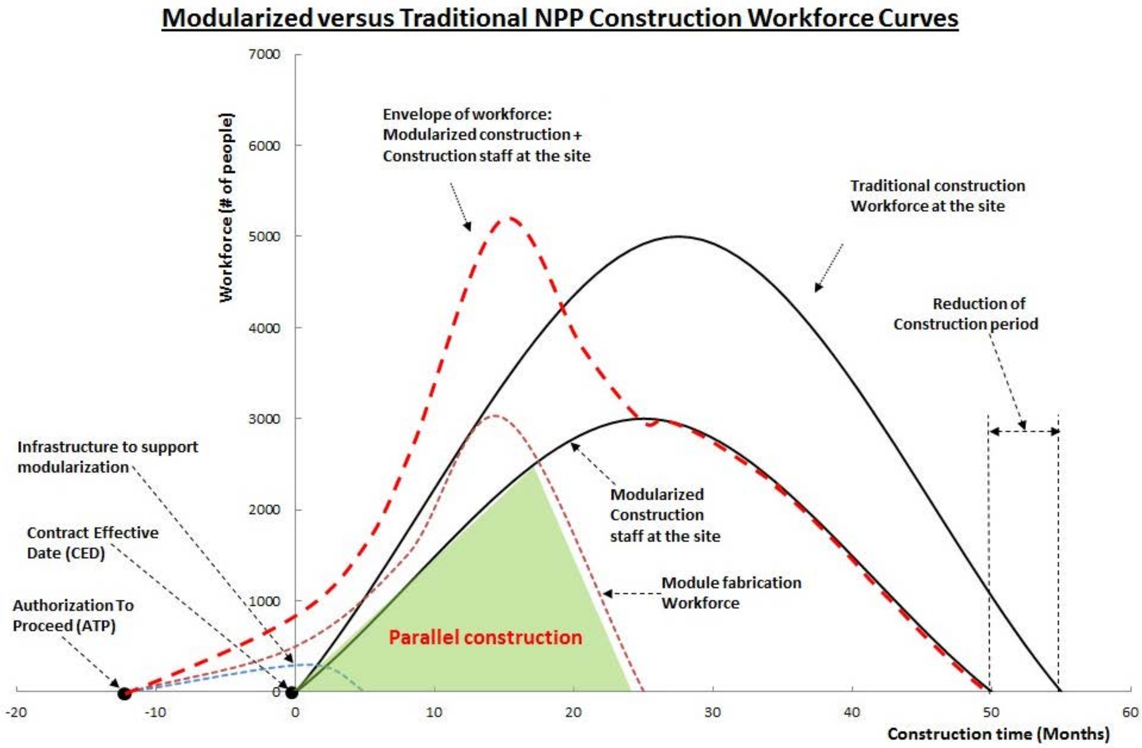


FIG. 8. Shift of the workforce utilization curve in a modularized NPP project.

Some of the key cost change drivers are listed below:

— Increased cost of the infrastructure at the site to support accessibility for oversized and overweight modular assemblies (see lower curve in Fig. 8);
— A higher workforce peak to implement parallel construction and installation of civil, mechanical and electrical work (see dashed line with the highest peak in Fig. 8);
— Increased cost of transportation to handle oversized modules;
— Higher rental fees associated with the use of special VHL cranes;
— Increased cost and effort required to mount and dismount temporary materials used to stiffen modules during transportation and lifting;
— Increased effort to create clean and protected work areas around the modules containing sensitive components after their installation, in order to allow parallel construction activities without risking damage to the installed modules;
— Increased surveillance to ensure that built-in anchor bolt locations and attachment holes on the modules meet tight tolerance requirements for module fit-ups;
— Increased risk of complex construction deviations associated with failed attempts to achieve tighter tolerances for anchors supporting the incoming modules;
— Increased precision and tighter alignment tolerances when connecting rigid large bore piping spools and other linear components across adjacent modules;

— Increased complexity and quality control of overhead welding in tighter working spaces inside modules and between modules;
— Increased difficulty in controlling deformation of large modules during fabrication, shipment and installation with possible consequences on the schedule.

In summary, assuming that everything is carried out correctly, modularization can mean a reduction in the construction schedule, and also earlier startups and electricity production. However, local conditions may not always favour modularization. The complexity of the planning and implementation associated with a fully modularized NPP construction project should be carefully analysed. The risk of failure is not to be ignored, especially for a first unit. If the risk of errors is high, the consequences should be carefully considered. Remediation and rework may cause important schedule delays and substantial cost increases.

In countries with a mature nuclear power industry, modules could be partly ordered nationally and partly outsourced abroad, depending on bid evaluations that independently consider quality, cost and schedule requirements.

In newcomer countries, if the cost of labour is low and unemployment is high, there may not be political and economic advantages in outsourcing module fabrication. In addition, if maximizing construction jobs in the country is encouraged through tax incentives or otherwise, a traditional stick based construction model may be preferable to a modularization model if module assembly must be carried out at fabrication sites abroad.

Every project is unique, and conditions vary greatly. Given the complexity of the decision making process regarding the use of modularization, decision tools, which include a decision support flow chart, a strategy analysis and a systematic review of partial modularization alternatives, can lessen the burden of decision making.

Appendix III

COUNTRY REPORTS

The following country reports have been provided to the IAEA by Member State representatives who reviewed this publication as a draft and contributed to it with first-hand experience from newcomer countries that were at the time involved in the preparation of feasibility studies for the introduction of nuclear power in their own countries.

III.1. VIET NAM

III.1.1. Brief description of feasibility study results

III.1.1.1. Project history and status

On 25 February 2008, the Communist Party Secretary Board of Viet Nam developed an investment policy for Ninh Thuan NPP. The 12th National Assembly of the Socialistic Republic of Viet Nam approved it with resolution 41/2009/QH12 (25 November 2009). Both the Ninh Thuan 1 and Ninh Thuan 2 NPP projects comprise two units of capacity 1000 MW(e) each, to be located in the Vinh Truong and Vinh Hai communes of Ninh Thuan province, respectively. The project goal is to supply electricity to the national power grid, contributing to the socioeconomic development of Ninh Thuan province, in particular, and of the country as a whole.

On 18 March 2010, the Prime Minister appointed EVN to be the project owner of Ninh Thuan 1 & 2. EVN established a nuclear power management board (EVNNPB) to execute the project. On 24 June 2010, the Prime Minister signed the approval of the ‘general development plan for the application of nuclear energy for peaceful purposes extending to 2020’.

The Government of Viet Nam decided to select the Russian Federation to cooperate with for Ninh Thuan 1 NPP construction and Japan for Ninh Thuan 2.

III.1.1.2. Economic background

- Population 2010: 86.2 million people; density: 260 persons/km^2;
- Gross domestic product (GDP) in 2011: $119 billion; average income: $1300/a; GDP growth rate: 6–8.5%/a;
- Economic structure and GDP composition: (i) agriculture, forestry and aquaculture (20%), (ii) industry and construction (42%), and (iii) services (38%);
- Recent energy demand and growth:
- Energy: 2001: 25.8 × 10^9 kW·h; 2010: 87.7 × 10^9 kW·h (increment: 3.4 times/9 years);
- Power: 2001: 5655 MW;2010: 15 453 MW (increment: 10.7%/year).

III.1.1.3. Project data

Ninh Thuan 1 NPP

- Site: Vinh Truong village, Phuoc Dinh commune, Thuan Nam district, Ninh Thuan province;
- Capacity: four × 1000 MW in two stages (stage 1: two × 1000 MW; stage 2: two × 1000 MW);
- Reactor type: advanced proven LWR technology;
- Project life: 60 years;
- Site area: 502 ha.

Ninh Thuan 2 NPP

- Site: Thai An village, Vinh Hai commune, Ninh Hai district, Ninh Thuan province;
- Capacity: 4 × 1000 MW in two stages (stage 1: two × 1000 MW; stage 2: two × 1000 MW);
- Reactor type: advanced proven LWR technology;
- Project life: 60 years;
- Site area: 514 ha.

III.1.1.4. Project organization

The Government appointed EVN to be the project owner for the Ninh Thuan 1&2 NPP projects. EVN established EVNNPB, which will be the management organization and contact point, and which will closely cooperate with consultants during project implementation as follows:

- Supervision of the site survey and other investigations for the SAD and the FS of the Ninh Thuan 1&2 NPP, and execute a review before acceptance according to the agreed schedule defined in the contract;
- Solve problems raised during the investigation and design processes, and support the consultants when required in its relationship with the local authority at the NPP site;
- To participate in all review meetings.

III.1.1.5. Contract type

- Project management during construction: EVNNPB;
- An EPC contract type is expected to apply for the construction of Ninh Thuan 1&2 NPPs.

III.1.2. Experiences and lessons learned from the preparation of the feasibility study

III.1.2.1. Objectives of the feasibility study

The main activities of this study are as follows:

- Conduct site surveys to evaluate if the NPP can be designed and constructed safely;
- Evaluate the site adequacy based on the site survey results while the environmental conditions are used as input information for the basic design;
- Evaluate the basic design and the type of advanced LWRs that the vendors are able to offer with the output capacity required in Viet Nam;
- Evaluate and propose the development of the infrastructures required at each of the construction, operation and decommissioning phases of the NPP projects;
- Conduct economic evaluations and financial analyses in order to confirm the feasibility and the business case for the NPP electricity generation project.

III.1.2.2. Methodology

Consultants conducted studies in order to examine the technical and economic feasibility of the NPP introduction project. These studies were largely categorized by one of two subjects: evaluation of the site adequacy or evaluation of the project's feasibility.

Evaluation of site adequacy [21], consisting of site surveys and site evaluation, was conducted to protect the public and the environment from the impact of radiation that may be released from radioactive materials, in accordance with the best international practices in terms of nuclear safety. Evaluation of project feasibility consisted of:

- Evaluation of the plant's basic design to confirm its technical feasibility, based on the reactor type selections and the NPP plot plan at the candidate site areas;

— Improvements to the area's capability to receive a NPP, such as the development of infrastructures;
— Economic studies to confirm the project's feasibility as a power generation business — these are to confirm the technical and economic viability to construct and operate the NPP under the environmental conditions of the candidate site locations.

III.1.2.3. Site selection and environmental impact analysis

Based on site survey results, evaluations of tsunamis, ground motions and data regarding wave directions and heights for the design basis are being conducted. These evaluation results will become input data to the plant's basic design. Seismic evaluation is the most important item in order to confirm the site adequacy; establishment of design basis ground motions is also important as it will be an input to the 'seismic design'.

In addition to the evaluation, items such as impact of radiation and environmental radiation control plans are being developed as part of the EIA on the site surroundings from the NPP operation. An emergency preparedness plan in case of accidents will also be produced.

III.2. TURKEY

III.2.1. Brief description of feasibility study results

III.2.1.1. Project history and status

Nuclear power first appeared in Turkish development plans in 1968. Turkey's first FS for nuclear power was launched in the early 1960s. Two suitable sites (Akkuyu and Sinop) were identified for building NPPs, and the Akkuyu site was licensed in 1976. Several more attempts were made to build a nuclear reactor at the Mediterranean site of Akkuyu Bay, but they did not get beyond the planning stage.

The political commitment to having greater nuclear power in the energy mix was reiterated in an electricity energy market and supply security strategy document issued in May 2009 by the Prime Minister's office, which set out a goal of 5% nuclear power generation by 2020. Hence, the Ministry of Energy and Natural Resources (MENR) negotiated with some countries in order to construct a NPP. Nuclear efforts have proceeded in the form of an intergovernmental agreement (IGA) between the Turkish and Russian Federation governments. The IGA was signed in May 2010. Akkuyu Nuclear Generating Station Elektrik Üretim A.Ş (or Akkuyu Electricity Generation JSC) was incorporated in Turkey in December 2010.

III.2.1.2. Economic background

This project is a Russian Federation company project, and does not include a State company from Turkey. A Russian Federation company is financially responsible for the project.

The IGA calls for the Turkish Electricity Trading and Contracting Company (TETAS) to buy 70% of the electricity from reactors 1 and 2, and 30% of the electricity from units 3 and 4 at an average weighted price of $0.1235/kW·h. The remainder of the electricity will be sold on the free market. The term of the power purchase agreement (PPA) is 15 years. Turkish and third party investors will have the opportunity to purchase stakes in the JSC. The Turkish party has the right to obtain 20% of the net profit of the project company after the PPA expiry dates. The Russian Federation party will always have the majority share of the power plant (i.e. a 51% share.).

III.2.1.3. Project data

The Turkish–Russian Federation IGA calls for the formation of a JSC, to be initially funded entirely by the Russian State nuclear entity ROSATOM, which will be responsible for the construction, operation and decommissioning of the NPP. The Russian group established a project company in Turkey (initially, 100% Russian Federation share). ROSATOM will serve as the contractor for the construction of four of its VVER-1200 (water–water power reactor) type nuclear reactors. The commissioning of the first unit is expected to be completed in 2019, as shown in Fig. 9, with subsequent units coming on-line over the following 3 years.

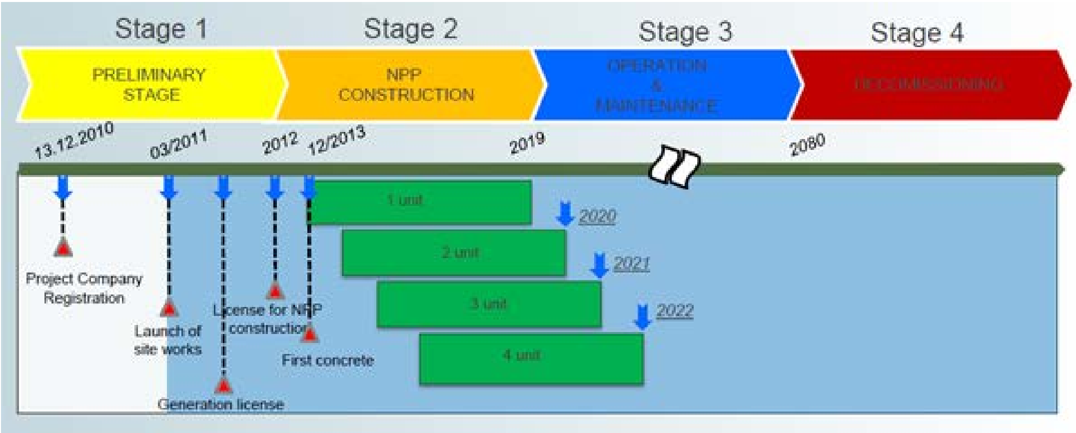


FIG. 9. *Major phases and milestones of the Akkuyu project.*

III.2.1.4. Project organization

The MENR is responsible for the preparation and implementation of all energy policy and planning studies in Turkey. The coordination of all nuclear power related activities fall within the responsibility of the MENR, as shown in Fig. 10.

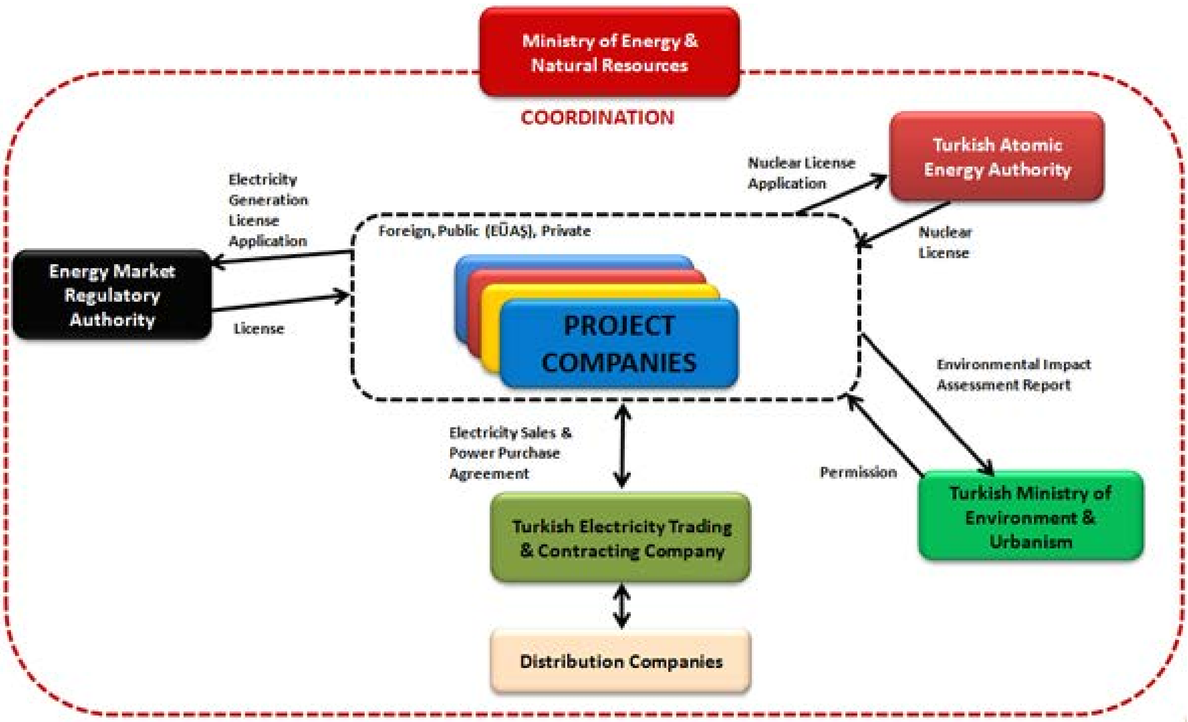


FIG. 10. *Nuclear project organization in Turkey.*

The Turkish Atomic Energy Authority (TAEK) is the regulatory body responsible for the licensing of all nuclear facilities, including NPPs. The TAEK is also responsible for physical security and safeguarding of nuclear sites, executing and supporting nuclear R&D, licensing of imports and exports of nuclear material, transport of nuclear material and nuclear facility inspection.

The Energy Market Regulatory Authority (EPDK) is responsible for granting licences, defining the rights and liabilities of the legal entities pertaining to their authorized activities (including nuclear power generation) in the electricity market.

The Ministry of Environment and Urbanization is responsible for carrying out the review and regulation of the EIA and implementation of the EIA for all power plants, including NPPs. TETAS is the wholesale public company responsible for electricity wholesales and purchases, making PPAs with the nuclear project companies.

III.2.1.5. Contract type

The contract type is the IGA model (BOO) and long term contracts in the frame of PPAs.

III.2.2. Experiences and lessons learned from the preparation of the feasibility study

III.2.2.1. Akkuyu project

(a) Objectives of the feasibility study

The objectives of the FSs, which were carried out previously, were to evaluate the proposed site for suitability for the NPP, to propose further investigations concerning the site geology, meteorology, hydrology, etc., to evaluate and compare the technical and economic features of the reactor types, to determine the requirements of nuclear fuel and capacity of plant, to determine a preliminary cost estimate for the plant's capital investment and operating costs, to prepare the construction schedule of the plant, and to review the conditions of connection of a NPP to the interconnected electrical system.

(b) Methodology

The contract type is the IGA model (BOO) and long term contracts in the frame of PPAs.

(c) Site selection and environmental impact analysis

The Akkuyu site was selected as the location to construct the NPP. FSs for this site have been carried out many times in the past. The EIA report for the Akkuyu site was presented to the Ministry of Environment and Urbanization by Akkuyu NGS Co.

(d) Project management approach

An IGA has been signed between the Turkish and Russian Federation governments.

(e) National involvement

In reference to the IGA signed for the Turkish–Russian Federation Akkuyu plant, NGS will provide the necessary equipment, as per the agreement. Additionally, in an effort to increase the localization rate within the context of this agreement, the MENR has been enlisted to assist with the implementation of certain activities.

(f) Project cost estimation

The Akkuyu project is expected to have a total capital expenditure of around $20 billion, with an operating life of 60 years.

(g) Stakeholder communication and involvement

For the IGA, Turkey's Ministry of Energy and Natural Resources, Turkey's Energy Market Regulatory Authority, the Turkish Atomic Energy Authority, TETAS, the grid operator, Turkey's Ministry of Environment and

Urbanization, governmental organizations, environmental authorities, local authorities, financing organizations, manufacturing industry, service companies and the local and national public are involved in the project. Communication with these stakeholders will be conducted during the construction and operation of the NPP project.

III.2.2.2. Sinop NPP

For another NPP site, Turkey has made an agreement with the Republic of Korea firm KEPCO, and is in talks to build a second nuclear reactor facility at Sinop on the Black Sea coast. The MENR favours a public–private partnership model for the Sinop project, whereby the Turkish side would participate in the investment and construction processes.

A joint declaration between KEPCO and Turkey's state owned electricity generation company was signed for the Sinop NPP in March 2010. KEPCO and EUAS conducted a joint study on the construction feasibility and economic viability of the adoption of four APR-1400 (advanced power reactor) in Sinop. A scope of study included tariff calculation, the regulatory and legal framework, the commercial provision of the project and financing issues, and a study of the environment, the fuel supply, safety, training, decommissioning and waste management. A detailed joint study report was prepared to improve the common understanding of the Sinop site information between Turkey and KEPCO. This study also produced some input data ready to estimate the construction cost by conducting and checking site surveys on the Sinop site.

III.3. NIGERIA

III.3.1. Project history and status

Presently, the main sources of energy generation in Nigeria are gas, oil and hydroelectricity. The total installed capacity is approximately 8000 MW(e), out of which only approximately 4000 MW(e) is generated. This has an adverse effect on the economic growth of the country, as economic growth is related to power generation and consumption. According to the latest statistics from the Power Holding Company of Nigeria (PHCN), the basic electricity generation required to sustain economic growth is 2.5 kW(e) per capita based on the current United Nations population estimate, which places Nigeria as the seventh most populous country, with over 170 million people. Currently, Nigeria's per capita generation is about 0.03 kW(e) (source: PHCN). With this shortfall, there is the requirement for alternative sources of energy. In a bid to address this gap, the Federal Government has embarked on a number of strategies and action plans, such as the building of a significant number of new power projects and expansion of the transmission network. Furthermore, the Federal Government has decided to unbundle the PHCN to ensure effective management and policy implementation.

These demand and supply analyses provide a long term energy security system that allows access to a diversified portfolio of source options. As a result of the need to urgently address the energy situation in the country, the IAEA and other institutions (notably, the Energy Commission of Nigeria) have provided integrated models for both demand and supply analysis, for example, MAED for the demand analysis using scenarios integrating social, economic and technical factors that influence energy demand.

As a follow-up to this, the Government came up with a policy and strategy for use of NPPs in electricity generation in Nigeria. In recognition of the role of nuclear energy in the electricity crises, the Government of Nigeria in 2006 reactivated act 46 of 1976, which established the Nigeria Atomic Energy Commission (NAEC). The act gave the NAEC mandate of the focal institution to develop a technical framework to harness and apply nuclear energy for peaceful uses.

The roadmap for the deployment of NPPs for electricity generation in Nigeria and its strategic implementation plan have been developed and approved for implementation by the Federal Government. The technical framework is a three phase plan aimed at positioning Nigeria to generate electricity from NPPs in 2020 with considerable national participation.

III.3.2. Experiences and lessons learned from the preparation of the feasibility study

The objective of the FS was to ascertain the possibility of siting and operating a NPP in the areas selected. The plant is expected to reduce the gap in energy between demand and supply.

To achieve the above objective, an appropriate committee consisting of experts in various fields was set up to perform the study. The committee made use of questionnaires and conducted oral interviews. In addition, they collected available data from relevant ministries and agencies, performed field visits to gather more data, analysed these data, and organized workshops and seminars where the results of data analysis were discussed with relevant stakeholders. This exercise took place between 2007 and 2009.

In order to ensure the successful deployment of NPPs in the country, site survey and evaluation exercises were carried out by the Commission, and four candidate sites were obtained and ranked. Two of the sites, located at Geregu in Ajaokuta local government area of Kogi State and Itu in the Itu local government area of Akwa Ibom State, which emerged as the most suitable, have been designated for further detailed characterization. They have been recommended to the Government for approval.

The EIAs of the two selected sites have been evaluated with respect to the release of radioactive material into the atmosphere, effect on aquatic organisms, flora and fauna, pollution of water sources, agricultural land use, effect on the sociocultural aspects of life of the people, etc. The results did not demonstrate any cause for alarm.

The legislative framework for the establishment of a national nuclear insurance policy and scheme to adequately address the civil liability component of the nuclear power industry is being developed in collaboration with relevant stakeholders. The Government is also being positively sensitized to ratify and domesticate all other relevant international statutes, treaties and conventions related to effective management of the NPP.

As an emerging economy with limited infrastructure, Nigeria would adopt an established NPP technology with a good track record and operational experience. Such a technology should be reasonably standardized, amenable to easy maintenance, with a clearly defined vendor support programmes.

Nigeria intends to enter into agreement with the reactor vendor for supply of nuclear fuel throughout the life cycle of the plant. In addition, as Nigeria does not intend to reprocess spent fuel, an appropriate agreement will be reached with the vendor to collect back spent fuel after usage. Furthermore, Nigeria is implementing a waste management policy, and a low and intermediary waste management facility is already being built in Sheda.

In recognition of the place of the public in the overall success of the nuclear power programme, NAEC has developed appropriate ways and means of communicating effectively with the public. This is achieved through the use of electronic and print media. In addition, seminars and conferences are often organized by stakeholders. The results obtained have been encouraging.

Partnership between the NAEC and universities provides a productive interface to quickly grow the critical workforce required for programme implementation and contributes to the development of local capacity in participating universities, which ultimately will take full ownership of the programme and its implementation.

III.4. JORDAN

III.4.1. Project history and status

The Jordanian nuclear power programme was officially launched in 2001, when the nuclear energy and radiation protection law established the Jordan Nuclear Energy Commission to both promote and regulate nuclear energy in the country. In July 2007, to clearly separate the responsibility for the promotion and regulation of nuclear power, two key agencies were established by law: the Jordan Atomic Energy Commission (JAEC) and the Jordan Nuclear Regulatory Commission.

Key activities associated with implementing a nuclear power programme have been initiated:

— Adoption of international nuclear treaties;
— Establishment of Jordanian nuclear legislation;
— Ongoing educational and training programmes for implementing the nuclear energy programme;
— Productive cooperation with the IAEA and other international organizations;
— Bilateral agreements with many countries for cooperation in the nuclear power area;

— Development of uranium exploration and mining;
— Implementation of a research reactor programme to be completed in 2015;
— Site selection for the first NPP;
— Selection of nuclear technology vendor and investor/operator for the first Jordanian NPP;
— Execution of a plant construction contract, including an early works phase;
— The start of commercial operation of Jordan's first nuclear power station is scheduled for 2021/2022.

Particular attention has been paid to the selection of the nuclear power technology. After initially investigating the available nuclear technology options, JAEC preselected three vendors and technologies. A competitive dialogue (CD) approach was implemented to expedite the final selection.

During the first phase of the CD, JAEC gathered detailed information from potential technology vendors and their owner/equity partners on the technical, project management, financial, ownership and contracting provisions that each had to offer. Three candidate reactor models, and therefore their vendors, successfully advanced to the next phase of the CD: the Canadian EC6, the French–Japanese ATMEA-1 and the Russian Federation AES-92.

A detailed BIS was developed and issued to the three technology vendors, with the BIS clearly specifying Jordan's requirements and evaluation criteria. The BIS was amended to address issues arising from the Fukushima Daiichi accident.

At the end of April 2012, following the completion of the bid evaluation, two models (ATMEA-1, AES-92) were shortlisted and recommended to the Government of Jordan (GoJ). In June 2012, these vendors were invited to revise their bids based upon an updated project profile. The revised bids will form the basis for final technology selection.

In parallel, an investor/operator invitation for expression of interest was issued in August 2011. The selected investor/operator will take a share in a utility company that will be formed to own and operate the plant. The GoJ will be a co-owner of this utility company.

III.4.2. The requirement for nuclear power in Jordan

Jordan is completely dependent on imports to cover its primary energy needs. About 96% of Jordan's electricity generation is fuelled by imports, of which 80% is imported natural gas from Egypt.

Jordan's total generation capacity is currently around 3000 MW. Its generation system consists of 1520 MW combined cycle gas turbine power plants, 860 MW steam units and 570 MW gas turbines. To operate the existing power plants, the system depends completely on imported natural gas.

A comprehensive electrical demand forecast for Jordan has been developed. The projected electricity demand requires a total electricity generation capacity of more than 14 000 MW by 2040, with an annual average growth rate of approximately 6%.

Nuclear power has been selected to play an important role in meeting this demand growth for the following reasons:

— NPPs are capable of providing sufficient baseload electricity to meet the projected steadily increasing energy demand.
— Use of nuclear energy will ensure diversification of energy resources away from imported fossil fuels.
— Nuclear energy and utilization of Jordan's uranium resources will increase the energy independence of the country.
— Use of nuclear energy instead of imported fossil fuels will improve the balance of payments position of Jordan.
— Nuclear power does not emit greenhouse gases (GHGs), and will make a considerable contribution to Jordan's efforts to reduce GHG emissions.
— Electricity from the NPP will be provided at a stable and competitive price.

III.4.3. Project details

III.4.3.1. Specification

Jordan requires a modern Generation III or III+ NPP of between 1000 MW and 12 000 MW that will meet the international standards of safety, fuel supply and waste management, operation and efficiency. The specific requirements of Jordan are to:

— Minimize the size of the emergency planning zone surrounding the plant after an accident;
— Sustain a high level seismic event;
— Sustain the impact of a large commercial aeroplane;
— Ensure the security of the fuel supply, fulfilling non-proliferation obligations and HLW management objectives;
— Minimize water use;
— Construct one unit with the option for a second unit;
— Have an operational lifetime of 60 years with an availability factor of over 90%.

Both of the shortlisted technologies satisfy all of these requirements.

III.4.4. Project structure

The financial structure has not been established, although the GoJ expects that it will have an ownership share of between 26% and 51%, with the balance of equity held by a strategic partner. The strategic partner is important to the project, as it will bring project management and operational experience to the project.

III.4.5. Project contract

The contracting approach will be an EPC turnkey contract. A technology transfer process will enable the owner to operate and maintain the plant in accordance with the requirements of the technology. The scope of the EPC contract will include design, all engineering, procurement of all plant equipment, labour, technical and professional services and construction activities associated with the works inside the plant fence from the contract effective date until the commercial operation date. The scope will also cover training, delivery, transportation, including loading and unloading, the simulator, testing, commissioning, supply of nuclear fuel for the first core and a number of reloads, as well as putting the NPP into operation and all necessary adjacent infrastructure, general management of the project, quality assurance and quality control, licence and permit support, and any other works required for delivery of an operational and licensable plant.

III.5. HUNGARY

III.5.1. Brief description of the feasibility study results

III.5.1.1. Project history and status

After several attempts for enlargement of the four WWER 440/V213 units of the Paks NPP in 2006, some studies were made by Hungarian institutions on a new nuclear build. A new project, named Teller, was established in mid-2007 inside the State owned utility MVM Ltd for preparation and acquiring parliamentary approval. Over a time period of approximately 6 months, 12 Hungarian firms and enterprises put together three documents, namely, an FS, a preliminary EIA, and an analysis of storage of spent fuel and radioactive waste from the new units. It was submitted to the Ministry, and on 30 March 2009, the Government and Parliament gave the go-ahead for continuation of work.

The projects carried out electrical system analyses, assessed demand and supply trends, and surveyed markets for the electricity trade and NPP procurements. The financing was made possible by investments of MVM and some strategic and financial investors, without any direct aid from State budget sources. The majority of MVM will be kept in the project company. Recently, some limited BOT options were also investigated.

III.5.1.2. Project data

Two units in the 1000–1600 MW range are on the Paks site, namely type III or III+ PWRs, with a lifetime of 60 years and a deep (50–100%) load following capacity (not a first of a kind unit). The startup of the first new unit is scheduled for the early 2020s (originally scheduled for 2020, but more realistically will be 2022–2023), and the time shift between the units is 2–5 years (type dependent).

III.5.1.3. Project organization

In the early stages of the preparatory projects, there was involvement by leading experts, mainly from the Paks NPP. Inside the plant, a new directorate was formed for the operative management of the project. At the same time, the financing and project leadership decisions were attributed to the MVM high ranked managers. Later, MVM also withdrew the operative leadership from its own control. Over the next few months, the project company worked to create a vision, and at this stage, there were approximately 40 experts working on the project on a full time basis, with several Hungarian contractors supporting the project efforts. In a few instances, some areas of the project also involved input from international experts, for example, for the BIS review, for a law consultant, for IAEA missions, etc.

III.5.1.4. Contract type

The first new unit will be turnkey. For the second, a deeper involvement of the buyer is anticipated.

III.5.2. Experiences and lessons learned from the preparation of the feasibility study

III.5.2.1. Objective of the feasibility study

Obtain Parliament approval, required by atomic law, to start preparatory activities for the extension of Paks NPP.

III.5.2.2. Methodology

For FSs, content determination and international good practices have been employed. The best domestic performers (research, engineering, design and investment institutes, consulting firms, banks, universities, law firms, electricity traders, public relations consultants, etc.) have been involved. Their knowledge in the very specific FS topics may not be as great or advanced as in the leading international firms, but they are certainly quite knowledgeable of the situation in Hungary, and their participation and experience accords them the possibility of being strong contributors to future nuclear projects.

III.5.2.3. Site selection and environmental impact analysis

In the late 1990s, a full review of the potential sites was made by the Hungarian Erőterv Ltd, with contributions by the Belgian organization Tractabel. Although they found four greenfield sites in the central–eastern region of the country, they maintained that the best site remained Paks, with its existing nuclear units.

III.5.2.4. Project management approach

In the early stages, there were two preparation projects (Teller and Lévai); later on, there was a new project company, as a daughter of the State owned MVM Ltd utility.

III.5.2.5. National involvement

During a survey conducted in the spring of 2011, approximately 200 applicant firms submitted their information packages in four main areas (mechanical, electrical, I&C, architect construction and engineering, scientific or service backgrounds). Following a selection process, more than half of them were considered as powerful potential participants. The list, contacts and short information packages will be attached to the BIS. The domestic participation share has been estimated by the project on a level no higher than 30–35%.

III.5.2.6. Project cost estimation

This was based on type and region specific costs. The original target value was between €7 and 10 billion, and during the last few years, owing to economic issues and the impact of the Fukushima Daiichi accident (safety enhancements and increased economic risk), this number has increased.

III.5.2.7. Stakeholder communication and involvement

In recent years, communication has been initiated with all stakeholders (i.e. the nuclear regulatory body, the grid operator, governmental organizations, environmental authorities, local authorities, financing organizations, manufacturing industries, service companies and the public). There are continued regular consultations with them, and the systematic public relations actions with respect to the general public are based on carefully developed communication strategies.

III.6. EGYPT

III.6.1. Brief description of the feasibility study results

III.6.1.1. Project history and status

The Egyptian economy has maintained robust growth momentum in recent years, with real GDP growth averaging 7.1% during 2005/2006–2009/2010. Among the principal stimulants of Egypt’s prominent economic performance is the implementation of structural reforms, coupled with increasing integration of the Egyptian market in the global economy, supported by favourable external conditions. In 2011, the actual GDP was $355 billion, and the GDP per capita was $2900.

III.6.1.2. Project data

— A PWR type was selected for the first plant, of model Generation III or III+;
— The lifetime of the plant is 60 years;
— A NPP consists of one or two units, with a rated power per unit of about 1000 MW(e) or more;
— Baseload operation, however, the plant could be operated in load following;
— A reference plant of proven design, with cooling by sea water;
— A financial proposal to cover at least 75%;
— A spent fuel pool capacity with 10 years of operation at least;
— A waste storage facility with at least 10 years of operation;
— An annual capacity factor of 90% and an annual availability factor of 90%;
— Licensing and safety of the NPP should comply with the national nuclear regulations of the contractor’s home country and IAEA Safety Standards.

III.6.1.3. Project organization

The NPP's Authority (NPPA), as the owner of the plant, is an authority within the Ministry of Electricity in Egypt, and its Chairman directly reports to the Minister for Electricity. The NPPA has been formed for the implementation and operation of the nuclear power programme in Egypt, and has been in existence since 1976.

III.6.1.4. Contract type

In view of the fact that this is the first nuclear power project in Egypt, the NPPA decided to select the turnkey contracting approach to implement the project.

The NPPA shall provide oversight functions and monitoring of the contractor activities through performing surveillance, audits and regular reviews of various contractor activities.

III.6.2. Experiences and lessons learned from the preparation of the feasibility study

III.6.2.1. Objectives of the study

The main objective of the study was to provide the decision makers with the necessary information regarding the technical and economic feasibility and viability of the nuclear option for electricity generation. In particular, the study was intended to provide the following information:

— Analysis of the Egyptian economic situation and estimation of future requirements for electricity and water;
— Technical and economic evaluation of nuclear power generation and desalination systems;
— Evaluation of local participation capabilities and impacts on Egyptian developmental efforts;
— Financing requirements and methods;
— Necessary conditions for launching a successful nuclear power project;
— Recommendations on the use of nuclear energy for electricity generation.

III.6.2.2. Methodology

— The present worth technique, based on constant money terms, is used to calculate the levelized power costs. In the levelized power costs estimation, the present worth of all revenues received from selling electricity is just equal to the present worth of all expenditure, e.g. return and investment costs, O&M costs, fuel costs, etc.
— The levelized electricity production cost is assumed to be constant throughout the lifetime of the power plant, and is calculated by dividing the annual required revenues by the annual electricity generation.

III.6.2.3. Site selection and environmental impact analysis

The NPPA has a qualified nuclear site at El Dabaa. The NPPA completed the required site permit application studies for the El Dabaa site and submitted it to the Egyptian Atomic Energy Authority on 23 February 2010. The general conclusion of the El Dabaa site studies was the suitability of the site to receive up to 4000 MW(e) units, as well as a desalination plant. The site studies and investigations were performed according to the French regulations and practices. Situated in an ideal coastal setting (150 km west of Alexandria), the El Dabaa site is well suited for basement construction owing to the low seismic activity of the area, and its highly desirable geological and topographical characteristics. Furthermore, it is known that there are minimal thermal, chemical and mechanical impacts in this area. The Egyptian regulatory body released the El Dabaa site permit in August 2010.

III.6.2.4. Project management approach

Since 1964, Egypt has accumulated a significant amount of experience introducing and constructing NPPs. Since then, three trials have been conducted, and the results demonstrate that Egypt's infrastructure is able to support NPP implementation. The NPPA was established by the Egyptian Government in 1976, and is the only utility in Egypt responsible for the introduction and construction of NPPs, for the purpose of electricity generation and water desalination, including any and all necessary actions and activities related to this. In 1977, the Nuclear Material Authority was established to research Egypt's nuclear ore potential, and tasked to manage all the activities and arrangements necessary to industrialize this potential.

The National Centre for Nuclear Safety and Radiation Control was established in 1982 and assigned the responsibility to regulate the nuclear and radiation application(s).

After a comprehensive review of the Supreme Council for Peaceful Uses of Nuclear Energy, it was decided that the council would be led by the President of the Republic and assisted by appropriate ministers.

The main responsibilities of this council include managing, coordinating and supporting the project activities.

The Ministry of Electricity and Energy is the lead organizer of all second level project management, while the membership of the project management committee is composed of the responsible corresponding authorities. The NPPA is directly responsible for the management and implementation of the project(s), with technical assistance provided by selected consultants with experience in the field.

III.6.2.5. National involvement

Local participation in the execution of El Dabaa NPP implies the use of material, workforce resources, construction, engineering and manufacturing capabilities, in Egypt, in all phases of the project. The NPPA has a list of qualified Egyptian suppliers in the areas of construction, engineering and manufacturing. Local participation will reach 30% of the total price for the first nuclear plant, and will increase to 40% for the second unit.

III.6.2.6. Stakeholder communication and involvement

The NPPA and the Ministry of Electricity have a plan with the communication responsibilities of each stakeholder.

III.7. BELARUS

III.7.1. Brief description of feasibility study results

III.7.1.1. Project history and status

Belarus began preparations for an NPP in the 1980s, with 2000 MW(e) near Minsk and for construction of a 6000 MW(e) in the Vitsebsk region. After the Chernobyl accident, both of these projects were cancelled. During energy planning activities, nuclear power was again considered in July 2006 when the Government of the Republic of Belarus included the evaluation of the introduction of nuclear power into the national energy development plan.

Currently, electricity in Belarus is generated mainly by thermal power stations, with a minor contribution from small hydroelectric power stations. There is a heavy reliance on oil and natural gas imports, mostly from the Russian Federation, although local peat and wood are also used as fuel. Belarus power stations capacity totals 8.2 GW. Belarus imports electricity from the neighbouring energy systems of the Russian Federation and Ukraine. The share of natural gas in the energy system for the generation of electricity and heat for centralized heating systems has reached 95%, which badly affects the country's energy independence. In this context, Belarus considers that the introduction of nuclear power can address this lack of energy independence.

For coordination of the Belarus nuclear power programme, an interdepartmental commission was created, which is headed by the First Deputy Prime Minister and reports to the Prime Minister. It includes members from all relevant ministries and organizations participating in the nuclear power programme. The interdepartmental commission meets monthly to discuss the issues related to the nuclear power programme and reviews the work performed by each organization. The interdepartmental commission is fully charged and authorized to prepare and oversee the execution of the national nuclear power programme.

III.7.1.2. Project data and contract type

After the political decision in 2008 to launch the nuclear power project, site selection studies and research by Belarus have demonstrated that potential sites for NPP location are available in Belarus. According to the results of studies and research, the Ostrovets site, located in the Grodno region, has been defined as the first priority among the three that were shortlisted. Krasnopolyansk and Kukshinov sites, located in Mogilev region, are reserve sites.

In May 2009, Belarus signed an IGA on cooperation in the field of atomic energy for peaceful purposes with the Russian Federation. This framework specified the main directions of cooperation in the development, design, construction and operation of NPPs, nuclear fuel supply, nuclear and radiation safety, as well as scientific cooperation, training and others.

On 15 March 2011, the agreement between the Government of Belarus and the Government of the Russian Federation on cooperation in NPP construction on the territory of Belarus was signed. Under this IGA, the Russian Federation will supply the nuclear fuel and take back the spent nuclear fuel. Belarus will be responsible for NPP licensing (for the site, design, construction, commissioning and operation). The agreement anticipates that the Belarus local participation will be in the range 30–50%.

The NPP design selected was the improved LWRs of the third generation of Russian WWER types (AES-2006), with a capacity of 1170 MW(e). The project will be implemented on a turnkey basis, with commissioning of the first unit in 2018 and the second in 2020.

On 25 November 2011, an interbanking agreement between VEB (Vnesheconombank, the Russian Federation State Corporation Bank for Development and Foreign Economic Affairs) and BELVEB (Belvnesheconombank, Commercial Bank of the Republic of Belarus) was signed for a $10 billion loan over 25 years in order to realize the project. In March 2012, a contract for preparatory works on the Ostrovets site was signed.

A general contract between the Directorate for Nuclear Power Plant Construction (DNPPC) and Atomstroyexport for NPP construction was signed on 18 July 2012. The plant designer will be Atomenergoproect of St Petersburg, and OKB Gidropress will be the main constructor. In Belarus, the Design Scientific Research Republican Unitary Enterprise 'Belnipienergoprom' will be responsible for the coordination of the design and documentation for construction of the NPP.

III.7.1.3. Project organization

The Ministry of Energy is responsible for implementation of the NPP project through the DNPPC. This is authorized under the master plan of key organizational measures for the construction of the NPP. The DNPPC will also be the operator of the NPP.

The resolution of the Council of Ministers of the Republic of Belarus on a working group to coordinate the implementation of State supervision of NPP construction (No. 1791, 30 December 2011) provides the Department of Nuclear and Radiation Safety Gosatomnadzor, a branch of the Ministry of Emergency Situations, with the authority for coordination among organizations with various regulatory responsibilities, such as those for nuclear materials, the environment and public health. This is important to ensure efficient and effective regulations related to the nuclear power programme.

III.7.2. Experiences and lessons learned from the preparation of the feasibility study

In Belarus, the interdepartmental commission acts as the NEPIO, headed by the First Deputy Prime Minister and reporting to the Prime Minister. Members of the interdepartmental commission are from all relevant ministries participating in the NPP programme. The interdepartmental commission meets monthly to discuss the issues related to the NPP programme and reviews the works performed by each organization. The interdepartmental commission follows up on the actions from previous meetings. The roles and responsibilities of each ministry or organization are defined in government documents. The interdepartmental commission is fully charged and authorized to prepare and oversee the execution of the national NPP programme. Each ministry involved in the NPP programme is responsible for its own budget, offices, equipment and reference material. Special decisions provide for the budget, financing and funding.

Before the general contract and loan agreement were signed, Belarus already had an effective project management system and budget to start preparatory work. The production and transportation infrastructure required for NPP construction was done. In the Byelorussian case, the high level authority to which the interdepartmental commission reports, the full participation by relevant ministries, and the frequency of its meetings can facilitate the swift resolution of any issues, and can be a model of good practice for other newcomers.

III.8. BANGLADESH

III.8.1. Brief description of the feasibility study

III.8.1.1. Project history and status

The proposal for the introduction of a NPP in the western zone of Bangladesh was first conceived in 1961. The Rooppur site in the Ishwardi subdistrict of Pabna alongside the river Padma (a distributary of the Ganges) was selected by considering the applicable criteria, and 292 acres of land (260 acres for the plant and 32 acres for residential purposes) was acquired. Since then, a number of FSs have been conducted, each of which established that the project is technically and economically feasible. However, the project could not be implemented owing to several problems, with financing being the main obstacle. However, the Government of Bangladesh has been working on launching various strategies and action plans to ensure electricity supply to the grid. Over the years, several structural changes in the power sector have been made, and different policies adopted for accelerating the growth of energy and electricity.

III.8.1.2. Economic background

Over the years, owing to the lack of indigenous energy resources, Bangladesh has become a gas dependent, mono energy based country. Currently, around 88% of energy used for power generation is from natural gas sources, 4% from coal, 6% from oil, and just 2% from hydro based power plants. The main source of national energy is found in its natural gas reserves, 55% of which is designated to the power generation sector, while 27% goes to factories and industry, 10% to household purposes and 5% to the automotive sector. With a derated capacity of around 5400 MW on an installed rating of over 6000 MW, only about 4200 MW is actually available. With a maximum generation of 4500 MW in mid-2011, increasing to 4700 MW in late 2011, the peak is anywhere from 5700 MW to 6000 MW, and only about 40–48% of the total population have access to electricity. The consumption (and availability) of 218–230 kW·h per capita is the lowest among any developing country in the world.

In 2005, in an effort to obtain a base electrical growth rate of 8%, the Government developed a power system master plan, which foresees an attainment of 5.2% of compound growth for the required 25% reserve amount. To achieve this by 2025 as peak generation levels reach 20 000 MW, there needs to be an increase in private sector involvement, which would assist in achieving the forecasted requirement of 100 000 GW·h of electrical energy. On the other hand, to accommodate the high growth in electricity (~12%), and to attain 8% compound economic growth, the peak generation should be about 42 000 MW in order to produce 220 000 GW·h of electrical energy in 2025. According to the revised master plan (2010), the forecasted demand would be 19 000 MW in 2021 and 34 000 MW in 2030. To meet this demand, the generation capacity should be 39 000 MW in 2030.

III.8.1.3. Project data

Nuclear energy was identified in the earlier national energy policy (2007) as an important component of the long term generation mix of the country, and the requirement for early implementation of Rooppur nuclear power project (RNPP) was also clearly identified in the policy. Pre-implementation phase activities for construction of two units of 1000 MW reactors on the Rooppur site with a time lag of 2 years was prepared systematically by the Bangladesh Atomic Energy Commission (BAEC) with support from the IAEA and other national organizations during the period 1999–2009. The implementation of two units of NPPs by 2018 and 2019, respectively, will enhance the security of supply of electricity in the country. If the country is able to move steadily forward with these plans for the expanded role of nuclear energy based on cost effectiveness, the security of the electricity supply will increase significantly.

III.8.1.4. Project organization

Considering the role of nuclear power as an important component of the long term generation mix of the country for attaining energy security, a cabinet committee on the RNPP headed by the Prime Minister was formed in 2007 to provide directions to expedite implementation of the project. Several meetings of the Implementation Committee were held, and decisions were taken to expedite implementation of the RNPP. The pre-implementation stage of the NPP is the project decision making stage; therefore, the following two broad strings of activities are planned:

- Technical, economic and financial management of the nuclear power programme;
- Safety and regulatory aspects.

Since these two categories of functions are to be ultimately conducted independently of one another, BAEC is considering addressing each of these for nuclear power in pre-implementation and implementation stages, including capacity building and human resource development activities.

III.8.1.5. Contract type

Another major challenge to the building of NPPs is financing. A project for the building of capital intensive NPPs requires the use of innovative financing schemes. Options such as BOO, BOT, partial financing by the supplier through supplier’s credit, and financing through foreign aid programmes are being considered. The Government will endeavour to explore the possibilities of bilateral funding for the project from friendly countries. Supplier’s credit, if available on favourable terms, would be welcomed. The Government would contact these sources as well as ECAs for this purpose. The Government will provide reasonable finance from its own resources, especially to cover the local scope of the work.

III.8.2. Experiences and lessons learned from the preparation of the feasibility study

III.8.2.1. Objectives of the feasibility study

The FS should identify what must be performed in order to achieve the NPP project goals. Goals and objectives are high level statements that describe what the project is intended to accomplish and what business value the project will achieve, respectively. It is necessary to have a wide range of national involvement as well as international agencies, whose concerted participation is essential to identify the goals and objectives of the study. A number of FSs were conducted, each of which established that the nuclear power project is technically and economically feasible.

III.8.2.2. Methodology

The inordinate delay in project implementation has brought about a number of changes in the planning process. Following three IAEA expert missions (December 2000 to June 2001), the site report was upgraded into a ‘site safety report’ incorporating all safety related parameters, as suggested by the mission. During this period, some additional investigations for the site, mainly in the areas of hydrology and morphological analysis, subsoil investigation, seismic studies and radiological dispersion studies have been carried out as per IAEA recommendations for finalizing the site safety report.

III.8.2.3. Site selection and environmental impact study

The site at Rooppur, located in the western zone of the country, meets internationally acceptable criteria applicable for construction and operation of an NPP. The site, located at a central location of that zone, is also found suitable for easy transmission and distribution of electricity. Nuclear power is found to be more compatible with the environment compared with any of its alternatives. Construction and operation of the plant at the designated site are not expected to cause any ecological or social problems. On the contrary, the project is expected to generate many indirect and spin-off social and economic benefits to the people resident in the locality.

III.8.2.4. Project management approach

A blanket administrative provision is essential to ensure efficient implementation of a Government decision on the national nuclear power programme. The Government of Bangladesh approved a Bangladesh nuclear power action plan recognizing the requirement for a proper institutional framework with adequate financial and administrative power, accountability and transparency. An institution named the Nuclear Power Authority of Bangladesh (NPAB) shall be formed, which, at the national level, shall be responsible to an apex body named the National Nuclear Power Council (NNPC) headed by the head of the government, and the minister in charge of the ministry dealing with matters related to nuclear power will be the vice-president of the NNPC.

The chief executive of NPAB shall be the member secretary of the NNPC. The NNPC will have other members including ministers and/or secretaries of the relevant ministries. The NNPC will provide general guidelines, define policies and review progress of all matters related to the nuclear power programmes of the country. The Ministry of Science and Information and Communication Technology will work as the focal ministry for the nuclear power project until the time it delegates part or whole of its power to the proposed institutional framework for nuclear power projects.

III.8.2.5. National involvement

The scope for national participation in the initial plants would be limited, and the experience and expertise of the manufacturer would form the core of the implementation process. An appropriate perspective plan would be made for the development of human resources, both for the plants as well as nuclear safety and radiation protection, so that the minimum programme can ensure safe, economic and reliable operation of the NPPs. The output of the above process would help determine the scope and extent of domestic participation in the long term perspective. In the case of the first NPP, the scope of the participation of the national industry in the project shall be limited to items that do not have safety implications, and such works, if undertaken by local parties, shall be coordinated under the supervision and total responsibility of the main contractor. The local construction firms and selected industries will have the option to participate in the implementation of subsequent units of NPPs, depending on the expertise acquired and other qualifications for undertaking similar jobs.

III.8.2.6. Project cost estimation

The capital costs of NPP are high, but once built, nuclear power typically has lower fuel and operational cost advantages than fossil fuel plants. According to an OECD NEA study [87], at a 5% discount rate, a 91% capacity factor and a 40 year plant life, the generation cost of nuclear power is approximately 2.37 ¢/kW·h (US), comfortably cheaper than coal (2.81 ¢/kW·h) in seven out of ten countries and cheaper than gas (3.23 ¢/kW·h). If the carbon tax is added (€20/t), the electricity prices for coal and gas increase to 4.43 and 3.92 ¢/kW·h, respectively. The generation of electricity from conventional sources will be more costly owing to rapid depletion of resources.

The Government of Bangladesh will endeavour to explore the possibilities of bilateral funding from friendly countries for the project. It is estimated that the total project cost for a 1000 MW NPP is about $2 billion. However, depending on the technology implemented, the host country, and the strength of the global economy, final costs may vary. The total construction time is estimated to be in the range 54–72 months. In the case of Bangladesh, where the plant is to be implemented as a turnkey project with opportunities of substantial shop fabrication, the construction schedule is expected to be about 66 months from the time of the first pour of concrete. The long term marginal cost of generation of a nuclear plant is much lower than the project sales price of electricity. Even if electricity is sold to the utility at a price lower than the present average generation cost of the national grid, the NPP would be able to generate lucrative profits after meeting all financial obligations.

III.8.2.7. Stakeholder communication and involvement

In May 2010, Bangladesh signed a peaceful atomic energy use with the Russian Federation. In February 2011, Bangladesh reached an agreement with the Russian Federation to build a 2000 MW NPP in Rooppur with two units, each of which will generate 1000 MW of power. The RNPP is estimated to cost up to $2 billion and to start operating by 2018. The IGA was officially signed on 2 November 2011. The project will be implemented as a joint venture with the Russian Federation Government as a build–operate–own–transfer project. The preferred type of contract is a turnkey package with total responsibility lying with the main plant contractor ROSATOM, the Russian State owned company. The proposed supplier will have a built-in mechanism for linkages with other relevant local government agencies, such as BAEC for R&D support, human resource development, nuclear safety, etc., with the MENR, Power Cell, Bangladesh Power Development Board and the Power Grid Company of Bangladesh Limited and other such institutions having the mandate for power purchase, transmission and distribution, as well as integration of the nuclear power projects into overall electricity generation planning.

Appendix IV

COMPARISON OF COUNTRIES CONTEMPLATING THE INTRODUCTION OF NUCLEAR POWER

Table 5 presents a data comparison of the various countries contemplating the introduction of nuclear power, their grid characteristics, business models and configurations resulting from their feasibility study recommendations regarding the acquisition of an NPP.

TABLE 5. COMPARISON OF COUNTRIES COMTEMPLATING THE INTRODUCTION OF NUCLEAR POWER (AS OF OCTOBER 2012)

Country	Total installed capacity (GW(e))	Contract scheme	Site	Unit capacity (MW(e))	Reactor type	Estimated first concrete pouring	Estimated COD	Feasibility study	Remarks (key barriers to the introduction of nuclear power)
Belarus	8.2	Turnkey	Ostrovets	2 × 1200	VVER-1200 (AES-2006)		Unit 1: 2018 Unit 2: 2020	Completed	RF loan terms and conditions Political counteraction (Litva) Lack of human resources
Bangladesh	5.8	IGA with Russian Federation	Rooppur	2 × 1000	VVER-1000 / AES-92		2018	In preparation	Political unrest Grid system (~9000 MW) International politics Trained workforce Transportation system Localization Trained regulatory body
Egypt	27	75% supplier at least	El Dabaa	4 × 1000–1650	VVER EPR APR AP-1000		Unit 1: 2019 Unit 2: 2021 Unit 3: 2023 Unit 4: 2025	In preparation	Load following
Jordan	6	Strategic partner, turnkey	Not yet chosen	2 × 1000	ATMEA-1 VVER-1000 / AES-92		Unit 1: 2021 Unit 2: 2025	Completed	Generation III+ Load following Vendor selection in 2013 Utility investment
Hungary	9.1	Finland model	Paks	~700–1400	EPR VVER APR-1400 ATMEA-1 AP-1000		Paks 5: 2020 Paks 6: 2025	Completed	Load following
Indonesia	56.5	Turnkey	Bangka Belitung	2 × 1000	APR-1000 OPR-1000 ATMEA VVER-1000 MHI 3-Loop ACR-1000 or SMR	2017	2027	In preparation	From 1976 to 2006 had to perform several FSs, but rejected by public near first nuclear power site and no government decision FSs for Bangka Belitung's site started 2010 Total capacity 3 GW 2024, 30 GW 2050 First technical assessment: six alternative reactor types as listed No NEPIO available yet Local infrastructure needs to be developed Human resource development

TABLE 5. COMPARISON OF COUNTRIES COMTEMPLATING THE INTRODUCTION OF NUCLEAR POWER (AS OF OCTOBER 2012) (cont.)

Country	Total installed capacity (GW(e))	Contract scheme	Site	Unit capacity (MW(e))	Reactor type	Estimated first concrete pouring	Estimated COD	Feasibility study	Remarks (key barriers to the introduction of nuclear power)
Nigeria	8	Discussed with ROSATOM	Geregu, Itu	1 × 1000			2020	In preparation	
Poland	25		Żarnowiec			2018	2030	In preparation	
Turkey	64	IGA with Russian Federation, BOO scheme	Akkuyu MERSIN	4 × 1180	VVER-1200 (AES-2006)	Unit 1: 2014 Unit 2: 2015 Unit 3: 2016 Unit 4: 2017	Unit 1: 2020 Unit 2: 2021 Unit 3: 2022 Unit 4: 2023	Completed	Financing (including global crisis) Human resources (Russian part) Grid system Localization
Viet Nam	22	IGA with Russian Federation	Ninh Thuan	2 × 1000 2 × 1000	VVER-100 / AES-92 Japan 2 units (PWR)	Unit 1: 2014	2020 1 GW(e) 2030 10.7 GW(e)	Processing FS by Japan and Russian Federation	

Note: ACR: Advanced CANDU Reactor; AP: Advanced Pressurized Water Reactor; APR: Advanced Power Reactor; ATMEA: Joint venture between AREVA and Mitsubishi Heavy Industries (MHI); BOO: build–own–operate; COD: commercial operation date; EPR: European European Pressurized Reactor; HRD: Human Resource Development; IGA: intergovernmental agreement; OPR: Optimized Power Reactor; MHI: Mitsubishi Heavy Industries; PWR: pressurized water reactor; SMR: small and medium sized reactor.

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CONTRIBUTORS TO DRAFTING AND REVIEW

Agu, M.N.	Nigeria Atomic Energy Commission, Nigeria
Alfstad, T.	International Atomic Energy Agency
Araj, K.J.	Jordan Atomic Energy Commission, Jordan
Chwas, A.	Ministry of Economy, Poland
Cserháti, A.L.	MVM Paks Nuclear Power Plant Ltd, Hungary
Elaswakh, I.S.K.K.	Nuclear Power Plants Authority, Egypt
Farag, H.A.A.	Nuclear Power Plants Authority, Egypt
Huda, M.Q.	Atomic Energy Research Establishment, Bangladesh
Hung, N.M.	Viet Nam Electricity, Viet Nam
Jalal, A.	International Atomic Energy Agency
Kang, K.S.	International Atomic Energy Agency
Khamis, I.	International Atomic Energy Agency
Koca, G.	Electricity Generation Co. Inc., Turkey
Maeoka, M.	International Atomic Energy Agency
Nuzzo, F.	International Atomic Energy Agency
Pane, J.S.	National Nuclear Energy Agency of Indonesia, Indonesia
Rotaru, I.	Elcomex IEA Cernavoda, Romania
Turkov, V.	Republican Unitary Enterprise Belnipienergoprom, Belarus
Vinh, D.T.	Ministry of Industry and Trade of Viet Nam, Viet Nam
Yang, I.S.	KEPCO Engineering & Construction, Republic of Korea

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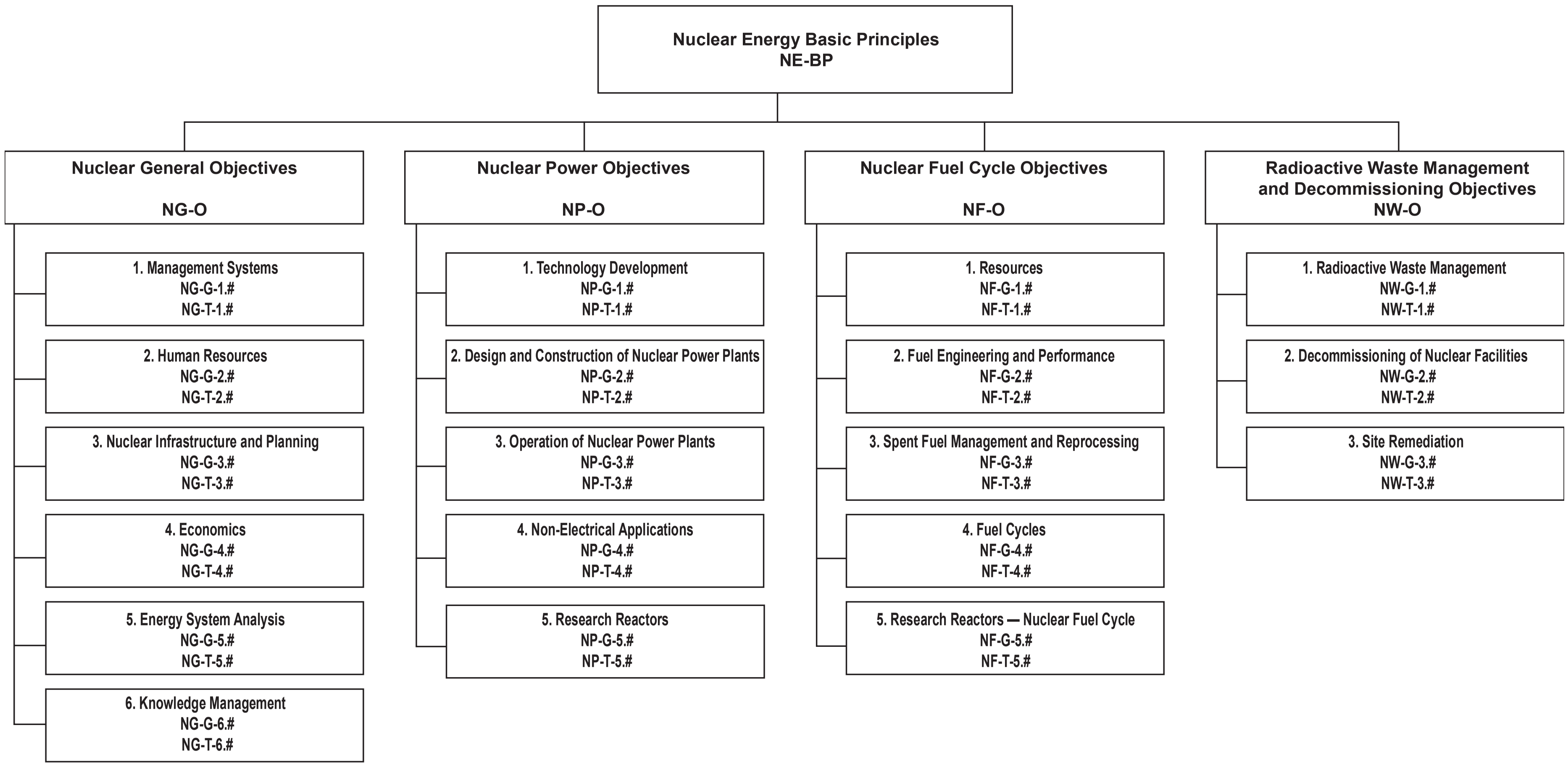

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