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WORKFORCE PLANNING FOR NEW NUCLEAR POWER PROGRAMMES

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Marketing and Sales Unit, Publishing Section
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Vienna International Centre
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FOREWORD

An appropriate infrastructure is essential for the efficient, safe, reliable and sustainable use of nuclear power. The IAEA continues to be encouraged by its Member States to provide assistance to those considering the introduction of nuclear power. Its response has been to increase technical assistance, organize more missions and hold workshops, as well as to issue new and updated publications in the IAEA Nuclear Energy Series. Milestones in the Development of a National Infrastructure for Nuclear Power, an IAEA Nuclear Energy Series publication (NG-G-3.1), provides detailed guidance on a holistic approach to national nuclear infrastructure development involving three phases. Nineteen issues are identified in this guide, ranging from development of a government's national position on nuclear power to planning for procurement related to the first nuclear power plant. One of these 19 issues upon which each of the other 18 depend is suitable human resources development.

As a growing number of Member States begin to consider the nuclear power option, they ask for guidance from the IAEA on how to develop the human resources necessary to launch a nuclear power programme. The nuclear power field, comprising industry, government authorities, regulators, R&D organizations and educational institutions, relies on a specialized, highly trained and motivated workforce for its sustainability and continued success, quite possibly more than any other industrial field. This report has been prepared to provide information on the use of integrated workforce planning as a tool to effectively develop these resources for the spectrum of organizations that have a stake in such nuclear power programmes. These include, during the initial stages, a nuclear energy programme implementing organization (NEPIO), as well as the future operating organization, nuclear regulatory body, government authorities and technical support organizations if a decision is made to initiate a nuclear power programme.

In the past, the development of human resources in the nuclear field has depended on considerable support from organizations in the country of origin of the technology. This is expected to continue to be the case in the future. However, there is also expected to be greater worldwide mobility of nuclear personnel in the future, making human resources management more demanding, particularly in ensuring that organizations in the nuclear field are attractive employers compared with other fields. These expectations suggest that development of suitable human resources to support the expected expansion of nuclear power will continue to require effective and continuing workforce planning in the context of an overall human resources development programme at the national and organizational levels.

The IAEA wishes to acknowledge the assistance provided by the external experts listed at the end of this report. B. Molloy (United Kingdom) drafted the original manuscript. The IAEA officer responsible for this publication was T. Mazour of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

With the recent upsurge in interest in, and support for, nuclear power, many Member States are considering the introduction of nuclear power as part of their national energy strategy. The introduction of a nuclear energy programme is a major undertaking with significant implications for many aspects of national infrastructure, ranging from the ‘hard’ (or physical) aspects of infrastructure, such as the capacity of the electricity grid, transport access and the manufacturing base, to softer (or human) areas, such as stakeholder involvement and human resources development. For a country that does not already have nuclear power, and even for those wishing to significantly expand an existing nuclear energy capability, it may take up to 10–15 years to develop the necessary infrastructure. Additionally, a commitment of at least 100 years is needed to sustain this national infrastructure throughout plant operation, decommissioning and waste disposal.

To facilitate progress towards the development of the necessary infrastructure for a country that is considering the introduction of nuclear power as part of its national energy strategy, the IAEA has issued a guidance publication entitled Milestones in the Development of a National Infrastructure for Nuclear Power [1] describing three distinct phases in the development of a national infrastructure for nuclear power:

— Phase 1: Considerations before a decision to launch a nuclear power programme is taken;
— Phase 2: Preparatory work for the construction of a nuclear power plant (NPP) after a policy decision has been taken;
— Phase 3: Activities to implement a first NPP.

The achievement of the infrastructure conditions for each of these phases is marked by a specific milestone at which point the progress and success of the development effort can be assessed and a decision made to move on to the next phase. These are:

— Milestone 1: Ready to make a knowledgeable commitment to a nuclear programme;
— Milestone 2: Ready to invite bids for the first NPP;
— Milestone 3: Ready to commission and operate the first NPP.

The publication goes on to detail a total of 19 different infrastructure areas that need to be addressed for each of the three phases. These areas are identified in Table 1.

When these milestones were introduced to Member States, the Member States requested additional assistance on how to implement this guidance. In particular, they indicated that they needed assistance in developing the necessary range of competencies required to implement a nuclear power programme. This report is intended to provide that additional assistance.

A number of other publications have also been developed to assist Member States, including:

— Responsibilities and Capabilities of a Nuclear Energy Programme Implementing Organization [2];
— Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators [3];
— Evaluation of the Status of National Nuclear Infrastructure Development [4].

Much of the detail of the roles and responsibilities of the NEPIO and the owner/operator organization is contained in these publications, and it is essential that users are familiar with their contents as well as the Milestones publication to ensure the appropriate application of the guidance contained in this report.

TABLE 1. INFRASTRUCTURE ISSUES AND MILESTONES

ISSUES	MILESTONE 1	MILESTONE 2	MILESTONE 3
National position			
Nuclear safety			
Management			
Funding and financing			
Legislative framework			
Safeguards			
Regulatory framework			
Radiation protection			
Electrical grid	CONDITIONS	CONDITIONS	CONDITIONS
Human resources development			
Stakeholder involvement			
Site and supporting facilities			
Environmental protection			
Emergency planning			
Security and physical protection			
Nuclear fuel cycle			
Radioactive waste			
Industrial involvement			
Procurement			

For the purposes of this publication, **workforce planning** is defined as:

The systematic identification and analysis of what an organization (and a country) is going to need in terms of the size, type and quality of workforce to achieve its objectives. It determines what mix of experience and competencies are expected to be needed, and identifies the steps that should be taken to get the right number of the right people in the right place at the right time. Further, the term **workforce** is intended to refer to **all** personnel involved in the programme.

Workforce planning should be seen as an integral part of an organization's human resources (HR) development strategy and plans, and should be consistent with other HR processes such as recruitment, training and development and remuneration, as illustrated in Fig. 1. Many of these issues are addressed in the IAEA report on Managing Human Resources in the Field of Nuclear Energy [5]. In turn, the management of human resources should be a part of the wider integrated management system in order to ensure safe and reliable operation, as discussed in the IAEA Safety Standards Series publication on The Management System for Facilities and Activities [6].

It is extremely important for the reader to understand that the prerequisites for nuclear power programme workforce planning are the establishment of clear roles, responsibilities and functions for all organizations involved in the programme. Absent these roles, responsibilities and functions, there is no framework/basis for workforce planning. The NEPIO should provide a basis for these roles, responsibilities and functions, as well as for coordination among those organizations involved in considering a nuclear power programme [2].

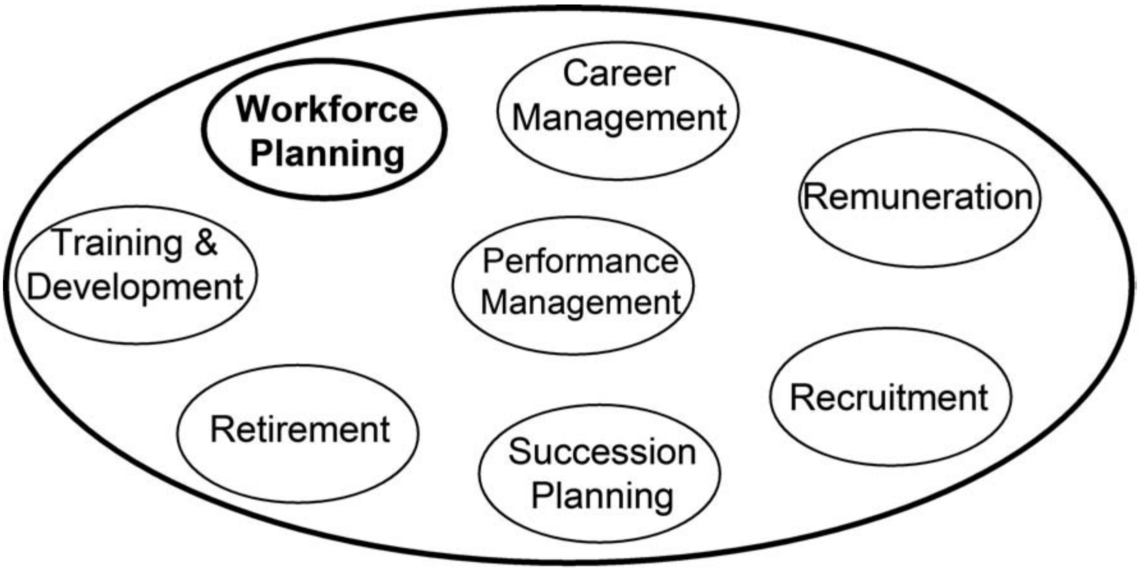

FIG. 1. Typical elements of a human resources development strategy.

1.2. OBJECTIVE

The objective of this publication is to assist Member States in developing an effective workforce plan, at both the organizational and national levels, by providing a structured approach to enable them to estimate the human resources needs of their programme, assess their existing level of capability, identify competence gaps and plan for how to fill these gaps according to the nature and scope of their nuclear power programme (see Fig. 2).

An important element of effective human resources management is the management of knowledge — the knowledge that individuals need as part of the competence requirements for assigned tasks and the additional knowledge they acquire in carrying out those tasks. This knowledge will be needed by several generations of the workforce during the lifetime of the nuclear energy programme. Therefore, this publication also includes details about the need for, and benefits of, establishing an appropriate knowledge management system within the nuclear energy programme to help ensure the sustainability of the programme in the long term.

An organizational approach is proposed outlining the needs of the three main organizations identified in the Milestones publication:

— The nuclear energy programme implementing organization (NEPIO);
— The regulatory body;
— The nuclear power plant operating organization.

These organizations are analysed based on their respective responsibilities for the implementation of various infrastructure requirements through the successive phases of the programme.

Appropriate case study material is also included to illustrate how these concepts were/are being achieved in reality for recently developed nuclear energy programmes.

1.3. SCOPE

This publication has been prepared as guidance on the workforce planning aspects of the development of a national infrastructure for nuclear power. Although it has been written as a stand-alone guide, users should be familiar with, and have access to, the Milestones publication, which provides guidance on options for the organization and allocation of responsibilities for implementation, as well as reports [2, 3] dealing with the NEPIO and operating organizations, respectively. This guidance is considered to be particularly important for Phases 1 and 2, when a Member State may have limited nuclear expertise and little external support to begin developing its initial workforce plans. By the time Phase 3 is begun, it is likely that the Member State may obtain considerable support from a chosen vendor and/or external specialist support.

A wide range of technical competencies (both nuclear and non-nuclear) are required to embark on a nuclear energy programme. It is also important to recognize that significant leadership, general management and specific project management competencies will be needed to successfully implement such a programme. The appropriate IAEA publications applicable to these fields are included in the Bibliography.

The first step recommended in the Milestones publication in the consideration of a nuclear energy programme by a Member State is the formation by the government of a group to study the feasibility of embarking upon a nuclear power programme in the country. This group is described as the NEPIO. The higher level responsibilities and capabilities of the NEPIO itself are addressed in the IAEA publication Responsibilities and Capabilities of the Nuclear Energy Programme Implementing Organization [2]. In the current publication, it is assumed that the NEPIO has been established and is functioning and that, as part of its responsibility to oversee the establishment of the national infrastructure necessary to implement the programme, the NEPIO will develop a workforce plan to complete Phase 1, implement Phases 2 and 3, and prepare for operations.

1.4. STRUCTURE

This publication is divided into several sections. Section 2 considers the Member State's nuclear energy goals, objectives and strategy, and how this may impact the resources needed. Sections 3 and 4 focus on the competencies and human resources needs of the various responsible organizations during each of the three phases associated with the development of the national infrastructure. Section 5 provides practical guidance, phase by phase, on the recruitment and staffing of the various responsible organizations. Guidance on operation, maintenance and eventual decommissioning of NPPs can be found in many other IAEA publications, and therefore these issues will only be addressed in this publication insofar as the infrastructure required to support them is an extension of that needed to achieve the first three phases and should already be in place by the time that Milestone 3 is achieved (commissioning of the first nuclear plant). Section 6 considers the role of other organizations, especially education and training institutions, in supporting the development of a nuclear energy programme. Section 7 introduces the concept of knowledge management at the outset of a new nuclear energy programme. Section 8 provides a summary of the key messages in this publication in the form of an overview of how to get started in the workforce planning process. Finally, Section 9 provides an overview of the case studies included as appendices to this publication, which are intended to present the real and varied experience of Member States that have experience in implementing a national infrastructure for nuclear energy.

It is assumed that a Member State considering the option of nuclear power would already have established a national infrastructure for radiation, waste and transport safety in support of other nuclear technologies being used in the country, such as nuclear medicine and radiography [1]. This assumption applies in this publication, and so the resource requirements considered here are only those specific requirements for the nuclear power programme beyond the requirements needed for other, less demanding nuclear applications.

An important consideration with respect to safety and regulation is the decision of whether to strengthen any existing regulatory body created to ensure the safety of industrially/medically utilized radionuclides or to create a new regulatory body to oversee the implementation of a nuclear energy programme. There are benefits and risks associated with both approaches, and if a new regulatory body is to be established, the potential for tension to arise between the two needs to be understood and properly managed. The IAEA has extensive guidance, tools and training materials available to support the detailed analysis of competence requirements and their subsequent development for a nuclear energy programme regulatory body staff. The most relevant publications on on-line materials are listed in the Bibliography.

The IAEA also has a substantial body of documentation and guidance to support the operation and improvement of existing nuclear power programmes; this publication, like the Milestones publication [1], is specifically aimed at the development of new nuclear power programmes. Again, the most relevant of these publications are included in the Bibliography.

1.5. USERS

Decision makers, advisers and senior managers in the governmental organizations, utilities, industry and regulatory bodies of a country with an interest in developing nuclear power, especially those with responsibilities for human resources development, may use this publication to identify and plan for the competencies and human resources needed to implement a nuclear power programme. Although, as has already been stated, the publication is aimed primarily at those countries considering nuclear power for the first time, much of the information contained may be equally useful to those countries considering a major expansion of an existing nuclear power programme, especially if significant time has elapsed since the construction of the last NPP.

This publication will also be of particular interest to national and international educational and training establishments, suppliers, and research and technical support organizations, which may be called upon to assist in developing the national infrastructure.

1.6. USING THE PUBLICATION

An overview of the workforce planning process for achievement of the milestones is presented in the flow chart in Fig. 2, which shows how the information contained within the publication relates to the different steps in the workforce planning process. Again, the reader is reminded that a prerequisite for starting this process in Phase 1 is clearly defined roles, responsibilities and functions for the NEPIO and other organizations that have a stake in considering a national nuclear power programme.

2. NUCLEAR ENERGY STRATEGY

2.1. SCOPE OF NUCLEAR ENERGY STRATEGY

Although the range of competencies needed to design, license, construct, regulate, commission, operate and eventually decommission an NPP are largely the same for any nuclear power programme, the planned scope and goals of the nuclear power programme, the desired levels of technology transfer, longer term capability, approaches to plant life management (PLM) and desired self-sufficiency in nuclear energy will all have a major impact on the extent to which these competencies need to be developed within the national capability, as opposed to being provided by external suppliers.

Also, the ultimate intended application of the nuclear power, such as electricity generation, desalination and public heating, will have some influence on the range of competencies needed. For the purposes of this publication, it is assumed that the primary purpose is for electricity generation.

2.2. APPROACH TO HUMAN RESOURCES DEVELOPMENT

When considering the extent to which a Member State wishes to develop its national capabilities, it is important to be realistic about the gaps in existing capability and to take due account of the scope of other existing or planned national infrastructure projects. Trying to develop national capability extensively during the project for a first NPP may create unacceptable risks in terms of time and cost. Also, extensive national involvement in the construction of a first NPP may place other national infrastructure projects at risk. It is also important to remember that, due to the long term nature (see Section 2.3) of a nuclear energy programme, the human resources

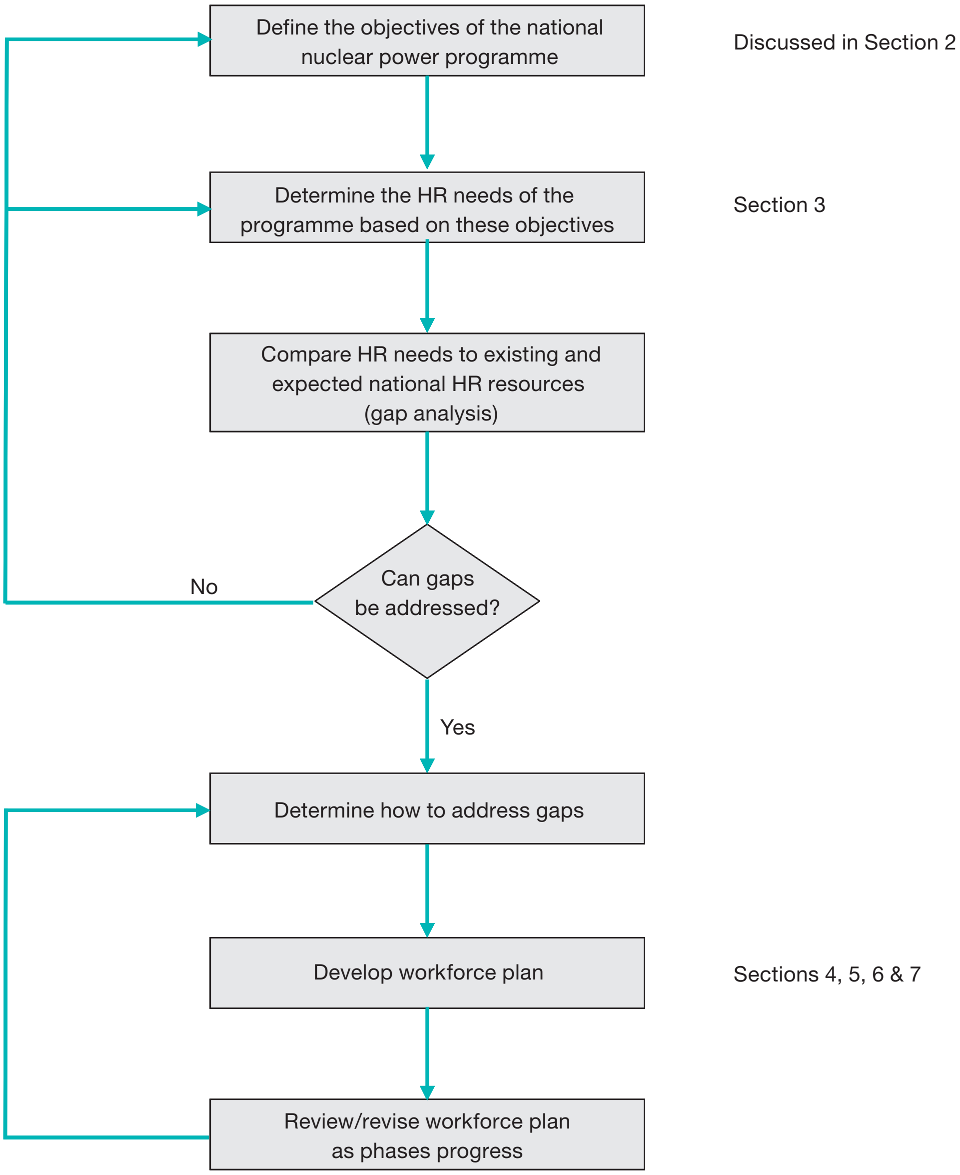

FIG. 2. Simplified flow chart for workforce planning process.

requirements will span several generations of the workforce, so workforce planning will be an ongoing process for all organizations involved in sustaining the nuclear energy programme.

If only a single NPP or a very small number of units are planned, then it may not be appropriate for a Member State to develop all the competencies identified in this publication, particularly those for the design, construction and commissioning of the plant. In this case, the Member State should focus on developing and maintaining the internal competencies to operate and maintain (and eventually decommission) the plant in a safe and secure manner and may contract out many of those competencies required during Phases 1 and 2 of the programme.

However, even in this scenario, the Member State must develop the competence to fulfil the role of the 'intelligent customer'[1], that is, the Member State must be able to assess its requirements, prepare an appropriate bid

[1] For the purposes of this publication, an intelligent customer is defined as an organization (or individual) that has the competence to specify the scope and standard of a required product or service and subsequently assess whether the supplied product or service meets the specified requirements.

invitation specification (BIS) [7] and confirm that any bids will meet the requirements of their specification, albeit with specialist support.

In reality, even within a turnkey contract (where a project is constructed by a vendor and handed over to the customer when ready to use), the Member State must still be an intelligent customer for the contract, and there may still be a variety of local infrastructure activities for which the Member State will retain responsibility (see Section 2.5).

At the other extreme, if a Member State plans to implement a significant NPP construction programme and has the ultimate desire to be self-sufficient in new plant construction, then it will be advantageous to develop (over time) all the required competencies across the 19 infrastructure areas, assuming the education and training capability exists/can be developed to support these competencies. This will need to be determined before preparing the bid specification, as any significant training/involvement requirement of national staff by a vendor should be included in the bid specification (in addition to any training requirements for operating staff).

An additional consideration is the extent to which national capability is to be embedded in particular organizations or used as a shared resource. At one extreme, each organization (NEPIO, regulatory body, operating organization) may be developed to have all the capabilities and resources it needs to fulfil its responsibilities employed within that organization, making those organizations more self-sufficient, but at the cost of higher overall resource requirements. At the other end of the spectrum, independent expert groups/organizations may be developed/strengthened to provide technical support to the various responsible organizations, thus reducing the overall resource requirements and alleviating the problem of retaining experts within each organization whose areas of expertise are only needed periodically.

2.3. NUCLEAR SAFETY CONSIDERATIONS

The decision of a country to embark on a nuclear power programme entails a long term commitment (of more than a century) to the peaceful, safe and secure use of nuclear technology based on a sustainable organizational, regulatory, social, technological and economic infrastructure. The need to maintain nuclear safety in operations and the safety and security of nuclear materials, especially non-proliferation aspects, make nuclear energy unique among the various energy options, and it is important for Member States to understand this from the outset. In this respect, valuable guidance is provided in INSAG-22, Nuclear Safety Infrastructure for a National Nuclear Power Programme [8]. Member States must understand, and be ready to commit to, the minimum international standards, especially those for nuclear safety and security.

Experience has demonstrated that reliance on robust design and engineered safety systems alone is insufficient to ensure nuclear safety [8]. Safe operation and the safe and secure handling and storage of nuclear materials are core competencies required by any Member State developing a nuclear energy programme, and the responsibility for safety cannot be delegated to another country or organization. Even the operational phase of a successful NPP is likely to span at least two generations of the workforce, so ongoing, integrated workforce planning is essential for safety. An NPP is operated by people, and thus the achievement of safety requires qualified managerial and operating personnel working professionally, to the highest standards, within an appropriate integrated management system. Commitment to nuclear safety is required by all elements of the government, regulatory, vendor and operating organizations, and it is important that these organizations establish the appropriate safety culture and standards from the outset of the programme.

2.4. IMPACT OF THE REGULATORY APPROACH

Key among the requirements to ensure nuclear safety is the establishment of a robust national legal and regulatory framework, including the creation of a competent, independent regulatory body to oversee the implementation and management of this framework. In terms of workforce planning, the approach to regulation adopted by the Member State may have a significant impact on both the size and the competence requirements of the regulatory body itself, as well as on the size of the operating organization.

The more proscriptive the regulatory framework is, the more resources are likely to be needed by the regulatory body (either as permanent staff or external support). Conversely, if the regulatory framework makes the operating organization primarily responsible for demonstrating compliance with requirements, then the operating organization may need more resources to achieve this.

Specific aspects of the legal and regulatory framework, such as working hours/shift working limits, use of local labour and limitations on the use of external experts, may also have a direct impact on resource requirements (e.g. the decision of whether to operate a plant with five, six or seven teams of shift personnel has a significant impact on the number of operating staff needed).

2.5. FIRST NUCLEAR POWER PLANT

It is generally accepted that the best practice to be adopted for the construction of a first NPP is that of a turnkey contract (at least for the 'nuclear island'; the Member State may have capability for the conventional plant and civil works), whereby a suitably proven design is implemented by an established vendor, with the Member State relying on international expertise and support organizations, such as the IAEA, the World Association of Nuclear Operators and reactor owners' groups, to support the various national stakeholders (Ministries, regulatory bodies, implementing organizations, internal suppliers, etc.) in fulfilling their obligations within the project, even if the longer term goal is to be self-sufficient. In situations where only one or two NPPs are to be constructed, as indicated previously, even some of the core functions may initially be provided/supported by external expertise (e.g. provision of technical support for regulation by the regulator from the country of origin of the design being implemented). However, even in this case, the Member State must have/develop the competence to be an 'intelligent customer' for this support. In addition, the Member State is likely to retain responsibility for a number of supporting infrastructure activities, such as grid enhancements, roads, housing and other facilities close to the site. In any event, it is the responsibility of the Member State, over time, to acquire nationally the competencies necessary to ensure the safe operation of the plant throughout its entire life cycle. There are also commercial considerations in terms of the risk of the ongoing viability of the main vendor/key component suppliers.

Whatever the case, it is necessary to develop a detailed workforce plan at an early stage to identify the level of resources and range of competencies needed for the various stages of the programme. Part of this planning process will be to identify what the existing national competencies are, how they can be best utilized/further developed and which new competencies can be acquired nationally, within the framework of the turnkey contract, so that agreed national recruitment, training and development requirements can be built into overall project plans and contracts. It is important at this point that Member States are realistic about their national technology base and capability to develop and maintain the competencies required, even with international support. Inputs for the national workforce plan will be needed from all relevant government departments, regulatory agencies, existing utility operators, national industry, the education and training sector, and any other stakeholders identified as having a role to play in the realization of a nuclear energy capability, each of which should be developing and maintaining their own plans.

3. ANALYSIS OF INFRASTRUCTURE ACTIVITIES, COMPETENCIES AND RESOURCE REQUIREMENTS

As indicated earlier, a prerequisite for developing a workforce plan to support a national nuclear power programme is to clearly define in Phase 1 (considering the feasibility of nuclear power for the country) the roles, responsibilities and functions of all the stakeholder organizations to be involved. As the programme progresses into Phase 2, this is likely to include, as a minimum, the NEPIO, an independent regulatory body and a designated operating organization. The workforce planning process can then be used to identify the major activities that need to be undertaken to achieve the milestones, which organizations should be responsible for these activities, and the competencies needed. A part of this process will be to determine which of these activities are within the current national capability, which could be undertaken nationally in the longer term (with training and support) and which should be contracted out from the outset.

In addition to the nuclear related activities of a nuclear energy programme, as with all major capital projects, significant non-nuclear resources will be needed, particularly in the early construction stages of the programme. For general guidance on workforce development for the implementation of a nuclear energy programme, Member States may find the IAEA publication on Manpower Development for Nuclear Power: A Guidebook [9] useful. Although this publication, issued in 1980, was based on the previous generation of nuclear energy programmes, much of the content is still relevant. For more detailed workforce planning, the main IAEA publications providing useful guidance are listed in Table 6 at the end of this section, indicating those organizations and the phases to which they are most applicable.

The workforce planning process for a specific nuclear energy programme should begin with a review of the activities identified under each of the 19 infrastructure issues, phase by phase (as identified in Ref. [1]), which should form the basis for an initial analysis of competence and resource needs. It is important to remember, however, that although the infrastructure issues have been separated into 19 discrete topics, in reality the activities associated with these topics are often integrated and interdependent. The same individuals may be engaged in various activities covering several infrastructure issues. Hence, for workforce planning purposes, it is more appropriate to consider these activities in terms of organizational responsibilities. In some cases, it is clear where responsibilities should be assigned for particular activities; in others, it will be a judgement based on the particular national organizational arrangements.

During Phase 1, the NEPIO is likely be the major responsible organization and, in addition to the information contained in the Milestones publication, an overview of its functions and responsibilities during Phase 1 is provided in Table 2, taken from Ref. [2].

During Phase 2, the regulatory body and operating organization will be assigned (assuming they were not already assigned in Phase 1), and responsibilities, and therefore resource requirements, will progressively be transferred to these organizations. Table 3 [2] provides an overview of the NEPIO’s functions and responsibilities during Phase 2, and a similar overview of the responsibilities of the operating organization during Phase 2 is included in Table 4 (taken from Ref. [3]). Useful sources when developing workforce plans for the regulatory body include Organization and Staffing of the Regulatory Body for Nuclear Facilities [10] and Training the Staff of the Regulatory Body for Nuclear Facilities: A Competency Framework [11].

TABLE 2. FUNCTIONS OF A NEPIO DURING PHASE 1

National position	Provide a recommendation for a national decision to undertake (or not undertake) a nuclear power programme based on a comprehensive understanding of the long term commitments inherent in such a programme. This recommendation should be supported by a comprehensive report covering all areas identified in Ref. [1] and recognizing the resources and timescales required for the activities to implement Phase 2.
Nuclear safety	Convey the importance of clearly recognizing that long term safety is a vital component of all activities associated with the design, manufacture, construction, operation and maintenance of a nuclear facility, decommissioning and commitments for spent fuel and waste management, and is best achieved by fostering a strong safety culture in all organizations involved.
Management	Provide a clear description of the scope and depth of management expertise needed within each organization associated with the nuclear energy programme and a strategy to obtain or develop that expertise. Define the form of the potential owner/operator and assist in building its capabilities. Make suggestions for allocations on specific responsibilities of each organization associated with the nuclear programme.
Funding and financing[a]	Design a strategy for funding the development of relevant institutional organizations (such as the regulatory body) and financing specific NPP projects, including decommissioning and waste management. The strategy may also include government funding in support of the nuclear power plant project itself, including public financing.

TABLE 2. FUNCTIONS OF A NEPIO DURING PHASE 1 (cont.)

Legislative framework	Identify all legislation, including international legal instruments, required to be implemented or enhanced to support a nuclear programme and a strategy for drafting and enacting it.
Safeguards	Provide a plan covering the conclusion of a comprehensive safeguards agreement (CSA) with the IAEA and establishment of a State system of accounting for and control of nuclear material (SSAC) with the relevant authorities. Provide a plan covering the drafting, implementation and enforcement of national legislation, policies and procedures relevant to safeguards.
Regulatory framework	Define the fundamental elements of an independent and effective nuclear regulatory body and a strategy to create or enhance, fund and staff it.
Radiation protection	Define the fundamental elements of a comprehensive radiation protection programme for all nuclear activities and a strategy for implementing those elements within each organization.
Electrical grid	Provide a comprehensive description of the grid size, configuration and reliability necessary to accommodate the addition of an NPP and the likely extent and cost of grid enhancements that will be needed.
Human resources development	Describe the knowledge, skills and attitudes of multiple disciplines required for a nuclear programme and a strategy for obtaining and maintaining the needed personnel.
Stakeholder involvement	Conduct surveys of opinions on the application of nuclear power within the country, and plans for ongoing education and consultation with identified stakeholders.
Site and supporting facilities	Identify potential sites and conduct a preliminary assessment of suitability for the nuclear facilities' construction and operation.
Environmental protection	Assess the additional environmental considerations necessary for nuclear power, assessment of existing environmental laws and regulations, and a strategy for their appropriate revision.
Emergency planning	Describe the fundamental elements of emergency planning for nuclear facilities and the individual role of each institution and organization.
Security and physical protection	Describe the fundamental elements of security and physical protection programmes, and provide a development strategy for these programmes.
Nuclear fuel cycle	Develop an understanding of the long term nuclear fuel cycle commitments necessary for completing realistic nuclear fuel cycle plans in Phase 2. Develop a strategy for obtaining a secure supply of fuel and the appropriate national involvement in the individual steps of the nuclear fuel cycle, including availability of natural resources, interim storage of spent fuel and longer term storage of spent fuel, taking into account various fuel cycle options.
Radioactive waste	Conduct an assessment of current capabilities for the handling and disposal of low level waste (LLW) and intermediate level waste (ILW), a strategy for handling the additional volume associated with nuclear facility operation and a strategy for determining the approach to the ultimate disposal of high level nuclear waste or spent fuel.
Industrial involvement	Conduct an assessment of local industrial capability and a strategy for developing the desired degree of localization of industrial involvement or support for the planned NPP projects.
Procurement	Design a strategy for procuring the equipment and services to support an NPP project, taking into account the need for bilateral agreements with foreign suppliers and quality requirements for both international and local suppliers.

[a] Funding is considered to be financial resources provided without recourse, usually by the government. Financing is commercially provided.

TABLE 3. FUNCTIONS OF A NEPIO DURING PHASE 2

National position	Coordinate the government activities, inter alia, to implement the necessary laws and international agreements, to establish policies and responsibilities for the long term issues and the independent regulatory body, and to continue to fund and support the nuclear infrastructure development. Coordinate technology strategy development and its implications among impacted organizations.
Nuclear safety	Work to ensure that the responsibilities for nuclear safety are clearly established in law and that all participating organizations are aware of their safety responsibilities and foster establishment of an appropriate culture and activities in all involved organizations.
Management	Coordinate promotional, operational, oversight and support activities, and monitor the creation and staffing of the independent regulatory body and of the owner/operator organization, and the readiness to prepare for bids and licensing procedures.
Funding and financing	Work with the government to encourage adequate funding for infrastructure development and with the government and the owner/operator to develop a realistic financing plan for the first NPP.
Legislative framework	Monitor the country’s process for implementing a comprehensive legal framework.
Safeguards	Confirm that a CSA with associated subsidiary arrangements is in force with the IAEA. Confirm that an SSAC has been established and that early safeguards related information has been provided to the IAEA.
Regulatory framework	Confirm that the independent regulatory body is established and staffed, has developed a licensing process, including appropriate regulations, codes and standards, and is prepared to review and license sites and reactor designs.
Radiation protection	Confirm the development and implementation of applicable laws, regulations and programmes by the government, the regulatory body and the owner/operator of formal radiation protection programmes.
Electrical grid	Confirm the development of necessary plans, schedules and funding of grid enhancements by the grid owner and/or the owner/operator to accommodate the addition of an NPP.
Human resources development	Confirm that all organizations have obtained the human resources necessary to carry out their functions at Milestone 2, and that programmes and plans are in place to develop, retain and replace human resources consistent with the country’s plans for construction, operation, maintenance and support of the future NPP and associated nuclear activities.
Stakeholder involvement	Confirm that the government, the regulatory body and the owner/operator have developed and are implementing programmes for public education and stakeholder involvement at all appropriate steps in the nuclear power programme development process.
Site and supporting facilities	Confirm that the owner/operator has identified, secured and characterized one or more suitable sites and that the site characteristics are included in the bid specifications.
Environmental protection	Confirm that enhancements to environmental law have been made and the responsibilities for environmental approval and oversight have been formally assigned.
Emergency planning	Confirm that the government has enacted the necessary laws, that the regulatory body has developed regulations and that the owner/operator is developing the appropriate emergency plans and protocols with local and national authorities.
Security and physical protection	Confirm that the appropriate laws, regulations, protocols and programmes have been established by the government, regulatory body and owner/operator for the security and protection of all nuclear materials and facilities.
Nuclear fuel cycle	Confirm that nuclear fuel cycle planning and strategy covers both the front and back ends of the fuel cycle and that strategies for a secure supply of nuclear fuel and fuel services, and for on-site spent fuel storage capacity, have been developed and are reflected in the owner/operator nuclear power plant bid request. Confirm the existence of an integrated plan for bidding and constructing fuel cycle facilities consistent with the power plant construction programme and national non-proliferation commitments.

TABLE 3. FUNCTIONS OF A NEPIO DURING PHASE 2 (cont.)

Radioactive waste	Confirm that the appropriate laws, regulations and facilities are in place or planned for handling, transporting and storing LLW and ILW. In addition, assist the government in developing strategies and policies with respect to eventual disposal of HLW and spent fuel.
Industrial involvement	Confirm that the owner/operator, the regulatory body and designated industries are cooperating in developing the industrial involvement envisioned by the country's policies developed in Phase 1.
Procurement	Confirm that the owner/operator has developed formal plans for procurement of the equipment and services to support NPP operation and maintenance consistent with the country's policies developed in Phase 1.

TABLE 4. TYPICAL FUNCTIONS OF THE OPERATING ORGANIZATION DURING PHASE 2

Issue	Owner/operator responsibilities
National position	— Create the owner/operating organization following the government decision.
Nuclear safety	— Establish an appropriate internal system to identify its safety responsibilities based on the legislation in force. — Initiate the necessary actions to establish and continuously improve the safety culture across the organization. — Ensure that an understanding of nuclear safety requirements is developed in the entire supply chain. — Together with the regulatory body, adhere to international legal instruments such as: • The Convention on Nuclear Safety; • The Convention on Early Notification of a Nuclear Accident; • The Convention on the Physical Protection of Nuclear Materials and its Amendment; • The Vienna Convention on Civil Liability for Nuclear Damage; • The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.
Management	— Establish a management system including an organizational chart of the owner/operator that is appropriate for the main tasks of this phase, which are to prepare the BIS and start to build a safety culture; — Ensure that the factors important for the development of a strong safety culture are considered throughout this phase; — Define the areas of competence to be established in the organization; — Implement a programme of staff recruitment and training; — Select the preferred NPP sites for the BIS; — Determine the preferred nuclear technology (reactor and fuel type); — Determine the fuel cycle and fuel procurement strategy; — Determine the strategy for spent fuel and radioactive waste; — Establish the preferred contractual approach (turnkey, split package, etc.); — Develop the financial strategy and financial plan; — Prepare the BIS, including the bid evaluation criteria; — Establish efficient and effective working relationships with the regulatory bodies and similar relationships with international and professional organizations; — Start to build a project management organization to manage the construction of the first NPP.
Funding and financing	— Develop a financing strategy and financial plan; — Arrange the financing for the project in consultation with the government authorities and foreign and local sources of finance.
Legislative framework	— Establish the necessary interfaces with the government, regulatory bodies and national agencies; — Understand the licensing process and the associated safety documentation.

TABLE 4. TYPICAL FUNCTIONS OF THE OPERATING ORGANIZATION DURING PHASE 2 (cont.)

Issue	Owner/operator responsibilities
Safeguards	— Consider a safeguards by design approach; — Start to establish procedures and train staff to meet safeguards requirements, and to demonstrate to the government authorities that this has been done; — Submit the necessary preliminary design information related to safeguards to the IAEA through the national regulator, according to the provisions set forth in the safeguards agreements; — Consult with operators of the same type of facility on technical features for implementing safeguards (e.g. installation of containment and surveillance devices, cabling, penetration of containment). In safeguards terminology, the national regulator is the state authority for State systems of accounting for and control of nuclear material (SSAC).
Regulatory framework	— Set up an effective working relationship with the regulators, maintaining open communication; — Ensure that other organizations that may be supplying goods or services to the NPP understand the national safety requirements; — Understand the safety regulations relevant to the bid process and be able to translate them into the bid specification.
Radiation protection	— Start to prepare a programme for radiation monitoring and radiation protection of the workforce, the public and the environment; — Perform the characterization of background sources of radiation at planned NPP sites in accordance with the regulations.
Electrical grid	— Provide information about the proposed NPP to the grid operator so that it can determine the necessary grid enhancements and design them; — Ensure that the proposed grid design would provide a sufficiently reliable grid connection and an adequate external electrical supply to the NPP for reactor trip and shutdown conditions; — Ensure that the possible schedule for grid enhancements is compatible with the likely schedule for construction of the NPP; — Include grid characteristics and requirements in the BIS.
Human resources development	— Recruit and train the staff needed for Phase 2 responsibilities; — Develop plans to recruit and train staff for Phase 3; — Request that the government develop any needed enhancements to the country’s educational and research institutions, and provide financial support if needed.
Stakeholder involvement	— Prepare and implement the strategy for dealing with the public; — Recruit experts in the areas of public communication and education, and train the NPP staff in these areas; — Explain the basic technology being employed and the plans for the construction schedule; — Openly discuss potential problems and difficulties, and plans to resolve them; — Communicate transparently and professionally with other organizations participating in the nuclear power programme; — Demonstrate that it is a competent and credible organization that deserves the confidence of the public. — Agree with local authorities near the NPP site on financial and technical support for social infrastructure development; — Open a public information centre near the NPP site and other places.
Site and supporting facilities	— Carry out detailed site investigations of the possible sites for the NPP and recommend the preferred site or sites; — Secure the availability of the chosen site or sites; — Identify local legal, political and public acceptance issues for the chosen site and plan for their resolution; — Include the characteristics of the site in the BIS; — Identify and plan any necessary improvements or upgrades to site characteristics and local infrastructure, such as improved road access and water supply. The candidate sites to be investigated may have been nominated or recommended by the government following an initial investigation in Phase 1.
Environmental protection	— Ensure that the necessary environmental impact assessment studies for the candidate sites are carried out; — Submit the environmental impact assessment and the application for environmental clearance to the environmental regulator; — Include any special environmental features of the site in the BIS.

TABLE 4. TYPICAL FUNCTIONS OF THE OPERATING ORGANIZATION DURING PHASE 2 (cont.)

Issue	Owner/operator responsibilities
Emergency planning	— Identify the local and national organizations that will take part in emergency planning; — Start to prepare the emergency plans and procedures.
Security and physical protection	— Establish an interface with the responsible national agency (security regulator); — Provide the inputs and expertise necessary to allow the security regulators and the concerned government authorities to define the design basis threats (DBTs); — Include security requirements in the BIS; — Define the physical protection features of the NPP site; — Introduce arrangements for security classification of the NPP data; — Develop a programme for the selection and training of security staff.
Nuclear fuel cycle	— Provide technical information to the government for nuclear fuel strategy; — Reach agreement with the government for nuclear fuel strategy including fuel procurement and management of spent nuclear fuel, particularly with regard to the national non-proliferation commitment (the strategy for spent nuclear fuel includes whether or not to reprocess the fuel and the arrangements for storage and disposal of spent fuel and/or HLW); — Introduce specifications related to nuclear fuel in the BIS to define what should be procured separately; — Submit through the national regulator to the IAEA the necessary safeguards related information according to provisions set forth in the safeguards agreements.
Radioactive waste	— Participate in the establishment of a radioactive waste management organization if no national agency exists; — Establish an interface with the radioactive waste management organization; — Provide technical information to the waste management organization to allow the policy for waste disposal to be established; — Ensure that relevant procedures are created for implementing safeguards should the waste contain nuclear material; — Include specifications for minimization, handling, treatment, conditioning and storage of radioactive waste in the BIS.
Industrial involvement	— Carry out a realistic assessment of potential local suppliers of goods and services; — Analyse the ability of local suppliers to meet the schedule and quality requirements, and provide input to the government; — Reach an agreement with the government for participation by local suppliers; — Define local supplier participation in the BIS, including technology transfer requirements.
Procurement	— Start to develop procurement management procedures and a quality assurance programme, including the establishment of approved vendor lists; — Start to establish the procurement team/department; — Include specific requirements for goods and services procurement in the BIS in accordance with local legislation.

From the beginning of Phase 3, the major workforce planning effort is likely to be focused on the operating organization in order to adequately resource, first, the commissioning and, subsequently, the operation of the NPP. Table 5 provides a summary of the responsibilities of the operating organization during Phase 3. The IAEA publication Commissioning of Nuclear Power Plants: Training and Human Resource Considerations [12] contains guidance for planning purposes. Inputs for workforce planning for the organizational and resourcing requirements of the operating organization to actually operate the plant, will depend, to some extent, on the design of the NPP selected. It is likely that the vendor of the chosen design will have recommendations in this area. Member States may find broader guidance on the recruitment, training and qualification of these staff in Refs [13, 14].

TABLE 5. TYPICAL FUNCTIONS OF THE OPERATING ORGANIZATION DURING PHASE 3

Issue	Owner/operator responsibilities
National position	— No direct responsibilities.
Nuclear safety	— Ensure the continuation of management commitment to foster the development of a strong safety culture; — Build and maintain technical knowledge and skills for the safe operation and maintenance of the NPP; — Ensure that the other involved organizations (construction, engineering and any others that are external to the owner/operator) understand and apply the national safety requirements and develop a strong safety culture; — Ensure participation in the activities related to the international legal instruments.
Management	— Issue the BIS to the bidders, including an identified site or sites; — Evaluate the bids and choose the preferred bidder or bidders; — Negotiate the contracts with a scope of supply consistent with the procurement strategy; — Sign the contracts for the first NPP; — Prepare technical documentation for the licensing application with contributions from the vendor or main contractor (this should include a preliminary decommissioning plan); — Submit the applications to the regulatory body for a site permit and a construction licence; — Make suitable contractual arrangements with fuel and fuel service suppliers; — Establish a team or department for public communication and information; — Implement a management system and perform audits in order to ensure that all participants in the first NPP, including subcontractors, meet the specific requirements (nuclear standards and codes, technical specification, etc.); — Train the operating personnel and arrange for them to be licensed if necessary.
Funding and financing	— Determine the NPP project budget based on the agreed contract and owner/operator participation; — Determine the required cash flow according to the NPP project schedule and contractual provisions (payment milestones); — Implement the financial plan based on the agreed contracts (loans, state funding, other financial mechanisms); — Follow the mechanism for provision of funding for the long term management of spent fuel and radioactive waste and for decommissioning.
Legislative framework	— Maintain the established interfaces with the government and different regulatory bodies, international agencies (e.g. the IAEA) and national agencies in order to understand the legislation and comply with it.
Safeguards	— Train staff to meet safeguards requirements and to demonstrate to the government authorities that this has been done; — Implement all safeguards measures and have the NPP safeguards system approved by the national regulatory body before receipt of the first nuclear fuel on the NPP site; — Provide to the national regulatory body or government the information on nuclear material subject to safeguard instruments to be supplied to the IAEA in accordance with international conventions.
Regulatory framework	— Maintain an effective working relationship and open communication with regulators; — Agree with regulators on the programme/schedule for licensing meetings, taking into account the important milestones of the first NPP construction schedule; — Submit the safety documentation required in the licensing process in a timely manner, and be prepared to respond to enquiries from the regulatory body; — Require organizations in the supply chain to comply with national safety requirements.
Radiation protection	— Implement all necessary radiation and environmental monitoring and protection programmes before the first nuclear fuel load is transferred to the NPP site; — Ensure all necessary services to implement the radiation protection programme using external subcontractors (for calibration services, laboratory analysis, etc.) where appropriate; — Develop the team/department and capabilities for safe implementation of radioactive waste management activities before the first criticality.

TABLE 5. TYPICAL FUNCTIONS OF THE OPERATING ORGANIZATION DURING PHASE 3 (cont.)

Issue	Owner/operator responsibilities
Electrical grid	— Agree with the grid operator on the schedule for grid upgrade projects to meet the NPP construction schedule; — Liaise with the grid operator during construction of grid upgrades and verify when they are complete; — Establish with the grid operator all necessary agreements for future operation (e.g. electrical supply during construction, licence for connection to the grid of the first NPP, etc.); — Establish and agree on procedures for the coordination of grid operations with NPP operations.
Human resources development	— Develop a human resources strategy for NPP operation, taking into account resources provided under the contract with the vendor and the availability of other service providers; — Recruit and train staff needed for NPP operation, maintenance and technical support, taking into account the training provided under the contract with the vendor; — Ensure that an adequate number of trained and certified staff/operators are available by the first fuel load; — Develop plans for continuing recruitment and training of staff and personnel development for the lifetime operation of the NPP.
Stakeholder involvement	— Explain the technology being deployed in the NPP and the plans for construction activities; — Routinely communicate progress during the construction phase and make preparations for operation; — Openly discuss problems and difficulties encountered, and how to resolve them; — Continually demonstrate that the owner/operator is a competent, transparent and credible organization that deserves the confidence of the public.
Site and supporting facilities	— Ensure that all site services (cooling water, electrical supply, offices, transport, lodging, communications, roads, heating, etc.) are available and functioning when needed for construction or commissioning; — Ensure that site security arrangements, environmental monitoring and emergency planning arrangements are functioning correctly before the first fuel load arrives on site at the NPP.
Environmental protection	— Complete the characterization of the site and its surroundings; — Establish systems for monitoring and assessing all environmental releases from the NPP in accordance with national laws and international standards, and implement all features before the first fuel load; — Agree with the environmental regulator on the arrangements for independent measurements of environmental releases from the NPP, if necessary; — Agree with the environmental regulator on how information on releases from the NPP will be reported or published.
Emergency planning	— Finalize the emergency plan and put it into effect; — Establish protocols and procedures for the interfaces with organizations involved in the emergency plan (police, ambulances, transport, local and national government organizations, etc.); — Arrange for systematic training of staff in the emergency service organizations so that they understand the special issues that can affect nuclear sites; — Perform emergency exercises at intervals jointly agreed by all the parties involved to ensure that the arrangements are fully effective before the first fuel load arrives at the NPP site.
Security and physical protection	— Set up a selection and qualification programme for the security staff; — Ensure that security and physical protection systems and procedures are in place before the first fuel load on the NPP site and obtain approval from competent authorities; — Ensure that sufficiently trained security staff are available; — Interface with national and local government bodies for security measures.
Nuclear fuel cycle	— Place contract(s) for the first fuel load; — Make contractual arrangements for future fuel reloads; — Ensure that adequate storage capacity is constructed at the NPP site for interim storage of spent fuel; — Ensure that the costs for long term storage and management of spent fuel are included in the operating costs and funded in accordance with the legislation; — Submit through the national regulator to the IAEA the necessary safeguards related information according to provisions set forth in the safeguards agreement.

TABLE 5. TYPICAL FUNCTIONS OF THE OPERATING ORGANIZATION DURING PHASE 3 (cont.)

Issue	Owner/operator responsibilities
Radioactive waste	— Ensure that a fully operational facility for treatment, conditioning and storage of radioactive waste is available at the NPP site by the first criticality; — Ensure that the facility is able to produce a waste form that would be acceptable to the waste management organization; — Ensure that the costs for radioactive waste management and disposal are included in the operating costs and funded in accordance with the legislation; — Ensure that relevant procedures have been created for implementing safeguards should the waste contain nuclear material.
Industrial involvement	— Reassess potential local suppliers of goods and services during the contract negotiations based on the specific vendor's technical requirements; — Specify in the contracts the final arrangements for the local supply of goods and services for the construction period; — Establish local supplier qualification requirements; — Place the contracts for the procurement of the local supply in accordance with the NPP schedule, if necessary; — Supervise the fabrication of the goods by local suppliers in accordance with specific requirements, if necessary.
Procurement	— Establish a procurement programme that is consistent with national policy on industrial participation; — Develop the capabilities to carry out procurement of full facilities, equipment and components for the NPP; — Establish a suitable procurement organization that may be based at the NPP site or centrally in order to provide the spares, consumables and services for future operation and maintenance of the NPP.

TABLE 6. SUMMARY OF KEY IAEA PUBLICATIONS RELATED TO WORKFORCE PLANNING

Responsible organization	Relevant IAEA publication		Phase		
	Ref. No.	Title	1	2	3
NEPIO	NG-G-3.1	Milestones in the Development of a National Infrastructure for Nuclear Power	✓	✓	✓
	NG-T-3.6	Responsibilities and Capabilities of a Nuclear Energy Programme Implementing Organization	✓	✓	
Regulatory body	GS-R-1	Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety	✓	✓	✓
	GS-G-1.1	Organization and Staffing of the Regulatory Body for Nuclear Facilities	✓	✓	✓
	GS-G-1.2	Review and Assessment of Nuclear Facilities by the Regulatory Body		✓	✓
	GS-G-1.3	Regulatory Inspection of Nuclear Facilities and Enforcement by the Regulatory Body		✓	✓
	TECDOC-1254	Training the Staff of the Regulatory Body for Nuclear Facilities: A Competency Framework		✓	✓

TABLE 6. SUMMARY OF KEY IAEA PUBLICATIONS RELATED TO WORKFORCE PLANNING (cont.)

Responsible organization	Relevant IAEA publication		Phase		
	Ref. No.	Title	1	2	3
Operating organization	NG-T-3.1	Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators	✓	✓	✓
	NG-T-2.2	Commissioning of Nuclear Power Plants: Training and Human Resource Considerations			✓
	NS-G-2.4	The Operating Organization for Nuclear Power Plants		✓	✓
	NS-G-2.8	Recruitment, Qualification and Training of Personnel for Nuclear Power Plants		✓	✓
	TRS 380	Manpower Development for Nuclear Power — A Guidebook		✓	✓
	NG-G-2.1	Managing Human Resources in the Field of Nuclear Energy		✓	✓

4. DEVELOPING A WORKFORCE PLAN

Summarizing the foregoing, for every country developing a nuclear energy programme, the workforce plans will be different, based on factors such as:

- Scope (and main purpose) of the construction build programme;
- Nature of construction build programme (fully turnkey versus transition to indigenous construction) and subsequent relationship with the vendor;
- Availability of nuclear expertise from non-energy applications (industry, medical, agriculture, applied sciences);
- Access to available international nuclear expertise;
- Existing (if any) nuclear educational programmes;
- Availability and quality of non-nuclear workforce.

The quantity and variety of resources needed to establish a nuclear energy programme can be phased in over the development of the programme and can begin with quite small numbers. For example, the owner/operator project team needed to manage the specification and contracting of the first NPP during Phase 2 may be as few as 30–35 personnel (assuming a turnkey project where the supplier has overall responsibility for management of construction and commissioning).

4.1. OVERVIEW

Workforce planning is an essential, ongoing human resources management process. Each organization involved in the nuclear energy programme should develop and maintain its own workforce plan; at least for Phases 1 and 2, the NEPIO should maintain an overall plan to enable an integrated national approach to resource utilization and development. In developing the national workforce plan, it is important to gain an understanding of how the workflow, and therefore the required resources and associated competencies, evolve as the programme develops:

- During Phase 1, the NEPIO will be responsible for most of the activities being undertaken. The number of staff involved will be relatively small and individuals may be drawn from various government departments, with much of the actual specialist work being done by external experts/expert groups. The work to be undertaken during Phase 1 will range from the development of recommendations concerning national policy in some areas through to more detailed analysis in others. Thus, some staff will be working at quite a high level, while others will be involved in more detailed activities (as stated earlier, Ref. [2] deals with the establishment and specific responsibilities of the NEPIO).

— At the beginning of Phase 2, the NEPIO will still be driving the programme, but the other key responsible organizations, including the regulatory body and the owner/operating organization, should be fully established and taking an increasingly active role. The core project team for the construction of the plant should be in place, as even at this early stage there will be a wide variety of activities to be managed, and early recruitment of those operations staff with long training lead times (see Section 5.4) should be under way. Towards the end of Phase 2, the NEPIO should have handed over many of its early responsibilities to the various responsible organizations and may indeed be considered to have completed its responsibilities.

— By the beginning of Phase 3, although the NEPIO may still have an oversight/coordination role, especially if the first NPP is part of a bigger programme, primary responsibility for management of NPP construction and commissioning should be with the operating organization. The regulatory body will be actively engaged in the licensing of the site and plant design as well as overseeing manufacturing and construction, as appropriate. The operating organization will be actively recruiting and managing the training of its permanent plant staff.

This profile of resource requirements is illustrated in Fig. 3. From an education/qualification perspective, during Phases 1 and 2 of infrastructure development, the majority of the core staff needed will be at the professional/graduate level. However, when staffing the NPP for the operations phase, the graduate component is generally the minority part of the total workforce, with the majority of the workforce being ‘technician’ level staff (i.e. staff who may only have high school level educational qualifications, coupled with some form of vocational skill certification and/or apprenticeship. These staff will require less ‘nuclear’ knowledge than their graduate counterparts but will need considerable training in order to understand the quality and safety requirements of working in a nuclear environment and why nuclear is different from other engineering and industrial environments.

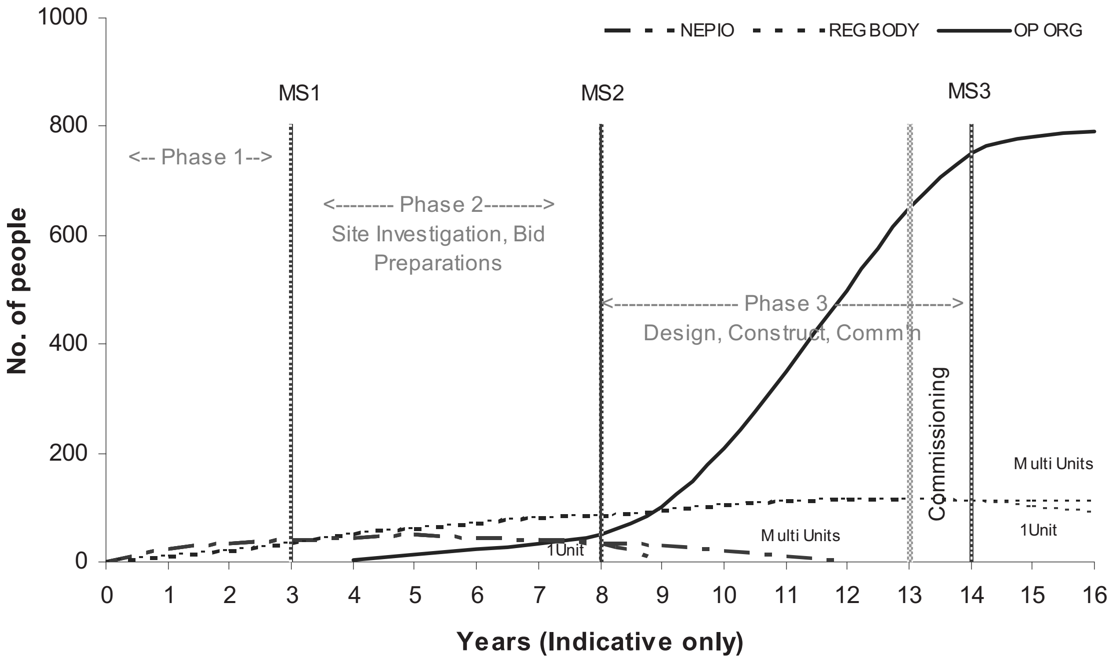

FIG. 3. Typical phasing of resource requirements.

4.2. RECRUITMENT CONSIDERATIONS

Even where there are no readily available resources with nuclear experience within the country, there are many opportunities for quickly accessing/developing such expertise, examples of which include:

— Attracting expatriate personnel who have worked in the nuclear sector abroad.
— Attracting experienced foreign personnel with appropriate remuneration packages, either as employees (if permitted by national labour laws/regulations) or as consultants. Such personnel can be a driving force in the development of the core national staff through coaching/mentoring and training.
— Recruiting experienced personnel from appropriate national industries, such as the fossil fired power generation, the process/production industries and the oil and gas industries, who will already have many of the required competencies to work in the nuclear industry.

In attempting to recruit expertise from overseas, it is important to recognize that this can be a two-way process. The nuclear community is currently truly global in nature, and this is unlikely to change in the near future; indeed, with the current upsurge in the prospect of new builds, the global demand for resources is likely to rise steeply. Hence, there is a high risk that indigenously trained personnel may be attracted to overseas opportunities, especially in more developed countries where salaries and living standards may be much higher than at home. An important element of the workforce planning strategy will therefore be the use of appropriate tools to monitor the engagement/satisfaction of employees, and to ensure that compensation packages are competitive with other opportunities nationally and, where possible, internationally. In any event, it would be prudent to build some redundancy into staff recruitment and training programmes to allow for these losses.

Another specific consideration is that of language. In many examples, when a country is constructing its first NPP, the project language and associated documentation has initially been in English, or another foreign language, sometimes with a transition into the national language at some time after the start of the NPP operation. This may be a factor in recruitment, and certainly the use of a project glossary to assist all parties concerned is recommended. It may also be necessary to consider allotting more time for additional training requirements (including language training) in workforce plans.

5. CONSIDERATIONS FOR STAFFING A NUCLEAR ENERGY PROGRAMME

5.1. OVERALL APPROACH

National recruitment processes and practices vary from country to country and may have a significant impact on the workforce planning process. However, nuclear energy programmes require staff of the highest calibre, and it is common practice for educational and/or qualification/licensing requirements to specified by the regulatory body, at least for certain safety related roles. It may therefore be necessary to implement a specific process for the recruitment of staff. Depending on the national education capability, some organizations are able to recruit their professional talent directly at the graduate level by a competitive process that may result in several hundred candidates applying for one or more jobs. This then requires screening to select perhaps 6–10 candidates for interview, which is a time consuming and resource intensive process. At the other extreme, some countries establish nuclear ‘academies’ or universities and select students directly from secondary education with the expectation that the vast majority of ‘graduates’ from these establishments will be employed directly by the industry, thereby simplifying the ‘recruitment’ process.

It is good practice to set limits on the duration of the recruitment process, from the announcement of a job opportunity to the day of appointment. This might be days or months, depending on whether the job is at a support staff or professional level, but it sets expectations on the part of both the recruiting organization and the applicants.

Another important consideration related to the duration of the recruitment process is the scope and duration of any job related training considered necessary prior to an individual's being authorized to undertake his or her allocated duties. This may range from a few weeks of familiarization for an experienced technical specialist working narrowly within his or her field to several years for a plant operator who may only have secondary education level qualifications.

Hence, for some positions (e.g. operations, reactor engineering, radiological safety and training), it will be necessary to begin the recruitment process several years prior to the individual's being needed to undertake his or her duties, even prior to signing the contract for the plant.

In an area where several Member States are considering implementing a nuclear energy programme, one practical approach might be to establish a regional training centre (RTC), thus sharing the burden as well as the benefits of specialist nuclear training among several Member States. There are a number of potential benefits in developing an RTC, including:

- Set-up as well as running costs are shared between several Member States.
- An RTC avoids competition between individual Member States in trying to attract scarce specialist resources to provide nuclear training.
- RTCs are more likely to attract the support of international organizations, such as the IAEA, and are more likely to be able to establish links/partnerships with other international training/educational institutions, operating organizations and suppliers.
- Member States may be less likely to lose staff to neighbouring countries if the whole region has adequate access to such specialist training resources.

Such RTCs where staff can receive training would be particularly beneficial during the early phases of a nuclear energy programme, before there is an operating NPP or even an NPP construction project.

An essential element of developing competence is the need to gain practical training and experience. Some elements of this are discussed in the next section, but, inevitably, it will be necessary to find a means of placing some personnel within existing nuclear operating organizations. The existence of an RTC and the possibility of such a facility establishing international links may also be of benefit in this respect.

5.2. PHASE 1

The initial resourcing of Phase 1 presents a major challenge in workforce planning, as a Member State is unlikely to have all or even many of the needed competencies, particularly those relating to nuclear power. Even starting with a zero baseline, the staff required for Phase 2 will have had the opportunity to develop their initial competence during Phase 1, and similarly for Phase 3. Hence, building competence during Phase 1 is vital for the success of the subsequent phases. An essential component of building that competence is giving staff real experience at the earliest possible opportunity.

One way of providing staff with the opportunity to gain experience during Phase 1 is to adopt a combined approach of importing international expertise to support the overall programme, while at the same time placing national staff overseas to gain experience. This approach may usefully be adopted by all responsible organizations: the NEPIO, regulatory body, operating organization, national industrial organizations hoping to participate in the manufacturing and/or construction of the plant, academic institutions involved in the development of national capability in the medium to long term, and those scientific/research and technical support organizations which may provide services to the plant throughout its life cycle.

External expertise has been successfully used in a number of different ways, for example:

- Contracting out whole work packages to experienced consultants, but including requirements to utilize/train national staff in delivering the work package (where little or no national competence exists in the particular area);
- Contracting with consultants to become 'temporary' staff working with nationals to deliver work packages, adding value in the more complex areas while developing national staff (where a modest level of competence exists);

— Engaging senior consultants to ‘coach’ national staff in specific areas of competence (where a higher level of national capability exists);
— Organizing national conferences/workshops where vendors and specialist support organizations can present their capabilities and services (care needs to be taken to ensure that no suggestion of preference or commitment to future business is implied).

Similarly, there are a variety of ways in which staff can be given the opportunity to build competence and experience overseas:

— Establishing bilateral and multilateral relationships with governments, regulatory agencies, vendors, utilities, educational institutions and others, which allow for placements and staff ‘swapping’;
— IAEA training courses, fellowships and internships;
— Formal courses of overseas study (e.g. vocational, undergraduate and postgraduate programmes, which may include industry assignments) and training (directly with utilities/national nuclear training organizations);
— Building staff training and development assignments into potential contracts with vendors, consultants, service providers, etc.;
— Developing ‘strategic alliances’ with vendors/equipment suppliers whereby national organizations obtain licenses to manufacture components in-country, which can include training and qualification in the country of origin.

Fortunately, the number of staff directly involved in Phase 1 is relatively small, maybe only 20–30 people, although this number would require the additional support of expert groups, either nationally or internationally. Most, if not all, of these staff will be within the NEPIO, and these staff are likely to be heavily supported by national/international expertise. An example of how this group might be organized is illustrated in Fig. 4.

If a Member State has an existing regulatory body for non-energy applications, this group can be used to undertake the initial work relating to the establishment/revision of legal and regulatory requirements for nuclear energy during Phase 1, even if a separate regulatory body for nuclear energy is to be established in due course.

While it may be difficult to make any long term staffing decisions prior to a formal decision on whether to proceed with a nuclear energy programme at Milestone 1, due to the constraints of the recruitment and training requirements described above, consideration should be given to commencing recruitment of some key staff during Phase 1, to be available for work in Phase 2.

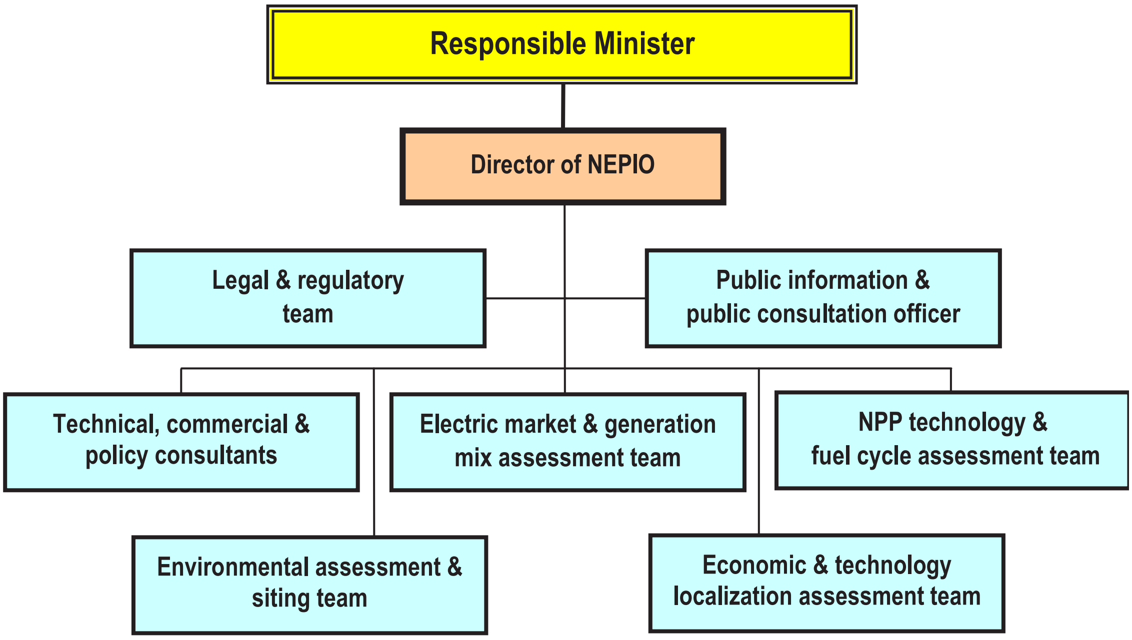

FIG. 4. Example of the organization of a NEPIO in Phase 1.

5.3. PHASE 2

This will be a very busy and diverse period in terms of workforce planning and staff recruitment, and so it is easier to address each of the three main groupings separately.

NEPIO

The staffing of the NEPIO will peak during this phase, as can be seen in Fig. 5, typically in the range on 20–50 staff members, depending of the level of specialist support available. By the end of Phase 2, many of their responsibilities should have been transferred to the other responsible organizations, especially the regulatory body and the operating organization. Depending on the size of the nuclear energy programme, the NEPIO may cease to exist as such (or its role may shift to one of purely coordination), with some of its oversight responsibilities (and resources) being transferred to the appropriate regulatory agencies and others being placed within those government departments which would normally be responsible for such activities. In addition, based on the experience they have gained, key NEPIO staff may be transferred into senior positions in the operating organization, either within the nuclear plant management structure (single NPP) or in the corporate organization (multi-unit programme). It is important however that, even if the NEPIO ceases to exist as an organization, the government continues to demonstrate its commitment to, and support for, the nuclear energy programme, and that key individuals within the appropriate government departments have the authority and responsibility to continue promoting the programme.

Regulatory body

The development of the work processes, human resources and competencies of the independent regulatory body is a high priority task in Phase 2 and will continue through Phase 3. During Phase 2, the regulatory body will be proposing and promulgating safety regulations and guides, as well as adopting appropriate industrial codes to properly cover all foreseen nuclear activities.

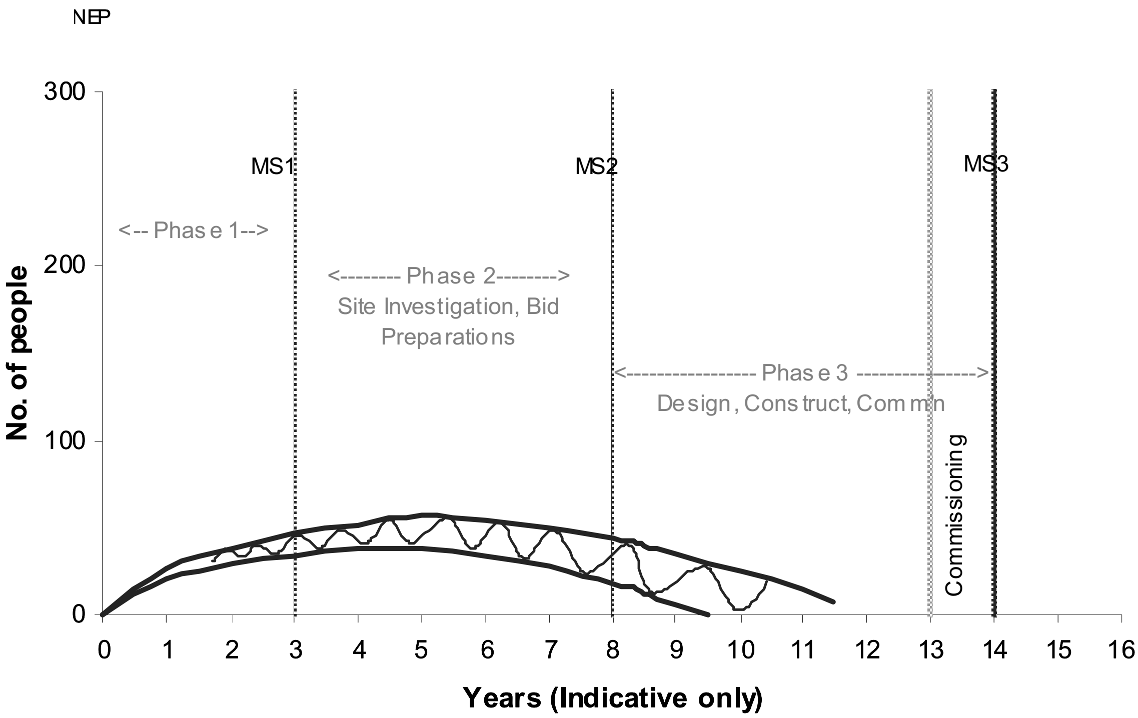

FIG. 5. Example of phasing of resource requirements for a NEPIO.

The number of staff of the regulatory body will depend on two key factors:

- — The number of organizations available to provide technical support to the regulatory body (Section 2.2);
- — The regulatory approach adopted by the Member State (Section 2.4).

Typically, the regulatory body may have a core staff of about 40–60 people with the competencies to develop or adopt safety regulations, develop and implement an authorization process, review and assess the safety and design documentation provided by the operating organization against the adopted regulations, and inspect the facility, the vendor and manufacturers of safety related components.

Peak numbers within the regulatory body may be higher, for example, up to 100–150 personnel, again dependent on the level of specialist independent support available and on the number of NPPs planned (workload). In the case of only one plant, these numbers should decline over commissioning, as illustrated in Fig. 6.

It is generally accepted that regulatory bodies should have competencies in four main areas:

- — Legal basis and regulatory processes;
- — Technical disciplines;
- — Regulatory practices;
- — Personal and interpersonal competencies.

Detailed guidance on the development of these competencies for regulatory body staff may be found in Ref. [11], and the IAEA can provide assistance in this area.

Operating organization

Purely from an operational point of view, the planning and recruitment of the staff that will eventually operate the plant needs careful consideration at an early stage in the programme for the following reasons:

- — The number of staff required is much larger than for the other organizations, typically in the range of 500–1000 for a single or twin unit plant, up to several thousand for a multiple unit plant (see Section 5.4).

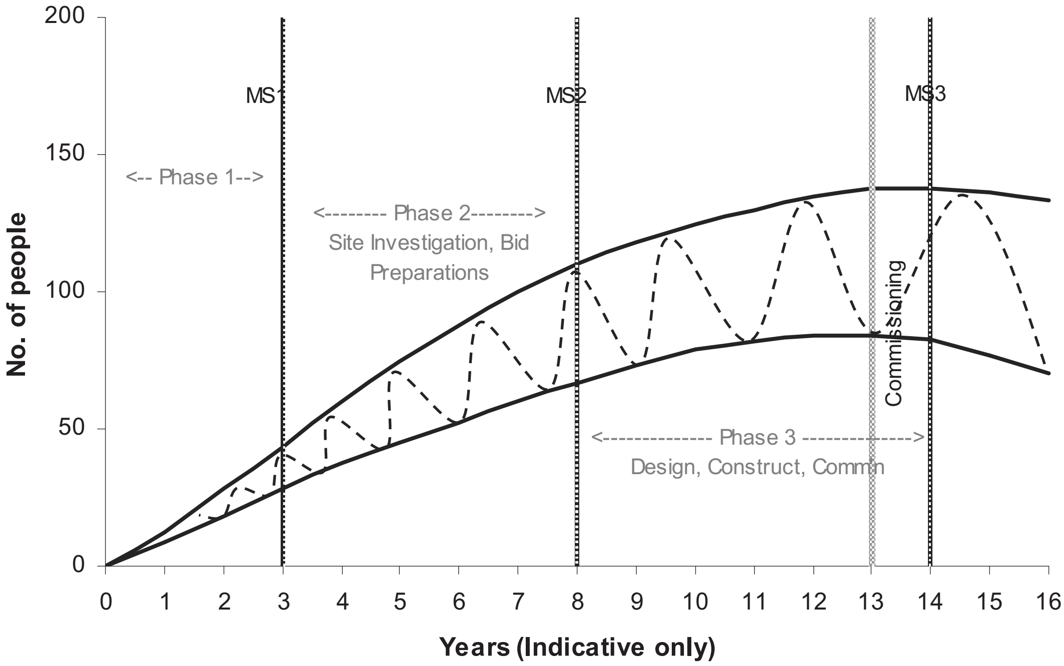

FIG. 6. Phasing of resource requirements for the regulatory body.

— Many of the operating organization staff have safety related roles as described above, requiring authorization, and hence have significant training programmes, required up to several years for completion (much of such training may be initially conducted at reference plant(s) overseas).
— The commissioning of an NPP, especially if it is a country's first plant, presents a unique opportunity for staff to gain practical experience. For those staff with specific responsibilities during the commissioning phase, their initial training must be completed. For other staff who do not have specific responsibilities, the commissioning phase still provides opportunities to observe activities and gain practical experience. For these staff to gain maximum benefit and to avoid resource conflict, at least initial classroom training should be completed prior to the main commissioning phase. The IAEA publication Commissioning of Nuclear Power Plants: Training and Human Resource Considerations [12] provides guidance in this area.

In addition, for a first NPP, there are many other activities to be carried out by the future operating organization, such as:

— Preparing the BIS;
— Preparing the environmental impact assessment report (EIAR);
— Establishing interfaces with the various national and international bodies associated with safeguards, security, physical protection, the nuclear fuel cycle and radioactive waste;
— Establishing the integrated management system needed to ensure the safe operation of the plant;
— Creating the foundations of an appropriate safety culture prior to commencing construction;
— Preparing a strategy for dealing with the public;
— Starting to prepare emergency plans and procedures;
— Other (see Ref. [3]).

In order to ensure that there are enough competent staff available for these activities, it will be necessary to begin the recruitment and training of operating organization staff early in Phase 2 (see Fig. 7).

5.4. PHASE 3

By the beginning of Phase 3, the majority of NEPIO staff is likely to have either transferred to one of the other responsible organizations or returned to one of the government departments with ongoing responsibility for the nuclear energy programme. The majority of regulatory body staff should be in place, undertaking training and discharging their responsibilities in respect of the licensing process.

A project team should be established within the operating organization and fully staffed and competent to meet its responsibilities. This team will oversee the project on behalf of the Member State/operating organization, as distinct from the vendor established project management team (PMT), which will manage the actual construction of the NPP and which may include representatives of the operating organization [3]. It is recommended that this team is part of the operating organization in order to retain their experience and expertise, although different practices may be found in different countries. This also depends on the size of the nuclear energy programme. A key issue here is to ensure that senior PMT staff are not also designated to be senior plant operations staff, as their project management responsibilities during commissioning are likely to conflict with the opportunities for operations staff to gain unique hands-on experience during the commissioning phase.

Plant staff

During this phase, the majority of the plant operating staff, especially technical staff, should be recruited and fully trained. In reality, the actual staff numbers required will vary from plant to plant. This is even true in Member States currently operating many NPPs. This can be for a variety of reasons, including:

— Stand-alone NPP or part of a fleet of NPPs with one operating organization and centralized support functions;
— Regulatory requirements specified by the Member State's national nuclear regulator;
— Regulatory requirements specified within the Member State by provincial regulators;

— Minor differences in design, even on twin/multi-unit sites;
— Concept of operations, including the level of plant automation and control, and approach to maintenance (in-house staff, joint maintenance by operating utility staff or external contractors);
— Physical attributes of the NPP — physical layout of plant systems/equipment;
— Local labour conditions;
— National/local laws/regulations on labour and employment practices;
— Support relationships with vendors/suppliers.

To give readers of this publication a better understanding of the staffing needed by the end of Phase 3 for the operating organization (the largest of the nuclear organizations to be established), Appendix I provides an example of the median staffing levels by function for some 67 one-unit and two-unit NPPs in operation in North America and western Europe (see notes in the appendix), giving totals of approximately 700 for a single unit plant and 1000 for a twin unit. A description of each of the functions is included in Appendix II for clarity. It must be emphasized that these figures are presented as examples only, as actual numbers will depend on many factors, including those listed above.

It should be emphasized that these numbers relate to direct plant staff only. If more than one NPP is to be built, it is likely that a central or 'headquarters' function will be established with its own resource requirements, which in turn may impact the numbers required on each unit if some of the functions are centralized (e.g. design authority, technical support, maintenance, finance, procurement). Additional comparative data on staffing numbers can be found in Ref. [15].

The phasing of recruitment of plant staff depends greatly on their training lead times (how long they need for formal training prior to authorization/certification for their duties), and these vary greatly, depending on their roles and responsibilities. Figure 7 provides an example of the phasing of recruitment in years before commissioning, based on the totals given above. An example breakdown of qualification and training requirements (including typical training lead times, based on the stated expected entry-level education requirements) for various functions at a typical US NPP is included in Appendix III. The reader is cautioned that such lead times will vary considerably based upon national norms and regulations regarding factors such as education, vocational training, labour laws and practices, and industry practices. This variability underlines the need for each country to analyse its own situation and needs through its detailed workforce planning.

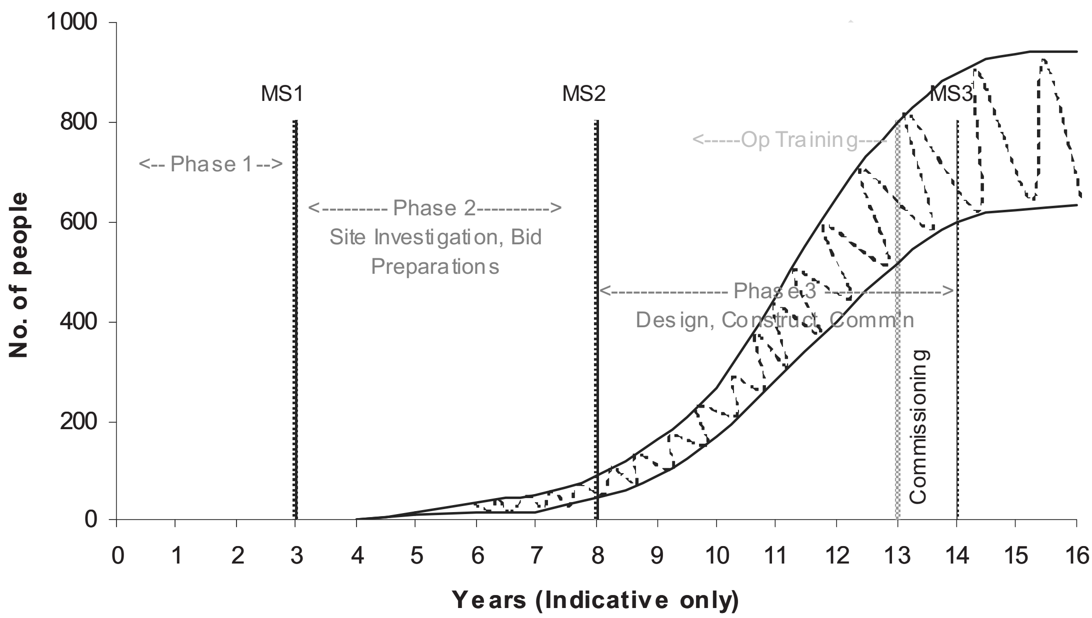

FIG. 7. Buildup of plant staff prior to commissioning.

In terms of staffing a first nuclear plant, a number of options have been used, including:

- — Initial operation by a national staff, which is already trained by the vendor but under the supervision of an experienced vendor supplied staff for an initial period;
- — An initial period of operation staffed by the turnkey contractor’s staff while training the main body of the national staff, with a subsequent formal handover to the operating organization after a period of one to three years;
- — A mixture of experienced and newly trained staff in appropriate positions (e.g. for early Chinese NPPs, approximately one-third of the staff were taken from other plants, one-third from research reactors and one-third from their ‘nuclear’ university).

5.5. POST–PHASE 3 (OPERATIONS, DECOMMISSIONING)

The completion of commissioning of the NPP marks the beginning of what should be, by current norms, a 40–60 year operating phase, followed eventually by decommissioning. Throughout this period of operations, specialist support (including research and development) will be needed for a variety of activities, for example:

- — Periodic routine maintenance;
- — In-service inspection (ISI) and other non-destructive testing (NDT) activities;
- — Refurbishment/replacement of obsolete systems/components;
- — Upgrading of reactor/turbine power output;
- — Development of the case and implementation of the necessary enhancements to extend the operating life of the plant (life extension).

The same can also be said for the decommissioning phase of the NPP. While the vendor and/or other specialist external contractors already exist to provide such support, and the timescales for the development of such national capability are longer, decisions need to be taken at an early stage concerning the extent of desired national involvement in these activities in order to build any requirements into the national workforce plan and contract tender requirements as appropriate. Some aspects of this are discussed in more detail in the next section.

6. THE ROLE OF SUPPORT ORGANIZATIONS

6.1. EDUCATION/RESEARCH AND TRAINING INSTITUTIONS

While it is advantageous to have an existing national nuclear engineering education/research infrastructure, this is not a prerequisite to begin a nuclear energy programme. What is necessary is to have a good general engineering (electrical, mechanical, control, process, etc.) and physics education infrastructure, producing high calibre graduates, who can then be trained on appropriate nuclear specifics either within the industry, in cooperation with other training or academic providers, or even as part of the turnkey contract by the vendor.

In Section 5.1, the concept of a regional training centre (RTC) was introduced. Should this option not be feasible, a Member State should consider establishing its own nuclear training centre (NTC) to provide the necessary link between the nuclear ‘education’ provided by universities and technical schools and the specific knowledge, skills, attitudes and experience required to develop the competence to work at an NPP. Such an NTC could be operated by the government, the owner/operator or an independent organization but could have links with appropriate universities to provide teaching support and specialist lectures within the training centre as described, for example, in the Daya Bay case study in Appendix V.

If a nuclear research capability already exists within the Member State, then it is important, as far as practicable, to align the activities of the education/research institutions and the nuclear energy programme to try to achieve a beneficial balance between academic rigour and industry oriented application. Such established research activities may provide a good source of expertise for the nuclear energy programme.

One of the benefits of an industry based postgraduate nuclear training programme is that the education and training can be of a much more ‘applied’ nature based on planned/actual designs being implemented and can be targeted at specific areas of activity (e.g. operations, engineering, maintenance, reactor performance).

If a strong undergraduate/postgraduate nuclear engineering education infrastructure does not already exist, but it is planned to build one as part of a national nuclear energy programme, it is important that both industry and academic institutions work closely to develop such programmes to ensure that they are practical and oriented to the national need.

When considering the development of the nuclear workforce, it is important not only to focus on the graduate/postgraduate sector but also to consider the vocational requirements of regulators and operating organizations. Experience shows that typically more than 50% of the workforce at an NPP may be technical staff with vocational qualifications and usually trained in technical schools, which rarely have nuclear specific programmes. This sector of the workforce is often recruited relatively local to the NPP (which helps to foster local support for the NPP), and so Member States should work closely with and endeavour to support those technical schools close to any sites being considered for an NPP. Regional or national training centres, as already described above, would play an important role in the training of these staff.

An important element of any relationship between the nuclear industry and any education or especially training institutions is the adoption of a systematic approach to training (SAT) to ensure that any education and training programmes proposed meet the needs of the industry. Establishing SAT at an early stage in the project will help to ensure that an effective training system is established within the project and that those areas where training services and support can be appropriately outsourced to vendors and/or national education and training organizations are correctly identified. The IAEA has extensive guidance on establishing and implementing SAT, and references are included in the Bibliography.

For the nuclear industry, there are many benefits to be gained from cooperating with educational institutions, including:

— The opportunity to shape undergraduate programme curricula to achieve a balance between the needs of industry and academic demands;
— Access to students in order to promote a career in the nuclear industry as an option for undergraduates;
— An opportunity to sponsor and give experience to the best undergraduates to encourage them to join the industry upon graduation.

There are a number of actions that the nuclear industry can take to help to develop and foster these relationships. These include such activities as:

— Providing work placement opportunities whereby students can gain experience in the various organizations (operating organization, regulatory body, support organizations) for a period from a few weeks up to a year to gain insight and experience in the organizations. Many Member States have undergraduate programmes that require students to work in the industry for a year during their studies in order to gain real experience in the field of their studies.
— Providing support for/funding an appropriate ‘Chair’ or Head of Faculty position (e.g. engineering, physics, nuclear sciences) at one of the better engineering universities.
— Funding relevant research such as material studies, fatigue mechanisms, diagnostic techniques, etc.; this will be of real benefit to the nuclear industry while at the same time attracting and encouraging high quality academic staff who will support the undergraduate and postgraduate programmes of the associated institution.

The level of national resource infrastructure building and the involvement of educational institutions to support this activity will depend on factors similar to those influencing the workforce planning strategy, including:

— The size of the planned nuclear power programme and, accordingly, the extent of international support for the planning, siting, design/reactor type, construction, commissioning and operation of the first NPP;
— The scope for international support (economic, political, etc.);

— The existing infrastructure, if any, to support non-power applications of nuclear energy (e.g. medicine, industry and agriculture);
— The current national industrial and technological base and its potential for development.

Existing national educational institutions (EIs) can enhance the support they provide for the development of human resources for the nuclear industry in a number of ways, such as by:

— Developing new or realigning existing nuclear engineering and science related degree curricula jointly with the responsible organizations (NEPIO, regulatory body, operating organization, industrial partners, etc.) to ensure alignment with future needs;
— Establishing working ‘councils’ with academic, government and industry representation to oversee the development of nuclear science training and development programmes nationally;
— Using senior responsible organization staff as visiting lecturers on nuclear engineering programmes;
— Placing undergraduate students in the responsible organizations for work experience as part of their undergraduate programme;
— Developing partnerships with EIs that have appropriate programmes in countries with mature nuclear power programmes, using this relationship to develop new programmes or gain accreditation of existing programmes;
— Developing fellowship or exchange programmes whereby national undergraduates get the opportunity to pursue a portion of their studies in a country with a well developed nuclear power programme; similarly exchange programmes could be established for lecturers to import international expertise while at the same time broadening the experience of national staff;
— Utilizing available international assistance (e.g. IAEA programmes, World Nuclear University, regional networks).

For EIs wishing to enhance the support they provide, particular attention should be paid to the selection and training of lecturers on nuclear plant specifics such as nuclear safety, plant design and characteristics of the plant equipment.

6.2. TECHNICAL SUPPORT AND R&D ORGANIZATIONS

Many Member States have exploited the establishment of a nuclear energy programme as a vehicle to facilitate a wider technology transfer and to upgrade the national technological capability. While in the short term the focus of the programme should be to establish nuclear energy in a timely and cost effective way, usually by a turnkey approach as described earlier, there will be many opportunities for national organizations to provide support in the longer term. Involvement of national organizations may even be specified within the turnkey contract, provided they have the capability and resources to meet the requirement of the project.

Regarding nuclear power, both operating organizations and nuclear regulatory bodies in a number of Member States have formal relationships with technical support organizations (TSOs) to provide them specialized assistance, rather than maintaining such competencies within their own organizations. When initiating a nuclear power programme, the use of such TSOs should be considered when developing a human resource development strategy and supporting workforce plans. Technical Support for Nuclear Power Operations, IAEA-TECDOC-1078 [16], and IAEA Safety Standards Series No. GS-R-1, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety [17], provide further information regarding TSOs for operating organizations and regulatory bodies, respectively. Some additional human resource issues for such organizations are also addressed in Ref. [5], Appendix II.

A wide variety of support will be needed by the NPP throughout its life cycle, as outlined in Section 5.5, as well as support for radioactive material (including fuel) handling, storage and disposal. An early decision on the extent of/potential for national involvement in these activities is needed to determine the workforce planning requirements for these areas.

The same issues of size and scope of the nuclear energy programme affecting the wider workforce planning strategy and involvement of education and training organizations apply to technical support and R&D organizations.

7. KNOWLEDGE MANAGEMENT FOR NEW NUCLEAR POWER

7.1. NEED FOR NUCLEAR KNOWLEDGE MANAGEMENT

It is important to remember that, as indicated at the beginning of this publication, the introduction of a nuclear energy programme involves a commitment of at least 100 years to cover the commissioning, operation and, ultimately, decommissioning phases of an NPP (i.e. several generations of the workforce). Many experts around the world are retiring, taking with them a lot of knowledge and corporate memory. Loss of employees who hold knowledge that is critical to either operations or safety poses an internal threat to the safety and operations of NPPs. Hence the issue of knowledge management, particularly knowledge about the design, construction and commissioning of the plant, is critical. For many mature nuclear operating organizations with many years of reactor operation, the need to manage knowledge for future generations was not recognized as a priority in the early years, and these organizations are facing a major challenge with renewed support for nuclear power and the desire to extend the lives of existing plants.

In IAEA-TECDOC-1510, Knowledge Management for Nuclear Industry Operating Organizations [18], knowledge management is defined as an integrated, systematic approach to identifying, managing and sharing an organization’s knowledge, and enabling persons to create new knowledge collectively in order to help achieve the objectives of that organization.

Member States embarking on a new nuclear energy programme have the opportunity to establish effective knowledge management systems and processes from the outset, with the added benefit of readily available hard and software systems designed for that purpose. Early establishment of a knowledge management system is especially important for turnkey contracts, where most of the necessary plant data will come from third parties and provision must be made for inclusion of all data, in an easily accessible format, within any contract specifications.

7.2. BENEFITS OF KNOWLEDGE MANAGEMENT

Knowledge is the key resource of most organizations in today’s world. Managing knowledge effectively requires understanding of and attention to the concept of organizational knowledge rather than just the traditional notion of individual centred knowledge. This shift can be addressed through the utilization of organizational core competencies that have proven themselves to be of value within many Member State organizations.

Knowledge management can be considered as a management philosophy in the same way as, for example, quality management and risk management are. Many of these other philosophies have reached a level of maturity whereby they are embedded in standard management practice. Nuclear knowledge management has not yet reached this stage of maturity worldwide. The IAEA recommends a management system to promote and support nuclear knowledge management as a primary opportunity for achieving competitive advantage and maintaining a high level of safety. This approach ensures that organizations are able to demonstrate their long term competitiveness and sustainability through actively managing their information and knowledge as a strategic resource that supports the establishment and maintenance of safe, high level organizational performance. The requirement to manage information and knowledge as a resource is an integral part of an operating organization’s management system [6].

Some additional information on aspects of knowledge management and steps to implement an effective knowledge management system are included in Appendix IV, and additional IAEA publications containing guidance on developing effective knowledge management systems and details are listed in the Bibliography.

8. SUMMARY: HOW TO GET STARTED

This section is intended to provide a very brief summary of the information provided in this publication, presented in the form of an overview of how to get started on effectively including human resources development when considering whether nuclear power is feasible for a Member State. This section is NOT intended to stand alone but rather to serve as an overall road map for addressing workforce planning in the context of considering a nuclear power programme (Phase 1 of the Milestones approach [1]).

The importance of recognizing workforce planning as an integral part of an organization's human resource development strategy and plans was emphasized in the introduction and is illustrated in Fig.1.

8.1. PREREQUISITES FOR WORKFORCE PLANNING (PHASE 1)

As stated previously, a prerequisite for effective workforce planning for a nuclear power programme is the establishment of clear roles, responsibilities and functions for all of the organizations that will have a role in considering a nuclear power programme. Absent these roles, responsibilities and functions, there is no framework/basis for workforce planning. The establishment of a NEPIO as described in Ref. [2] is one way in which to effectively develop these roles, responsibilities and functions, as well as to foster coordination among those organizations involved in considering a nuclear power programme. However, these roles, responsibilities and functions can certainly be determined without having a NEPIO in place.

8.2. KEY STEPS FOR WORKFORCE PLANNING IN THE CONTEXT OF A HUMAN RESOURCES STRATEGY

It is recommended that the following activities related to workforce planning be implemented when getting started (for Phases 1 and 2):

(1) Produce a brief (1 or 2 page) conceptual statement on human resources development for the nuclear programme (to be developed during Phase 1 in support of a 'road map' for the nuclear power programme).
(2) Develop a human resources development strategy for the entire nuclear programme that considers all of the areas identified in Fig. 1 to be included in the feasibility study (which is the principal output of Phase 1).
(3) Develop a workforce plan for all activities to be conducted during Phase 1 and for those expected to be performed in Phases 2 and 3 if a decision is made to go forward with the programme. This plan should be continually updated as the project goes forward.
(4) Based on the outputs of 2 and 3 above, identify the requirements for NPP personnel selection, recruitment, training and authorization for which assistance is to be sought from the vendor (to be developed during Phase 2 as an input to the bid invitation specification).

A project approach should be taken to develop the above outputs driven by a suitable project manager. When a NEPIO has been established, one of the members of the NEPIO should be assigned for managing/coordinating human resources development activities.

The initial workforce plan may be efficiently developed in the following manner:

- Start with a self-evaluation of infrastructure status [4];
- Identify gaps for all 19 issues, phase by phase, based on organizational responsibilities and activities;
- Identify underlying causes, including lack of competent personnel;
- Define solutions, including human resources related solutions in terms of numbers of people needed, organizations, competencies;
- Implement solutions;
- Evaluate effectiveness of actions/solutions.

9. OVERVIEW OF CASE STUDIES

Finally, a number of case studies have been developed to highlight the real experience of different Member States as related to different phases of infrastructure building. Appendix V addresses the early development of the Chinese nuclear energy programme, which was based on a very specific partnering at the national level with France. The example from the Republic of Korea, detailed in Appendix VI, illustrated a more broad based approach, where early experience was taken from a number of nuclear experienced countries. Appendix VII looks at nuclear workforce development from an Indian perspective.

At the time of writing, the United Arab Emirates (UAE) had just agreed on a contract, consistent with completion of Phase 2, with a consortium from the Republic of Korea to build and operate their first NPP, and their approach to human resources development is summarized in Appendix VIII.

The IAEA is supporting Armenia in an evaluation of its human resources needs in conjunction with a new build as part of a broader study of the feasibility of new builds. Armenia’s case is unusual in that, although it currently operates an NPP, that plant was built during the era of the Soviet Union, and it does not currently have much of the infrastructure required for a new build. A summary of the evaluation of human resources development needs is included in Appendix IX. Finally, details of a software modelling tool that may be of help in developing workforce planning strategies are included in Appendix X.

Appendix I

AN EXAMPLE OF NPP STAFFING NUMBERS BY FUNCTION

This appendix provides median staffing levels (current at the time of writing) from 67 operating North American and western European nuclear power plants. They include several different one and two unit nuclear reactor designs. Some of the plants achieved commercial operations in the 1960s, and some came on-line as late as the 1990s. Some of the plants are in a ‘fleet’ where one operating organization runs more than one nuclear site, while others are the only NPP operated by a particular utility or operating company.

The data does not reflect significantly different approaches to staffing levels that are driven by regulatory, cultural and operating organization preferences/requirements. This means that the median value shown may be significantly different from the minimum or maximum level at a particular NPP. The history of staffing approaches varies across a significant spectrum. Some NPPs had significantly lower staffing levels at startup that grew over time with operational experience and regulatory development. Other NPPs began commercial operations with very high levels because they retained many of the architect/engineering/construction staff after startup and then slowly reduced staff over long periods of time. The reader is reminded that the data in this appendix represents only about 15% of the 435 NPP units that were in operation at the time of writing. Consequently, the data shown in the referenced table does not address many of the variables that affect staffing levels in other regions or for other technologies than those represented in this sample. Thus, the staffing data shown should only be used as a general guide for new organizations contemplating deployment of a new NPP, and not for developing specific target staffing levels. The numbers shown represent the staffing numbers of mature nuclear operating organizations and should not be considered as near term targets for first NPPs, which may be higher.

For further information, see IAEA-TECDOC-1052, Nuclear Power Plant Organization and Staffing for Improved Performance: Lessons Learned (1998). This publication provides examples of staffing levels and factors that affected these staffing levels. Even though this data is over 10 years old, much of it continues to be relevant.

	Nuclear plant staffing		
	1-unit		2-unit
Nuclear work function	Median		Median
Admin/clerical	25		42
ALARA	4		4
Budget/accting	7		9
Chemistry	17		26
Communications	2		2
Computer engineering	3		4
Contracts	1		3
Decon/radwaste	11		12
Design/drafting	5		7
Document control/records	11		12
Emergency preparedness	5		5
Environmental	3		3
Facilities	21		27
Fire protection	1		2
HP applied	17		28
HP support	8		10
Human resources	4		4
Information management	13		14
Licensing	7		9
Maintenance/construction	119		186
Maintenance/construction support	22		39
Management	30		35
Management support	2		2
Materials management	3		4
Mods engineering	22		33
Nuclear fuels	4		7
Nuclear safety review	6		6
Operations	74		122
Operations support	20		20
Outage management	5		7
Plant engineering	33		47
Procurement engineering	5		6
Project management	7		11
Purchasing	4		7
QA	8		11
QC/NDE	7		7
Reactor engineering	4		5
Safety/health	2		3
Scheduling	11		15
Security	119		128
Technical engineering	19		31
Training	32		43
Warehouse	9		14

Total	732		1012

Appendix II

WORK FUNCTION DEFINITIONS

This appendix provides a brief definition of each of the 43 work functions for the 67 NPP units from North America and Western Europe that were the basis for the data in Appendix II. This information is provided to help the reader understand this data or to compare a given situation or plan to these functions. It is NOT intended to endorse this particular identification of workforce functions, as there is considerable variability in NPP workforce functions and organization worldwide based upon factors such as technology, national norms and culture, labour rules and laws, and industry practices.

II.1. ADMINISTRATION/CLERICAL

Includes all secretaries, clerks and clerical pools. It also includes administrative assistants who provide administrative support in a function but who themselves are not functional professionals. Also included are staff performing administrative support functions such as conference coordination, graphics work and non-technical analysis of data. Supervisors of clerical pools are included in the function, as are telephone receptionists. This group also includes persons maintaining site-wide procedures.

II.2. ALARA/RADIOLOGICAL ENGINEERING

Includes persons planning and controlling the as low as reasonably achievable (ALARA) programme, and performing and evaluating radiation dose and shielding calculations. It also includes staff reviewing complex radiation work permits.

II.3. BUDGETING/ACCOUNTING

Responsible for operation of budget and accounting systems under nuclear group control. Disseminates accounting and budget information and organizes budget input. Oversees preparation of budgets and provides ongoing accountability reports to managers. Prepares nuclear group business plans and interfaces with joint owners.

II.4. CHEMISTRY

Includes chemistry technicians for normal and emergency shift functions such as chemical additions and chemical/radiochemical analyses. Also includes persons coordinating all aspects of the chemistry programme and providing guidance on chemistry standards; conducting evaluations of plant chemistry programmes; and addressing and resolving chemistry operating problems. Also includes staff responsible for radioactive effluents programme.

II.5. COMMUNICATIONS

Media representatives, internal communications and tour guide staff are included in this function. Also included are those persons serving as community contacts, answering local questions, organizing publicity projects and operating or providing tours at plant visitor/information centres.

II.6. COMPUTER ENGINEERING

Responsible for hardware and software engineering associated with plant process computers, radiation monitoring system and other operational and support computers and systems. Includes personnel who provided similar services for the training simulators.

II.7. CONTRACTS

Coordinates placing of bids, and awarding and monitoring of performance on contracts for labour and services. Controls contract changes and associated claims. Coordinates administration and enforcement of contract terms and conditions such as bonus/penalty clauses and cost-plus provisions.

II.8. DECONTAMINATION/RADWASTE PROCESSING

Includes all persons performing decontamination and cleanup inside the power block, and those responsible for dry radwaste systems, and for packaging and transport of contaminated materials.

II.9. DESIGN/DRAFTING

Performs manual and computer aided design and engineering functions. Resolves field questions, and maintains piping and instrument diagrams and electric power line diagrams. Prepares stress isometrics. Can perform simple calculations.

II.10. DOCUMENT CONTROL/RECORDS

Receives, prepares, microfilms and indexes nuclear records and drawings. Controls and distributes station documents. Coordinates other aspects of document processing, records management, and central files and libraries. Clerical personnel performing records duties are included in this category, not with clerks.

II.11. EMERGENCY PREPAREDNESS

Develops, implements and maintains the emergency preparedness programme. Trains and qualifies emergency exercise participants. Responsible for emergency preparedness facilities, including the emergency operations facility (EOF) and tactical support centre (TSC). Focal point for local, state and federal legislation on emergency preparedness issues.

II.12. ENVIRONMENTAL

Includes persons responsible for the non-radiological environmental monitoring programme and related requirements such as environmental licences and permits, audits and thermal monitoring.

II.13. FACILITIES

Includes persons directing and performing routine preventive maintenance, corrective maintenance and predictive maintenance activities on non-power block buildings, systems and components other than substations. Also includes persons responsible for general yard work, telephone systems and vehicle maintenance.

II.14. FIRE PROTECTION

Administers the fire protection programme, including surveillance. Responsible for fire protection programme inspections. Includes personnel who serve on full-time fire brigades.

II.15. HEALTH PHYSICS APPLIED

Includes radiation protection technicians involved with activities such as routine and special surveys, and data reading and analysis. Also includes persons collecting and analysing radiation system samples.

II.16. HEALTH PHYSICS SUPPORT

Personnel responsible for technical oversight of health physics programme. Includes persons involved with respiratory protection, radiological environmental and dosimetry programmes, including clerical staff maintaining dosimetry records.

II.17. HUMAN RESOURCES

Responsible for implementation and operation of human resources, and personnel programmes and systems such as appraisal, benefits, compensation, vacancy selection and promotion. Coordinates employment and equal employment opportunity activities, as well as management development training. Typically includes the central point of contact for union relations.

II.18. INFORMATION MANAGEMENT

Responsible for dedicated software and hardware support for business and management application and database management for nuclear group systems. Provides software related system design, revision and user information services. Provides operations and system administration resources for hosts and servers. Also provides system hardware design, revision and user information services. Responds to technical and information requests from internal and external sources.

II.19. LICENSING/REGULATORY AFFAIRS

Primary contact for licensing and other regulatory issues with national regulatory body (regulatory body). Coordinates and reviews responses to regulatory body routine and special information requests, including licensee event reports (LERs), notices of violation and generic letters. Coordinates annual FSAR update process.

II.20. MAINTENANCE/CONSTRUCTION

Includes persons whose primary function is to perform maintenance and construction work within the power block. This includes routine preventive maintenance, corrective maintenance and predictive maintenance activities on plant components. It also includes the installation of minor and major modifications and metrology work. Persons who directly supervise these activities are also included in the function. Includes mechanical, I&C and electrical maintenance staff and their supervisors.

II.21. MAINTENANCE/CONSTRUCTION SUPPORT

This function includes people who support the work of maintenance/construction. This includes those involved in job package development, and assembling, completing and reviewing documentation associated with the maintenance effort; non-engineering degreed maintenance technical experts; non-engineering degreed persons developing maintenance strategies and resolving maintenance rule issues; personnel coordinating with plant engineers on the development of corrective maintenance procedures and other technical matters; and full-time maintenance procedure writers. Also included in this group are personnel who support plant modification work such as coordination of contractor labour, and cost and schedule estimating. Tool room attendants are included in this function. The function does not include schedulers, designers or plant engineers.

II.22. MANAGEMENT

Includes all management personnel above first line supervisors in each organization up to and including the company's chief nuclear officer.

II.23. MANAGEMENT ASSIST

Includes personnel assigned to multifunctional special projects supporting managers. Includes persons supporting organizational or plant wide projects.

II.24. MATERIALS MANAGEMENT

Includes persons responsible for inventory control, disposal of surplus materials, and management and operation of inventory re-order point programmes. Also includes responsibilities for assigning stock numbers, consolidating stores inventory and maintaining ordering information.

II.25. MODIFICATIONS ENGINEERING

Provides modification engineering services and ensures design integrity for:

- Civil/structural engineering, including site buildings, roads, bridges and waterfront structure. Performs soil and foundations analyses, and reviews and approves hanger and support locations. Provides stress analysis and support evaluation services. Provides architectural and site layout services.
- Electrical/I&C engineering, including high, medium and low voltage distribution systems (including DC and instrument power), related components (including motors, circuit breakers, transformers, batteries, chargers and inverters) and instrumentation and control systems and components.
- Mechanical engineering, including primary, secondary and auxiliary systems, and associated components, including piping, insulation and hangers.

II.26. NUCLEAR FUELS

Performs and/or reviews reload safety evaluation, reload design analyses, and thermal, hydraulic and transient analyses. Provides support to operations for core analysis. Supports fuel licensing and fuel management activities. Includes personnel who manage and monitor the nuclear fuel acquisition process.

II.27. NUCLEAR SAFETY REVIEW

Responsible for off-site and on-site safety review activities. Reviews operating abnormalities and advises management on overall quality and safety of operations. Reviews operational and regulatory related documents such as LERs, and license and technical specification changes. Reviews plant and industry event reports for applicability and lessons learned. Performs coordination function for INPO contacts. Includes Independent Safety Engineering Group (ISEG) activities and dedicated corrective action programme personnel. Also includes human performance programme activities and the employee concerns programme.

II.28. OPERATIONS

Includes on-shift staff, supervisors and shift managers responsible for operating primary, secondary and liquid radwaste systems; if performed by shift staff, includes preparing or reviewing responses to operating events and associated inquiries from other organizations.

II.29. OPERATIONS SUPPORT

This function includes non-shift personnel supporting the operations staff, including dedicated procedure writers, scheduling coordinators, technical specialists and training coordinators. Also included are persons in licensed operator training classes.

II.30. OUTAGE MANAGEMENT

Includes persons planning and coordinating all outage activities. Central contact point for refueling and maintenance outage planning and management, and forced outage management. Includes dedicated outage work window managers.

II.31. PLANT ENGINEERING

Includes persons evaluating system and component performance, and monitoring system operating performance parameters (system health). These persons provide engineering assistance to maintenance in the development of corrective maintenance actions; develop and review procedures and technical reports/responses; and review surveillance, modifications and system related studies generated internally and externally. Responsible for coordination and review of post-maintenance and post-modification testing and surveillance testing programmes, and for conducting and reviewing the local leak rate test (LLRT) and integrated leak rate test (ILRT) programmes. Serves as site point of contact for technical and procedural system and component testing issues. Also includes component and field engineers.

II.32. PROCUREMENT ENGINEERING

Responsible for materials qualification process, including parts substitution. Identifies and resolves supplier non-conformance. Manages and performs commercial parts dedication testing and supports like-for-like replacement analyses.

II.33. PROJECT MANAGEMENT

Directs, controls and monitors contractor and in-house design packages and other work in support of engineering functions. Reviews products to ensure high quality work. Participates in developing bid packages. Establishes and monitors milestone schedules for assigned work. Assists in reviewing contractor proposals and recommending contract awards. Coordinates resolution of technical questions directed to or originated by contractors.

II.34. PURCHASING

Includes buyers, expediters and other procurement personnel responsible for obtaining contracted materials and services by evaluating and processing purchase requisitions and proposals. Persons are responsible for managing the return of damaged goods and are primary vendor liaisons.

II.35. QUALITY ASSURANCE (QA)

Ensures the implementation of the approved QA programme through periodic audits and surveillances. Provides follow-up in areas of concern from audits. Analyses the status and adequacy of operational QA programme and established QA policy for management approval. Develops and maintains required QA procedures and manuals. Includes persons who operate the vendor audit programme. Supports and reviews organizational self-assessments.

II.36. QUALITY CONTROL/NON-DESTRUCTIVE EXAMINATION (NDE)

Implements inspection hold point programme and performs associated inspections of ongoing activities. Reviews work activities to ensure compliance with QA programme requirements. Performs receipt inspections for QA programme materials. Includes personnel who perform non-destructive examinations, including radiography/sonography of welds and fittings.

II.37. REACTOR ENGINEERING

Includes personnel analysing fuel performance, performing core performance monitoring and trending, and providing support and technical direction to operations during refueling, startup and shutdown.

II.38. SAFETY/HEALTH

Focal point for Occupational Safety and Health Administration (OSHA) requirements and contacts. Manages and maintains the industrial safety programme. Also includes personnel responsible for medical exams and emergency medical assistance.

II.39. SCHEDULING

Includes persons who schedule non-refuelling outage work activities for operations, maintenance and surveillance activities. Also includes persons coordinating with maintenance, construction management and engineering for daily schedule review and update. Persons preparing system outages and forced outage schedules are included with this function. Includes work week managers.

II.40. SECURITY

Provides physical site security. Responsible for development of security plans and procedures. Addresses technical issues pertaining to security regulations and requirements. Also includes staff responsible for site access control and fitness for duty programmes.

II.41. TECHNICAL ENGINEERING

Researches and analyses technical engineering issues but does not perform modification design package development. Provides support to modification engineers and plant/system engineers. Dispositions, non-conformances and other assigned items. Responds to design basis and configuration control issues and questions. Serves as technical consultant on engineering issues. Responds to technical inquiries and information requests from internal and external sources. Responsible for engineering services and key programmes in specialized technical areas not included in other engineering functions, such as equipment qualification, configuration management, in-service inspection, fire protection engineering and probabilistic risk assessment. Ensures design integrity for assigned specialized areas.

II.42. TRAINING

Provides or coordinates all formal training for nuclear staff including all INPO accredited programmes. Coordinates training schedules and produces training reports. Provides instructor training and development as well as instructional system design and implementation. Operates plant simulators.

II.43. WAREHOUSE

Includes all persons directly associated with physical inventories, including persons performing materials inspection, tracking and maintenance. May deliver materials from warehouse or other storage locations to staging points in support of maintenance/construction or modification activities.

Appendix III

AN EXAMPLE OF QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION

The information in Table III.1 is provided to further assist the reader in understanding the information provided in Appendices II and III regarding staffing levels and functions for a sample of some 67 NPP units. This information is based upon the education, experience and training requirements/practices in the United States of America (USA). The reader is cautioned that there is considerable variability in these requirements/practices in other countries that currently have operating NPPs. For example, in the USA there is NO requirement for NPP control room operators to have a bachelor’s degree in science or engineering, whereas in some of the 29 other countries that have operating NPPs, there is. The table also shows the reliance upon national standards/norms (such as ANSI 3.1).

TABLE III.1. QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION

Nuclear work function	Competencies/Experience requirements	Educational requirements	Training requirements	Lead time required
Admin/Clerical	Basic computer software competence (word processing, presentations, etc.)	Secondary/High school diploma or equivalent	NPP general employee training (GET)	N/A
ALARA/Radiological engineering	Basic computer competence; experience at commercial NPPs; health physics experience	Bachelor's degree in sciences, health physics or related discipline	NPP general employee training (GET)	5 years
Budget/Accounting	Basic computer competence; financial and analytical capabilities	Bachelor's degree in business, finance, accounting, or related field	Government and/or NPP owner requirements for accounts reporting systems	N/A
Chemistry	3 years work experience in chemistry field	Secondary/High school diploma or equivalent, university level chemistry and mathematics	Certification such as ANSI 3.1 1978 chemistry, NPP plant specific systems training	3 months
Communications	Excellent written and verbal communication competence; knowledge of local language and grammar, human relations, internet technology and industry trends	Bachelor's degree in journalism, public relations or related field	N/A	N/A
Computer engineering	Basic computer competence; NPP experience; technical understanding of nuclear plant process computer and full scope simulator	Bachelor's degree in engineering or a related technical field	Plant technical training	2 years
Contracts	Basic computer competence; knowledge of contracting concepts; good communications competence; financial analysis skills; negotiation skills	Bachelor's degree	Government and/or NPP owner requirements for contracting and contracts reporting systems	1 year
Decontamination/Radwaste processing	2 years of radwaste process experience	Secondary/High school diploma or equivalent	Radwaste worker course, waste treatment and radwaste operators course	1 month
Design/Drafting	Basic computer competence; experience with reading and interpreting schematic drawings	Secondary/High school diploma or equivalent; some requirements for bachelor's degree in a technical field	Plant technical training; computer aided design (CAD) systems training	1 year
Document control/Records	Basic computer competence; understanding of document control and records management	Secondary/High school diploma or equivalent	Government and/or NPP owner requirements for document control/records management systems	3 months

TABLE III.1. QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION (cont.)

Nuclear work function	Competencies/Experience requirements	Educational requirements	Training requirements	Lead time required
Emergency preparedness	Experience in operations and/or radiation protection	Bachelor’s degree or professional certification	NPP general employee training (GET); operations certification required in some cases	5 years
Environmental	Experience in environmental science, sample collection and reporting requirements	Bachelor’s degree or professional certification	Government and/or NPP owner requirements for environmental safety and reporting requirements	6 months
Facilities	Physical fitness; basic mechanical competence	N/A	NPP general employee training (GET)	N/A
Fire protection	Knowledge of fire protection engineering principles, including fire hazard analysis, fire protection technology, fire system design, codes and regulations	Bachelor’s degree in engineering technology or a similar discipline	NPP general employee training (GET)	1 year
Health physics applied	Physical fitness requirements; understanding of physical sciences	Secondary/High school diploma or equivalent	Rad worker training	1 month
Health physics support	Understanding of physical sciences	Secondary/High school diploma or equivalent	Rad worker training	1 month
Human resources	Basic computer competence; experience with retirement plans, and health and welfare benefits; must be familiar with national labour laws	Bachelor’s degree in human resources, business, mathematics or finance	NPP general employee training (GET)	N/A
Information management	Advanced computer competence; experience with computer hardware and software systems, including database administration, cyber security and network administration	Bachelor’s degree in computer science, information management or related field	NPP general employee training (GET)	3 months
Licensing/Regulatory affairs	2+ of years of experience in nuclear industry, basic computer competence, nuclear engineering	Bachelor’s degree in a technical field	NPP general employee training (GET)	6 months

TABLE III.1. QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION (cont.)

Nuclear work function	Competencies/Experience requirements	Educational requirements	Training requirements	Lead time required
Maintenance/Construction	Physical fitness; basic mechanical competence; good communication competence	Secondary/High school diploma or equivalent	Apprentice, journeyman, master level discipline skill level training required (mechanical, electrical, I&C); certification training for non-discipline craft such as crane and rigging operators, fork lift operators, scaffolding and insulation, etc.	Varies (for discipline craft): some national governments require a 3 year apprentice training programme prior to initial work at the nuclear plant; others allow OJT provided by the plant owner with initial training times as short as 6 weeks prior to OJT
Maintenance/Construction support	Planner: experience in NPP operation and basic computer competence; Other support roles: experience in basic plant operations and industrial safety	Secondary/High school diploma or equivalent	OJT within specific area, i.e. scaffolding assembly and disassembly, insulation removal and replacement, work package plan development, etc.	Planner: 5 years; Other support roles: 1–3 months
Management	Understanding of design and operation of power plant systems	Bachelor’s degree normally required	Supervisory, management and/or leadership training, typically provided by the NPP owner	Years, when considering hiring a new employee and developing that employee into a position of responsibility at least one level above first line supervisor
Management assist	Varies by the role as defined the by NPP owner; may include basic computer competence, good communication competence, project management experience, etc	Secondary/High school diploma or equivalent; some positions require a bachelor’s degree	NPP general employee training (GET); some will require operations training or engineering technical training	Varies, but typically less than 1 year
Materials management	Experience with inventory management approaches and systems	Secondary/High school diploma or equivalent	NPP owner provided training for the NPP’s/owners’ supply chain inventory management systems	1 month
Modification engineering	Understanding of design and operation of power plant systems and knowledge of applicable codes, standards and environmental regulations; experience with project management often required	Bachelor’s degree in mechanical electrical or civil engineering	Plant technical training, professional engineer license often required	3–5 years

TABLE III.1. QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION (cont.)

Nuclear work function	Competencies/Experience requirements	Educational requirements	Training requirements	Lead time required
Nuclear fuels	Engineering economics or other formal financial experience; nuclear fuel cycle and financial analysis experience	Bachelor’s degree in engineering, business administration or a related field	Plant technical training	5 years
Nuclear safety review	Experience with root cause analyses, human performance evaluations, collection and analysis of industry operating event reports	Secondary/High school diploma or equivalent; some positions require a bachelor’s degree	Plant technical training	5 years
Operations	Basic mechanical and computer competencies	Generally required: a secondary/high school diploma or equivalent; some governments and/or nuclear plant owners require a bachelor’s degree	Plant equipment and nuclear plant control room operations training, typically provided by either a government agency or the nuclear plant owner	2–5 years depending on job position
Operations support	Basic mechanical and computer competencies; NPP experience.	Bachelor’s degree in engineering or other technical discipline; or 2 year college/technical degree with additional direct job experience; or secondary/high school diploma or equivalent with several more years of additional direct job experience in nuclear plant operations	Initial operator training or reactor operator training or senior reactor operator training	6–10 years depending on educational background
Outage management	Basic computer competence; NPP experience; technical understanding of nuclear generation principles and operations	Bachelor’s degree in engineering or other technical discipline	NPP owner provided training in plant scheduling systems	5 years
Plant engineering	Basic computer competence; NPP experience; technical understanding of nuclear generation principles and operations	Bachelor’s degree in engineering or a related technical field	Plant technical training	2 years
Procurement engineering	Basic computer competence; NPP experience; technical understanding of nuclear plant equipment and design	Bachelor’s degree in engineering or a related technical field	Plant technical training	2 years
Project management	Basic computer competence; project management competence; good communications and negotiation competencies; data analysis competence	Bachelor’s degree in a technical or management related field	Basic project management training course	3 years

TABLE III.1. QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION (cont.)

Nuclear work function	Competencies/Experience requirements	Educational requirements	Training requirements	Lead time required
Purchasing	Basic computer competence; knowledge of category and supply management concepts; good communications; data analysis and negotiation competencies	Bachelor’s degree in engineering, business administration or a related field	Government and/or NPP owner requirements for procurement and procurement reporting systems	3–5 years
Quality assurance	Experience in NPP design, operations, maintenance or other nuclear related activities; experience in quality assurance programmes and concepts; senior reactor operator licence or certification preferred for operations area; design or system engineering experience preferred for engineering area; maintenance or work control experience preferred for the maintenance area	Bachelor’s degree in a technical field	Government and/or NPP owner requirements for quality assurance reporting systems	6 years
Quality control/ Non-destructive examination	Physical fitness; basic computer competence; general knowledge of QC and NDE inspection and examination techniques	Secondary/High school diploma or equivalent	ANSI qualification training programme: combination of classroom training and field work	Varies by level of certification: up to 8 years for a Level IV certified inspector
Reactor engineering	Basic understanding of physical sciences; advanced computer competence; understanding of nuclear and reactor physics	Bachelor’s degree in engineering	Nuclear plant reactor-specific training (PWR, BWR, CANDU, AGR, VVER, etc.)	2 years
Safety/Health	Ability to interpret, implement and communicate occupational health codes and standards; demonstrated skills in the application of personal protective equipment, industrial hygiene monitoring and sampling, risk assessment and mitigation of workplace safety, health and environmental issues	Bachelor’s degree in environmental science, engineering, industrial hygiene, public health or other physical science	Industrial safety training programme; first aid/first responder training	6 months
Scheduling	General power plant experience in maintenance, operations or engineering, including plant system knowledge; good communications competence	Bachelor’s degree in a technical field	NPP owner provided training in plant scheduling systems	8 years of nuclear plant experience in maintenance, operations or engineering

TABLE III.1. QUALIFICATION AND TRAINING REQUIREMENTS BY WORK FUNCTION (cont.)

Nuclear work function	Competencies/Experience requirements	Educational requirements	Training requirements	Lead time required
Security	Physical fitness and/or agility requirements; psychological testing/fitness may be required	Secondary/High school diploma or equivalent	Basic plant operations principles; fire arms training may be required	3–6 months
Technical engineering	Basic computer competence; nuclear power plant experience; technical understanding of nuclear generation principles and operations	Bachelor's degree in engineering or a related technical field	Plant technical training	2 years
Training	Detailed knowledge of plant procedures and regulations in assigned area; detailed knowledge of plant systems and processes; working knowledge of computer software programs supporting assigned area	Secondary/High school diploma or equivalent; senior reactor operator certification for operations training; master level competency in required discipline (mechanical, electrical, or instrumentation and controls) for maintenance training; bachelor's degree in an engineering field for engineering/technical training	Instructional training	5 years, due to on the job experience requirements
Warehouse	Physical fitness; heavy lifting safety	Secondary/High school diploma or equivalent	Industrial safety training; fork lift operations	1 month

Appendix IV

KNOWLEDGE MANAGEMENT

Knowledge management is an evolving subject area based on two notions:

- That knowledge is a fundamental aspect of effective organizational performance;
- That specific steps need to be actively taken to promote knowledge creation and use.

Two common approaches to knowledge management that are often used in combination include:

- Knowledge management focused on the capture of explicit knowledge and sharing this via technology;
- Knowledge management focused on managing tacit knowledge without necessarily making it explicit, and creating new knowledge as well as sharing existing knowledge.

In the context of human resources development, knowledge management is strongly tied to strategy and is activity oriented. Properly applied knowledge management improves organizational efficiency and productivity through reducing process times, introducing technology to assist finding relevant information and instituting techniques to remedy poor quality outputs. Knowledge management also promotes innovations, which can result from initiatives such as developing social networks for knowledge exchange, providing leadership to encourage risk taking and capturing the lessons learned from past activities. Both of these benefits require openness to change and a drive for continual improvement.

Other benefits of knowledge management include improved decision making, retaining organizational memory and organizational learning, as well as improving morale. Knowledge management can be used on its own or in collaboration with other management disciplines and tools to establish an environment that will enable the organization to realize these benefits.

Summarizing the effective management of nuclear knowledge includes ensuring the continued availability of qualified personnel. As the nuclear workforce ages and retires, and with support uncertain for university programmes in nuclear science and engineering, this issue has become critical to ensuring safety and security, encouraging innovation and making certain that the benefits of nuclear energy related to different applications including electricity supply remain available for future generations.

IV.1. THE PHASES OF KNOWLEDGE MANAGEMENT

The scope of knowledge management can be at different levels — applied to a whole organization or more broadly, or simply to a small office or work group, depending on organizational needs or resources. Examples of knowledge management applications include developing an organization wide knowledge strategy linked to human resource development, incorporating knowledge management into existing projects and processes (e.g. NPP personnel training) and implementing projects with a specific knowledge goal.

For different knowledge management applications or initiatives, three phases of implementation can be identified:

- Understanding the context for knowledge management and establishing a special purpose for the initiative, which may include promoting knowledge sharing, improving the management of explicit knowledge, fostering innovation and knowledge creation, and developing a knowledge management strategic plan for the organization. The aim of this phase is to develop an understanding of the internal and external environment of the organization through examining strategy, organizational capability and culture, as well as drivers.
- Examining knowledge gaps. This phase encourages more investigation of the desired knowledge environment. This desired situation should reflect the organizational strategy and the context of the organization, and give a vision of the knowledge environment as it could be. A useful framework for analysis of the knowledge environment comprises four knowledge elements — people, process, technology and content. The analysis of knowledge gaps may have revealed a number of gaps or weaknesses. Examples may

include barriers to knowledge sharing, problems with management of explicit knowledge and lack of awareness of tacit knowledge.
- Facilitating knowledge in action. The aim of this phase is to select and implement approaches, methods and tools to address the identified knowledge gaps. Examples of knowledge management techniques related to human resources development in nuclear organizations can be found in IAEA-TECDOC-1510, Knowledge Management for Nuclear Industry Operating Organizations (2006). Knowledge management does not end with the implementation of an initiative. It is necessary to review and monitor the initiative, the environment and organizational strategy, and to continue working towards further improvement and alignment.

Effective knowledge management should become part of the initiative itself. Explicit and tacit knowledge developed during the course of the initiative should be captured, managed and shared.

IV.2. SOME KEY CONSIDERATIONS

IV.2.1. Explicit and tacit knowledge

Explicit knowledge is easier to manage through capturing all important information in electronic form or hard copy, to create manuals, databases, project design documents, maintenance manuals, project variation orders and so on. Identification of documentation requirements and associated procedures for the creation, maintenance and updating of documents needs to be addressed, however, also as an upfront project requirement during the design phase and should not be added on later as an afterthought.

Tacit knowledge primarily makes up the core competence within an organization and is more difficult to preserve and transfer to successors. Where the transfer of tacit knowledge has not been incorporated into the organizational learning process, an organizational memory loss occurs when key persons leave, which has often been the main reason for a project’s failure. Organizational memory shapes an organization’s culture, management approach, decision making process, communication strategies and lastly the definition of its operating boundaries captured in its job descriptions. Tacit knowledge, by its very nature, is an elusive concept and cannot be captured easily by conventional means. Standards and codes are also made by national bureaus of standards of various countries as well as professional societies, and these also help in knowledge preservation. The nuclear industry has to submit detailed documentation for clearance to national regulatory bodies, and this requirement has helped in documenting nuclear and radiation safety information in detail.

The real challenge facing knowledge management is the capture of this vital component of organizational continuity, particularly within rapidly changing organizations undergoing the turmoil of downsizing or reengineering processes. New techniques and tools for knowledge preservation such as learning audits and the establishment of oral histories have now been added to the traditional technique of exit interviews.

Tools to facilitate the capture of tacit knowledge have been developed and are being continuously improved. The experience in building these tools and the lessons learned through their use include the following key insights:

Planning for knowledge management, implementing and evaluating

Organizations should develop a knowledge management strategy, provide organizational structure for its implementation, allocate an adequate budget for the planned activities, provide incentives to the staff to implement and improve the process, and at the end of each activity, evaluate the performance compared with the expected results to enable feedback for continuous improvement of the process.

Fostering a knowledge sharing culture

In a knowledge based economy, knowledge sharing is not merely an alternative strategic option, it is required for organizational survival. Measures for the aggregation and sharing of knowledge should be initiated, and a more open, knowledge sharing culture should be fostered within the organization. Capturing what is already known by someone else in the group and adding one’s own knowledge is faster and more efficient than reinventing a solution.

The sharing of knowledge has particular relevance to the nuclear energy sector, where actions taken now may have consequences for the planet for tens of thousands of years.

Starting and implementing knowledge sharing in an organization must be done from inside the organization, not grafted from outside. Experience indicates that most successful knowledge sharing programmes are driven by insiders. The insiders must own the process, be involved in all aspects of it, make the changes happen and encourage others to make the changes. At the same time, the insiders must use the outside world to validate and push the agenda forward within the organization. For example, using the external recognition and knowledge fairs and expos as ways of showing that what is happening internally is valid and useful in adding value.

Establishing communities of practice

The phenomenon of communities of practice is known under different names such as thematic groups, learning communities, learning networks, best practice teams and so on. It is essentially the formation of professional groups facilitating staff to come together voluntarily to share similar interests and learn from one another. Knowledge sharing on a significant scale is observed to be taking place only in organizations that have organized themselves into communities of practice. These communities need to be integrated into the company's strategy and its organizational structure. Communities, however, are a non-hierarchical phenomenon, and management hierarchies have generally had considerable difficulty in learning how to nurture them. Modern organizations have been built on a rational and mechanistic approach to problem solving. However, experience shows that communities of practice only flourish when their members are passionately committed to a common purpose. This is a hard lesson for companies and executives who have spent their lives trying to keep emotion out of the work place.

Upgrading information management

Successful knowledge organizations have learned that building web sites and offering knowledge management IT tools neither create nor transfer knowledge by themselves. Employees stop visiting these web sites or using these IT tools if a community of practice is not bringing credibility and contributing content to these instruments. IT tools are made to facilitate knowledge sharing among users rather than constraining the emergence of a sharing culture by imposing complex technical requirements. An important insight is that building a learning organization requires building communities within which that learning can take place. Without communities linked to structure, organizations do not learn very fast at all.

IV.2.2. Risk management of knowledge loss

Developing and maintaining nuclear competencies in the nuclear industry and nuclear regulatory authorities will be one of the most critical challenges in the near future for countries with existing nuclear power programmes, as well as for countries considering the introduction of nuclear power. The loss of employees with critical nuclear knowledge and corporate memory poses a clear internal threat to the continued development or operation of nuclear power facilities. In addition, the loss of this knowledge and expertise could impact future plans for the construction of new, advanced designed nuclear units.

The IAEA has developed practical guidance on knowledge loss risk management (see the Bibliography). The guidance is based upon actual experiences of IAEA Member State operating organizations and is intended to increase awareness of the need to develop an integrated and strategic approach to capture critical knowledge before it is lost. Specific objectives of such guidance are to enable nuclear organizations to:

- Conduct knowledge loss risk assessments to identify specific knowledge loss threats;
- Evaluate the consequences of the loss of critical knowledge and skills;
- Develop action plans to retain this knowledge;
- Utilize this knowledge to improve the skill and competence of new and existing workers.

It is important that tools and processes of knowledge loss risk management methodology are not stand-alone initiatives but are a part of an overall knowledge management system.

IV.2.3. Nuclear safety and nuclear knowledge

One of the most crucial roles of knowledge management lies in the field of nuclear safety, since lapses in safety, due to loss of knowledge, would have severe consequences for the industry. Implementing effective knowledge management systems in the field of nuclear safety is beneficial not only for the safety of plant personnel and the general public but also for improving the public’s perception of the nuclear industry and enhancing the commercial performance of plants. With fully trained, highly skilled and well equipped operational staff, nuclear safety can be maintained without much difficulty. Plants that are run safely also operate efficiently and reliably; production is maximized, which should ultimately have a positive effect on company balance sheets.

A wide variety of activities were initiated by the IAEA related to knowledge management and networking in the area of nuclear safety, and a holistic approach has been adopted to enhance the effectiveness of programme delivery. Innovative approaches are being utilized to capture, create and share safety knowledge and to assist Member States in their efforts to develop and to maintain sustainable education and training programmes. A major nuclear safety challenge is to foster a global knowledge sharing culture to achieve the motto that ‘a safety improvement anywhere is an improvement of safety everywhere’. The measures being implemented include mapping and retrieving safety knowledge, developing of process flows and facilitating the development of regional safety networks such as the Asian Nuclear Safety Network.

Appendix V

CASE STUDY OF DAYA BAY: A POSITIVE TRANSFER OF TECHNOLOGY BETWEEN FRANCE AND CHINA

V.1. INTRODUCTION

This appendix presents the workforce and education plan established between France and China for the construction of two nuclear reactors in Daya Bay in the 1980s. This cooperation was planned in the initial contract, and therefore mainly concerned the training of key Chinese staff for the operation of the units. Hence, this study aims to describe practically some key elements related to Phase 3 of the Milestones publication (i.e. after Milestone 2, when a commercial contract has been signed) from the France–China experience.

Some more general facts and figures are included for the workforce and training planning related to the two first phases of the Milestones publication, based on the French experience. They must be adapted for a specific country's context on a case by case basis.

The case presented hereafter is to be considered strictly as an example within its own context and not as a reference case for future projects.

V.2. HISTORICAL CONTEXT: INDUSTRIAL STEPS UNDER INTERGOVERNMENTAL AGREEMENT

The idea of a civil nuclear power programme was first raised in China in the early 1970s. The Nuclear Industry Ministry was created and took the decision to build a first 300 MW nuclear reactor in Qinshan. Preliminary contacts between France and China were established at this time in order to prepare turnkey procurement for other nuclear reactors on another site.

In 1979, economic and technical feasibility studies began for a project in Daya Bay (Guangdong). In 1982, the project was incorporated into the State construction programme of the Chinese Government. Following the interest of M. Li Peng, Chinese Vice Minister of Water and Electricity, in the French nuclear power programme, a memorandum allowing electronuclear cooperation between the two countries was signed on 5 May 1983 at the governmental level. It was planned that France could provide a 900 MW(e) nuclear pressurized water reactor (PWR) to China, allowing for some technology transfer.

On the Chinese side, a dedicated structure, the Guangdong Nuclear Power Joint Venture Co. Ltd (GNPJVC) was formed in February 1985 by the Guangdong Nuclear Power Holding Company Ltd (75%) and China Light & Power (CLP) (25% through its 100% subsidiary, Hong Kong Nuclear Power Investment Company, Ltd (HKNPIC)). It was formally established bearing exclusive responsibility for construction and operation.

The cooperation between GNPJVC and Electricité de France (EDF) started in 1986. GNPJVC chose Framatome for the nuclear islands, GEC-Turbine Generators Ltd for the conventional islands, and EDF for architect engineering assistance, with French plants Gravelines 5 and 6 as a reference. For that first project, EDF was responsible for overall technical design, manufacturing surveillance, supervision of construction (direction and work control) as well as commissioning activities while working completely integrated into the Chinese teams.

The first concrete was poured in August 1987, the first reactor criticality occurred on 28 July 1993 and the second reactor criticality on 21 January 1994. The first reactor was connected for commercial operation on 1 February 1994 and the second on 6 May 1994; both are M310 Framatome type 1000 MW reactors.

The safety of the plant has been under China National Nuclear Safety Administration supervision. Significant technical assistance was provided by the Institute for Protection and Nuclear Safety (IPSN), which subsequently became an independent organization, the Institute for Radiological Protection and Nuclear Safety (IRSN).

Of the electricity generated from the Daya Bay plant, 70% goes to Hong Kong and 30% to Guangdong province. Two dedicated high voltage transmission lines were built in the framework of the project: 400 kV to Hong Kong and 500 kV to increase the capability of the Guangdong province grid.

V.3. INITIAL CONDITIONS AND ASSUMPTIONS

Before estimating the number of specialists to be trained, some assumptions need to be established, because the training plan will naturally depend on the chosen technology, the chosen number of units, the number of sites and the purchasing methods selected by the authorities (turnkey, technology transfer with local manufacture). The Daya Bay project relied on global intergovernmental agreement and industrial contracts, as described previously; however, the lessons learned from this case could apply to a more general situation for the development of nuclear power with the following characteristics:

— Two[2] 1000 MW(e) units on one site, using a proven technology (PWR).
— Foreign supply for nuclear and conventional islands (with each island supplied in a single batch), auxiliary installations and shared utilities (water supply, waste and demineralization facilities, etc.).
— A plan leading to a connection to the grid 7 years after the purchasing process (approximately 12 years for the whole process).
— Consortia of local and foreign companies to take care of the civil engineering and erection.
— Knowledge and technology transfer enabling at least:
  • The receiving country government to cope with its nuclear responsibility through its safety authority, regulatory body and operator;
  • The future operator to manage the project and site operation, including maintenance of the power plant.
— No technology transfer for design and manufacture, and no account taken of local manufacture (monitoring of design and manufacture in the suppliers' country of origin).

V.4. WORKFORCE DEVELOPMENT BEFORE THE BID

It is assumed that some nuclear expertise (research reactor, isotope production, etc.) and theoretical courses in nuclear physics exist in-country, but that a degree of foreign experience will be necessary to complete the development of expertise in the construction, operation and safety of a nuclear power plant and/or the legislative and regulatory instruments governing the licensing process.

Assuming the necessary domestic political consensus has been obtained at the national and local levels (concerning the choice of site, for example), it is assumed that 12 years (144 months) are needed to plan and execute the whole programme**,** from the start of the feasibility study to generation of the first electrical current.

Using a reverse planning process, as indicated previously, the following steps have to be taken:

— Feasibility study (T0 – 144 months): A team of 30 people working for two years is typically necessary. The first training actions must begin at the same time.
— Planning of the programme and procedures for choosing the supplier (T0 – 120 months): The necessary skills for the role the operator needs to play as 'competent buyer'[3] in order to enter into a dialogue with the candidate construction companies must be available and organized by this deadline. The project stakeholders must be clearly identified within the organization at the start of this planning phase, in particular:
  • The safety authority and its technical support body, which must have significant technical expertise;
  • The operator and owner responsible for the power plant, which will receive the operating licence from the safety authority;
  • The consortium of industrials, mainly for civil engineering and erection.

Some project ownership assistance type skills will be necessary from early in the programme planning and supplier selection phase. Most of the personnel on the project management team will finish work when the power plant is commissioned. After that, the work to which they are allocated will depend on whether the authorities wish to continue developing a nuclear fleet. Some may join the operator of the first power plant, but experience has

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[2] Investment in training is not significantly different for one or two units.
[3] Similar to 'intelligent customer', as defined in the main body of this report.

shown that a large scale transfer of personnel between the project management team and the operator cannot be taken for granted; the operator must start its own skills training separately.

Total number of personnel to be trained (as an example):

— For the overall project management, about 360 people (see Table V.1) of whom approximately 180 should have a master's degree and 180 a bachelor's degree;
— On the construction site, qualified workers should be recruited locally and should require, as a minimum, specific training on quality assurance and the use of quality procedures.

V.5. SAFETY AND RADIATION PROTECTION — PARTNERSHIP WITH THE IPSN[4]

Within the general framework of the agreement on analysing nuclear safety, the IPSN and the China National Nuclear Safety Administration (NNSA) decided to work in cooperation to evaluate safety at the Daya Bay power plant.

As part of this cooperation, general training was given on the French approach (structure of France's regulatory and quasi-regulatory texts, general approach to evaluating safety), notably to the project leader within the Chinese safety authority.

It was agreed that the actual safety assessment would be broken down into 14 areas (which dealt with the main safety assessment areas):

— Classification, qualification of equipment;
— Fire, other internal hazards;
— Core and fuel assembly design;
— Reactor coolant system, safety injection and containment spray systems, stress analysis;
— Civil engineering design;
— Fuel handling and storage;
— Electrical power supplies;
— Protection system, control room;
— Feedwater supply system for steam generators;
— Heat sink;
— Effluents;
— Accident analysis;

TABLE V.1. WORKFORCE NEEDED FOR PROJECT MANAGEMENT (APPROXIMATE FIGURES)

	Total	MSc[a]	BSc[a]
Project manager	1	1	
Project management team	10	7	3
Engineering and procurement	40	40	
Construction	175	80	95
Testing — startup — commissioning	95	55	40
Contracting monitoring (MSc & BSc)	30		
Quality assurance/surveillance (MSc & BSc)	10		

[a] BSc: Bachelor of Science; MSc: Master of Science.

[4] The Institute for Protection and Nuclear Safety (IPSN) is now the Institute for Radiological Protection and Nuclear Safety (IRSN), part of the French nuclear safety system.

— Technical specification, emergency response plan, emergency operating procedure, surveillance tests, startup testing, maintenance;
— Quality assurance.

The support of the IPSN was sought in two forms:

— With certain areas, account was taken of the fact that the Chinese bodies concerned were able to take direct responsibility for some of these areas. The IPSN was involved in these cases in an advisory capacity through experience acquired on similar plants. It facilitated the work of the Chinese teams by giving them advance warning of difficulties experienced in the past, which meant they could focus their efforts and save time, while ensuring that the maximum amount of knowledge was transferred to the Chinese.
— With the majority of the areas, the IPSN's technical contribution took the form of direct participation in the analysis within Franco-Chinese teams set up for each area. These joint teams involved Chinese trainees coming to Fontenay-aux-Roses, France, and frequent exchange missions to determine the progress of the safety analysis work.

Chinese participation in these areas, overall, was estimated at 26 engineers, including the project leader and the Chinese contact at the Daya Bay site. The corresponding participation of the IPSN was estimated at about 16 engineers, including the IPSN's 'China' project leader.

Between 1986 and 1994, the years during which the Daya Bay power plant was commissioned, purely for safety and radiation protection analysis purposes, there were:

— 9 Chinese delegations making a total of 48 trips to France.
— 8 French delegations making a total of 28 trips to China.
— 76 placements were organized for 59 Chinese engineers.
— Cumulatively these placements lasted 965 months, with an average duration of about 13 months (longest placement: 28 months; shortest placement: 4 months).
— The longest placement (28 months) was given on aspects of 'commissioning'. Aspects of classification/qualification, monitoring during operation, and radiation and environmental protection received particular attention. The other point to note concerns training on accident analysis and the use of the CATHARE code (six placements, with a cumulative duration of 54 months).

Lessons learned

The most effective training was when trainees were integrated into host teams engaged in a particularly relevant activity for a period of at least six months, preceded by two months on a safety engineer course (SAIS) and specific training. A sufficient level of French was necessary for engineers to be integrated in this way.

In view of IPSN's experience and the delicate nature of licensing procedures, which involve a variety of authorities and combine legal, administrative and technical aspects, it is essential for competent organizations in the experienced country to make a major effort to help the newcomer authorities to set up their own licensing system.

In this example, 60 was deemed to be a good number of trainees to be trained in nuclear safety and radiation protection (including its regulatory aspects) for a country starting out in nuclear power generation with two units of 1000 MW(e) each. Assuming the average duration of training is between 12 and 18 months, the cumulative duration of training should be between 700 and 1100 months.

Among these trainees, about 10 experts (level: PhD) should be provided. Their training (in reactor physics/fuel, metallurgy, thermal hydraulics, radiation protection) should begin at the start of the project (feasibility study). They should, as a priority, be placed with the safety authority technical support body, a limited number of such experts being needed in the operator staff.

V.6. PARTNERSHIP WITH EDF FOR OPERATIONS STAFF TRAINING

First it is necessary to clarify how many personnel out of the total active workforce on the site will have nuclear expertise. Of the 12 000 people working on the Daya Bay site during the building phase, approximately 200 could be considered to have specific nuclear expertise.

Phases

The industrial phase[5] lasted approximately 84 months that can be divided as follows, using reverse planning[6]:

— Design from T0 – 84 months to T0 – 20 months;
— Manufacture from T0 – 78 months to T0 – 25 months;
— On-site construction from T0 – 60 months to T0 – 10 months;
— Commissioning tests from T0 – 4 months to T0;
— Project management, operation and maintenance.

The start of construction coincided with the beginning of training for operational personnel.

Workforce for a nuclear site in operation (two units):

— Site management (director, operations director, maintenance director, logistics director, commercial and sales director, engineering and outages, cross-company assignment manager): about 10 people.
— Unit operation/control: about 200 people including:
  • The management (10 people);
  • The operation shift teams: 6 teams of 20–25 people working on a 3×8 hour shift roster, plus the daytime personnel;
  • Chemistry and radiochemistry for plant and environment monitoring (20 people);
  • Test and performance (10 people);
  • Reactor physics and core management (10 people).
— Safety technical advisors and quality auditors: about 18 people. The presence of the nuclear operator's own staff responsible for compliance with and inspection of nuclear safety, radiation protection and environment policy should also be mentioned. These staff are closely associated with the running of the power plant but are totally independent of the operating department.
— Simulator instructors and classroom instructors: about 10 people.
— Maintenance and technical support: about 270 people. Among them, the workforce for maintenance ownership (prevention, surveillance, technical and safety appraisal, quality, etc.) must be under station control in order to enable it to fulfil its safety responsibility. Other parts of the maintenance activities may be contracted to specialized entities, depending on local policy.
— On-site emergency response and crisis management plan: around 80 people on call simultaneously on a 4–7 week rota, consisting of the site management, maintenance staff, technical support staff, communication staff, medical staff, etc. The emergency response team comprises personnel with other full-time jobs in the plant, who receive ad hoc training.
— Support functions (human resources, finance, purchasing, procurement, access control, medical service, firefighters and information technology staff) require about 160 people, some of whom can be contracted according to local policy.

[5] The industrial phase corresponds to Phase 3 of the Milestones publication: from the date the supplier is chosen to the first commercial connection to the grid.

[6] The reverse planning runs from the choice of the supplier (T0 – 84 months) to the startup of the first reactor (T0).

Therefore, the total number of personnel to be trained (over seven years) to manage and maintain the power plant is in the range of 550–650 people according to the operator subcontracting policy, of whom approximately 110–150 will have, at least, a MSc degree.

Acquisition of knowledge

A project services contract was signed between EDF and GNPJVC, planning for the training of 118 Chinese engineers for the key operational functions. This contract specified the formation of five groups of trainees depending on their future duties as well as the dates and the modalities of the training in Europe:

— G1: Site organization and quality control teams (12 trainees);
— G2: Management staff of the team in charge of reactor tests (20 trainees);
— G3: Reactor operation staff (first group — 46 trainees);
— G4: Reactor operation staff (second group — 24 trainees);
— G5: Reactor operation staff (additional group trained in English in China — 38 trainees).

Except for the last group, the training language was French. Three-month training sessions focused on scientific language for groups G3 and G4 were organized in China by a French teacher recruited by EDF.

Some documents were elaborated in the framework of the training process in order to bring together the contractual procedures:

— GNPJVC Project Procedures Manual setting the respective roles of EDF and GNPJVC in the training contract;
— Engineering manual setting the technical and methodological rules for the training project;
— EDF engineering manual providing the necessary practical guidelines to the EDF employees contributing to the training project;
— QA manuals of the engineering and operations departments of EDF covering the whole programme.

The Chinese side asked for a qualification certificate to be delivered to trainees at the end of the periods in Europe, which led EDF to formalize the quality control of the training process with precise educational objectives:

— Development of adequate behaviours (safety, security, respect of procedures, etc.);
— Improvement of theoretical and technological knowledge, and command of the specific physical phenomena;
— Development of individual and collective experience (analysis of incidents, implementation of operation and maintenance procedures, etc.).

In order to reach these objectives, EDF implemented a training process based on ‘shadow training’. This method was implemented to improve the organized transfer (in situ) of competencies and know-how between each trainee and one EDF counterpart (who holds, in an EDF plant, the job that the trainee is to do when back in China). This ‘shadow training’ accounted for the most important part of the whole training programme (60% of the training in Europe), the rest being theoretical training and simulator training.

This responsibility represents an additional task for the counterpart and needs to be compatible with the operation of the host plant. This task was initially estimated at 20% of the total work time of the counterpart but proved to represent closer to 30% of the work time. Seven hundred EDF employees assumed this counterpart role during more than a week, attracted mainly by interest in the activity (significant voluntary participation) rather than by any additional financial compensation.

In addition, a tutor was in charge of several trainees during their shadow training in order to maintain a permanent link between the trainees, the trainers, the counterparts and the hierarchy. Two hundred and twenty tutor months were mobilized on the project.

Ensuring a quality organization for such an extensive training programme involved verifying compliance with the rules defined in the procedures through audits.

Three types of audit were performed during the project:

- Audits of subcontractors by the project organization (5 performed);
- Audits of the project organization by the EDF nuclear inspectorate (4 evaluations performed at corporate headquarters, sites and training centres);
- External audit by GNPJVC, which proved to be necessary and profitable for both parties (11 performed).

All these audits were performed in due respect of the IAEA 50 CQA.

Pre-OSART

In November 1990, in the framework of the Pre-OSART mission held at the Daya Bay site, the IAEA evaluated the training performed in Europe. The result was satisfactory but might have been better if an evaluation of the level reached had been done.

Lessons learned

- For the operator, an adequate number of experts (PhD level) should be about 1% of the workforce in order to enable it to:
  - Fulfil its entire nuclear responsibility through a thorough knowledge and understanding of some phenomena (reactor physics, simulations, core calculations, material fatigue, thermal hydraulics);
  - Maintain high quality exchanges with the safety authority and the ministries to which it is accountable.
- It should be stressed that experts can only maintain their skills and peer recognition by being involved in research activities.
- Regarding the prerequisites for trainees, the profiles required for key positions such as deputy plant manager, civil works manager, information system unit manager, and deputy manager of the local training centre raised a number of challenges. Pre-selection criteria for Chinese trainees had to take into account the specifics of Chinese engineering degrees, which differ from French engineering degrees. For example, in groups 3 and 4, most of the trainees had just finished university (without any previous experience in operating a conventional power plant, as might have been expected), and were to hold key positions in the nuclear plant. Their participation in the startup phases was therefore all the more important. However, such difficulties can be solved through internships in conventional power stations prior to the training period in nuclear power stations.
- It remains clear that issuing qualification certificate credentials at the end of the training period under EDF coaching only acknowledges the potential of each trainee. It is not an authorization to hold a specific position in a nuclear power station, which remains the Chinese authority's responsibility and is also requested by law (reactor operators and senior reactor operators have to be licensed on the simulator that represents the actual unit). On-site training is still required under the operator's responsibility and if necessary with technical assistance. In this regard, a diploma would perhaps have been preferable, acknowledging the completion of the training process with satisfactory results.
- It seems appropriate to set up a dedicated team with a project management type structure for such a large training project.
- The support of top management was essential, given the number of units of the company involved and the workload generated.
- It appeared to be more efficient and economically interesting to provide the training in French after providing linguistic training, rather than providing the training in English.

V.7. CURRENT SITUATION

The GNPJVC has since developed its own training capacity in China and now has at its disposal:

- The DNMC Nuclear Training Centre, which can manage 2500 person-months of training per year (i.e. 40 full-time simulator instructors, staff of around 200 persons, two full-scope simulators, one basic principles simulator, 22 000 m² of laboratories). At the end of 2008, this centre had trained and licensed about 300 operators for Daya Bay, Ling Ao, and trained all requested operation and maintenance engineers.
- An agreement signed between three engineering universities (located in Harbin, Xian and Shanghai) and the DNMC Nuclear Training Centre to develop nuclear engineering courses in order to prepare future operations and maintenance personnel. These persons acquire basic knowledge of the operation and maintenance of PWR nuclear power plants. This national manpower represents 28 professors, 28 professors' assistants and 44 instructors.

V.8. CONCLUSIONS

In conclusion, a key success factor was to integrate the main structure and organizations that were applied in France and to adapt them to the Chinese framework. The main idea was to take a well known system and to adjust it to the specifics of the recipient country in order to give priority to experience instead of theory. This method required, from the recipient country, pragmatism and some important adaptation capacities and, from the technology holder, the ability to apply a way of doing something and not a rigid structure. Therefore, the selection of the people involved was a very important step. Hence, the Chinese trainees were selected based not only on their current results but also on their high potential for integration.

V.9. SUMMARY: HUMAN RESOURCES REVERSE PLANNING

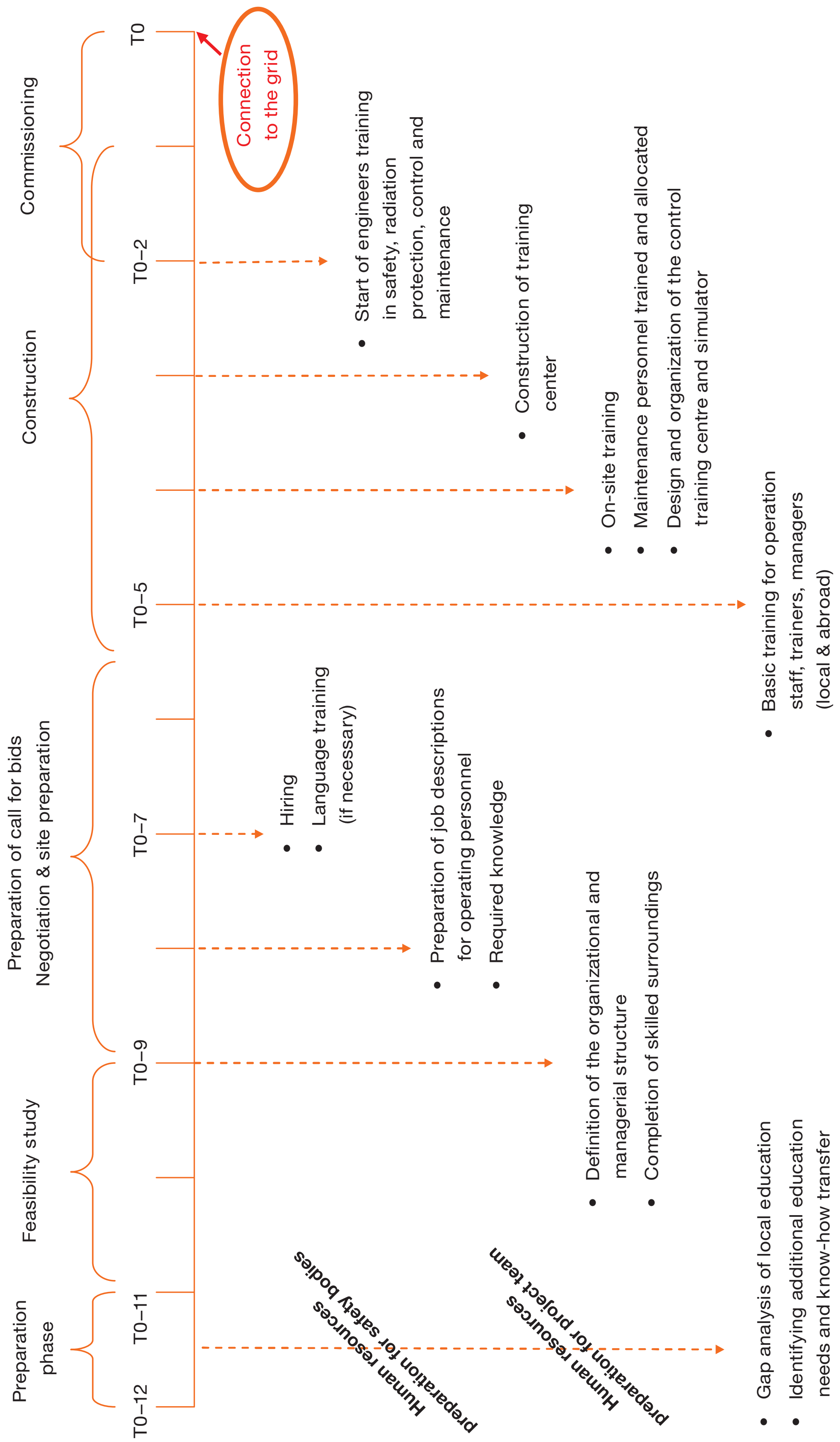

FIG. V.1. Human resources reverse planning.

Appendix VI

LESSONS LEARNED FROM THE NUCLEAR POWER PROGRAMME IN THE REPUBLIC OF KOREA[7]

VI.1. INTRODUCTION

During the last forty years, 33 countries have established large scale commercial nuclear power programmes. All of their experience can be valuable as lessons for prospective countries considering nuclear power as a part of their long term energy supply. Major countries began their first NPP on the foundation of their strong industrial and financial standing. The Republic of Korea, however, began its first NPP under barren social, economic and industrial conditions, which have greater relevance to today's developing countries. Therefore, it is worthwhile to document the history and characteristics of the Republic of Korea's successful nuclear power programmes for the sake of prospective developing countries.

As of 2006, the Republic of Korea ranked sixth in the world in total nuclear power generation, using 20 units totalling 17 454 MW(e), which supplied 38.6% of the total electricity demand. NPPs in the country were successfully operated at the highest average availability factor (93.22%) and capacity factor (90.83%)[8] in the world between 2001 and 2006. Based on the positive experiences, the Government of the Republic of Korea has recently decided to expand its nuclear power programme as a part of a long range plan to further reduce energy imports and greenhouse gases. By 2030, nuclear power is expected to supply 59% of the total electricity demand [VI.1, VI.2].

Upon the construction of the first three NPPs on a turnkey basis and the next six NPPs on a non-turnkey basis, the Republic of Korea's nuclear industry had successfully localized most technology to build NPPs with its own designs, namely OPR 1000 and APR 1400 [VI.5]. Therefore, this country's experience, evolving from one of the least developed countries into one of the world's most successful nuclear power states in about forty years, may provide valuable lessons to developing countries pursuing their first NPP project. On these grounds, the history and processes of the nuclear power programme in the Republic of Korea are described in this appendix, with highlights on the successes and mistakes.

VI.2. ESSENTIAL LESSONS — A BRIEF OVERVIEW

This appendix is intended to give a brief overview for readers who want to learn the essential lessons from the nuclear power programme in the Republic of Korea. However, it is recommended that those involved in the development of a national nuclear programme read the full information provided in Chapter 3 of this report.

VI.2.1. Integration of diverse knowledge and experience

Nuclear power technology is the product of integrated knowledge from comprehensive R&D and a broad industrial basis with extensive field experience. The assessments of viable options for a first NPP in a country require various inputs from a wide range of disciplines and diverse sources. According to the concept of the IAEA Milestones publication [VI.6], the NEPIO is an integral organization that plays the central planning role by disseminating and evaluating the options based on knowledge and experience. With the strong support of government, the NEPIO can be established by organizing competent and extensive human resources from diverse fields.

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[7] This appendix is extracted from: SUNG YEOL CHOI, EUNJU JUN, IL SOON HWANG, "Lessons Learned from the Republic of Korea Nuclear Power Programme: Based on Milestones in the Development of a National Infrastructure for Nuclear Power, NG-G-3.1", IAEA, Vienna, 2009.

[8] The net capacity factor of an NPP is the ratio of the actual output of an NPP for a period of time to its output if it had operated at full nameplate capacity for the entire period. The availability factor of an NPP is the ratio of the amount of generation time over a period to the time length of the entire period.

For the establishment of the NEPIO, not only scientists and engineers but also economists, lawyers and psychologists are required. The Korean NEPIO established in the 1960s consisted of a strong government agency and several associated cooperating organizations. With the leadership of the government agency, the NEPIO was able to command a wide range of knowledge and experience in diverse fields, including nuclear engineering, electronics, physics, chemistry, mechanical engineering, economics, physiology, politics and diplomacy. The NEPIO, which was empowered to direct all relevant organization members, disseminated necessary information effectively and developed judicious plans.

VI.2.2. Strong national commitment to the nuclear power programme

The execution of an effective national nuclear power programme requires close collaboration with many domestic and international organizations. It was fortunate for the Republic of Korea that there was a strong national consensus and firm governmental commitment to the programme. The Government of the Republic of Korea has been determined to implement nuclear energy as a vehicle for introducing advanced science and technology as well as for meeting the soaring demand for electricity. The first President of the country, Syngman Rhee, moved to make agreements with the USA and the IAEA in an effort to obtain much needed international support. The Atomic Energy Department was soon established directly under the President with the authority to plan and promote the programme without major administrative obstacles. Because the mandate of the nuclear power programme was to deliver safe, economical and stable electricity, the strong nationwide commitment has been maintained for approximately forty years since the establishment of the NEPIO.

VI.2.3. Synergy between the nuclear power programme and other national development programmes

The nuclear power programme has been a part of the national economic development plan during the whole period. It obviously could not be promoted without a systematic cooperation system with other national programmes for successful implementation. For example, an NPP could not even start its operation without a commensurate basis of thermal and/or hydraulic power and an appropriate electric grid capacity. In order to finance a huge nuclear power programme, a strong economic basis is required. Without a fundamental basis for heavy and chemical industry (HCI), a country may not succeed in the localization of the nuclear power technology.

The Republic of Korea needed close coordination with the national economic development plan and the HCI development plan to complete its first NPP. The success of the nuclear power programme provided an ample and stable electricity supply, which greatly accelerated economic development. This accelerated economic development, in turn, generated sufficient capital to construct additional NPPs. This cycle is one of the most valuable lessons learned from this experience and contributed to making the Republic of Korea one of the advanced industrial countries today. Energy planners and decision makers in developing countries should keep this lesson in mind to avoid the typical but critical problem of inadequate coordination of a broader national development programme.

VI.2.4. Strategies for securing human resources and establishing a self-reliant education system

The Government recognized the importance of competent human resources for the nuclear power programme. The NEPIO launched human resources development programmes to provide the personnel needed to launch, execute and upgrade the national nuclear power programme. The strategy of human resources development in the country consisted of securing high quality staff, supporting overseas education, in collaboration with the IAEA and the USA, and preparing for domestic education and training programmes.

To immediately secure high quality human resources, the government guaranteed high level positions and salaries for qualified personnel coming from other fields and provided good working environments. In order to meet the demand for high level expertise not available domestically, foreign experts were invited at all phases of development, including the operational phase of the first NPP. The Government soon realized that up-to-date education and training could not be effectively provided in the Republic of Korea and began overseas training for young talent.

To establish a long term human resources development programme, the Government launched undergraduate nuclear engineering departments at universities from the early period. The brightest and most enthusiastic students rushed into this new, exciting field with strong governmental support. Moreover, the Government provided grants to encourage nuclear research at the universities in an effort to attract the entire academic world to the programme. The national support for radiation applications in agriculture, health, physics, chemistry and biology led the nuclear power programme to play a key role in the promotion of advanced science and technology in the Republic of Korea. With the return of the first wave of overseas trainees, universities in the country were able to strengthen the nuclear engineering education. Moreover, training centres in research institutes invited foreign experts to give lectures and to develop various lecture programmes for establishing higher education and training.

VI.2.5. Localization through technology transfer

With KEPCO's initiative in the national nuclear power programmes, the first three NPPs were started on turnkey contracts. In the initial stage, the Government correctly assessed and concluded that domestic industries were not capable of meeting the requirements for nuclear quality assurance related to the construction of NPPs. This was why the country decided to introduce its initial NPPs on a turnkey basis and to restrict domestic roles to non-safety-related areas such as civil engineering and construction work with the supervision of foreign contractors. KEPCO gradually increased the role of domestic industry but as subcontractors to foreign main contractors. From this stage, the technology transfer approach can be best described by 'on the job training' and 'on the job participation' under the direction of foreign suppliers. KEPCO developed the NPP localization plan for the completion of the country's fourth plant by starting a non-turnkey basis contract for the NPP. The plan was carried out in close collaboration with foreign vendors for the development of a standardized NPP for the Republic of Korea. With the growing construction, operation and localization experience, KEPCO undertook the main contractor's role for the tenth NPP in 1987.

This localization policy contributed not only to saving foreign currency but also to increasing the capacity factor with the faster supply of spare components from localized suppliers. The quality management responsibility of local suppliers also became a strong driving force to improve the quality of both nuclear and non-nuclear products, leading to the country's trading competitiveness. This benefit of nuclear power technology transfer spread to other industrial sectors, including steelmaking, shipbuilding and heavy equipment manufacturing.

VI.2.6. Successful investigation and reflection of world nuclear power trends in planning

A national nuclear power programme in isolation cannot evolve competitively because it should be tailored to meet the many international standards and rules. Hence, close international collaboration and study of world technology and safeguards are among the most important activities in the launch of a nuclear power programme. National energy planners should consider and incorporate the results of these trends into their plans.

After the world's first operation of a commercial NPP in 1956, many countries rushed into the development of an NPP. The news media in the Republic of Korea closely followed this trend and reported important issues in the nuclear industry. Many intellectuals described, by writing in the news media, how the nation could be changed and would advance in the new world. Under the national atmosphere for growth, the Government studied international situations by sending people abroad, participating in international cooperation programmes and establishing overseas offices. The NEPIO effectively utilized the information network for the development of the nuclear power programme. Whenever the NEPIO faced difficult questions, lessons from reference countries were collected to help reach rational conclusions. In this process, the Government dispatched special investigation teams with people from various organizations. The investigation teams visited key organizations in advanced countries to collect information and check their policies, as well as to finalize plans for NPP developments. The investigation encompassed major issues, including the current state of technology development, the economic efficiency of their plants, the know-how of their nuclear power programmes, the construction and operation experience of NPPs and the process of site selection, fuel cycle policy, strategy of securing nuclear fuel and financing options for NPPs.

VI.2.7. Slow preparation of a safety regulatory system

With the confirmation of the first NPP construction plan, the Government started to prepare the nuclear safety regulation system. The preparation of a regulatory framework was a time consuming process and resulted in a heavy workload. Due to tight schedules and a shortage of personnel, most technical rules were borrowed from the country of the reactor's origin, the USA. In parallel, Japan, an industrialized neighbour, was a model for the Government driven economic development programme. As a consequence, the legal framework of the Japanese nuclear power programme was also introduced. The coexistence of different rules from the USA and Japan caused conflict and confusion at various levels of the regulatory process.

The initial regulatory system did not encompass safeguards and nuclear materials control until the IAEA introduced 'Additional Protocols'. The experience of the Republic of Korea highlights the importance of early development of a regulatory framework for safety and safeguards. It is desirable to begin the effort as early as possible to establish a streamlined and independent regulatory system.

Phase 1 (1956–1960), Phase 2 (1961–June 1968), Phase 3 (June 1968–1978) and Operational Phase (until 1990)

1956

— Delegation to the first ICPUAE
— Republic of Korea/USA Atomic Energy Agreement (the first international agreement)
— Established atomic energy section
— First exhibition for Atoms for Peace

1957

— Joined as a member of IAEA

1958

— Enacted Atomic Energy Act
— Established Atomic Energy Department
— Established Department of Nuclear Engineering at Hanyang University
— Contracted for the first research reactor

1959

— Opened Atomic Energy Research Institute
— Established Department of Nuclear Engineering at Seoul National University

1961

— Established KEPCO (owner/operator)
— Promoted long term plan for NPP
— Launched the first five-year economic development plan

1962

— Launched first five-year electric power development plan
— Operation of the first research reactor

1964

— Started NPP site evaluation and selection

1966

— Confirmed site for NPP

1967

— Established Ministry of Science and Technology
— Established Office of Atomic Energy

1968

— Confirmed long term plan for national nuclear power programme
— Invited bid for the first NPP
— Signed NPT

1970

— Signed the contract for the first NPP

1971

— Started the construction of KORI-1, the first NPP, on turnkey basis

1975

— Entry into force of NPT
— Joined Comprehensive Safeguards Agreement (CSA)

1976

— Signed the contract of KORI-2

1978

— Started the operation of KORI-1, the first NPP
— Signed the contract of KORI-3, 4th NPP on component approach, non-turnkey basis

1981

— Established Nuclear Safety Center (regulatory body) under KAERI

1986

— Started seeking nuclear waste sites

1987

— Signed the contract for Yonggwang 3&4 NPP, with KEPCO as the prime contractor

1989

— Joined COCOM

1990

— Established Korea Institute for Nuclear Safety (regulatory body)

2005

— Acquired sites for LILW

FIG. VI.1. Chronological table of the nuclear power programme in the Republic of Korea.

VI.3. THE HISTORY AND PROCESS OF NUCLEAR POWER DEVELOPMENT IN THE REPUBLIC OF KOREA AND LESSONS RELATED TO HUMAN RESOURCES

VI.3.1. Phase 1 (from 1956 to 1960): Considerations prior to a decision to launch a national nuclear power programme

In the early period of the nuclear power programme in the Republic of Korea, a management group was formed and began studies on how to launch a national nuclear power programme. The study group focused on the development of management expertise and generated an understanding of the scope and depth of management required to pursue the full implementation of a nuclear power programme [VI.6].

The IAEA Milestones publication [VI.6] deals with the wide range of issues essential to the development of a national nuclear power programme. It also suggests a phased approach by assigning issues with different priorities to different stages of the programme. For example, there are some issues such as the spent fuel, radioactive waste management and disposal that can be deferred to later phases. Nevertheless, an early assessment of all issues can help lead to effective and advanced plans for a successful national nuclear power programme, provided that enough human resources are available.

Human resources development

Human resources development was one of the top priority tasks of the Government. With limited human resources in the areas of radiation protection and application strategy, it was difficult to launch domestic education systems on nuclear engineering. This was when the Government obtained valuable advice from W.L. Cisler, who emphasized the development of human resources by saying:

> “This one gram of uranium can provide the same amount of the energy that comes from three tons of coal. Coal is the energy dug from ground, but nuclear power is the energy dug from human brain. Countries such as Korea that are poor in resources should develop the energy that can be dug from human brain. If you want to operate a nuclear power plant, you should develop human resources first. If Korea brings up the young talents now, then Korea becomes the country that can turn on electric lights from nuclear power 20 years later.”[9] [VI.18]

TABLE VI.1. MAJOR ROLE OF ORGANIZATIONS IN A NATIONAL NUCLEAR POWER PROGRAMME

Organization	Role and function in a nuclear power programme
AEC	Ultimate decision making commission
AED, BO	General administration, investigation and planning, and control of radioactive isotopes
AERI	Basic study and technical support
Ministry of Foreign Affairs	International cooperation
Ministry of Commerce and Industry	Electricity generation and electric grid programme
Economic Planning Board	Decisions on budget of country and support of nuclear power programme with economic knowledge base
University	Human resources development and basic research
Industry	Participation in a nuclear power programme with own special field

[9] Translated from Cisler’s speech written in Korean.

With Cisler's advice, the Government recognized the importance of human resources development for its nuclear power programme. When the AES (pre-NEPIO) was established, it failed to launch a human resources development programme. The AES started with only seven staff members who were drawn from informal study group. They were the only available human resources in the Republic of Korea for the nuclear energy programme. The reason for establishing the AES under the Ministry of Education, not the Ministry of Commerce and Industry, was because the Republic of Korea hoped that the education of young scientists and engineers would become the most important task.

The Government soon realized that up to date education and training could not be provided within the country and began supporting overseas training of young researchers. From 1956 to 1958, most human resources development was made through overseas training, funded by the Government despite the extreme scarcity of foreign currency. In March 1959, the AED established a human resources development plan, which mainly consisted of an overseas training programme for 200 people. From 1955 to 1964, 237 persons were trained abroad. Among these, 127 persons were funded by the Government, 80 persons were supported by the IAEA, three persons were on the Colombo plan and 27 persons were sent by other overseas aid [VI.19]. More than half of the people went to the USA and the UK to learn the emerging nuclear power technology.

For establishing a long term human resources self-development programme, the Government also implemented a domestic system by launching undergraduate education. Nuclear engineering departments had been established at Hanyang University and Seoul National University in 1958 and 1959, respectively. Natural science, physics and subjects related to radioactive isotopes were taught to the brightest students who rushed into the new, exciting field. Significant numbers of students continued studying nuclear engineering at overseas universities, research institutes or domestically at AERI after graduating with a BSc degree. It was about ten years later, upon the return of the first graduate students from their overseas studies, that engineering subjects (i.e. nuclear reactor analysis and design, material, chemical and waste disposal) could be taught at universities [VI.8].

In addition, at the end of 1950s and the early 1960s, special privileges existed for securing high quality human resources for the nuclear power programme. In contrast to other national organizations and research institutes, the staff of the AED took high positions in government institutions. The director of the AED held the same position as other ministers and as the director of BO and AERI; this was the rank of deputy minister. Moreover, the section head of each subsystem was a first class public official, and their staffs were also considered as high-ranking public officials. Their salaries were high enough to include a basic salary, research allowances and a danger allowance in order to attract high quality human resources working at universities and other domestic and overseas industries and research institutes. The location of the nuclear power programme institution also played an important role in attracting human resources. Specifically, AERI was located near the Seoul National University campus to promote convenient collaboration with competent human resources at a reputable educational institution. Moreover, the Government provided grants to encourage nuclear technology research at universities. There was no precedent for providing the grants for the encouragement of research at universities before that time. This special support contributed to stimulating the entire academic world, including students, and helped gather human resources for the nuclear power programme [VI.10].

The initial human resources development efforts are summarized in Table VI.2. Table VI.3 shows the development of nuclear engineering departments in the domestic education system, especially universities, over the entire period.

Stakeholder involvement

It is important to evaluate stakeholder involvement when defining and pursuing nuclear power programme goals. Since 1956, the United Kingdom (UK) and the USA began the first operation of commercial NPPs. This stimulated many countries to develop or plan commercial NPPs. The news media in the Republic of Korea closely followed this trend of world nuclear energy. In daily newspapers, journalists reported important advancements in nuclear energy, and many intellectuals wrote editorials about how the country would be changed and could advance. Also, many magazines provided the public with a great deal of information about the internal and external

TABLE VI.2. HUMAN RESOURCES DEVELOPMENT EFFORTS AT THE END OF THE 1950s [VI.9, VI.20]

	Activities for human resources development	Note
9 April 1956	1st ISNSE[a]	2 persons (Argonne Lab.)
3 September 1956	2nd ISNSE	5 persons
25 January 1957	3rd ISNSE	
April 1957	4th ISNSE	Date indefinite
10 September 1957	5th ISNSE	3 persons
1 January 1958	6th ISNSE	4 persons
1 March 1958	The establishment of a Nuclear Engineering Department at Hanyang University	
10 September 1958	7th ISNSE	30 persons: USA 20, UK 8, France 2
7 October 1958	8th ISNSE	15 persons: Australia 6, West Germany 9
1 March 1959	The establishment of a Nuclear Engineering Department at Seoul National University	
9 January 1959	9th ISNSE	2 persons: France 2
1 March 1959	The opening of AERI	
15 July 1959	First Nuclear Science Council	Predecessor of the Korean Nuclear Society: one time per year
6 August 1959	10th ISNSE	22 persons

a ISNSE: International School of Nuclear Science and Engineering (the human resources development programme for sending people to overseas educational institutions through internal and external sources of funding)

TABLE VI.3. ESTABLISHMENT OF DEPARTMENTS OF NUCLEAR ENGINEERING[a] [VI.20]

Year	University
1958	Hanyang University
1959	Seoul National University
1979	Kyunghee University
1981	Korea Advanced Institute of Science and Technology
1985	Chosun University
1985	Cheju National University

a This does not include specialized schools only for non-electric uses.

situation through featured articles. The peaceful use of atomic energy became the focus of public interest. The Republic of Korea–US Atomic Energy Agreement[10] further prepared the public to expect the introduction of an NPP.

[10] The official name is the Agreement for Cooperation between the Government of the Republic of Korea and the Government of the United States of America Concerning Civil Uses of Atomic Energy.

The Government held an exhibition on the peaceful use of atomic energy to gain further support from the public. Photos and models provided by the US Government were displayed for six days in six cities: Seoul, Busan, Daegu, Gwangju, Daejun and Junju. The exhibitions attracted over one million people. It was a great experience for the public and succeeded in softening their image of the atomic bomb and illustrating how nuclear technology could be used in a peaceful manner [VI.12].

Industrial involvement

Nuclear facilities require a much higher level of quality assurance than do other industrial systems. The NEPIO and industrial leaders exploring the involvement of domestic industry in a nuclear power programme had to fully examine accumulated experience and the ability to meet high quality standards. The Republic of Korea had virtually no high quality industrial basis in the initial phase despite the fact that many construction companies seriously wanted to obtain opportunities in this emerging new business. The country established a ‘learning by participating’ strategy for helping the domestic industry to accumulate experience through strictly controlled participation.

In the process of constructing the research reactor, the NEPIO decided that GA, the vendor of the research reactor, would take charge of the entire quality control process for all the facilities. They limited the domestic involvement to non-safety grade construction activities. The NEPIO set up a committee for selecting domestic industry participants [VI.8].

However, even with the restricted involvement, domestic industry participants were found to cause delays in the schedule. The cost increased due to insufficient industry experience in handling a large and technically demanding project. It was a very difficult experience for the NEPIO, even though the construction of a research reactor is a very small project compared with that of a commercial NPP. The painful experience was found to be a key learning opportunity towards satisfying high quality standards in future NPP projects.

Nuclear safety

Nuclear safety was always regarded as the top priority issue during the planning, implementation and operation of the nuclear power programme. Most of the infrastructure for nuclear power has some impact on safety. An important lesson was learned that participating in a network of international cooperation in nuclear safety leads to significant benefits for a country starting a nuclear power programme. At the pre-project phase, detailed and across-the-board actions are not required beyond the recognition of the need and regulations for nuclear safety in planning a nuclear power programme.

Emphasis on nuclear safety was given to all individuals involved in the country’s programme. As a neighbouring country, many of its citizens were killed or injured when atomic bombs were dropped on Japan. Nuclear power was associated with the image of the atomic bomb, which had the effect of forming the safety culture for nuclear reactor facilities in the country. However, the shortage of trained human resources did not allow for the preparation of a dedicated organization for nuclear safety regulation during Phase 1.

With the widespread fear of radiation and the atomic bomb, the Republic of Korea tried to manage and control the use of radioactive isotopes and radiation facilities. When the Atomic Energy Act was enacted, the safety regulation activities regarding radioactive isotopes licensing, supervision and penalties were explicitly defined as nuclear-specific provisions, distinguished from other provisions for general industrial activities.

VI.3.2. Phase 2 (1961–June 1968): Preparatory work for the construction of an NPP after a policy decision has been taken

Human resources development

In the early phase, with few domestic NPP experts, the development of human resources involved two major activities: sending trainees abroad and inviting experts for lectures, reviews and research. Trainees were trained in the USA and Europe. The wide range of information that they brought in led to thoughtful decisions for selecting the first NPP and reactor types.

From 1955 to 1964, the country sent 234 persons abroad, but only 150 persons returned to the Republic of Korea (Table VI.4). The Government training programme was triggering a ‘brain drain’ problem because many people did not take advantage of the job opportunities in the domestic nuclear power programme, the country’s preferred field, and decided to take better jobs overseas. To solve the problem, in 1961, the Government imposed return obligations on all students on Government scholarships [VI.10]. Students studying abroad at Government expense had to work in domestic organizations for a prescribed period. Contributing factors to the ‘brain drain’ were that the Government had limited support in the basic sciences in which many students were specialized, and it did not have a detailed plan to distribute these human resources [VI.9].

When the first wave of trainees returned, the Republic of Korea began domestic education by establishing nuclear engineering departments at universities and opening special lectures in government research institutes. International education experts were instrumental in establishing these domestic programmes. For example, in 1960, the Government invited an IAEA mobile laboratory for radioactive isotopes to operate in four cities for four weeks each. After the establishment of the Radiological Research Institute and Radiation Research Institute in Agriculture, the Government began domestic lecture programmes on radiation for medicine and agriculture that were offered twice a year [VI.9]. In 1968, when a detailed plan for nuclear power construction was confirmed, KEPCO assembled international and domestic experts to begin a specialized six week course titled “An Elementary Course on Nuclear Power Plant Operation” for training their staff working in thermal power plants. From the end of Phase 2 to the beginning of Phase 3, many classes were held on non-destructive testing, quality evaluation of construction, and systems and components of nuclear power plants.

The initial university curriculum for nuclear engineering mostly consisted of atomic physics and radiation. Because of the shortage of professors, researchers from AERI taught students. Nevertheless, nuclear engineering emerged as one of the most popular fields among young students. Some of the brightest and most enthusiastic students rushed into the nuclear power field. By 1963, nuclear reactor physics became a regular course in nuclear engineering. With the construction of the NPP in 1970, university programmes expanded beyond theoretical education into engineering courses such as the design process of an NPP, nuclear fuel cycle, nuclear power economy, reactor safety analysis and heat transport. This comprehensive education programme on nuclear engineering was the product of about 15 years of human resources development since the first ICPUAE [VI.6]. Many graduates of the new education programme entered national nuclear power programme organizations such as KEPCO to become today’s nuclear industry leaders.

Other important human resources for the nuclear power programme were the large population of Korean scientists and engineers working in foreign organizations with advanced degrees in areas related to nuclear engineering. The Government encouraged them to relocate in the country by providing generous compensation for relocation.

TABLE VI.4. PEOPLE RETURNED FROM STUDYING NUCLEAR POWER ABROAD [VI.12]

Sources Year	Government		IAEA		ICA		Other		Total	
	Send	Return	Send	Return	Send	Return	Send	Return	Send	Return
1955–1964	127	78	81	61	10	9	17	2	234	150
1965	—	—	13	6	—	—	3	1	16	7
1966	2	3	5	2	—	—	6	2	13	7
1967	—	—	10	11	—	—	5	2	15	13
1968	—	—	17	17	—	—	4	4	21	21
1969	—	—	10	4	—	—	1	2	11	6
Total	129	81	135	101	10	9	36	13	310	204

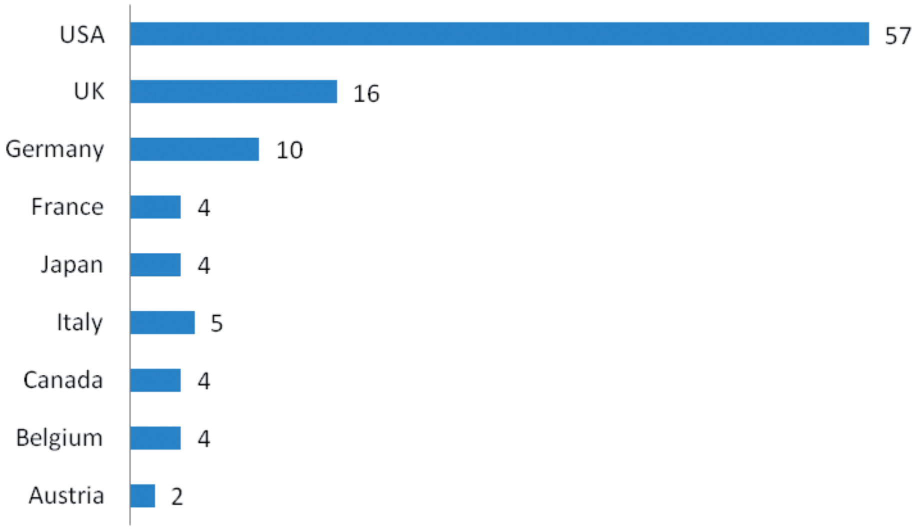

FIG. VI.2. The geographical distribution of people studying abroad in 1969.

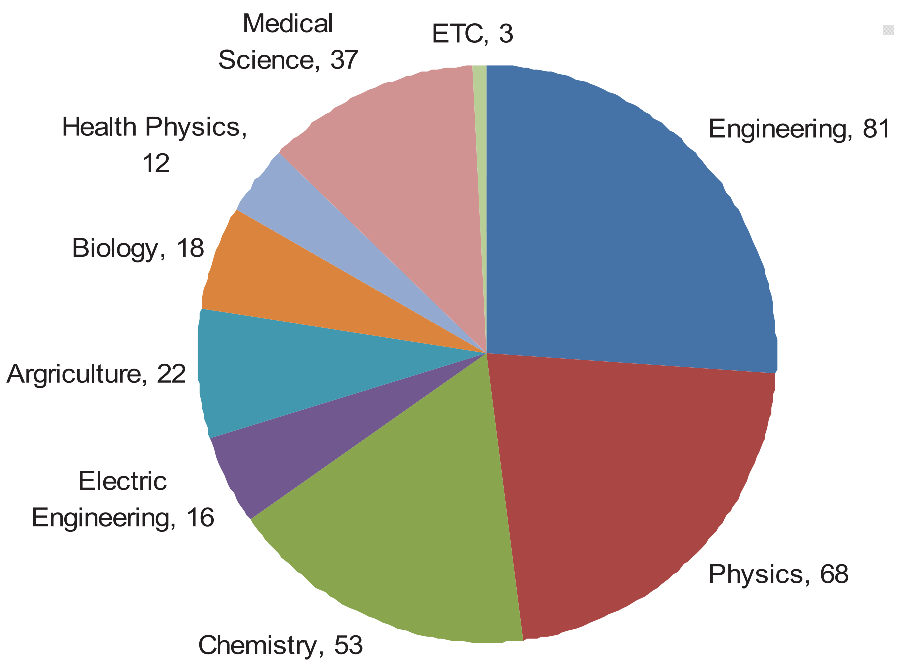

FIG. VI.3. Distribution of people studying abroad in 1969 by area of study.

Stakeholder involvement

In order to draw public interest to nuclear energy, the Government regularly opened exhibitions on nuclear technology in several cities every year starting in 1960. This also included photo exhibitions on the commercial, industrial, medical and agricultural uses of nuclear power. In addition, a public lecture and symposium was held in three to four cities per year starting in 1962. Through these efforts, the Government wanted to remove the negative image of nuclear energy among the general public and industry, and to demonstrate the peaceful uses of atomic energy.

The Government published basic informational books for the public titled “You and Atomic Energy,” “Atomic Energy Class,” and “Atomic Energy Story”, and translated academic books for students and intellectuals as well as pamphlets published by the US Atomic Energy Commission for public distribution. The Government also published the magazine “Nuclear Power Today” three or four times a year from 1960 to 1972. It provided scientists and the public with news and information on nuclear power research and applications at home and in foreign countries. In the 1960s, television was not widely available. Hence, newspapers and books were the most important mass media used to inform the public [VI.9].

Industrial involvement

In planning for NPP construction, the Government evaluated the capability of domestic industries to supply commodities, components or services to the NPP. They found that the domestic industry could not satisfy the nuclear quality assurance requirements. That was why the Republic of Korea decided on a turnkey contract for the first NPP. Under a turnkey basis, bid specification and participation of the domestic industry were limited to non-nuclear safety related areas such as civil engineering. From the 1970s, the Government started to develop HCI under the Five Year Economic Development Plan. With the enhanced HCI ability, the participation of domestic industries expanded from a peripheral role to the provision of core technology. The Republic of Korea’s industry participation can be described simply as ‘Learning by Participating’, as described in Phase 3 under HCI development [VI.41].

Procurement

With the launch of the First and Second Economic Development Plans, domestic industries also grew rapidly. However, this was limited only to labour intensive industries, and there was no capability to meet the high entrance criterion for nuclear technology. In the 1960s, the Republic of Korea was not yet able to start an HCI development plan, yet it still remained an assignment. This was one of the reasons that the first NPP was constructed on a turnkey basis with limited participation in civil engineering.

Nuclear safety

The Republic of Korea introduced provisions for licensing and supervision in the Atomic Energy Act, and ICRP and other authorized international standards were reflected in domestic radiation safety regulations. Also, there was regulatory inspection for people handling radioactive isotopes. This radiation safety management was aimed at minimizing health and physical damage caused by radiation exposure during industrial radiation applications and research activities [VI.12].

In the installation and operation of the first research reactor, located next to Seoul National University, reactor safety was considered one of the most important issues. The country decided to install the research reactor on a turnkey basis with the emphasis on quality control for safety while having limited domestic participation in non-safety areas.

VI.3.3. Phase 3 (from June 1968 to 1978) and the Operational Phase (from 1979 to 1990): Activities to implement the first nuclear power plant, maintenance and continuous infrastructure improvement

Human resources development

In the long range nuclear power programme plan of 1968, the demand for human resources related to nuclear technology was estimated for the next 20 years. Based on the plan, the Nuclear Training Centre was established in KAERI in 1967. This institute not only developed human resources but also helped technology transfer and cooperation among research institutes and industries. The KAERI Nuclear Training Centre helped provide human resources development of government and private industries at the various stages from elementary knowledge of nuclear power to regulation for domestic industry and government organization [VI.39]. This human resources development role steadily expanded from the research institute to private training programme, facilities and courses on nuclear industries.

Moreover, in 1979, the KAERI Nuclear Training Centre invited IAEA experts as part of its Training Course on Safety Analysis and Review for Nuclear Power Plants. In addition to the IAEA delegates, experts came from the USA, Canada and France. By 1988, the programme offered 36 courses by 247 foreign lecturers on introductory and advanced nuclear power technology to 1511 students. There were lecturers from within the country who provided course overviews and summaries to overcome the language barrier. Also, all foreign lecturers prepared presentation materials in a uniform context. The local lecturers later localized the course by becoming post-lecturers to their own classes [VI.5]. After the PWR was confirmed as the first NPP, KEPCO frequently sent staff to a PWR plant in Japan. In addition, KORI-1 set up a sister plant relationship with the Genkai plant and made regular visits [VI.11].

With the expectation of commercial NPP operation in the Republic of Korea, KEPCO estimated that about 170 people were needed for its operation, but it had secured only 92 people by the end of 1972. KEPCO contracted with WEICO for training on operations and control for repair and on fuel management. Additional staff were trained at existing thermal plants and research organizations. Also, KEPCO opened training centres for continued education and for beginning plant operations at the KORI-1 site. Table VI.5 summarizes overseas training programmes held during the construction period of KORI-1 [VI.8, VI.47]. Table VI.6 shows KEPCO training courses for new plant operators, including domestic and overseas courses.

The NSC launched a human resources development programme through overseas training with the support of the NPP and related facilities suppliers, the USA, Canada and France. Also, many IAEA experts visited the Republic of Korea to support the regulation programme and hold on-the-job training courses at NPP sites. Some experts stayed several months with the NSC staff at NPP sites to support and observe the country's regulatory activities [VI.43].

TABLE VI.5. OVERSEAS TRAINING PROGRAMME FOR KEPCO STAFF DURING CONSTRUCTION OF KORI-1

Field	No. of staff	Period	Note
Planning	More than two persons a year	July 1968	
Executive	21	March–November 1970 (9 months)	Training with WEICO
Technical aids and components (spare)	20	March–November 1971 (9 months)	
Repair	45	March–November 1971 (9 months)	
Operation (control)	85	August 1972–April 1973 (9 months)	

TABLE VI.6. KEPCO TRAINING COURSES FOR NPP OPERATORS

Step	Content	Period
TR-1	Elementary course of thermal power plant	3 months
TR-2	Elementary course of nuclear power plant	3 months
TR-3	In-service training	6 months
TR-4	Overseas training	3–24 months
TR-5	Startup training at new NPP	12 months
TR-6	Supplementary education	1 week–3 months

Stakeholder involvement

After India's nuclear test, the Nuclear Suppliers Group (NSG) formed the London Club, which limited sensitive technology transfer and aimed at international confidence in each country's nuclear power programme. The Republic of Korea had already established the Atoms for Peace policy by signing the NPT and other international agreements. The multinational technical cooperation with other countries helped promote nuclear power as a key option for electricity supply [VI.9, VI.15].

During the construction of KORI-1, the Republic of Korea and the USA closely cooperated and agreed to launch the Republic of Korea–US Joint Standing Committee on Nuclear and Other Energy Technologies in 1976. Also, the Republic of Korea established the Joint Consultation Committee with France and Canada prior to the operation of the fuel fabrication facility and Wolsung [VI.8].

Industrial involvement

Only turnkey basis contracts were employed for the first three plants. As KORI-1 was constructed on a turnkey basis, domestic industries and technicians participated in civil engineering, construction and non-destructive testing[11]. Local industries tried to establish a quality control database and experience by participating in the construction of the second and third NPP. Based on the long term plan, in 1975 the Republic of Korea encouraged the development of local architectural engineering (AE). It established Korea Atomic Burns and Roe (KABAR) with Burns & Roe as a local AE firm. A year later, KAERI acquired it and renamed it Korea Nuclear Engineering & Services (KNE). KNE was operated by KAERI, the main owner, in order to easily secure human resources [VI.49]. KNE began participation as a subcontractor to the engineering design and construction of the fifth NPP.[12] KNE staff received training from Bechtel Corporation, the primary AE contractor, before participating in the actual project. All of the contracted AE companies were required to undertake joint engineering work with KNE. In the 1980s, domestic companies became the main contractors with foreign companies working as subcontractors.

In addition, the Government established the indigenous content policy not only for engineering but also for NPP components. The Government classified NPP components by local content feasibility per component, importance and targeted schedule. Private enterprises were established for development and manufacturing using specifications from KAERI. Quality management for local suppliers also became a driving force to improve the quality of both nuclear and non-nuclear products. This also had a very positive influence on the steel making industry and the ship building industry [VI.9].

Tables VI.7 and VI.8 indicate contract conditions and indigenous portions of NPP construction in the Republic of Korea. A 'learning by participating' strategy was also applied in the commercial NPP construction.

Procurement

The first three NPPs were contracted on a turnkey basis, which allowed for limited domestic participation. From the fourth NPP, the contract terms were specified to ensure a certain level of indigenous content with the approval of foreign contractors. The indigenous portion was increased over time. All of the indigenous components were required to pass inspection in accordance with the same standards applied to foreign-made components. Ultimate responsibility for NPP performance was placed on the main contractors who promoted suppliers' active participation in quality control of subcontractors.

From the fourth to ninth NPPs, these projects were contracted on the non-turnkey, component approach basis, in which the total project scope was divided into several main contracts among contractors, and the foreign main contractors were obliged to bear the contract liabilities with local subcontractors under their supervision. This contract scheme not only stimulated the expansion of the indigenous portions but also sped up nuclear technology transfer.

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[11] Hyundai Engineering and Construction Co, Ltd.: Subcontractor for the reactor system; Dong Ah Construction: Subcontractor for the turbine generator; Yuyang Atomic Energy: Main contractor for non-destructive testing.

[12] In 1982, KNE was moved to KEPCO and changed to its present name, Korea Power Engineering Company (KOPEC).

TABLE VI.7. CONTRACT CONDITIONS OF NUCLEAR POWER PLANTS IN THE REPUBLIC OF KOREA[a] [VI.50]

Plant	Type (MWe)	NSSS (Sub)	TG (Sub)	AE (Sub)	Date order	Construction start	Commissioned
KORI-1 (turnkey)	PWR (587)	WEICO	GE	Gilbert	1969	November 1971	April 1978
KORI-2 (turnkey)	PWR (650)	WEICO	GE	Gilbert	1974	May 1977	April 1983
Wolsung-1 (turnkey)	PHWR (679)	AECL	NEI	Canatom	1973	May 1977	April 1983
KORI-3	PWR (950)	WEICO (KHIC)	GE (KHIC)	Bechtel (KOPEC)	1978	April 1979	September 1985
KORI-4	PWR (950)	WEICO (KHIC)	GE (KHIC)	Bechtel (KOPEC)	1978	April 1979	April 1986
Yonggwang-1	PWR (950)	WEICO (KHIC)	WEICO (KHIC)	Bechtel (KOPEC)	1978	December 1980	August 1986
Yonggwang-2	PWR (950)	WEICO (KHIC)	WEICO (KHIC)	Bechtel (KOPEC)	1978	December 1980	June 1987
Ulchin-1	PWR (950)	Framatome (KHIC)	Alsthom (KHIC)	Framatome (KOPEC)	1980	March 1982	September 1988
Ulchin-2	PWR (950)	Framatome (KHIC)	Alsthom (KHIC)	Framatome (KOPEC)	1980	March 1982	September 1989
Yonggwang-3	PWR (1000)	KHIC (CE: sub)	KHIC (GE)	KOPEC (SL: sub)	1987	June 1989	March 1995
Yonggwang-4	PWR (1000)	KHIC (CE: sub)	KHIC (GE)	KOPEC (SL: sub)	1987	June 1989	March 1996

[a] Sub (Subcontractor), NSSS (Nuclear Steam Supply System), TG (Turbine Generator), BOP (Balance of Plant), AE (Architectural Engineering), WEICO (Westinghouse Electric International Company), AECL (Atomic Energy of Canada Ltd.), Framatome (Framatome et Compagnie), KHIC (Korea Heavy Industries and Construction Co.; Present name: Doosan Heavy Industries & Construction Co., Ltd), GE (General Electric Company), CE (Combustion Engineering), NEI (NEI Parsons Ltd), Gilbert (Gilbert Associates Inc.), KOPEC (Korea Power Engineering Company), SL (Sargent and Lundy Co.).

TABLE VI.8. INDIGENOUS CONTENT OF NUCLEAR POWER PLANTS (%) [VI.50][a]

Unit	NSSS	TG	BOP	CE	A–E and design
Kori-3 and 4	10	11	33	95	37
Ywongkwang-1 and 2	19	30	42	95	44
Ulchin-1 and 2	26	40	55	95	46
Ywongkwang-3 and 4	63	94	73	95	95

[a] The indigenous portion is defined as the amount of money related to domestic suppliers' involvement to the amount of the total construction cost in NSSS, TG, BOP and CE; AE is defined as a person-hours of domestic staff involvement in AE.

From the tenth NPP, Yonggwang-3 and 4, KEPCO decided to pursue an ambitious plant standardization programme based on the construction experience of the NPP with the same authorized power, 950 MW(e), from the third unit to the ninth unit. The country succeeded in constructing Yonggwang Units 3 and 4 as the reference plants of the Korea Standard Nuclear Power Plant. Ultimate responsibility for NPP performance was placed on the main contractors, which promoted active participation of suppliers according to the indigenous policy. It allowed local companies to perform most of the design and engineering work, construction and maintenance services and further procure most NPP components from domestic suppliers.

Nuclear safety

The IAEA Milestones publication [VI.6] emphasizes nine items for establishing nuclear safety infrastructure. They include: operator skills and attitudes; management system; safety culture; legal framework; regulatory independence, competence and authority; technical competence; financial stability; emergency preparedness; and international connectivity. These issues were already discussed in other parts of this publication.

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ABBREVIATIONS USED IN APPENDIX VI

AE	Architectural Engineering
AEC	Atomic Energy Commission
AED	Atomic Energy Department (1958–1967)
AERI	Atomic Energy Research Institute
AES	Atomic Energy Section (1956–1958)
AP	Additional Protocol
APR 1400	Advanced Power Reactor 1400
BO	Bureau Office
BOP	Balance of Plant
COCOM	Coordinating Committee for Multilateral Export Control
CSA	Comprehensive Safeguards Agreement
GA	General Atomic
HCI	Heavy and Chemical Industry
HLW	High Level Waste
IAEA	International Atomic Energy Agency
ICPUAE	International Conference on the Peaceful Uses for Atomic Energy
ICRP	International Commission on Radiological Protection
KAERI	Korea Atomic Energy Research Institute
KEPCO	Korea Electric Power Corporation
KEPRI	Korea Electric Power Research Institute
KINS	Korea Institute for Nuclear Safety (1990–)
KNE	Korea Nuclear Engineering & Services
KNFC	Korea Nuclear Fuel Company
KNIST	Korea National Institute of Standards and Technology
LILW	Low and Intermediate Level Waste
MOST	The Ministry of Science and Technology
NEPIO	Nuclear Energy Programme Implementing Organization
NPP	Nuclear Power Plant
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NSC	Nuclear Safety Center (1981–1990)
NSG	Nuclear Supplier Group
NSSS	Nuclear Steam Supply System
OAE	Office of Atomic Energy (1967–1973)
OP	Operational Permit
OPR 1000	Optimized Power Reactor 1000
PWR	Pressurized Light Water Reactor
SSAC	State System of Accounting for and Control of Nuclear Material
SNF	Spent Nuclear Fuel
TCNC	Technology Center for Nuclear Control
TG	Turbine Generators
UKAEA	United Kingdom Atomic Energy Authority
USAEC	US Atomic Energy Commission

Appendix VII

NUCLEAR WORKFORCE DEVELOPMENT: AN INDIAN PERSPECTIVE[13]

VII.1. THE INDIAN NUCLEAR INDUSTRY: A SNAPSHOT

The Indian nuclear power industry stands today at a crucial juncture in its history. Having grown at a steady pace in the past four decades, it is now ready to make a quantum leap in terms of capacity addition. Beginning in 1969 with a capacity of a mere 320 MW(e), it grew to 470 MW(e) by 1979, 1010 MW(e) by 1989, to 4120 MW(e) in 2009. Aiming for a capacity of 6780 MW(e) by 2011, the industry is planning and rolling out projects at a searing pace.

By and large, the indigenous effort of a not-so-large, dedicated nuclear workforce in India, with initial technological inputs and support from Canada and the USA, has come a long way, as India stands on the threshold of international civil nuclear commerce. The nuclear industry in India has undergone the entire cycle of development to enter the present era of commercial maturity.

The late 1960s and 1970s represented the *demonstration phase*, wherein the Tarapur Atomic Power Station Units 1 and 2 (2 × 160 MW(e)) with BWRs were built with technological support from the USA. This project was chosen to gain experience in all aspects — construction, commissioning, operation, safety review and regulatory process of an NPP. These units were commissioned in 1969 and have been operating since then. The nascent Indian nuclear industry gained insight into integrating nuclear power reactors with the Indian grid. Next, in collaboration with Canada, the first two PHWRs were established in Rajasthan (RAPS 1 and 2) in 1973 and 1981, respectively.

The 1980s marked the *technological development phase* of the Indian nuclear power industry, when the buzzword was indigenization and experimentation. End-to-end nuclear technology expertise was achieved vis-à-vis construction of reactor equipment, steam generators, end shields, instrumentation, controls, and so on, through the efforts of the various units of the Department of Atomic Energy of India (DAE). The Madras Atomic Power Station Units 1 and 2 (PHWRs) epitomized this phase of the Indian nuclear power industry.

Throughout the 1980s and early 1990s, indigenously developed technology was standardized for error free duplication at new sites such as the Narora Atomic Power Station Units 1 and 2 (PHWRs). In this *phase of standardization*, the Indian nuclear industry began reaping the benefits of its associated economies.

The establishment of the Kakrapar Atomic Power Station Units 1 and 2 (PHWRs) in the 1990s marks the *consolidation phase* of the nuclear industry in India.

India stepped into the 21st century with experience and expertise in nuclear technology, mature enough to initiate its *commercial phase*. With the signing of the Indo–US nuclear deal, access to international uranium markets has resolved the demand–supply mismatch for fuel. In order to meet the accelerating demand of electricity, to feed the growth of Indian services and industry and maintain the country’s GDP growth rate at between 7 and 8%, India is now planning to build nuclear power generation capacity of about 20 GW(e) during the next decade and about 40 GW(e) by the year 2050.

VII.2. EVOLUTION OF ORGANIZATIONS

VII.2.1. The three stage nuclear power programme

Despite being a newly independent, underdeveloped nation, India played a pivotal global role in steering the course of nuclear energy towards electricity generation and other peaceful applications. Homi Bhabha, the “Father of the Indian Atomic Energy Programme”, was a contemporary of the initiators of the atomic energy movement — Dirac, Pauli, Fermi and Bohr. Keeping in mind the limitations set by the natural resources of the country, Bhabha

[13] This report has been prepared by consultants from the Nuclear Division of PM Dimensions Pvt. Ltd (www.pmdimensions.com).

conceptualized a three stage nuclear power programme for India comprising utilization of natural uranium as fuel in PHWR plants in Stage I, development of fast reactor plants using the plutonium reprocessed from Stage I as spent fuel in Stage II, and development of breeder reactors using thorium and uranium fuel in Stage III. India has abundant reserves of thorium but limited uranium reserves. This set the stage for all nuclear related research and development in India within the scope of this comprehensive three stage nuclear power programme.

Based upon this blueprint, India has rolled out the majority of its nuclear facilities of PHWRs in accordance with the first stage (RAPS-2 in 1981; MAPS 1 and 2 in 1984 and 1986, respectively; NAPS 1 and 2 in 1991 and 1992, respectively; KAPS 1and 2 in 1993 and 1995, and so on) and is now entering Stage II with the setting up of a prototype fast breeder reactor at Kalpakkam. Even now, the plan is to implement the Stage I programme on a large scale by establishing several nuclear power generation parks in the country of 10 GW(e) at each location.

VII.2.2. Bhabha Atomic Research Centre

Bhabha established the Tata Institute of Fundamental Research (TIFR), in Mumbai, during the pre-independence era, in 1945, for research on atomic energy and allied fields of science and technology. It was a landmark event in infrastructure development for R&D in atomic energy. As early as 1948, the Atomic Energy Act was passed and the Atomic Energy Commission (AEC) came into existence.

By 1956, the Atomic Energy Establishment, Trombay (AEET) was established by the AEC. All scientists and engineers engaged in the fields of reactor design and development, instrumentation, metallurgy, material science and the like, were transferred along with their respective programmes. TIFR became fully dedicated to fundamental research in nuclear science.

In 1967, AEET was renamed the Bhabha Atomic Research Centre (BARC) in memory of Homi Bhabha. Thus, AEET/BARC emerged as the premier institute in India offering young scientific talent the opportunity to enter research in the field of nuclear energy, its applications and associated fields. AEET/BARC is the first institution in India that developed nuclear personnel.

VII.2.3. Nuclear Power Corporation of India Ltd

In 1967, the Power Project Engineering Division (PPED), a unit of DAE, was formed for the purposes of designing, constructing and operating NPPs. In 1984, PPED was converted into the Nuclear Power Board (NPB) with substantial powers delegated to it. In September 1987, the NPB was transformed into the Nuclear Power Corporation of India Ltd (NPCIL) with the aim of shifting experimental nuclear power to the commercial domain. Currently, NPCIL is a public sector enterprise of the DAE.

NPCIL’s function is to operate the atomic power stations and implement new atomic power projects for the generation of electricity. Today, it has 17 nuclear power reactors in operation with a gross generation capacity of 4.2 GW(e). NPCIL is designing and executing nuclear power projects ranging from 220 MW(e) to 1000 MW(e) capacity. MoUs have been signed with global vendors such as Westinghouse Electric Company, USA; AREVA, France; and General Electric Hitachi, USA. Domestically, NPCIL has signed an MoU for nuclear power generation with NTPC Limited, India’s largest power generating company; and with Bharat Heavy Electricals Limited, for engineering, procurement and construction (EPC) activities. NPCIL is also considering export of NPPs of small capacity (up to 500 MW(e) capacity).

NPCIL’s ambitious plans, which are translating into a macro nuclear reality at such a rapid pace, have set the ground for equally fast paced personnel development for the nuclear industry in India.

VII.2.4. Department of Atomic Energy

In 1954, the Department of Atomic Energy (DAE) was formed. DAE acts as the umbrella organization, under the aegis of the AEC, to a large number of organizations closely associated with the Indian nuclear industry. Figure VII.1 depicts the composition of the DAE.

This vast network of organizations needs an inflow of workforce with a base in science, nuclear technology and allied fields. Currently, the main feeder for skilled human resources to these organizations is BARC.

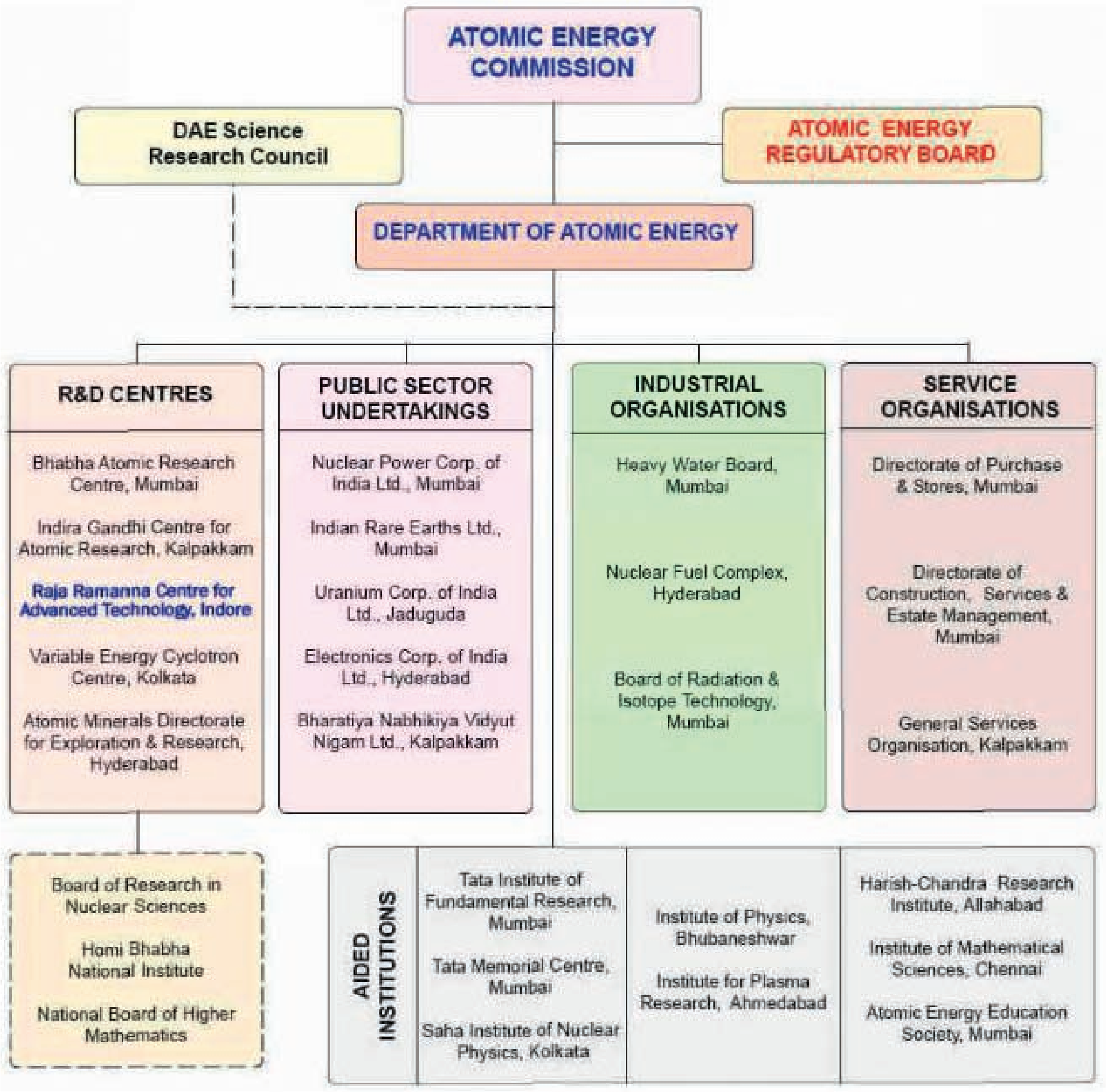

FIG. VII.1. The organizational chart of the DAE.

VII.2.5. Atomic Energy Regulatory Board

An organization independent of the control of the DAE, called the Atomic Energy Regulatory Board (AERB), was formed in 1983 to take up the responsibilities of regulation of the nuclear industry, including nuclear power, in India. The AERB organized safety reviews and regulation of the entire nuclear industry and nuclear power in the country. The staff of the regulatory body was recruited from NPCIL offices and plants, universities and institutions, government departments and the private sector.

VII.3. HUMAN RESOURCES DEVELOPMENT

VII.3.1. Bhabha Atomic Research Centre

In 1956, BARC started work on the construction and commissioning of a research reactor. The CIRUS reactor was built with the cooperation of Canada. The core team for operation of this reactor was recruited to BARC and trained in Canada. The senior operators and engineers for this plant received their training for up to two years in a similar plant located in Canada where the Indian team supported the commissioning and initial operation of the Canadian research reactor as a part of their training in Canada. This valuable hands-on experience gained by Indian nuclear scientists was passed on to the subsequent batches of operators and other specialists in India. A programme of well structured training and licensing for the key operating positions was launched and reviewed continuously. The engineering and scientific personnel was regularly drawn from the BARC training school as well as from other scientific institutions and industry in India and overseas. Thus, BARC became the premier Indian institute for imparting nuclear training.

Currently, BARC runs the following nuclear training programmes (Table VII.1):

— Orientation Course for Engineers and Scientists (OCES) for postgraduates;
— DAE Graduate Fellowship Scheme (DGFS) for engineering graduates and physics postgraduates;
— Orientation Course for DAE Fellows (OCDF);
— K.S. Krishnan Research Associateship (KSKRA).

BARC is organized into several groups, which are further divided into many divisions (Table VII.2).

VII.3.2. Diversification of nuclear training

As the need arose, BARC diversified its nuclear training to the following institutes and locations.

TABLE VII.1. BARC NUCLEAR TRAINING PROGRAMMES

Programme	Duration	Eligibility	Vacancies per year
OCES	1 year	B.Tech/MSc	250–300
DGFS	2 years	B. Tech/MSc(Physics) & GATE, selected for M.Tech (at IITs)	25–50
OCDF	4 months	DGFS fellows	25–50
KSKRA	2 years	PhD/M.Tech with 2 years R&D experience	8–15

TABLE VII.2. ORGANIZATIONAL GROUPS AT BARC

1.	Administrative Group	11.	Knowledge Management Group
2.	Beam Technology Development Group	12.	Materials Group
3.	Bio-Medical Group	13.	Nuclear Fuels Group
4.	Chemical Engineering Group	14.	Nuclear Recycle Group
5.	Chemical Technology Group	15.	Physics Group
6.	Chemistry Group	16.	Radio Chemistry and Isotope Group
7.	Design, Manufacturing and Automation Group	17.	Reactor Design and Development Group
8.	Electronics and Instrumentation Group	18.	Reactor Group
9.	Engineering Services Group	19.	Reactor Projects Group
10.	Health Safety and Environment Group		

VII.3.2.1. Indira Gandhi Centre for Atomic Research (IGCAR)

Since the activities involved in the development of fast reactors were quite large, a separate dedicated research centre was started at the Indira Gandhi Centre for Atomic Research (IGCAR) in southern India, at Kalpakkam, near Chennai. IGCAR started a research cum demonstration plant called Fast Breeder Test Reactor (FBTR). A prototype plant design has already been completed by this centre and a prototype fast reactor of 500 MW(e) capacity is under construction in the vicinity of this centre. The implementation of this programme has been entrusted to a newly formed company called Bhartiya Nabhikiya Vidyut Nigam (BHAVINI).

VII.3.2.2. Electronics Corporation of India Ltd (ECIL)

The electronics, instrumentation and reactor control groups of BARC were hived off as a separate organization known as the Electronics Corporation of India Ltd (ECIL), located in Hyderabad, Andhra Pradesh. ECIL started functioning in 1970 for design, development and provision of manufacturing support for all instrumentation needs at NPPs. This is the prime organization responsible for designing, erecting, supplying and commissioning radiation instruments, reactor regulation and protection and process instruments, including plant simulators. Experts from BARC and ECIL impart training in the area of electronics and instruments to the core group of engineers.

VII.3.2.3. Centre of Advanced Technology (CAT)

BARC diversified yet again. A new centre known as the Centre of Advanced Technology (CAT) was established in central India — in Indore, Madhya Pradesh. This centre was dedicated to R&D related to nuclear particle accelerators and plasma technology.

VII.3.2.4. Nuclear Fuel Complex — Heavy Water Board (NFC-HWB)

This institution, located in Hyderabad, specializes in process development, design, engineering, construction, operation and maintenance of plants with regard to nuclear fuel and heavy water.

VII.3.2.5. Homi Bhabha National Institute (HBNI)

The latest training organization, a university established in 2005, HBNI is involved in broad-based basic research, through its grant-in-aid institutions, and is responsible for technology and product development through its R&D centres.

VII.3.2.6. Board of Research in Nuclear Sciences (BRNS): Encouraging Careers in Advanced Nuclear Research

The Board of Research in Nuclear Sciences (BRNS) is the nodal funding agency that supports advanced scientific research by awarding fellowships and grants to research scholars to encourage people with a scientific inclination to take up careers in the nuclear industry.

VII.3.2.7. Nuclear Training Centres

NPCIL developed excellent in-house training facilities attached to the NPPs. These facilities were developed as Nuclear Training Centres (NTCs), also known as Station Training Centres (STCs). The NTCs of NPCIL developed well equipped laboratories and workshops. These centres also acquired full scope nuclear plant simulators and several part task system simulators for giving hands-on training for managing operations and emergency situations at NPPs. An important aspect to be highlighted here is that the key operating personnel are licensed for a three year term only, at the end of which they have to undergo retraining and renewal of their licence for an additional three years.

The following discussion highlights various aspects of the operational training conducted at the various nuclear facilities of NPCIL for operational personnel:

— An operations group is responsible for the commissioning and operation of the plant in accordance with the procedures, technical specifications and standards for quality assurance laid down in the manual.
— The name of the training design — Systematic Approach to Training (SAT) — is self-explanatory. Each trainee is taught in detail the skills, knowledge and attitude with regard to his/her functions.
— The streams of training are divided into five paths — level 1, level 2, level 3, level 4, and level 5, with level 5 being the lowest level and level 1, the highest. Level 5 training is imparted to high school pass or Industrial Training Institute pass technician level personnel. A senior technician could be promoted to level 4 and further to level 3. Diploma holders at the supervisory level are imparted training for level 3. These persons can progress to level 2 and then level 1. A few promising persons may also move to the management level.
— An exclusive, higher level is also recognized — the management level. Managerial level training is imparted to outstanding performers. Invariably, engineering graduates or postgraduates in science and engineering who are initially trained at level 2 progress to join the management level. Incentives are commensurate with the position held.
— It is mandatory for an employee to requalify by examination, even to retain the same level, on completion of every three years.
— The training curricula cover a wide range of subjects from science and engineering basics to plant equipment, systems and integrated plant operation in normal and emergency conditions. Safety and radiation related training is imparted to each level to a varying degree suitable for each level.
— The training system is continuously reviewed and upgraded to suit the requirements of the organizations.
— The training system is specific to each unit/plant in the NPCIL organization.
— Training manuals, work sheets, procedures, checklists and exercises (practice sessions) are used for training at each level.
— The people appointed for commissioning a plant are trained on the equipment/system/plant during the commissioning phase. Vendors, designers and safety experts are deployed to impart training to the commissioning team members. Around 150 people participate in the commissioning phase of each plant. This group acquires a very high level of competence for operation and maintenance.

VII.3.3. Post-training placement avenues

Table VII.3 describes placement opportunities after nuclear training at BARC and its allied training centres. After the training, most of the skilled personnel is absorbed by the organizations under the DAE umbrella.

TABLE VII.3. PLACEMENT OPPORTUNITIES FOR TRAINING SCHOOL GRADUATES

Training school	Orientation of training	Probable placement after training
BARC, Mumbai (since 1957)	Operation and maintenance, R&D and engineering related to broad-based nuclear science and technology	Mainly in BARC and also in AMD, BRIT, RRCAT, HWB, IGCAR, NFC, NPCIL and VECC
IGCAR, Kalpakkam (since 2006)	R&D and engineering related to fast breeder reactors	Mainly in IGCAR and also in BHAVINI, BARC and NPCIL
RRCAT, Indore (since 2000)	R&D and engineering related to lasers, accelerators, plasma physics, cryogenics and superconductivity	Mainly in RRCAT and also in BARC, IGCAR and VECC
NFC-HWB, Hyderabad (since 2001)	Operation and maintenance and engineering related to nuclear facilities and production plants	Mainly in NFC and HWB and also in AMD, BARC, BRIT and IGCAR
NPCIL, Kaiga, Kalpakkam, Kudankulam, Rawatbhata, Tarapur (since 1980)	Engineering, project management, construction and operation and maintenance related to nuclear power plants	Mainly in NPCIL and also in BARC

VII.4. INDIAN MODEL FOR NUCLEAR WORKFORCE DEVELOPMENT

Entry level qualification/training	Trained and deployed at	Position held
Indian schools: 12th standard with math/science	1. BARC (research reactors, central workshop, other operations) 2. NPCIL project/plant (through NTC) 3. Industrial units like HWB/NFC	Operators
ITI (Industrial Training Institute) — 2 year technical course after 10th standard	1. BARC (research reactors, central workshop, other operations) 2. NPCIL project/plant (through NTC) 3. Industrial units like HWB/NFC	Tradesmen/Skilled Technician (maintainance and construction)
Diploma colleges (polytechnics) — 3 year diploma in technical field after 12th standard	1. BARC 2. NPCIL Project/Plants (a) NTC (1 year) (b) Supervisors for construction 3. Industrial units 4. NPCIL HQ	Plant Supervisor
Engineering, BSc, MSc colleges — 4–5 year bachelor’s degree after 12th standard	1 or 2 year course in Training School and Nuclear Training Centre	Engineer/Scientific Officer
Advanced Learning Institutes — postgraduate and research experience	1. BARC Training School (one year) — BARC/AERB/Other DAE (a) BARC/AERB/Other 2. NPCIL (a) Projects/Plants (b) NTC 1 year – Plant O & M (2 years) 3. Industrial units 4. NPCIL — HR	Management Research Administration
Industry Thermal power plants Abroad (NPP & Industry)	BARC/NPCIL/Other DAE units NPCIL/Industrial units 1. BARC 2. NPCIL 3. AERB 4. Industrial units	Engineer/Scientific Officer

VII.5. FUTURE OUTLOOK

(1) Expansion of BARC training school into a fully fledged centre for education and research in nuclear science and engineering;

(2) Initiation of new programmes at diploma/graduate/postgraduate and research levels at BARC and other institutions for nuclear science and related fields;

(3) Development of training schools and centres at other DAE units to provide special training in the specific areas of nuclear power development;

(4) Start of nuclear science and engineering courses in selected universities/institutions in India progressively;

(5) Further development and integration of nuclear training centres, nuclear safety training and regulatory system training with leading indian engineering and scientific institutions.

VII.6. SUMMARY

Key considerations of nuclear workforce development in India are:

— Began with international cooperation and then internalized and indigenously developed in a structured manner;
— Based on prudent, detailed planning and comprehensive development of competence in every aspect of the nuclear power programme;
— Development of indigenous technology made it imperative to develop indigenous infrastructure for research and training;
— Training imparted to aspirants defined by on-the-job requirements, as opposed to being academically oriented;
— Quality of training continuously reviewed for effectiveness and regularly upgraded and aligned with technological changes;
— Trainers regularly exposed to latest developments in NPP technology and management.

It is anticipated that phased privatization, increased international participation and possible export of technology and human resources will expedite the development of a highly competent Indian nuclear workforce, which, known to be skilled and cost effective, will play a pivotal role in global nuclear commerce.

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Appendix VIII

WORKFORCE PLANNING: CASE STUDY OF THE UNITED ARAB EMIRATES — HUMAN RESOURCES DEVELOPMENT

VIII.1. INTRODUCTION

Faced with tremendous increases in the long term projected demand for electricity in the United Arab Emirates (UAE), the Government of Abu Dhabi conducted a comprehensive evaluation of its energy needs and potential solutions beginning in 2006. The evaluation was wide-ranging and resulted in the following findings:

- The volumes of natural gas that could be made available to the nation's electricity sector would be insufficient to meet future demand.
- The burning of liquids (crude oil and/or diesel) would be logistically viable but both costly and environmentally harmful.
- Coal fired power generation, while potentially cheaper, would be environmentally unacceptable, and potentially vulnerable from a security of supply standpoint.
- The deployment of renewable and other alternative energy supplies, while desirable and an important part of the nation's future energy portfolio, would only be able to supply approximately 6–7% of the required electricity generation capacity by 2020.

Peaceful civil nuclear energy emerged as the most effective solution to the demand needs. Four factors supported the decision to begin the UAE programme:

- Economics: Well run nuclear energy plants are among the most efficient producers of electricity.
- Security of fuel supply: NPPs have high availability factors (in excess of 90%) and can operate for 18–24 months on a single fuel load.
- Environment: Nuclear plants emit no greenhouse gases and represent an important tool for combating climate change.
- Industrial development: A sustainable nuclear energy programme will create new service industries and high value jobs, while enhancing economic development throughout the UAE.

Following the passage of a federal law governing peaceful civil nuclear energy in 2009, which established the Federal Authority for Nuclear Regulation, and the official establishment of the Emirates Nuclear Energy Corporation (ENEC), in December 2009, a contract was awarded to a consortium led by KEPCO (Korea Electric Power Corporation) to build four 1400 MW nuclear power plant units in the UAE. The award of the contract to build the first NPP is consistent with the achievement of Milestone 2 in the IAEA publication Milestones in the Development of a National Infrastructure for Nuclear Power (IAEA Nuclear Energy Series No. NG-G-3.1).

Under the contract, ENEC will be responsible for the operations of the plant (the licensee) and KEPCO is to provide operational support services. The operating staff will be trained initially in the Republic of Korea and eventually in the UAE as the training infrastructure is delivered. This arrangement allows ENEC to build on the experience, training and operating model of a well established nuclear power infrastructure as it starts its own nuclear power programme. KEPCO will provide operational support services through its technical support staff to supplement ENEC's operations staff.

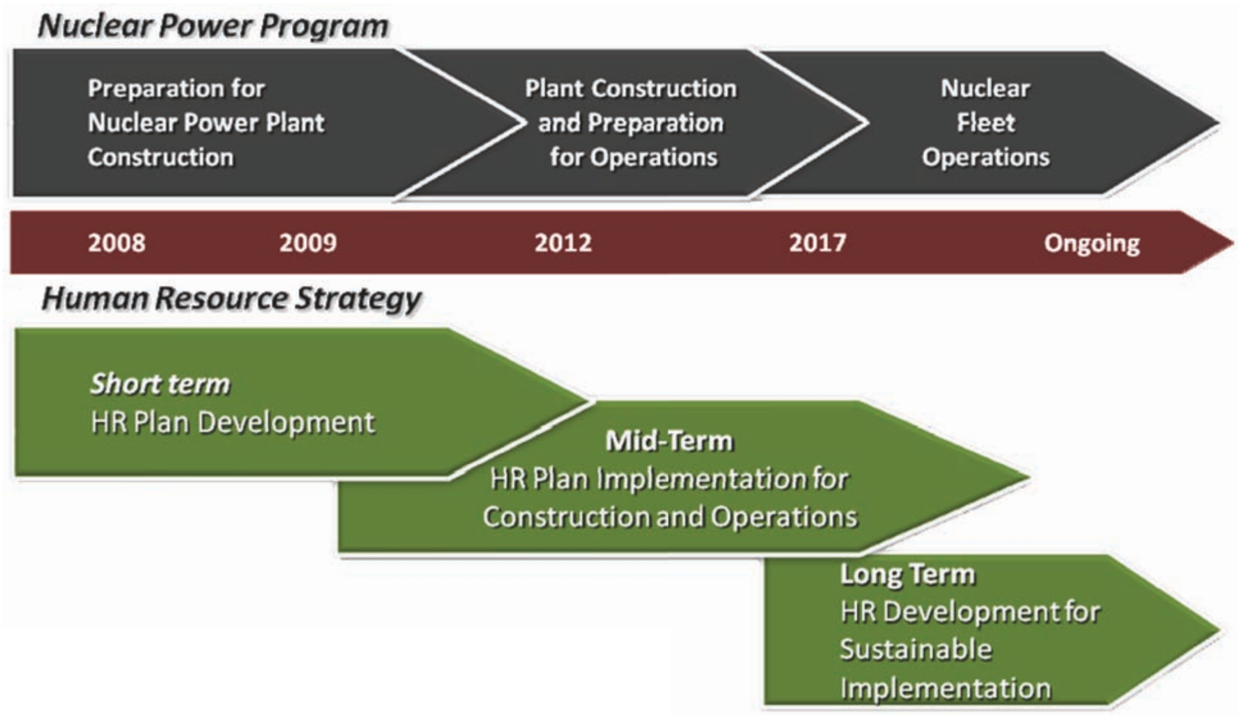


FIG. VIII.1. Human resources development planning.

VIII.2. BUILDING HUMAN RESOURCES CAPACITY

ENEC developed a strategy for capacity building of human resources that included four specific goals:

(1) Resource the pipeline of talent to support development and operations of the UAE civil nuclear power industry;
(2) Meet the human resources demands of a world class nuclear utility organization, including establishing world class educational programmes;
(3) Create a sustainable education system to maintain ongoing pipeline flow of staff into the UAE nuclear industry;
(4) Establish sustainable nuclear technology programmes that provide nuclear expertise, training and research.

These goals were underpinned by a Human Resources Development Plan which was divided into three phases and linked to the deployment of the NPPs in the UAE (Fig. VIII.1).

Short term (2008–2009)

The key activities included in the short term plan (largely complete at the time of writing) focused on the development of detailed staffing and qualification studies. These studies led to the identification of engineering and technician estimates to support the new nuclear programme in the UAE. The level of detail in the studies provided sufficient data to move forward with discussions with local universities and technical high schools to identify programmes in support of the new nuclear industry.

Medium term (2009–2017)

Consistent with its vision of the majority of plant staff being UAE nationals, the main requirements identified within the medium term human resources plan are:

— Execute the Human Resources Plan to include existing local talent in sustainable long term support of the nuclear industry;
— Develop education and work opportunity programmes with partner utilities, suppliers and universities;
— Implement contracting strategies consistent with developing human resources;
— Develop requirements for operator licensing and training and develop implementation plan;
— Establish technical training programmes that will provide training support for skilled workers, technicians and operators;
— Continue recruitment of long term workforce.

Long term (2017–ongoing)

The main objective of the long term human resources plan is the achievement of world class operating performance, underpinned by:

— Maintaining a fully staffed NPP of world class operation with significant UAE staffing resources;
— Maintaining direct involvement in the human resources pipeline;
— Monitoring the progress of students and technicians;
— Monitoring the programmes of the Nuclear Training Institute;
— Developing continuing education programmes for engineering professionals in the UAE’s civil nuclear power programme.

VIII.3. IMPLEMENTING THE EDUCATION PLAN

ENEC estimated an initial need of approximately 1300 staff to run its early plants, of which it estimates 60% will be UAE nationals. It also recognizes the need for both graduate professionals and qualified technicians. ENEC developed detailed staffing models that provided a breakdown of the anticipated operating organization by function, training, experience and educational requirements. This was accomplished initially by linking the detailed staffing model to the training and experience matrix provided in the present publication. The detailed staffing forecasts allowed the local educational institutions to take informed early action and initiate the processes, programmes and scholarships to implement the education plan based on the anticipated need.

ENEC allied itself with both local and international academic institutions and is coordinating closely with FANR (the Federal Authority for Nuclear Regulation — the UAE’s regulatory body) and Khalifa University in Abu Dhabi to allow the UAE nuclear industry to develop resources to supply the broad spectrum of needs for a new nuclear programme — operational, regulatory and educational. For the short term, selected overseas nuclear engineering BSc and MSc programmes (USA, UK, France) have been identified and 40 students have already been enrolled in these programmes through the UAE Nuclear Scholarship programme. In parallel, Khalifa University is identifying partners for its own MSc programme in nuclear engineering. The UAE’s Institute of Applied Technology (IAT), which provides secondary and post-secondary technical education programmes, is developing specific programmes to support the training of technicians for the plants.

As part of the contract with the KEPCO consortium, a multilateral agreement on education and human resources development was concluded between Khalifa University, the IAT and the Korea Advanced Institute of Science and Technology (KAIST), Korea Electric Power Corporation, Human Resources Development Service of Korea (HRD) and the Korea Development Institute. Under the agreement, the UAE envisages the creation of new departments; exchange of university professors, researchers and students; development of academic programmes; joint cooperation in recruitment of experts and professionals; establishment of laboratories; on the job training for students in diverse areas such as electrical, mechanical and electronic engineering, nanotechnology, biological sciences; and exchange of expertise on nuclear power safety with the Korean Institute for Nuclear Safety (KINS). Under the agreement, KAIST will receive 300 students per year.

Appendix IX

FEASIBILITY STUDY OF NUCLEAR ENERGY DEVELOPMENT IN ARMENIA: EVALUATION OF HUMAN RESOURCES NEEDS IN CONJUNCTION WITH NEW BUILD

IX.1. INTRODUCTION

This case study provides a brief summary of the IAEA technical cooperation project report ARM 005 Feasibility Study of Nuclear Energy Development in Armenia: Evaluation of Human Resource Needs in Conjunction with a New NPP Build. The ARM 005 report represents one of the chapters of the feasibility study, addressing human resources management issues. The project also evaluated activities associated with developing the human resources capabilities that would be required by any country planning to build a new nuclear power unit.

IX.2. BACKGROUND OF NUCLEAR POWER IN ARMENIA

Currently, Armenia relies on nuclear power for 40–45% of its baseload electricity. In an effort to meet increasing demands for power and to enhance its energy independence, it has taken steps to build a new nuclear power plant (NPP) by the end of 2016. This effort is part of a broad energy strategy which focuses on developing a diverse mix of power generation, with nuclear power serving as the major source of baseline generation.

Armenia's existing nuclear power station is located at Metsamor, about 40 km from the capital Yerevan. The site originally operated two WWER-440 MW reactors that were designed, constructed and commissioned during the era of the former Soviet Union. Both units were shut down in 1988 after a severe earthquake raised concerns about their seismic vulnerability. While Unit 1 remains shut down, Unit 2 was restarted in 1995 to meet critical power needs. The unit is scheduled for shutdown at the end of its operational life in 2016.

To compensate for the loss of power when Unit 2 is shut down, Armenia has initiated efforts to build a new nuclear unit at the existing Metsamor site. This decision was supported by an Energy and Nuclear Power Planning (ENPP) study for Armenia conducted through the technical cooperation programme of the IAEA. The outcome of the study (IAEA-TECDOC-1404, published in 2004) was supportive of the option to construct a new nuclear unit. This option was recognized as preferable by Armenia. In 2006, the Ministry of Energy and Natural Resources (MoENR) used this study as a basis for the drafting of the following documents:

— Plan for Least-Cost Energy Generation;
— Overall Strategy for the Country's Power Generation;
— Action Plan for Upgrading of the Energy Sector.

Currently, Armenia is moving forward with plans to construct and commission a new unit by the end of 2016. This effort is supported by the IAEA, the USA, and the Russian Federation.

IX.3. OBJECTIVE

The objective of the IAEA ARM 005 project was to provide an evaluation of the human resources needed to support the construction and operation of a new NPP. The report addresses the area of human resources management, developing proposals based on a strategic and integrated approach to ensure that qualified staff are available when needed to carry out work at all stages of the life cycle of the new NPP. To accomplish this objective, staffing demands and actions required to meet the demands were considered at all stages — pre-preparation through commissioning of the new NPP.

As noted above, the two existing units were built during the era of the former Soviet Union. Therefore, while nuclear power generation is not new to Armenia, the construction and commissioning of a new NPP will be a first for this country. Since this is a new experience, other countries considering nuclear power for the first time can gain valuable insights.

IX.4. OPTIONS FOR CONSTRUCTION OF A NEW NPP

Several nuclear power unit designs are available for construction. The following options for the construction of a new NPP were discussed with MoENR and other involved organizations:

— Power unit construction using Armenian resources;
— Power unit construction on a turnkey basis.

Based on the analysis of the human resources requirements conducted as a part of this study, the best option appears to be to build the new power unit on a turnkey basis. This view is based on the existing levels of technical expertise available in construction, engineering, installation and research organizations. In addition, the short time frame planned to bring the unit on-line (end of 2016) was considered. In any event, it is anticipated that active efforts will be made to involve, to the extent practical, human resources from within Armenia.

IX.5. DESCRIPTION OF STANDARD PROCESSES ASSOCIATED WITH CONSTRUCTION WORK ON NEW-BUILD NPPs

On the basis of experience with similar projects carried out in IAEA Member States, as well as the current situation in Armenia, the following main stages (processes) involved in the building of a new NPP were identified:

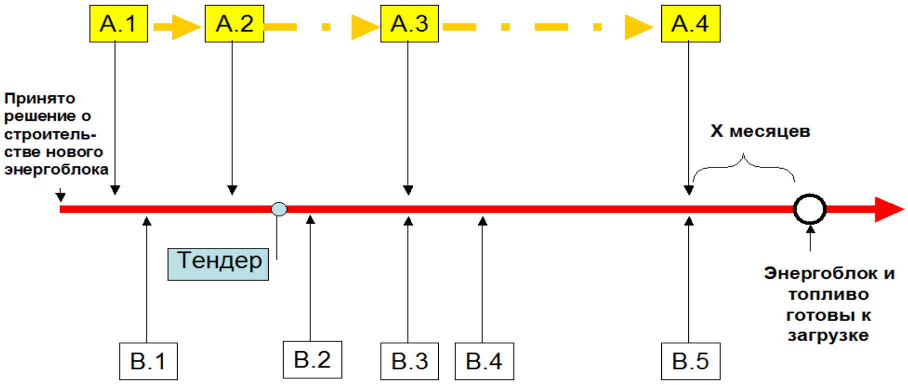
For the customer

- A.1: Pre-preparation;
- A.2: Preparation;
- A.3: Human resources mobilization;
- A.4: Readiness to adopt responsibility for staged introduction of equipment, buildings and facilities.

For the general contractor

- B.1: Preparation for tender process announced by the customer;
- B.2: Work under contract for turnkey construction;
- B.3: Human resource mobilization;
- B.4: Full scale work on-site;
- B.5: Preparation for placing the site under the responsibility of the customer, and handover of responsibility to the customer.

The analysis covers all stages of construction of the new nuclear power unit and relates to both the customer (stages A.1–A.4) and the general contractor (stages B.1–B.5). In addition, the report considered activities required by the Armenian Nuclear Regulatory Authority (ANRA). The duration of each stage is also addressed. Links between the customer and general contractor processes are illustrated in Fig. IX.1.



[at left, below A.1:]	Decision taken to build new power unit
[below A.2:]	Tender
[to right of A.4, above red line:]	X months
[to right of A.4, below red line:]	Power unit and fuel ready for loading

FIG. IX.1. Links between processes for customer and general contractor.

IX.6. CUSTOMER ACTIONS AT VARIOUS STAGES LEADING UP TO COMMISSIONING

Sections of the report provide a sequential description of the processes and actions needed to support human resources development for the commencement and subsequent implementation of work to fit out (complete) the power unit. The full report provides a sufficient level of detailed information to make it possible for Armenia to evaluate the levels of work required and to prepare and subsequently deploy adequate levels of qualified staff. Consideration was given to the links between processes to be carried out during the different stages of construction. The responsibilities and actions for the four customer stages are also elaborated in detail. For stages A.1 and A.2, most actions will be carried out by MoENR and ANRA. For stages A.3 and A.4, actions are expected to be carried out largely by MoENR, ANRA and the on-site customer representative. An example of subprocesses for stage A.1 (Pre-preparation work) is shown below.

A.1 Pre-preparation work subprocesses:

- A.1.1: Establishment of a strategic plan for human resources development in Armenia;
- A.1.2: Planning the necessary human resources and establishing the necessary structures to carry out pre-preparation work;
- A.1.3: Gathering, analysing, reviewing and developing new requirements for all supervisory agencies to take account of the demands of the new construction work;
- A.1.4: Performance of the necessary organizational work to establish the infrastructure for subsequent preparation to tender, including development of the tender procedures;
- A.1.5: Regular evaluation, checking and upgrading of efforts invested at the national level to achieve the objectives of human resources development;
- A.1.6: Establishment of infrastructure to support the introduction of an integrated knowledge management system.

The full report contains details of actions at each customer stage (A.1 through A.4), listing all subprocesses associated with individual stages. Descriptions of the work, actions required, indicators of success and recommended staffing levels are provided for each subprocess. The customer's most important task, in all stages of the project, is to ensure effective coordination of work with that of the general contractor.

IX.7. ASSESSMENT OF HUMAN RESOURCES NEEDS FOR TWO OPTIONS

Two options were selected for evaluation of human resources needs during all stages of the new build project; the Russian Federation WWER-1000 and the Westinghouse AP-1000. This approach provided realistic examples to Armenia of human resources requirements for these options.

IX.7.1. Option to construct a WWER-1000

The WWER-1000 option considers the requirements of Russian normative documents for a standard two unit NPP project with WWER-1000 reactors. The following general approach is provided:

- Staff must be recruited and trained in advance of the established commissioning date.
- Staffing levels are based on norms established in the enhanced standards for baseline staff numbers (industrial and operations staff) at NPPs with WWER type reactors.
- Calculation of the total number of employees at a new build NPP facility (power unit) is done by the customer or customer representative when drawing up the feasibility study, or making technical/economic calculations, and is revised in the design documentation.
- The demand for employees, broken down by post and occupation, for a new build NPP facility should be established on the basis of the overall projected employee numbers and requirements for production and work management.
- A list of posts and occupations for employees of a new build NPP facility and their skill requirements should be drawn up in line with the requirements shown in skills reference sources.
- Calculation of staff numbers by year to complete construction, installation and fine-tuning work should be made by the general contractor on the basis of design data and the features of the particular site, taking into account the proposed construction methods.

At the stage of fitting out the new NPP, the establishment of a New Power Unit Construction Directorate using the following standard pattern is envisaged (see Fig. IX.2). The customer for the State is OAO Kontsern EnerRoAtom. The design organization serves as the general supplier. A customer representative is selected (customer–builder) from the Central Capital Construction Administration (CCCA), which is responsible for the recruitment and training of customers brought in to perform construction and assembly work on-site. It plays a coordinating role among those involved in the construction work. Within the Capital Construction Administration (CCA), a capital construction section, a staffing section and an intake control group should be set up. The post of Deputy Director for Capital Construction may be introduced for the construction period.

The data shown in Table IX.1 provide staff mobilization requirements by year of construction leading up to commissioning of the WWER-1000.

IX.7.2. Option to construct an AP-1000

The Westinghouse AP-1000 is a two loop, four RCP unit with a power rating of 1154 MW. Because the AP-1000 is a new advanced design reactor that currently is not operational and is only in the early stages of construction (e.g. the Sanmen site in China), staffing data are limited to projections based on the reactor design, improved construction technologies and past experience with existing NPPs.

Westinghouse provided the following construction schedule for a 2004 US Department of Energy (DOE) study:

- 69 months: Contract effective date to commercial operations;
- 36 months: First concrete to fuel load;
- 6 months: Fuel load to commercial operations.

In discussions with the MoENR, Westinghouse provided estimates of the peak construction workforce at 1500–2000 for one unit. US utility representatives indicated that they estimated peak construction employment at 2600 for two units. While some labour efficiency in two unit construction is expected, the higher Westinghouse estimate of 2000 at peak appears to be reasonable for one unit construction.

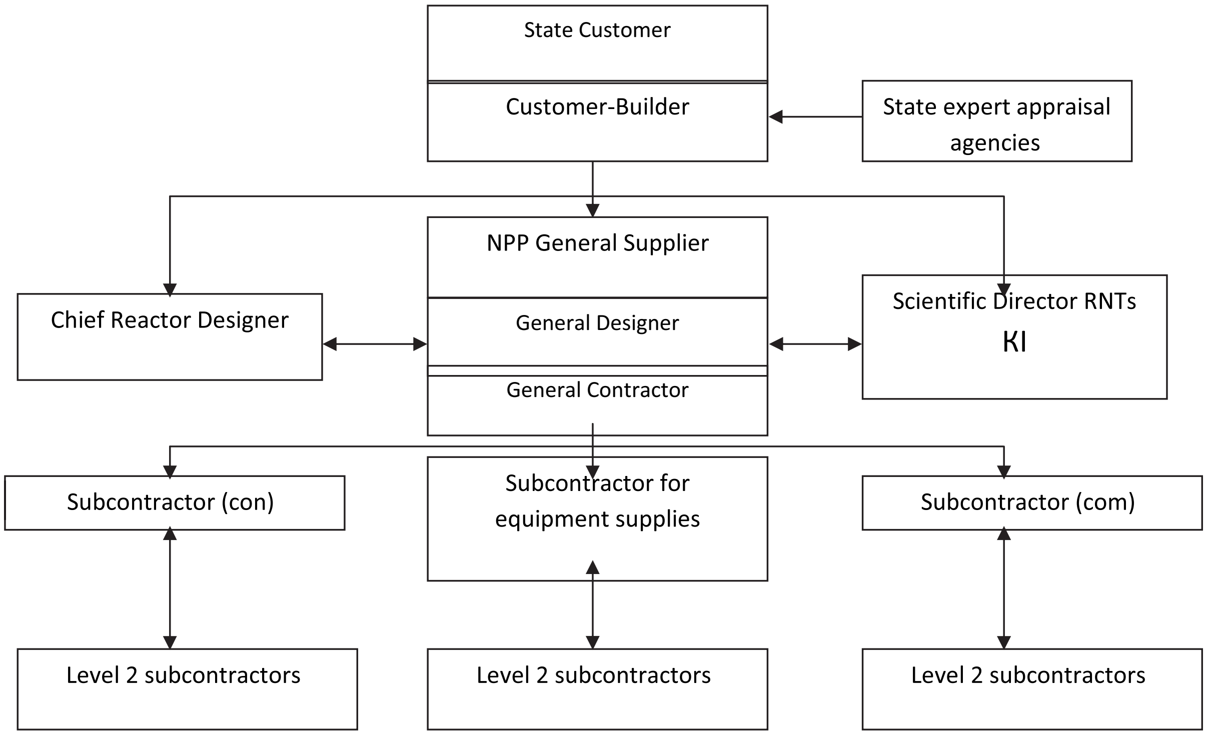


FIG. IX.2. Standard chart for the Construction Directorate for NPPs with WWER reactors (con: construction and installation work; com: commissioning work).

The Westinghouse construction schedule considers parallel construction through modularization and open top (open roof) construction to achieve the overall schedule. The extent of modularization possible for this project is not clear but the potential benefits of fewer on-site work activities are evident. The general contractor and/or architect and engineering firm selected will need to explore the feasibility of off-site construction/assembly and the location and availability of qualified facilities.

A typical schedule for US utilities (two unit construction) is shown in Fig. IX.3.

With a planned date of 2016 for startup of the new NPP and shutdown of the existing unit, Armenia should begin efforts as soon as possible to develop a strategic national approach to human resources development to support the construction of the new unit. While it is understood that the construction of the new NPP will be a turnkey contract, several factors should be considered:

- Status of the current workforce in Armenia;
- Training needs for existing organizations (e.g. ARMATOM, ATOM, etc.);
- Attracting qualified workers who have emigrated to other countries;
- Improvements in construction technology;
- Early training for future operations and maintenance staff to prepare for commissioning;
- Human resources that may be available from the existing ANPP.

A significant amount of operation and maintenance (O&M) staffing data are available for existing US NPPs. In addition, staffing projections for advanced design reactors, including the AP-1000, were obtained from the 2004 DOE report and from utilities pursuing construction of the AP-1000. Staffing comparisons for existing operational NPPs and estimates for the AP-1000 are shown in Table IX.2.

The projections from the DOE study appear to be consistent with expected staffing levels based on the advanced, simplified design (fewer pumps, valves, piping, electrical cable, etc.) of the AP-1000. However, when developing staffing plans for a new NPP, care should be taken to account for specific site physical characteristics, regulatory requirements, industrial capacity, supply chain efficiency, etc. For example, security staffing for a single

TABLE IX.1. PERSONNEL MOBILIZATION FOR YEARS OF NPP CONSTRUCTION

Годы строительства								
Виды работ	Подготовительный период, чел		Основной период чел.			Монтаж реакторной установки		
	1	2	3	4	5	6	7	
Строительные работы	1430	2150	2650	2900	3900	3700	1500	
Электромонтажные работы	15	15	30	40	80	1200	700	
Тепломонтажные работы		20	20	50	800	2200	1100	
Химзащита и изоляция		10	30	90	250	320	200	
Вентиляция		10	20	70	150	250	180	
ПНР					120	370	260	
Всего:	1445	2205	2750	3150	5300	7720	3940	

Key to table: All columns – Years of construction; Years 1–2 – Preparation period, individuals; Years 3–7 – Main period, individuals; Year 6 – Reactor unit installation. Column 1 – Types of work: Construction; Electrical; Heat; Chem. protection and insulation; Ventilation; Total

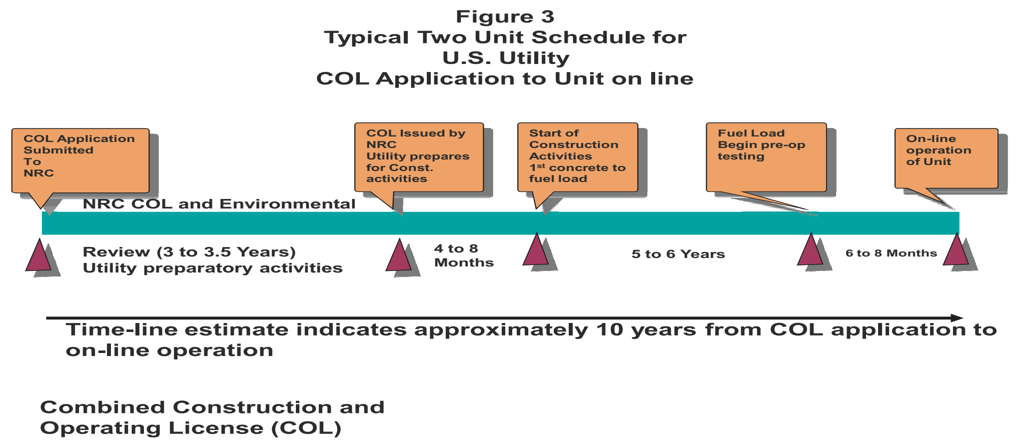


FIG. IX.3. Typical two unit schedule for a US utility from submission of application for combined construction and operating licence to unit on-line.

TABLE IX.2. O&M STAFFING LEVELS (PWR UNITS)

	On-site	Off-site	Total
Existing US 2 Unit	759	188	947
Existing US 1 Unit	607	202	809
DOE Report 1 Unit	647	51	698

unit plant may be as high as for a multiple unit site depending on the size and layout of the protected boundary. Also, if the supply chain and industrial base is not capable of supporting non-core work activities, additional staffing may be required.

IX.8. CONCLUSIONS

IX.8.1. Comparison of design options

Having considered the information and data from available sources (the Internet, printed publications, utility experience, etc.) concerning the construction of power units with WWER-1000 and AP-1000 reactors, the following conclusions are offered:

— In the event that the AP-1000 installation is selected, staff mobilization at the site during construction stages may be significantly reduced, since the plan is to use pre-assembled modular components and advanced construction technology. However, the question of the integral costs linked to the involvement of assembly workers (number, housing on-site, training in special NPP construction processes, delivery of special installation equipment and other issues) remains open. There is currently inadequate data for the situation to be resolved.

— Further attention is needed on the question of whether it is possible to deliver pre-assembled modules to the power unit construction site using available means of transport. An assessment of the capital investment in the transportation infrastructure required to achieve such delivery is needed.

— Available information on the AP-1000 is limited because NPPs with this type of reactor are not yet in the operation stage and are only under construction. Consequently, projections have been used, taken primarily from the US industry, including the duration of construction work and the required human resources. Nevertheless, it can be said that the estimated construction period for an AP-1000 unit is less than the equivalent period for a WWER-1000. However, the time needed to create the infrastructure for such modular construction must be considered. This makes it difficult to draw a comparison between equivalent time and cost characteristics for the AP-1000 and WWER-1000.

— Both approaches are based on the assumption that staff already available at the ANPP site could be utilized on a permanent and temporary basis during the construction period. For either choice, language issues should be taken into account. If an AP-1000 is built, local skilled workers will need to be taught English, or a fair quantity of working documentation will need to be translated into Armenian. As an alternative to this, it would be necessary to keep local staff involvement to a minimum, which would in turn lead to an increase in the overall cost of construction. If a WWER-1000 design is chosen, potential language problems would also need to be kept in mind. While Russian is the language used in operations at the existing NPP[14], new workers may not be fluent in the language. It is not entirely clear at present what type of language problems should be considered in the event that the WWER-1000 design is chosen.

— For a WWER-1000 installation, the entire range of ancillary production processes is located on-site and forms part of the cost of the turnkey project. A list of ancillary production processes is given in

[14] Experience in IAEA Member States shows the language of operation is also important; as a rule the language of operation is largely chosen on the basis of design data; in the event of an AP-1000, clearly this should be English. For the Tianwan NPP, for example, the language of operation is English (the same as the language of the contract); documentation is drawn up in English and Russian, and in the event of any discrepancy, the English version takes precedence.

document OTP-86 (RF), which the Armenian side has. In addition, ANPP staff has the relevant competence in working with WWER technologies. Because of this, extra study of the capital component will be needed (in view of the return-on-investment requirements) with the selection of any project.
- Staff training will have its specific features, such as the measurement system (US versus SI system), operator computer control systems and human–machine interface solutions.

IX.8.2. Differences in proposed technologies

WWER technology is familiar to ANPP staff (the existing power unit is a WWER-440). Experience in the retraining of staff has shown that little extra work is required to draw up and introduce training programmes and training hardware that take into account the specifics of the system and the equipment of a new power unit with WWER-1000s. Such efforts should be comprehensive in nature and should be applied primarily with a view to matters relating to the unit's computer control system and the power system.

The AP-1000 technology is new and generally less known. This will give rise to extra demands in the drawing up and delivery of training programmes, including a large amount of training of the customer's staff by the general contractor and equipment suppliers. Corresponding efforts will also have to be made at the higher education level, to ensure that the relevant information is reflected in study plans and curricula at Armenian higher education institutions (currently all training in the nuclear sphere at higher education institutions is oriented towards WWER technology).

Comparison of staff numbers for operation, technical servicing and maintenance is difficult, as staffing projections for the AP-1000 are based on expected improvements in construction technology and advanced design features. For a WWER-1000, the average numbers are known.

IX.8.3. Main conclusions

Based on the analysis carried out during this project, the main conclusions are as follows:

- Developing a skilled workforce (engineers, skilled trades, project managers, etc.) to support construction and operations of a new NPP requires many years. Strategic planning and initial actions to develop these human resources capabilities should be initiated as early as possible in the project (pre-preparation and preparation stages). Key stakeholders (universities, technical organizations, trade unions, Ministry of Education, etc.) should be involved in these initiatives. Such efforts are not dependent on the selection of a specific design.
- To ensure that construction work is conducted in an efficient and cost effective manner, recommendations are provided in the full report (appendix 1, with diagram in appendix 2) that should be considered during key construction activities. This approach is not dependent on the selected design technology.
- The assessments of labour outlay (cost and staffing numbers) should be carried out in a comprehensive way, taking into account matters relating to the development of infrastructure for the new construction work. Developments in the proposed technologies should be used in assessing the required labour cost and staff needs for each stage of NPP construction.
- On the basis of the data presented during the study, the overall assessment is that labour outlays to construct a new NPP using WWER-1000 technology may be smaller than equivalent figures for the AP-1000 design. A final assessment will only be possible, however, when more information is available regarding the AP-1000 design.

Appendix X

MODELLING WORKFORCE DEVELOPMENT FOR NEW NUCLEAR POWER PROGRAMMES[15]

Models can be useful tools to understand systems with large uncertainty or complex relationships. A model allows investigation of the influences of different aspects of the system by allowing the user to adjust parameters and evaluate how the system operates under different conditions and assumptions. This can increase understanding and inform decisions on issues related to implementing a new programme or setting the course for an existing programme.

A model of a national nuclear power programme has been used to examine the workforce requirements for a new nuclear power programme. The model is useful in allowing the adjustment of several key parameters to examine the sensitivity of the workforce to uncertainty in the programme and to potential decisions that may be made as the programme progresses, such as the rate of nuclear power expansion and the timeline for building a new plant.

The nuclear power programme model discussed below is constructed in the 'iThink' systems dynamics software by 'isee' systems.[16] The model includes workforce, infrastructure and fuel cycles, all of which are linked to form a logically consistent structure. The model is adjusted to reflect a particular country by adjusting parameters in a spreadsheet input file, which outline the initial conditions and baseline plan for nuclear power in that country. While running the model, variations in the demand for power, the rate of nuclear power growth and some workforce assumptions can be made.

X.1. A MODEL OF A NUCLEAR POWER PROGRAMME

A viable plan for nuclear power requires power plants, workforce and fuel services to be developed in a coordinated fashion, or the programme runs the risk of failure to produce power as scheduled or costly actions to mitigate mismatches. The nuclear power programme model discussed here consists of linked submodels of workforce, infrastructure and fuel cycle. These submodels are linked to ensure logical consistency of decisions; infrastructure drives workforce requirements and relies on workforce and fuel services for operation. The advantage of using such a model is that explicitly including these dependencies ensures that the analysis does not optimize one facet of the programme without ensuring consistency with other areas. In the model, nuclear power demand is driven by the country's demand for electricity with a target fraction to be provided from nuclear power, reflecting national objectives.

The infrastructure model is structured around the life cycle of nuclear power plants, namely design, licensing, construction, operation, life extensions and decommissioning. Increasing generating capacity is constrained by industrial capacity, licensing timelines, and availability of design services, which is workforce limited. Operation of plants requires operating staff and fuel. The model is configured to allow multiple kinds of plants (BWR, PWR, etc.) and for differences in generating capacity.

The fuel services model includes mining, enrichment, irradiation and waste storage/disposal. This model is also capacity limited and can reflect indigenous fuel capacity or foreign fuel agreements. The fuel model is configured to allow multiple fuel types (LEU, MOX, etc.).

The workforce model includes craft labour and skilled labour. Craft labour categories included in the model are shown in Table X.1 with the peak staffing required for a 1000 MW(e) power plant. Craft labour is mostly used during the construction phase, and the total working on nuclear plants at any time should not be a large fraction of a national total. Thus, craft labour is modelled as being drawn from a national pool for the plant construction period. The pool is continuously replenished by newly trained workers from craft schools and depleted by retirements. Some craft labour workers are retained for the operation of the plant. Engineers and skilled workers differ, as they represent a limited workforce and require extensive, specialized training, compounded by the current ageing demographics of the experienced workforce. The engineering workforce is thus modelled in greater detail, with educational pipelines, career paths and retirement represented. The skilled labour workforce is limited by the

[15] Based on a paper by C. Dale, K. Kern, and S. Scott, Los Alamos National Laboratory, USA.

[16] See www.iseesystems.com

educational capacity and retirement rates. The model has the ability to examine alternative approaches to workforce training, outsourcing and sensitivity to retirement policy.

X.2. INPUTS TO THE MODEL REPRESENT SPECIFIC COUNTRY CASES

The model represents a generic nuclear power programme. To model the nuclear power programme of a given country requires a data set that contains the specific parameters for that country. This is imported into the model from a spreadsheet. Data required include initial conditions for the overall electricity consumption and growth rate, the nuclear power generating capacity and plans for expansion (including plant ages), and the workforce numbers and age demographics. Data requirements are shown in Table X.2.

TABLE X.1. PEAK CONSTRUCTION CRAFT LABOUR REQUIREMENTS[a]

Craft description	Craft per cent	Peak personnel average single unit
Boilermakers	4	60
Carpenters	10	160
Electricians/Instrument fitters	18	290
Iron workers	18	290
Insulators	2	30
Labourers	10	160
Masons	2	30
Millwrights	3	50
Operating engineers	8	130
Painters	2	30
Pipefitters	17	270
Sheetmetal workers	3	50
Teamsters	3	50
Total construction labor	100	1600

[a] MPR, “DOE NP2010 Nuclear Power Plant Construction Infrastructure Assessment”, MPR-2776 (2005).

TABLE X.2. DATA INPUTS TO THE MODEL

Data	Description
Reactors	Current plants in an array by age, including those with life extensions, the number of plants under construction, the number of applications in process and the initial number of anticipated applications
Generating capacity	Capacity of current plants, capacity factor and power for future plants
Timelines	Expected design life of reactors and anticipated duration of life extensions, licence application time and construction time
Electrical demand	Initial total country demand for electricity with expected growth rate and fraction initially generated from nuclear
Workforce requirements	Number of each type of craft labour for construction, number of operations staff, etc., on a per plant basis
Workforce availability	National pool of workers of each type, age demographics for skilled workforce, retirement rates, educational system capacity

X.3. RUNNING THE MODEL — UNCERTAINTIES AND DECISIONS IN THE NUCLEAR PROGRAMME

With a loaded data set that represents a particular country case, the model is configured to evaluate variations in a set of choices on the nuclear power programme. These controls were designed based on uncertainties that warrant evaluation, several key decisions in the US power programme and key decisions for a new programme.

Uncertainties that can be evaluated in the current model are:

- Growth rate for electrical demand: The data include an assumed baseline growth rate from public sources. The model allows variation of the growth rate over a range smaller and greater than the baseline rate, which can be used to reflect different assumptions on population growth, energy efficiency initiatives, growth of heavy industry, and more.
- Operational workforce size: The baseline data include estimates of staff required for operating a plant. Actual experience as documented in open literature shows that staffing size varies substantially. The model is configured to allow variation in plant staffing from 80% to 120% of the baseline size.
- Construction workforce: Construction workforce can vary based on the design of the plant but also owing to delays due to weather and supply, or can be reduced by construction approaches such as prefabricating components. The model allows for using optimistic or pessimistic construction workforce sizes.
- Skilled workforce training: An issue impacting skilled workforce is retention during the educational and training pipeline. The model allows variation in attrition during education from 20% to 70%.

Key options facing the US nuclear programme that are modelled are granting life extensions to the current fleet of reactors, replacing the current fleet as reactors reach the end of their lives (with or without an extension), and building those plants currently in the planning and licensing phase. For existing and new programmes, the decision to expand nuclear power from the current capacity and what capacity to target in the future are also options that can be evaluated in the model.

The set of parameters and decisions that can be modelled provides a very flexible tool that can be used to examine a large range of potential programmes.

X.4. MODEL OUTPUTS — WHAT CAN WE LEARN?

In the model, new plants are built to meet the energy demand as specified in the set-up. Plants are retired as they reach end of life, and workforce is generated to meet the demand for construction and operation and to replace retiring workers. The model tracks many parameters related to the plants, generating capacity and workforce. For electricity generation, the model can show total electrical demand and the portion met by nuclear, as installed capacity or fraction of demand. The model tracks the number of plants in every phase of the life cycle: applications, construction, operation and decommissioned.

Workforce is determined in multiple categories and phases. The number of craft labour workers in the categories shown in Table X.1 working construction on nuclear power plants is shown generated by the model on a yearly basis. These can also be expressed as fractions of a national workforce. Skilled workers (nuclear, electrical, civil and mechanical engineers) that are used in operating plants are also shown as a total employed workforce. As the model tracks age demographics for these workers, it can generate the fraction of workers approaching retirement, new hires and anticipated future needs.

X.5. EXAMPLES FROM THE US CASE AND NEW PROGRAMME CASE

Some example results are shown below to illustrate the flexibility of the model and to show what types of sensitivity studies might be made using the model. The results below are for illustration only and should not be interpreted as an analysis of a specific country or the specific plan for a country.

Figures X.1 and X.2 illustrate how a combination of different factors can lead to very different answers for questions regarding overall nuclear power programme objectives. In the two figures, two cases are shown for the US power industry, with the US electrical demand shown in Fig. X.1 and the installed nuclear capacity in Fig. X.2. In the case illustrated with blue curves (marked 1), the growth rate for electrical power is the current projected rate

FIG. X.1. Electical power demand for the USA with currently projected electrical growth rate (blue curve, marked 1) and for a higher growth rate (red curve, marked 2).

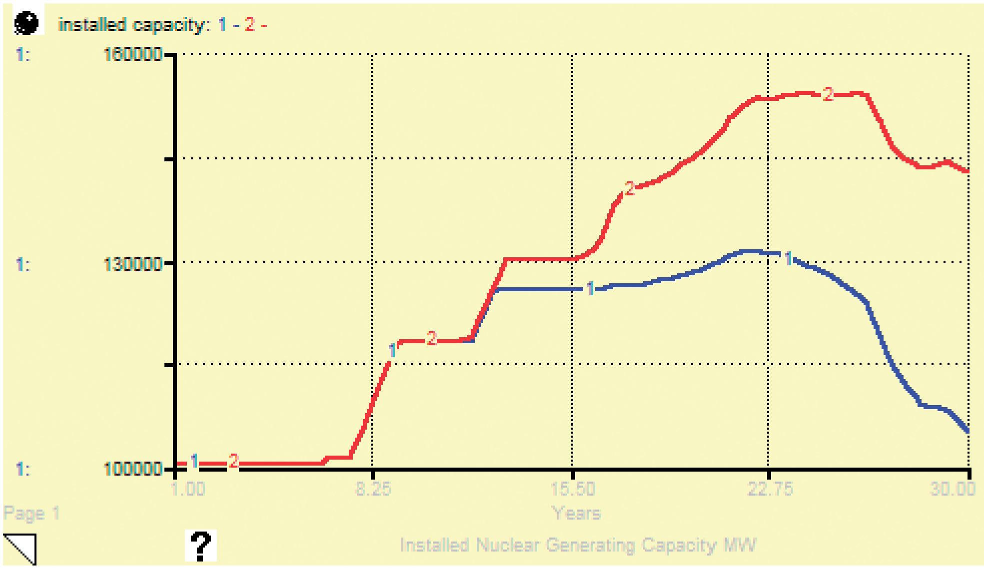


FIG. X.2. Installed nuclear power capacity for the USA with varying electrical growth rate as in Fig. X.1 and a nuclear market share of 20% (blue curve, marked 1) and with a nuclear market share of 25% by 2030 (red curve, marked 2).

of 1%[17], with the nuclear industry maintaining a roughly 20% market share. In the case illustrated with red curves (marked 2), a higher growth rate is assumed, and the nuclear industry targets a 25% market share by 2030. The combination of changing two factors in the model results in markedly different behaviour in the system starting in year 12 (year 1 being 2009). The implication of this difference is 50% more licence applications being filed annually by 2015 and 25% higher staffing for skilled operations personnel in the long term (more than 20 years from now). Similar behaviour is not seen in a representative new programme, since only a single plant is built during the timeframe of the analysis. In this case, the time phasing for building the first plant in a new programme will drive the associated workforce requirements.

Alternatively, given programme objectives, the model can be used to examine the effects of technical decisions on human resources requirements. For example, Fig. X.3 shows the skilled workforce requirements for

[17] ENERGY INFORMATION ADMINISTRATION, "Annual Energy Outlook 2008 with Projections to 2030, Electricity Demand", http://www.eia.doe.gov, 2008.

the US programme in three scenarios. In the baseline case (blue curve marked 1), nuclear power maintains a roughly 20% market share, and significant workforce growth is required in about nine years, meaning the educational pipeline would need to begin expanding soon. For a case in which the market share provided by nuclear power targets 25% by 2030 (orange curve marked 2), there is a substantially greater need for engineering staff by the late 2020s than in the baseline case. However, the third case (pink curve marked 3) assumes the same increased market share as the second case but also shows the impact on requirements if new plants could be designed with greater operational efficiency or mechanisms that increase efficiency for the overall nuclear power infrastructure (e.g. cross-training, central support) and require reduced staffing. As a result, the larger market share is achieved with the same or lower workforce demand as in the baseline case, and a lower growth rate would be required in the educational pipeline.

A related issue particular to new programmes is the coordination of establishing national capabilities with infrastructure development. The model can be used to examine the time phasing of the workforce with the life cycle of the nuclear power plant. In Figure X.4, the workforce requirements for constructing and operating a plant are shown for two cases. In the first case, the first power plant is constructed assuming a baseline schedule with optimistic workforce projections, while in the second case, a less optimistic schedule and workforce are assumed (including final operating workforce). The result is a delay in when the staffing demand for operations increases and a need for a larger construction workforce for a longer period. This illustrates a key risk in implementing a new programme; if construction delays occur, a strategy is needed to retain the skilled workforce until the plant is ready.

A wide variety of other timing and staffing issues associated with the construction workforce may be examined using this model. For a new programme, a large craft labour workforce would be required for a few years, after which the demand from the nuclear industry ceases. In addition, estimates of the number of craft workers can vary by a factor of two depending on the complexity of the plant design, experience of the construction contractor and other factors. Clearly establishing an indigenous craft workforce for the entire need may not be practical, and benefits/impacts of potential strategies for meeting all or part of this demand with imported labour might be appropriate to consider — and the impact of those decisions fed back into the model.

X.6. CONCLUSION

Models are useful tools for investigating how a system might behave under various conditions. This appendix demonstrates a model of a nuclear power programme that allows investigation of the integral influence of key factors. This model may be used to inform decisions on potential strategies for constructing nuclear plants and for understanding and managing workforce issues.

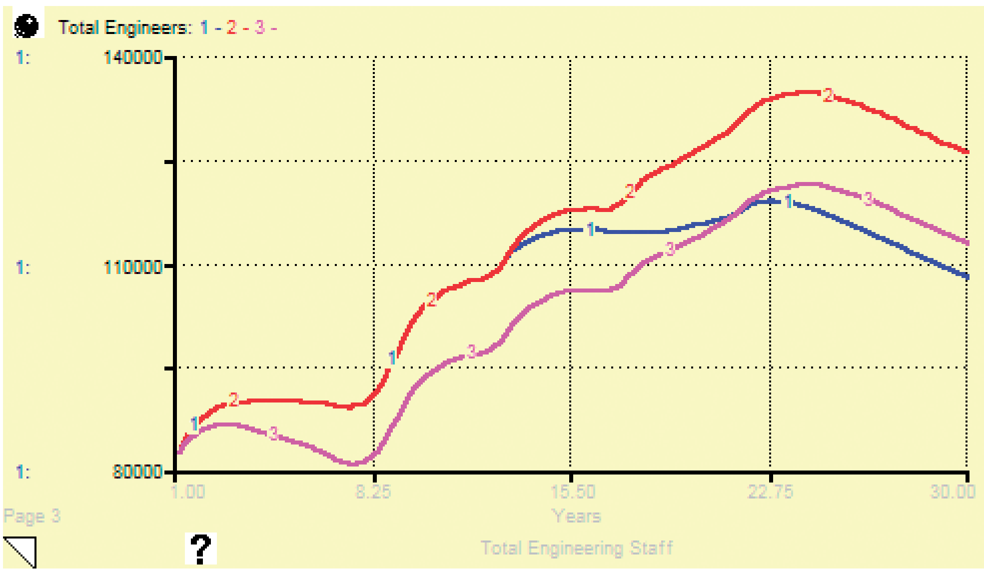


FIG. X.3. Skilled workforce requirements for the US case in three scenarios.

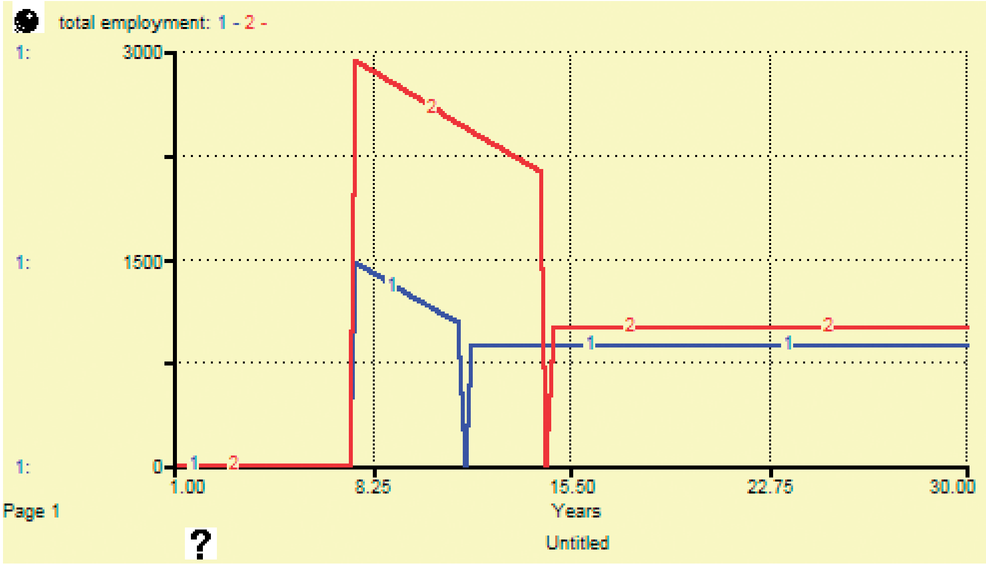


FIG. X.4. Total workforce required for a new programme with and without a construction delay.

Note: This work, and the engagement with the IAEA regarding the utility of this analysis approach and tool, was performed as a part of the Global Nuclear Energy Partnership Infrastructure Development Working Group activities.

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Regulatory control e-text book: http://www.iaea.org/ns/tutorials/regcontrol/intro/default.htm

General

INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual — Overview of the Methodology, IAEA-TECDOC-1575 Vienna (2009).

CONTRIBUTORS TO DRAFTING AND REVIEW

Alhammadi, K.	ENEC, United Arab Emirates
Al-Qaradawi, I.Y.	Qatar University, Qatar
Araj, K.J.	JAEC, Jordan
Awaise, A.S.M.	NPPA, Egypt
Balogun, G.I.	NAEC, Nigeria
Bastos, J.	International Atomic Energy Agency
Boyles, E.	HR Consultant Services, United States of America
Cherf, A.	International Atomic Energy Agency
Chongkum, S.	TINT, Thailand
Crete, J.M.A.	International Atomic Energy Agency
Dulinets, L.	Ministry of Energy, Belarus
Godard, A.	Permanent Mission of France
Goodnight, C.T.	Goodnight Consulting, United States of America
Guerrero,V.	CCHEN, Chile
Htet, A.	CNESTEN, Morocco
Infante Montt, R.P.X.J.	CNE, Chile
Jackowski, T.	Ministry of Economy, Poland
Kazennov, A.	International Atomic Energy Agency
Kern, K.	Los Alamos National Laboratory, United States of America
Kosilov, A.	International Atomic Energy Agency
Li, X.	International Atomic Energy Agency
Mazour, T.	International Atomic Energy Agency
Molloy, B.R.	Private Consultant, United Kingdom
Philippe, H.	ENEC, United Arab Emirates
Ribakovas, V.	VATESI, Lithuania
Salleh, M.A.S.	MNA, Malaysia
Sciukaite, G.	Visagino Atomine Elektrine, Lithuania

Starz, A.	International Atomic Energy Agency
Suri, A.K.	Bhabha Atomic Research Centre, India
Ume, J.	NAEC, Nigeria
Wui, S.-Do	KHNP, Republic Of Korea
Younis, A.M.	FANR, United Arab Emirates
Yuzhakov, A.Y.	VNIIAES, Russian Federation

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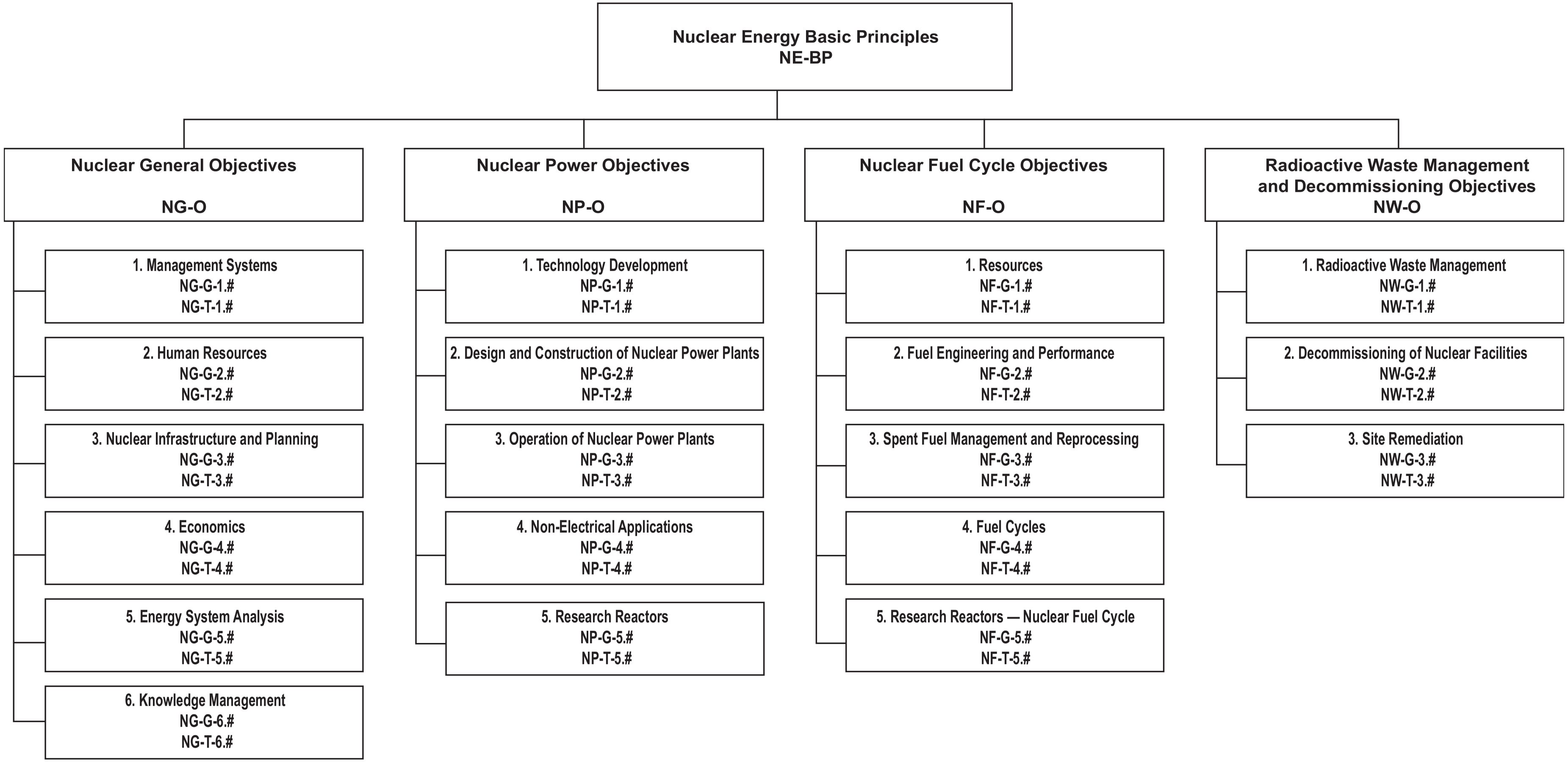

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