IAEA NUCLEAR ENERGY SERIES NO. NG-T-3.10

# WORKFORCE PLANNING FOR NEW NUCLEAR POWER PROGRAMMES

**January 2010**

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2009

## 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. The IAEA is responding to their needs through increased technical assistance, missions and workshops, and with new and updated technical 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, over 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 NPP. One of these 19 issues for which the other 18 all depend upon is suitable human resource 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 to launch a nuclear power programme. The nuclear power field, comprising industry, government authorities, regulators, R&D organizations and educational institutions, relies for its continued success on a specialized, highly trained and motivated workforce for its sustainability, 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 including; during the initial stages a nuclear energy programme implementing organization (NEPIO), as well as, if a decision is made to initiate a nuclear power programme, the future operating organization, nuclear regulatory body, government authorities, and technical support organizations.

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 continuing to ensure that organizations in the nuclear field are attractive employers compared with other related choices. 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 resource development programme at national and organizational levels.

The preparation of this report was based upon contributions from external experts. The IAEA wishes to acknowledge the assistance provided by the contributors listed at the end of the 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.

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# 1. INTRODUCTION

## 1.1. Background

With the recent upsurge in interest in, and support for, nuclear power, many Member States (MS) 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 resource development. For a country which 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 which is considering the introduction of nuclear power as part of its national energy strategy, the IAEA has produced a guidance document "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. These are:

- 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 after a policy decision has been taken;
- Phase 3: Activities to implement a first nuclear power plant.

The achievement of the infrastructure conditions for each of these phases is marked by a specific milestone at which 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 nuclear power plant;
- Milestone 3: Ready to commission and operate the first nuclear power plant.

The document goes on to detail a total of nineteen different infrastructure areas which need to be addressed for each of the three phases. These nineteen areas are identified in Table 1 below.

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 | CONDITIONS | CONDITIONS | CONDITIONS |
| Electrical grid | | | |
| 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 | | | |

When the Milestones guidance was introduced to Members States, they requested additional assistance on how to implement this guidance. In particular, Member States indicated that they need assistance on how to develop the necessary ranges of competencies needed to implement a Nuclear Power programme. This report is intended to provide that additional assistance.

A number of other documents have also been developed to assist Member States and these include:

- Responsibilities and Competencies of a Nuclear Energy Programme Implementing Organization (NEPIO) for a National Nuclear Power Programme [2]

- Initiating a Nuclear Power Programme - Responsibilities and Capabilities of the Owner/Operator [3], and

- 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 organisations is contained in the above documents and it is essential that users should be familiar with the contents of these documents as well as the “Milestones” document to ensure the appropriate application of the guidance contained in this report.

For the purposes of this document, **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*

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*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 organisation'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 Figure 1. Many of these issues are addressed in the IAEA Document on 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 Standard "The Management System for Facilities and Activities" [6].

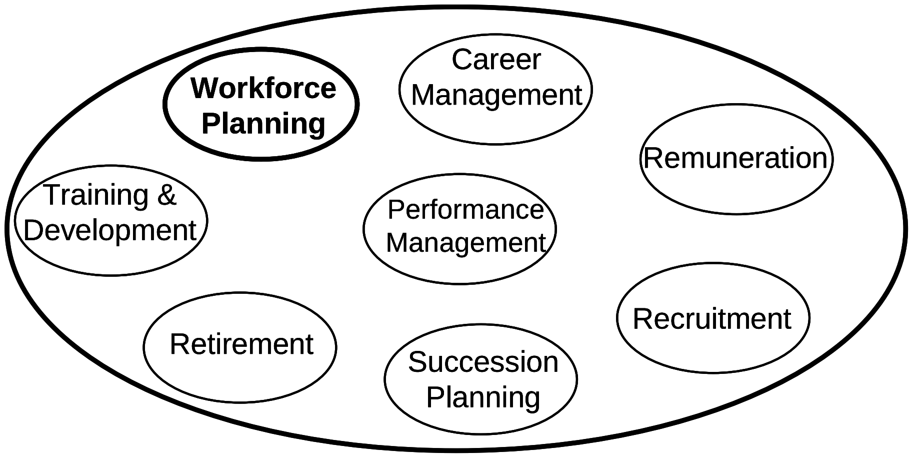


*FIG.1. Typical Elements of Human Resource Development Strategy*

It is extremely important for the reader to understand that the pre-requisites for workforce planning for a nuclear power programme are 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 and there is no framework/basis for workforce planning. The NEPIO, as described in [2] 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.

## 1.2. Objective

The objective of this document is to assist Member States in developing an effective Workforce Plan, both at organisational and national levels, by providing a structured approach to enable them to estimate the human resource 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 Figure 2).

An important element of effective human resource 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 the document also includes details about the need for, and benefits of, establishing an appropriate Knowledge Management system within the Nuclear Energy Programme to help to ensure the sustainability of the programme in the long term.

An 'organisational' approach is proposed where the needs of the three main organisations identified in the Milestones document;

- the "Nuclear Energy Programme Implementing Organisation" (NEPIO)
- the regulatory body (RB), and
- the nuclear power plant oprtating organisation (OO)

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 included to illustrate how these concepts were/are being achieved in reality for recently developed Nuclear Energy programmes

### 1.3. Scope

This document has been prepared as guidance for the Workforce Planning aspects of the development of a national infrastructure for nuclear power and, although it has been written as a standalone document, users should be familiar with, and have access to, the "Milestones" document, which provides guidance on options for the organisation and allocation of responsibilities for implementation, as well as documents [2] and [3] dealing with the NEPIO and Operating Organisations 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 documents applicable to these fields are included in the Bibliography.

The first step recommended in the "Milestones" document in 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 "Nuclear Energy Programme Implementing Organisation" (NEPIO). The higher level responsibilities and capabilities of the NEPIO itself are already addressed in the IAEA document "Responsibilities and Competencies of the Nuclear Energy Programme Implementing Organization (NEPIO)" [2]. In this document 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.

This document is divided into several sections. Section 2 considers the Member State's nuclear energy goals, objective and strategy, and how this may impact the resources needed. Sections 3 and 4 focus on the competencies and human resource needs of the various responsible organisations 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 organisations. Guidance regarding operation, maintenance and eventual decommissioning of nuclear



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power plants (NPPs) are the subject of many other IAEA guidance documents and these issues will only be addressed in this document 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 NPP). Section 6 then considers the role of other organisations, 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 document 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 document, intended to present the real, and varied, experience of Member States which have experience in implementing a national infrastructure for nuclear energy.

In [1] it is assumed that a Member State considering the option of nuclear power would already have in place 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. This same assumption applies in this document and so the resource requirements considered in this are only those **specific** requirements for the nuclear power programme, beyond those needed for other, less demanding nuclear applications.

An important consideration with respect to safety and regulation is the decision whether to ‘strengthen’ any existing regulatory body (RB), created to ensure the safety of industrially/medically utilised radio-nuclides, or to create a new RB to oversee the implementation of a Nuclear Energy programme. There are benefits and risks associated with either approach and, if a new RB 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 RB staff for a nuclear energy programme. The most relevant documents on on-line materials are referenced in the Bibliography.

Note: The IAEA also has a substantial body of documentation and guidance to support the operation and improvement of existing Nuclear Power programmes; this document, like the “Milestones” document [1], is specifically aimed at the development of new Nuclear Power programmes. Again, the most relevant of these documents are included in the Bibliography.

### 1.4. 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 resource 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 document 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 to an existing nuclear power programme, especially if significant time has lapsed 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 organisations, which may be called upon to assist in developing the national infrastructure.

### 1.5. Using the document

An overview of the process of Workforce Planning for achievement of the milestones is presented in the flowchart in Figure 2 below. This flowchart shows how the information contained within the document relates to the difference steps in the workforce planning process. Again, the reader is reminded that a pre-requisite 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.

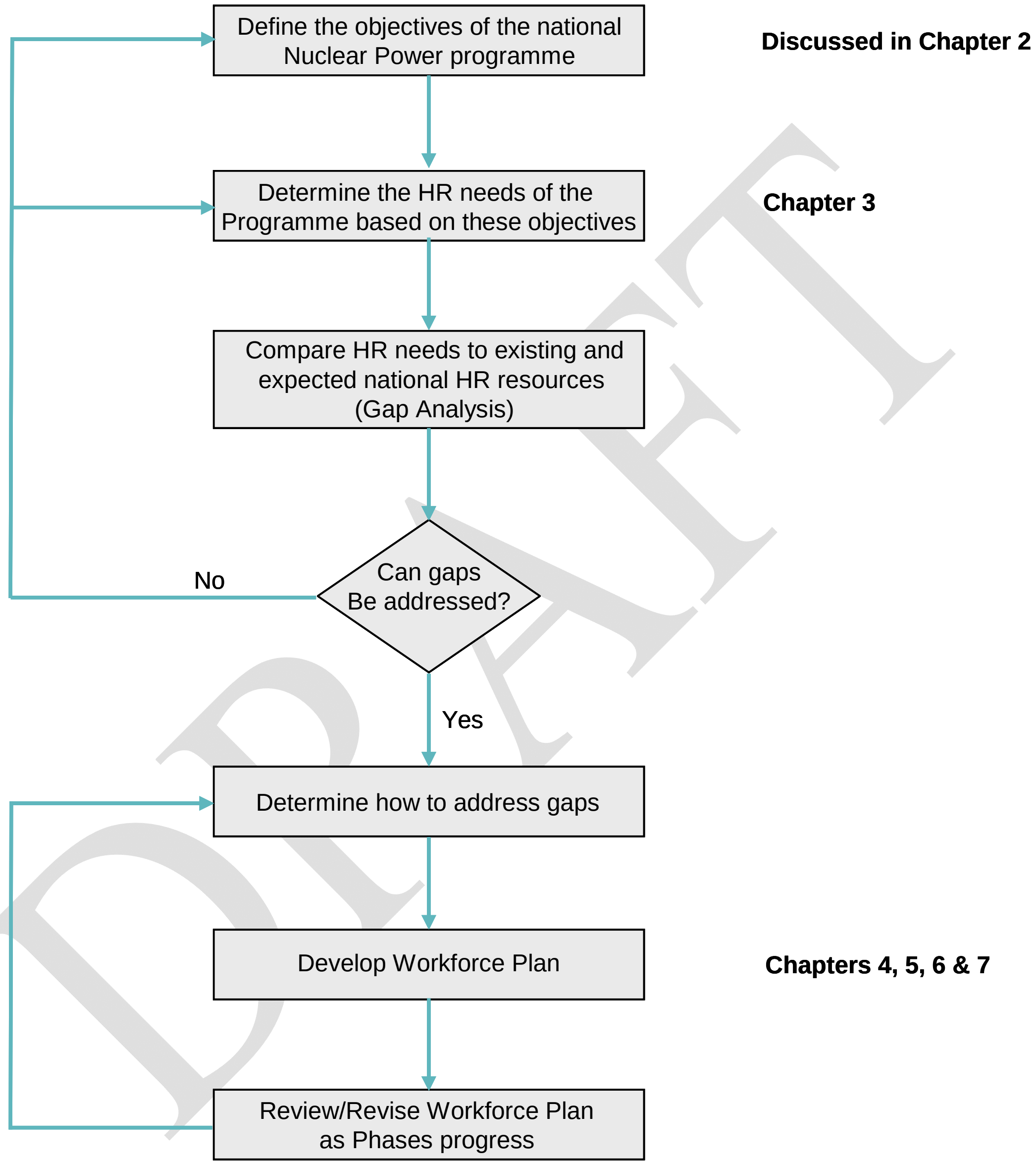


*FIG.2. Simplified Flowchart for Workforce Planning Process*

## 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 the 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 those which may be provided by external suppliers.

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

## 2.2. Approach to Human Resource 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 2.3) of a nuclear energy programme, the human resource requirements will span several generations of the workforce, so Workforce Planning will be an ongoing process, for all organisations 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 document, 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 MS must develop the competence to fulfil the role of 'Intelligent Customer'[1], that is, the MS must be able to assess its requirements, prepare an appropriate bid invitation specification [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 MS must still be an Intelligent Customer for the contract and there may well still be a variety of local infrastructure activities for which the MS will retain responsibility (see Section 2.5).

At the other extreme, if a Member State plans to implement a significant programme of NPP construction 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 nineteen infrastructure areas, assuming the education and training capability exists/can be developed to support these competencies. This will need

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[1] For the purposes of this document an **Intelligent Customer** is defined as: *An organisation (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.*

to be determined in advance of preparation of 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 into particular organisations, or used as a shared resource. At one extreme, each organisation (NEPIO, Regulatory Body, Operating Organisation, etc) may be developed to have all the capabilities and resources it needs to fulfil its responsibilities employed within that organisation, making those organisations more self-sufficient, but at the cost of higher overall resource requirements. At the other end of the spectrum, independent "Expert" groups/organisations may be developed/strengthened to provide technical support to the various responsible organisations, thus reducing the overall resource requirements and alleviating the problem of retaining experts within each organisation whose expertise is 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. A nuclear power plant 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 Regulatory Approach

Key amongst 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 competence requirements of the RB itself, and also on the size of the operating organization.

The more proscriptive the regulatory framework is, the more resources are likely to be needed by the RB (either as permanent staff or external support). Conversely if the regulatory framework makes the Operating Organisation primarily responsible for



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demonstrating compliance with requirements, then the Operating Organisation 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, any limitations on the use of ‘external’ experts, etc., may also have a direct impact on resource requirements e.g. the decision whether to operate a plant with 5, 6 or 7 teams of shift personnel has a significant impact on the numbers 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 MS relying on international expertise and support organisations such as IAEA, WANO, Reactor Owners’ Groups, to support the various national stakeholders (Ministries, Regulatory bodies, Implementing Organisations, 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 MS must have/develop the competence to be an ‘Intelligent Customer’ for this support. In addition, the MS is likely to retain responsibility for a number supporting Infrastructure activities such as grid enhancements, roads, housing and other facilities local to the site. In any event, it is the responsibility of the MS, 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 utilised/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 realisation 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 necessary pre-requisite 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 organisation. The workforce planning process can then be used to identify the major activities that need to be undertaken to achieve the milestones, which organisations 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 my find the IAEA document "Manpower Development for Nuclear Power" [9] useful. Although this document, published 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 documents providing useful guidance are listed in Table 6 at the end of this chapter, with an indication those organisations 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 nineteen infrastructure issues, phase by phase (as identified in [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 discreet topics, the activities associated with these topics are often integrated and interdependent in reality. 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 organisational 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 organisational arrangements.

During Phase 1, the NEPIO is likely be the major responsible organisation and, in addition to the information contained in the Milestones [1] document, an overview of their functions and responsibilities during Phase 1 is provided in Table 2 below, taken from the "Responsibilities and Capabilities of a NEPIO" document [2].

During Phase 2, the regulatory body and operating organisation will be assigned (assuming they were not already assigned in Phase 1) and responsibilities, and therefore resource requirements, will progressively transfer to these organisations. Table 3 [2] below provides an overview of the NEPIO's functions and responsibilities during Phase 2 and a similar overview of the responsibilities of the operating organisation during Phase 2 is included in Table 4 (taken from IAEA document "Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators [3]). Useful sources when developing Workforce plans for the Regulatory body include the IAEA Safety Guide "Organization and Staffing of the Regulatory Body for Nuclear Facilities" [10] and IAEA TECDOC "Training the Staff of the Regulatory Body for Nuclear Facilities: A Competency Framework [11]

TABLE 2. FUNCTIONS OF 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 NG-G-3.1 [1] and recognizing the resources and time scales 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 organization and assist in building its capabilities. Make suggestions for allocations on specific responsibilities of each organization associated with the nuclear programme. |
| Funding and Financing[2] | 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. |
| 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 on Accounting for Control of Nuclear Materials (SSAC) with requisite authorities.<br>Provide a plan covering the drafting, implementing 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 a nuclear power plant and the likely extent and cost of grid enhancements that will be needed. |
| Human Resource Development | Describe of 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 a preliminary assessment of suitability for nuclear facilities' construction and operation. |
| Environmental | Assess the additional environmental considerations necessary for nuclear power, |

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

| | |
|---|---|
| Protection | 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 and intermediate level waste, 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 nuclear power plant projects. |
| Procurement | Design a strategy for procuring the equipment and services to support a nuclear power plant project, taking into account the need for bilateral agreements with foreign suppliers and quality requirements for both international and local suppliers. |

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TABLE 3. FUNCTIONS OF 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 nuclear power plant. |
| 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 relevant 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 a nuclear power plant. |
| Human Resource 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 nuclear power plant 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, including the 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. |
| Radioactive Waste | Confirm that the appropriate laws, regulations and facilities are in place or planned for handling, transporting and storing low level waste (LLW) and intermediate level waste (ILW). In addition, assist the government in developing strategies and policies with respect to eventual disposal of high level waste (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 nuclear power plant operation and maintenance consistent with the country's policies developed in Phase 1. |

TABLE 4. TYPICAL FUNCTIONS OF OPERATING ORGANISATION DURING PHASE 2

| Issue | Owner/operator Responsibilities |
|---|---|
| National Position | – Create the owner/operator organization following the Government decision. |
| Nuclear Safety | – Establish an appropriate internal system to identify its safety responsibilities based on the legislation in force.<br>– Initiate the necessary actions to establish and continuously improve safety culture right across its organization.<br>– Ensure that an understanding of nuclear safety requirements is developed in the whole supply chain.<br>– Together with the regulatory body, adhere to international legal instruments such as:<br>o Convention on Nuclear Safety<br>o Convention on Early Notification of a Nuclear Accident<br>o Convention on Physical Protection of Nuclear Materials and its Amendment<br>o Vienna Convention on Civil Liability for Nuclear Damage<br>o Convention on Assistance in Case of a Nuclear Accident and Radiological Emergency |
| Management | – Establish a management system including organizational chart of the owner/operator, adequate to the main tasks of this phase which are to prepare the BIS and start to build a safety culture<br>– Ensure that the factors important for the development of a strong safety culture are considered all through this phase<br>– Define the areas of competence to be established in its organization.<br>– Implement a programme of staff recruitment and training.<br>– Select the preferred nuclear power plant sites for the BIS<br>– Determine the preferred nuclear technology (reactor and fuel type).<br>– Determine the fuel cycle and fuel procurement strategy<br>– Determine the strategy for spent fuel and radioactive waste<br>– Establish the preferred contractual approach (turnkey, split package, etc).<br>– Develop the financial strategy and financial plan.<br>– Prepare the BIS, including the bid evaluation criteria.<br>– Establish efficient and effective working relationships with the regulatory bodies and similar relationships with international and professional organizations.<br>– Start to build a project management organisation to manage the construction of the first nuclear power plant |
| Funding and Financing | – Develop financing strategy and financial plan.<br>– 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.<br>– Understand the licensing process and the associated safety documentation. |
| Safeguards | – Consider a safeguards by design approach<br>– Start to establish procedures and train its staff to meet safeguards requirements, and to demonstrate to the government authorities that it has done so.<br>– 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.<br>– Consult with operators of the same type of facilities on technical features for implementing safeguards (e.g. installation of containment and surveillance devices, cabling, penetration of containment, etc.).<br>In safeguards terminology, the national regulator is the State Authority for State systems of accounting for and control of nuclear material (SSAC). |

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| Issue | Owner/operator Responsibilities |
|---|---|
| Regulatory Framework | – Set up an effective working relationship with the regulators with open communication.<br>– Ensure that other organizations that may be supplying goods or services to the nuclear power plant understand the national safety requirements.<br>– 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, public and the environment.<br>– Perform the characterisation 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.<br>– 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.<br>– Ensure that the possible schedule for grid enhancements is compatible with the likely schedule for construction of the nuclear power plant.<br>– Include grid characteristics and requirements in the BIS. |
| Human Resource Development | – Recruit and train the staff needed for Phase 2 responsibilities.<br>– Develop plans to recruit and train staff for Phase 3.<br>– Request the Government to 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<br>– Recruit experts in the areas of public communication and education, and train its own staff in these areas.<br>– Explain the basic technology being employed and the plans for the construction schedule<br>– Openly discuss potential problems and difficulties, and plans to resolve them.<br>– Communicate in a transparent and professionally with other organisations participating in the nuclear power programme<br>– Demonstrate that it is a competent and credible organization that deserves the confidence of the public<br>– Agree with local authorities near the NPP site the financial and technical support for social infrastructure development.<br>– Open a public information centre near the nuclear power plant site and other places. |
| Site and Supporting Facilities | – Carry out the detailed site investigations of the possible sites for the NPP, and recommend the preferred site or sites.<br>– Secure the availability of the chosen site or sites.<br>– Identify local legal, political and public acceptance issues for the chosen site, and plan their resolution<br>– Include the characteristics of the site in the BIS<br>– Identify and plan any necessary improvements or upgrades to site characteristics and local infrastructure, such as improved road access and mains water supply.<br>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<br>– Submit the environmental impact assessment and the application for environmental clearance to the environmental regulator<br>– Include any special environmental features of the site in the BIS. |
| Emergency Planning | – Identify the local and national organisations that will take part in emergency planning<br>– Start to prepare the emergency plans and procedures. |

| Issue | Owner/operator Responsibilities |
|---|---|
| Security and Physical Protection | – Establish an interface with the responsible national agency (security regulator)<br>– Provide the inputs and expertise necessary to allow the security regulators and the concerned government authorities to define the Design Basis Threats (DBT),<br>– Include security requirements in the BIS<br>– Define the physical protection features of the nuclear power plant site.<br>– Introduce arrangements for security classification of the nuclear power plant data.<br>– Develop a programme for the selection and training of security staff |
| Nuclear Fuel Cycle | – Provide technical information to the government for nuclear fuel strategy.<br>– 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 high level waste.)<br>– Introduce specifications related to nuclear fuel in the BIS to define what should be procured separately.<br>– 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.<br>– Establish an interface with the radioactive waste management organization.<br>– Provide technical information to the waste management organization to allow the policy for waste disposal to be established.<br>– Ensure that relevant procedures are created for implementing safeguards, should the waste contain nuclear material.<br>– 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<br>– Analyse the ability of local suppliers to meet the schedule and quality requirements and provide input to the Government.<br>– Reach an agreement with Government for participation by local suppliers.<br>– 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.<br>– Start to establish the procurement team/department.<br>– 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 organisation in order to adequately resource first the commissioning and, subsequently, operation of the NPP. Table 5 provides a summary of the responsibilities of the Operating Organisation during Phase 3. IAEA document "Commissioning of Nuclear Power Plants: Training and Human Resource Considerations [Ref 12] contains some useful guidance for planning purposes. In considering inputs for Workforce Planning for the organisational and resourcing requirements of the Operating Organisation to actually operate the plant; this will depend, to some extent, on the design of NPP selected. It is likely that the Vendor of the chosen design will have their recommendations in this area. Member States may find broader guidance on the recruitment, training and qualification of these staff in IAEA documents "Recruitment, Qualification and Training of Personnel for Nuclear Power Plants" [Ref 13] and "Nuclear Power Plant Personnel Training and its Evaluation [Ref 14].

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TABLE 5. TYPICAL FUNCTIONS OF OPERATING ORGANISATION 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.<br>– Build and maintain technical knowledge and skills for the safe operation and maintenance of the nuclear power plant.<br>– 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.<br>– Ensure participation in the activities related to the international legal instruments. |
| Management | – Issue the BIS to the bidders including an identified site or sites.<br>– Evaluate the bids and choose the preferred bidder or bidders.<br>– Negotiate the contracts with a scope of supply consistent with the procurement strategy.<br>– Sign the contracts for the first nuclear power plant.<br>– Prepare technical documentation for the licensing application, with contributions from the vendor or main contractor. This should include a preliminary decommissioning plan.<br>– Submit the applications to the regulatory body for a site permit and a construction licence.<br>– Make suitable contractual arrangements with fuel and fuel service suppliers.<br>– Establish a team or department for public communication and information.<br>– Implement a management system and perform audits in order to ensure that all participants in the first nuclear power plant project, including subcontractors, meet the specific requirements (nuclear standards and codes, technical specification, etc.).<br>– Train the operating personnel and arrange for them to be licensed if necessary. |
| Funding and Financing | – Determine the nuclear power plant project budget based on the agreed contract and owner/operator participation.<br>– Determine the required cash flow according to the nuclear power plant project schedule and contractual provisions (payment milestones).<br>– Implement the financial plan, based on the agreed contracts (loans, state funding, other financial mechanisms).<br>– Follow the mechanism for provision of the 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 (e.g. the IAEA) and national agencies in order to understand the legislation and comply with it. |
| Safeguards | – Train its staff to meet safeguards requirements and to demonstrate that it has done so to the government authorities.<br>– Implement all safeguards measures and have the nuclear power plant safeguards system approved by the national regulatory body before receipt of the first nuclear fuel on the nuclear power plant site.<br>– 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.<br>– Agree with regulators on the programme/schedule for licensing meetings, taking into account the important milestones of the first nuclear power plant construction schedule.<br>– Submit the safety documentation required in the licensing process in a timely manner and be prepared to respond to enquiries from the regulatory body.<br>– Require organizations in the supply chain to comply with national safety requirements. |

| Issue | Owner/operator Responsibilities |
|---|---|
| Radiation Protection | – Implement all necessary radiation and environmental monitoring and protection programmes before the first nuclear fuel load is transferred to the nuclear power plant site.<br>– Ensure all necessary services to implement the radiation protection programme using external subcontractors (for calibration services, laboratory analysis, etc.) where appropriate.<br>– Develop the team/department and capabilities for safe implementation of radioactive waste management activities, before the first criticality. |
| Electrical Grid | – Agree with the grid operator on the schedule for grid upgrade projects to meet the nuclear power plant construction schedule.<br>– Liaise with the grid operator during construction of grid upgrades and verify when they are complete.<br>– 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 nuclear power plant, etc.).<br>– Establish and agree on procedures for the coordination of grid operations with nuclear power plant operations. |
| Human Resource Development | – Develop a strategy for human resources for nuclear power plant operation, taking into account resources provided under the contract with the vendor and the availability of other service providers.<br>– Recruit and train staff needed for nuclear power plant operation, maintenance and technical support, taking into account the training provided under the contract with the vendor.<br>– Ensure that an adequate number of trained and certified staff/operators are available by the first fuel load.<br>– Develop plans for the continuing recruitment, and training of staff, and personnel development for the lifetime operation of the nuclear power plant. |
| Stakeholder Involvement | – Explain the technology being deployed in the nuclear power plant and the plans for construction activities.<br>– Routinely communicate progress during the construction phase and make preparations for operation.<br>– Openly discuss problems and difficulties encountered, and how to resolve them.<br>– 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.<br>– Ensure that site security arrangements, environmental monitoring and emergency planning arrangements are functioning correctly before the first fuel load arrives on site at the nuclear power plant. |
| Environmental Protection | – Complete the characterization of the site and its surroundings.<br>– Establish systems for monitoring and assessing all environmental releases from the nuclear power plant in accordance with national laws and international standards, and implement all features before the first fuel load.<br>– Agree with the environmental regulator on the arrangements for independent measurements of environmental releases from nuclear power plant, if necessary.<br>– Agree with the environmental regulator on how information on releases from the nuclear power plant will be reported or published. |
| Emergency Planning | – Finalize the emergency plan and put it into effect. (Further information is provided in Refs. [27, 28]).<br>– Establish protocols and procedures for the interfaces with organizations involved in the emergency plan (police ambulances, transportation, local and national government organizations, etc.).<br>– Arrange for systematic training of staff in the emergency service organizations so that they understand the special issues that can affect nuclear sites.<br>– 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 nuclear power plant site. |

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| Issue | Owner/operator Responsibilities |
|---|---|
| Security and Physical Protection | – Set up selection and qualification programme of the security staff.<br>– Ensure that security and physical protection systems and procedures are in place before the first fuel load on the nuclear power plant site and obtain approval from competent authorities.<br>– Ensure that sufficient trained security staff are available.<br>– Interface with national and local government bodies for security measures. |
| Nuclear Fuel Cycle | – Place contract(s) for the first fuel load.<br>– Make contractual arrangements for future fuel reloads.<br>– Ensure that adequate storage capacity is constructed at the nuclear power plant site for interim storage of spent fuel.<br>– 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.<br>– Submit through the national regulator to the IAEA the necessary safeguards-related information according to provisions set forth in the safeguards agreement. |
| Radioactive Waste | – Ensure that a fully operational facility for treatment, conditioning and storage of radioactive waste is available at the nuclear power plant site by the first criticality.<br>– Ensure that the facility is able to produce a waste form that would be acceptable to the waste management organization.<br>– Ensure that the costs for radioactive waste management and disposal are included in the operating costs and funded in accordance with the legislation.<br>– 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 technical requirements.<br>– Specify in the contracts the final arrangements for local supply of goods and services for the construction period.<br>– Establish local supplier qualification requirements.<br>– Place the contracts for the procurement of the local supply in accordance with the nuclear power plant schedule, if necessary.<br>– 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.<br>– Develop the capabilities to carry out procurement of full facilities, equipment and components for the nuclear power plant.<br>– Establish a suitable procurement organization that may be based at the nuclear power plant site or centrally in order to provide the spares, consumables and services for future operation and maintenance of the nuclear power plant. |

TABLE 5. SUMMARY OF KEY IAEA PUBLICATIONS RELATING TO WORKFORCE PLANNING

| Responsible Organisation | Relevant IAEA Document | | 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 Competencies of a Nuclear Energy Programme Implementing Organization (NEPIO) for a National Nuclear Power Programme | ✓ | ✓ | |
| 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 | | ✓ | ✓ |
| Operating Organisation | NG-T-3.1 | Initiating a Nuclear Power Programme - Responsibilities and Capabilities of the Owner/Operator | ✓ | ✓ | ✓ |
| | 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

Summarising 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 intended build programme.
- Nature of 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 over the development of the programme and can begin with quite small



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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 Resource management process. Each organisation involved in the Nuclear Energy programme should develop and maintain its own Workforce Plan and, at least for Phases 1 and 2, the NEPIO should maintain an overall plan to enable an integrated national approach to resource utilisation 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 numbers of staff involved will be relatively small and 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 and so some staff will be working at quite a high level, while others will be involved in more detailed activities. (As stated earlier [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 organisations, including the regulatory body (RB) and the owner/operating organisation (OO) 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 underway. Towards the end of Phase 2, the NEPIO should have handed over many of its early responsibilities to the various responsible organisations and may indeed be considered to have completed it's 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 organisation. The regulatory body will be actively engaged in the licensing of the site and plant design and overseeing manufacturing and construction, as appropriate. The operating organisation will be actively recruiting and managing the training its permanent plant staff.

This profile of resource requirements is illustrated in Figure 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 type educational qualifications, coupled with some form of vocational skill certification and/o 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.

### 4.2. Recruitment Considerations

Even where there are no readily available nuclear experienced resources 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 fossil fired power generation, process/production industries, 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 recognise that this can be a two-way process. The nuclear community is currently truly global in nature and this is unlikely to diminish 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 monitoring that compensation packages are competitive with other opportunities nationally and, where possible, internationally. In any event, it will 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 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 factor time for additional training requirements (including language training) into Workforce Plans.

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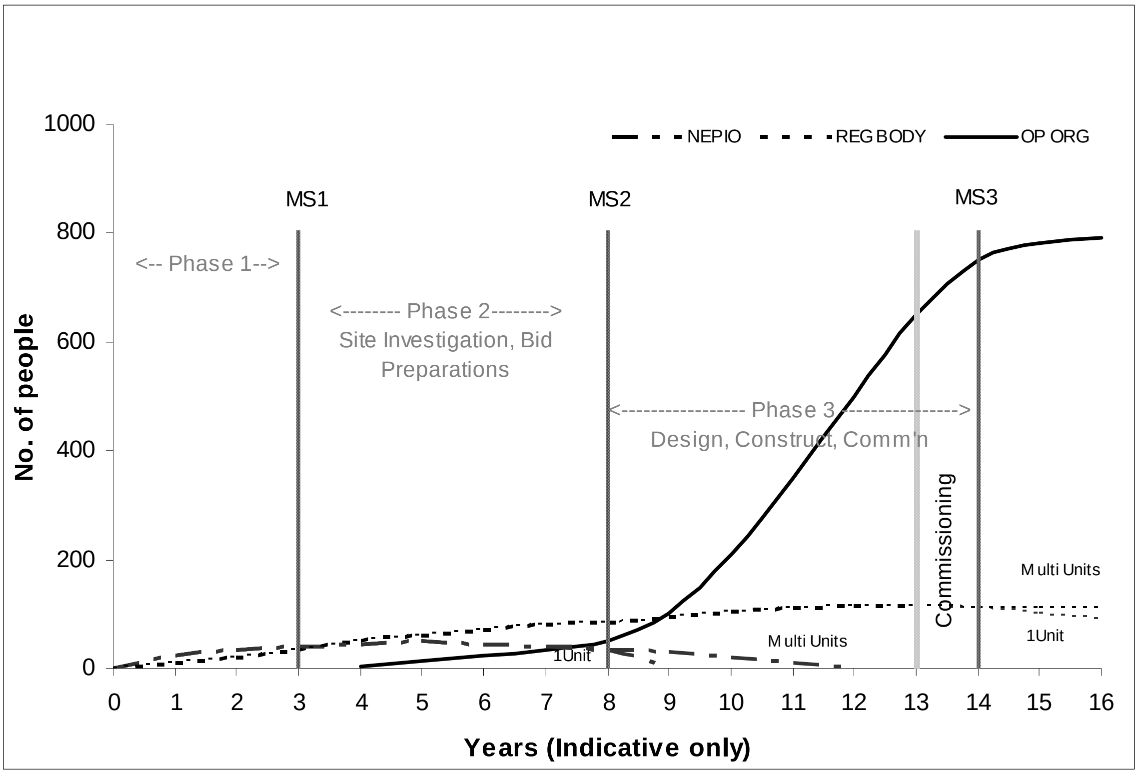


*FIG.3. Typical Phasing of Resource Requirements*

## 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 which may result in several hundred candidates applying for one, or a few, 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 direct from secondary education, with the expectation that the vast majority of 'graduates' from these establishments will be employed directly in the industry, so the actual 'recruitment' process is much simplified.

It is good practice to set limits on the duration for 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 organisation and any applicants.

Another important consideration, coupled to the duration of recruitment process, is the scope and duration of any job-related training considered necessary prior to an individual being authorized to undertake their allocated duties. This may range from a few weeks of familiarization for an experienced technical specialist working narrowly within their 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 being needed to undertake their 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 MS. There are a number of potential benefits in developing an RTC including:

- Sharing set-up, as well as running, costs between several MS

- It avoids competition between individual MS in trying to attract scarce specialist resources to provide nuclear training

- RTCs are more likely to attract the support of international organisations such as the IAEA, and are more likely to be able to establish links/partnerships with other international training/educational institutions, operating organisations and suppliers

- MS may be less likely to lose staff to neighbouring countries if the whole region has adequate access to such specialist training resources

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

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 organisations. 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 One

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 organisations: the NEPIO, regulatory body, operating organisation, national industrial organisations 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 organisations 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 utilise/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).
- Organising national conferences/workshops where vendors and specialist support support organisations can present their capabilities and services (care needs to be taken to ensure 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 Bi- and Multi-lateral relationships with governments, regulatory agencies, vendors, utilities, educational institutions, etc., which allow for placements and staff 'swapping'.
- IAEA Training courses, Fellowships and Internships.
- Formal courses of overseas study (e.g. vocational, under- and post-graduate programmes, which may include industry assignments) and training (directly with Utilities/national nuclear training organisations).
- Building staff training and development assignments into potential contracts with vendors, consultants, service providers, etc.
- Developing 'strategic alliances' with vendors/equipment suppliers whereby national organisations obtain licenses to manufacture components in-country, which can include training and qualification in the country of origin.

Fortunately the numbers of staff directly involved in Phase 1 are 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 organisation and these staff are likely to be heavily supported by national/international expertise. An example of how this group might be organised in illustrated in Figure 4 below.

If an MS 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 RB 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.

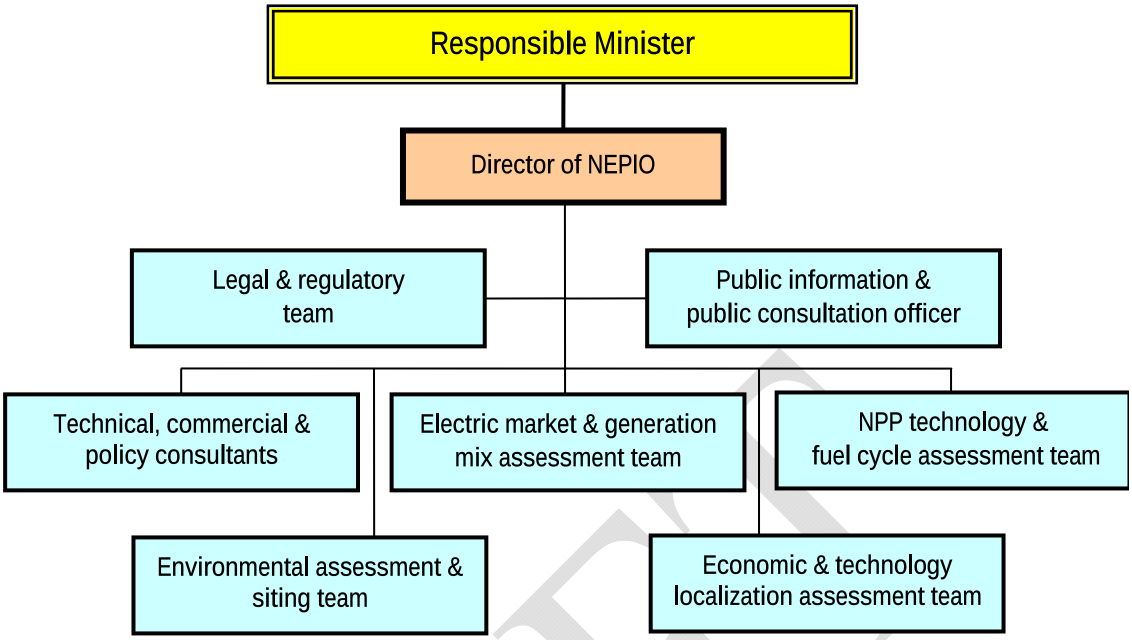


*FIG.4. Example of Organisation of NEPIO in Phase 1*

### 5.3. Phase Two

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 Figure 5, typically in the range on 20 – 50 personnel, 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 organisation, either within the nuclear plant management structure (single NPP) or into the corporate organisation (multi-unit programme). It is important however that, even if the NEPIO ceases to exist as an organisation, 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.

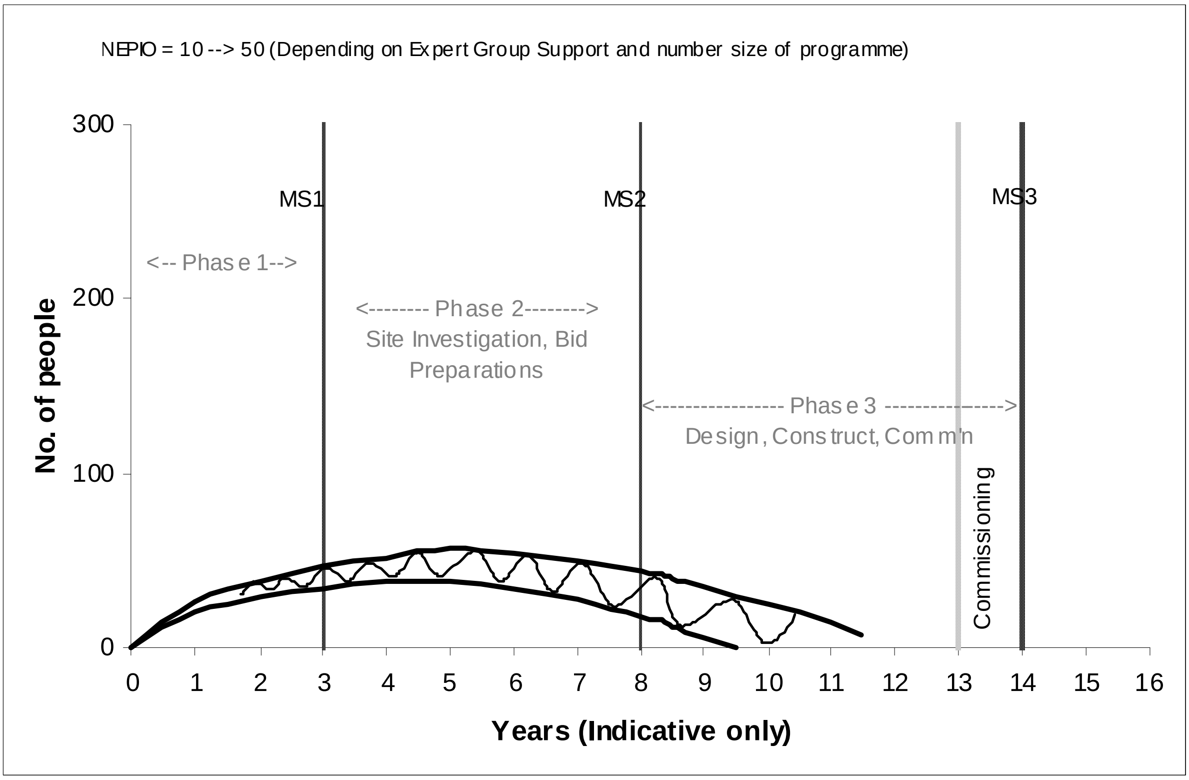


*FIG.5. Example of Phasing of Resource Requirements for NEPIO*

Regulatory Body:

The development of the work processes, human resources and competences 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 and adopting appropriate industrial codes to properly cover all foreseen nuclear activities.

The number of staff of the regulatory body will depend on 2 key factors:

- the number of organizations available to provide technical support to the regulatory body (Section 2.2), and

- the regulatory approach adopted by the Member State (Section 2.4).

Typically the regulatory body may have a core staff of about 40 to 60 people, with 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 Organisation 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 around 100 - 150 personnel, again dependent on the level of specialist independent support available and on the numbers of NPPs planned (workload). In the case of only one plant these numbers should reduce post-commissioning, as illustrated in Figure 6.

It is generally accepted that regulatory bodies should have competencies in 4 main areas:

- Legal basis and regulatory processes;

- Technical disciplines;

- Regulatory practices; and
- Personal and interpersonal competencies.

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

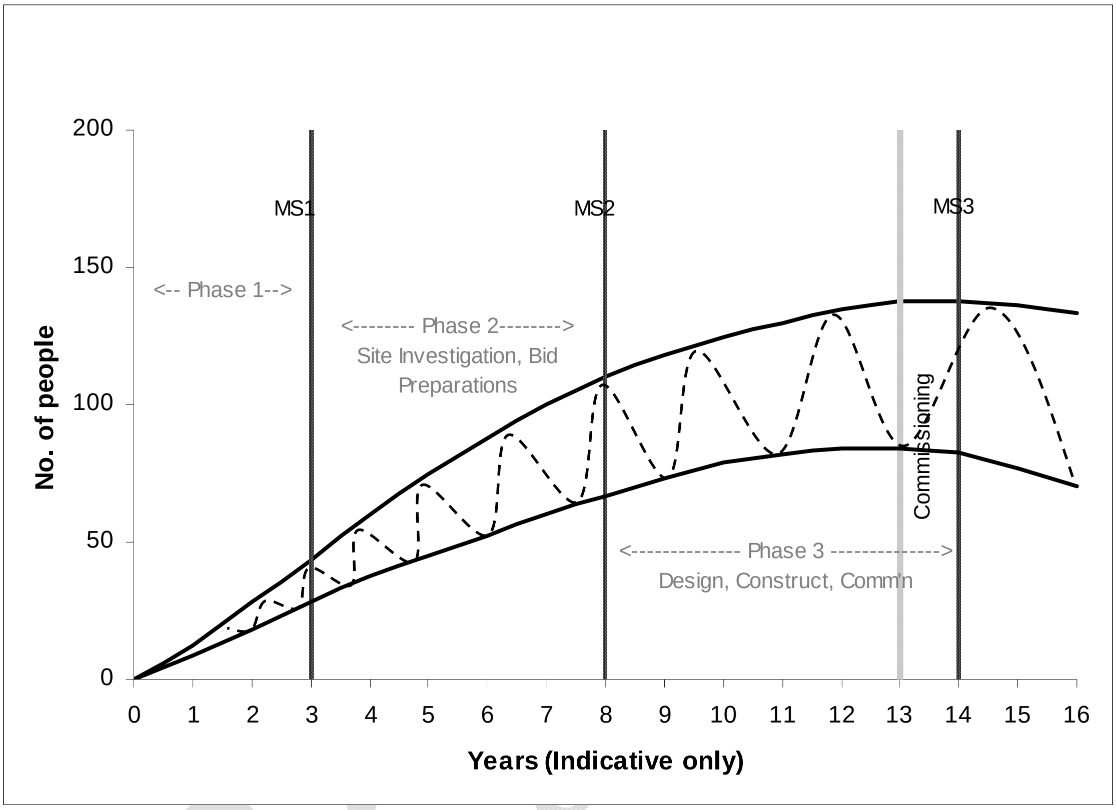


*FIG.6. Phasing of Resource Requirements for Regulatory Body*

<u>Operating Organisation</u>:

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 numbers of staff required are much larger than for the other organisations, typically in the range of 500 – 1000 for a single or twin unit plant, up to several thousand staff for a multiple-unit plant(see Section 5.4 below).

— Many of the operating organisation staff have safety related roles as described above, requiring authorisation and hence have significant trainging programmes, needing 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 training classroom training should be completed prior to the main commissioning phase. IAEA document, "Commissioning of Nuclear Power Plants: Human Resource Considerations [15], provides useful guidance in this area.

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

- Preparing the Bid Invitation Specification (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
- Etc, etc. (see [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 organisation staff early in Phase 2 (see Fig 7).

### 5.4. Phase Three

By the beginning of Phase 3, the majority of NEPIO staff are likely to have either transferred to one of the other responsible organisations or returned to one of those government departments with ongoing responsibility for the nuclear energy programme. The majority of RB 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 organisation and fully staffed and competent to meet its responsibilities. This team will oversee the Project on behalf of the Member State/operating organisation, 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 organisation [3]. It is recommended that this team is part of the Operating Organisation 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 Project Team 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 centralised 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 document 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 1 provides an example of the median staffing levels, by function, for some 67 1-Unit and 2-Unit NPPs in operation in North America and Western Europe (see notes in 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 2 for clarity. It must be emphasised that these figures are presented as examples only as actual numbers will depend on many factors including those listed above.

It should be emphasised 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 centralised (e.g. Design Authority, Technical support, Maintenance, Finance, Procurement). Additional comparative data on staffing numbers may be found in IAEA document "Nuclear power plant organization and staffing for improved performance: lessons learned" [16].

The phasing of recruitment of plant staff depends greatly on their training 'lead-times' (how long they need for formal training prior to authorisation/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 a typical US NPP is included in Appendix 3. 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 analyze their own situation and needs through their detailed workforce planning.

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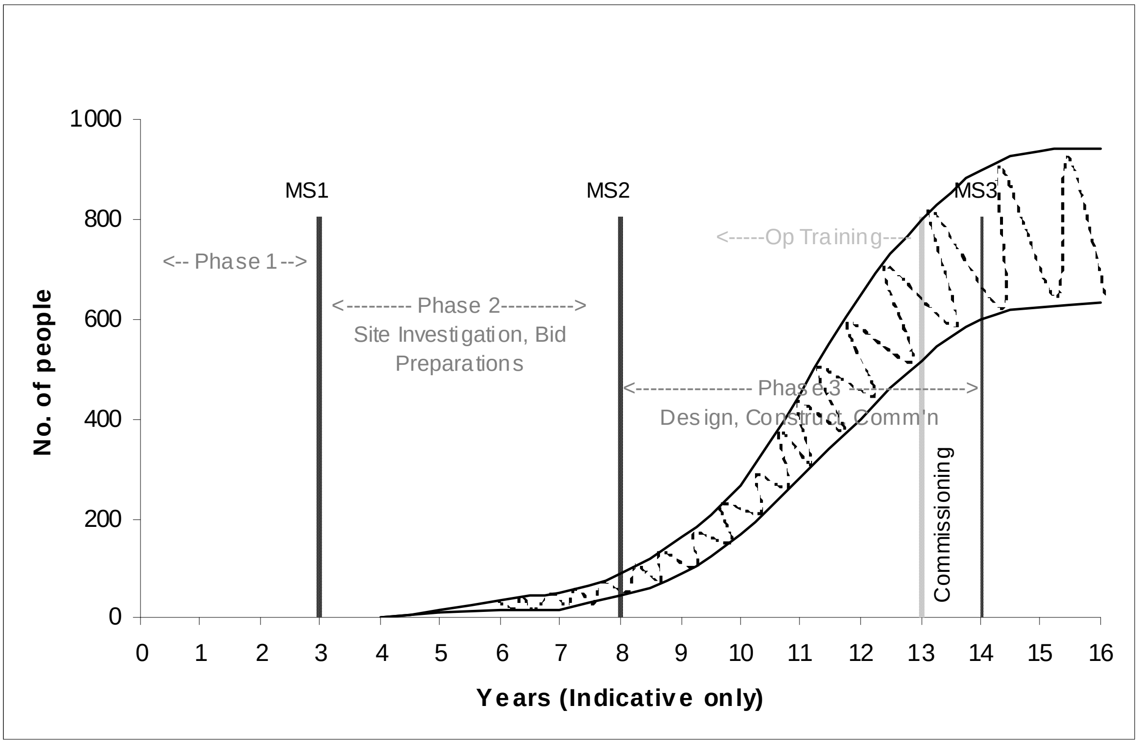


*FIG.7. Build-up of Plant staff prior to Commissioning*

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

- Initial operation by national staff, already trained by the vendor, but under the supervision of experienced vendor supplied staff, for an initial period
- An initial period of operation, staffed by the 'Turn-key' contractor's staff while training the main body of national staff, with a subsequent formal hand-over to the operating organisation after a period of, say, 1 – 3 years.
- A mixture of experienced and newly trained staff in appropriate positions (e.g. for early Chinese NPPs, approximately 1/3 of the staff were taken from other plants, 1/3 from research reactors and 1/3 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
- Developing the case, and implementing 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 ORGANISATIONS

## 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 pre-requisite 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 in an NPP. Such an NTC could be operated by the government, the owner/operator or an independent organisation 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 5.

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 post-graduate 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, etc.

If a strong undergraduate/post-graduate 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 to focus not only on the graduate/post-graduate sector but also to consider the 'vocational' requirements of regulators and operating organisations. Experience shows that typically more than 50% of the workforce at an NPP may be 'technician' type staff with vocational qualifications, usually trained in 'technical' schools, which rarely have nuclear specific programmes. This sector of the workforce are 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 also.

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An important element of any relationship between the nuclear industry and any education and, 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 organisations 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 organisations (OO, RB, support organisations, etc.) for a period from a few weeks up to a year, to gain insight and experience in the organisations. Many Member States have undergraduate programmes which require students to work in 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 under- and post-graduate 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 similar factors 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 (EI) 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 organisations' (NEPIO, RB, OO, industrial partners, etc.) to ensure alignment with future needs

- Establishing working 'Councils' with academic, government and industry representation to oversee the development of nuclear sciences training and development programmes nationally

- Using senior 'responsible organisation' staff as visiting lecturers on nuclear engineering programmes

- Placing undergraduate students in the 'responsible organisations' for work experience, as part of their undergraduate programme

- Develop partnerships with EIs with 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 study 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.

- Utilising available international assistance e.g. IAEA programmes, World Nuclear University, regional networks, etc.

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, characteristics of the plant equipment, etc.

### 6.2. Technical Support and Research & Development Organisations

Many Member States have exploited the establishment of a nuclear energy programme as a vehicle to facilitate 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 organisations to provide support in the longer term. Involvement of national organisations 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. IAEA-TECDOC-1078, Technical support for nuclear power operations [17] and IAEA Safety Standard GS-R-1, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport

Safety [18] provide further information regarding TSOs for operating organizations and regulatory bodies, respectively. Some additional human resources issues for such organisations are also addressed in [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 organisations applies to technical support and research & development organisations.

# 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 document, 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 a nuclear power plant 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 either critical to operations or safety poses an internal threat to the safety and operations of nuclear power plants. Hence the issue of knowledge management (KM), particularly knowledge about the design, construction and commissioning of the plant, is critical. For many 'mature' nuclear operating organisations with many years of reactor operation, the need to manage knowledge for future generations was not recognised as a priority in the early years and these organisations 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 Organisations" [19] the IAEA defines "Knowledge Management" 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 KM systems and processes from the outset, with the added benefit of readily available hard and software systems designed for the purpose. Early establishment of a KM 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-centered 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. 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 approach in [6] includes to requirement to manage information and knowledge, as a resource, as an integral part of an operating organization's management system.

Some additional information on aspects of KM and steps to implement an effective KM system are included in Appendix IV, and additional IAEA guidance on developing effective KM systems and details are provided 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 document, presented in the form of an overview of how to get started in effectively including human resource development when considering if 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 recognising workforce planning as an integral part of an organisation's human resource development strategy and plans was emphasised in the introduction and illustrated in Figure 1.

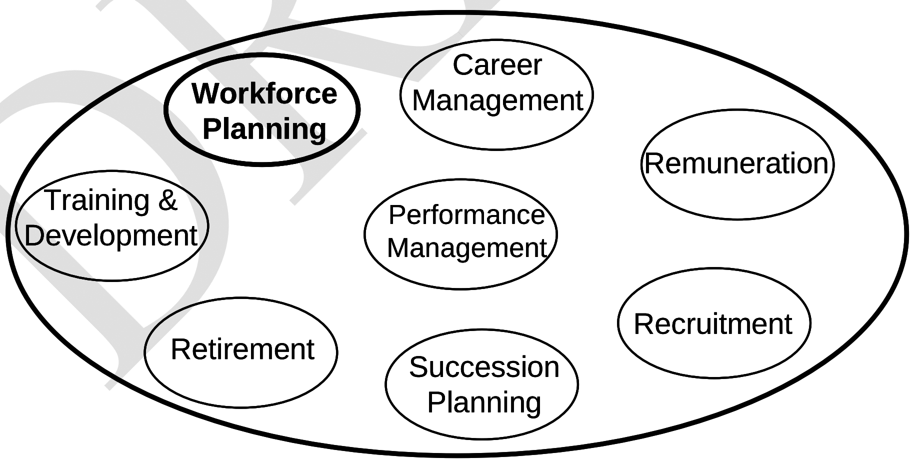


*FIG.1. Typical Elements of Human Resource Development Strategy*

## 8.1. Pre-requisites for Workforce Planning (Phase 1)

As stated previously, a pre-requisite 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 and there is no framework/basis for workforce planning. The establishment of a NEPIO, as described in [2] is one way in which to effectively develop these roles, responsibilities and functions, as well as for 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 an HR Strategy

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

1. Produce a brief (1 or 2 page) conceptual statement on HR 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 strategy for HR development for the entire nuclear programme that considers all of the areas identified in Figure 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 those expected to be performed for 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, with a suitable project manager be assigned. When a NEPIO has been established, one of the members of NEPIO should be assigned for managing/coordinating HR 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 organisational responsibilities and activities

- Identify underlying causes (including lack of competent personnel)

- Define solutions (including HR-related solutions in terms of numbers of people needed, organizations, competencies)

- Implement solutions

- Evaluate effectiveness of your 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 a national level, with France. The Korean example, detailed in Appendix VI, illustrated a more broad-based approach, where early experience was taken from a number of nuclear-experienced countries.

*(Need to include line on Indian Case Study(AppVII) when content known.)*

At the time of writing this document, the United Arab Emirates (UAE) had just agreed a contract, consistent with completion of Phase 2, with a Korean consortium to build and operate their first NPP and their approach to human resource development in summarised in Appendix VIII.

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

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# APPENDIX I.

## AN EXAMPLE OF NPP STAFFING NUMBERS BY FUNCTION

This Appendix provides median staffing levels (current at the time of this report) 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 1960's, and some came on-line as late as the 1990's. 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 than 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 start up 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 start up, 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 this report. 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 organisations, 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 document 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 Work Function | Nuclear Plant Staffing 1-Unit Median | | Nuclear Plant Staffing 2-Unit 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 |

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# APPENDIX II.

## WORK FUNCTION DEFINITIONS

The following is 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 to understand this data, or to compare their situation/plans 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.

### ADMINISTRATION/CLERICAL

This function 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 is staff performing administrative support functions such as coordinating conferences, graphics work, and non-technical analysis of data. Supervisors of clerical pools are included in the function, as well as telephone receptionists. This group also includes persons maintaining site-wide procedures.

### ALARA/RADIOLOGICAL ENGINEERING

Persons planning and controlling the As Low As Reasonably Achievable (ALARA) program, and performing and evaluating radiation dose and shielding calculations. Also includes staff reviewing complex radiation work permits.

### BUDGET/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.

### 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 chemistry program and providing guidance on chemistry standards; conducting evaluations of plant chemistry programs; and addressing and resolving chemistry operating problems. Also includes staff responsible for radioactive effluents program.

### 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 in plant visitor/information centers.

**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.

**CONTRACTS**

Coordinates placing of bids, and awarding and monitoring of performance on contracts for labor 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.

**DECONTAMINATION/RADWASTE PROCESSING**

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

**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.

**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.

**EMERGENCY PREPAREDNESS**

Develops, implements and maintains the emergency preparedness program. Trains and qualifies emergency exercise participants. Responsible for emergency preparedness facilities, including the Emergency Operations Facility (EOF) and Tactical Support Center (TSC). Focal point for local, state and federal legislation on emergency preparedness issues.

**ENVIRONMENTAL**

Persons responsible for the non-radiological environmental monitoring program and related requirements such as environmental licenses and permits, audits, and thermal monitoring.

**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.

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**FIRE PROTECTION**

Administers the fire protection program including surveillances. Responsible for fire protection program inspections. Includes personnel who serve on full-time fire brigades.

**HP APPLIED**

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

**HP SUPPORT**

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

**HUMAN RESOURCES**

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

**INFORMATION MANAGEMENT**

Responsible for dedicated software and hardware support for business and management application and data base 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.

**LICENSING/REGULATORY AFFAIRS**

Primary contact for licensing and other regulatory issues with national Regulatory Body (RB). Coordinates and reviews responses to RB routine and special information requests including Licensee Event Reports (LERs), Notices of Violation, and Generic Letters. Coordinates annual FSAR update process.

**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 craft and their supervisors.

## MAINTENANCE/CONSTRUCTION SUPPORT

This function includes people who support the work of maintenance/construction craft. This includes job package development, 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 labor, and cost and schedule estimating. Tool room attendants are included in this function. The function does not include schedulers, designers, or plant engineers.

## MANAGEMENT

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

## MANAGEMENT ASSIST

Personnel assigned to multi-functional special projects supporting managers. Includes persons supporting organizational or plant-wide projects.

## MATERIALS MANAGEMENT

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

## MODIFICATION ENGINEERING

Provides modification engineering services, and ensures design integrity for:

Civil/Structural Engineering, including site buildings, roads, bridges, and waterfront structure. Performs soils and foundations analyses, and reviews and approves hanger and support locations. Provides stress analysis and support evaluation services. Provides architecture 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.

## 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.

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## NUCLEAR SAFETY REVIEW

Responsible for offsite 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 program personnel. Also includes human performance program activities and the employee concerns program.

## 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.

## OPERATIONS SUPPORT

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

## 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.

## 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 surveillances, modifications, and system related studies generated internally and externally. Responsible for coordination, and review of post maintenance and post modification testing and surveillance testing program, and for conduct and review of local leak rate test (LLRT) and integrated leak rate test (ILRT) programs. Site point of contract for technical and procedural system and component testing issues. Also includes component and field engineers.

## PROCUREMENT ENGINEERING

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

## 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 award. Coordinates resolution of technical questions directed to, or originated by contractors.

**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.

**QUALITY ASSURANCE(QA)**

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

**QUALITY CONTROL/ NON-DESTRUCTIVE EXAMINATION (NDE)**

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

**REACTOR ENGINEERING**

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

**SAFETY/HEALTH**

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

**SCHEDULING**

Includes persons who schedule non-refueling 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.

**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 programs.

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## TECHNICAL ENGINEERING

Researches and analyzes technical engineering issues, but do 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 consultants on engineering issues. Responds to technical inquiries and information requests from internal and external sources. Responsible for engineering services and key programs 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.

## TRAINING

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

## WAREHOUSE

Includes all persons directly associated with physical inventories. Persons performing materials inspection, tracking, and maintenance are also included. 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 the table below is provided to further assist the reader to understand 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 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 NOT a requirement for NPP control room operators to have a Bachelor degree in science or engineering, whereas in some of the 29 other countries that have operating NPPs there is. This table also shows the reliance upon national standards/norms (such as ANSI 3.1).

| 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 nuclear power plants; health physics experience | Bachelor 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 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 communications competencies; Knowledge of local language and grammar, human relations, internet technology and industry trends. | Bachelor degree in journalism, public relations or related field | N/A | N/A |
| **Computer Engineering** | Basic computer competence; Nuclear power plant experience; Technical understanding of nuclear plant process computer and full scope simulator | Bachelor 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 degree | Government and/or NPP owner requirements for contracting and contracts reporting systems | 1 Year |
| **Decontamination/Radwaste Processing** | 2 years radwaste process experience | Secondary/High School Diploma or equivalent | Radwaste worker course, Waste treatment and radwaste operators course | 1 month |

| Nuclear Work Function | Competencies/Experience Requirements | Educational Requirements | Training Requirements | Lead Time Required |
|---|---|---|---|---|
| **Design/Drafting** | Basic computer competence; Experience with reading and interpreting schematic drawings | Secondary/High School Diploma or equivalent; Some requirements for Bachelor 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 Document Control/Records management systems | 3 months |
| **Emergency Preparedness** | Experience in Operations and/or Radiation Protection | Bachelor 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 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 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 & welfare benefits; Must be familiar with national labor laws | Bachelor 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 degree in computer science, information management, or related field | NPP General Employee Training (GET) | 3 months |
| **Licensing/Regulatory Affairs** | 2+ years experience in nuclear industry, basic computer competence, nuclear engineering | Bachelor degree in a technical field | NPP General Employee Training (GET) | 6 months |
| **Maintenance/Construction** | Physical fitness; basic mechanical competence; Good communications competence | Secondary/High School Diploma or equivalent | Apprentice, journeyman, master level discipline skill level training required (mechanical, electrical, instrumentation & controls); certification training for non-discipline craft such as crane and | Varies (for discipline craft): some national governments require a 3 year apprentice training program prior to initial work at the nuclear plant; others allow OJT provided by the plant owner with initial training times as short as 6 |

| Nuclear Work Function | Competencies/Experience Requirements | Educational Requirements | Training Requirements | Lead Time Required |
|---|---|---|---|---|
| | | | rigging operators, fork lift operators, scaffolding and insulation, etc. | weeks prior to OJT |
| **Maintenance/Construction Support** | Planner: Experience in nuclear power plant operations 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 degree normally required | Supervisory, management, and or leadership training, typically provided by the NPP ower | 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 Support** | Varies by the role as defined the by NPP Owner; May include basic computer competence, good communications competence, project management experience, etc | Secondary/High School Diploma or equivalent; Some positions require a Bachelor 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 |
| **Modifications 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 degree in mechanical, electrical, or civil engineering | Plant Technical Training, Professional Engineer License often required | 3-5 Years |
| **Nuclear Fuels** | Engineering economics or other formal financial experience; Nuclear fuel cycle and financial analysis experience | Bachelor 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 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 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; Nuclear power plant experience. | Bachelor in engineering or other technical discipline; or 2 year college/technical | Initial operator training or reactor operator training or senior reactor | 6-10 years depending on educational background |

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| Nuclear Work Function | Competencies/Experience Requirements | Educational Requirements | Training Requirements | Lead Time Required |
|---|---|---|---|---|
| | | 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 | operator trains | |
| **Outage Management** | Basic computer competence; Nuclear power plant experience; Technical understanding of nuclear generation principles and operations | Bachelor in engineering or other technical discipline | NPP Owner provided training in plant scheduling systems | 5 years |
| **Plant Engineering** | Basic computer competence; Nuclear power plant experience; Technical understanding of nuclear generation principles and operations | Bachelor degree in engineering or a related technical field | Plant technical training | 2 years |
| **Procurement Engineering** | Basic computer competence; Nuclear power plant experience; Technical understanding of nuclear plant equipment and design | Bachelor 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 degree in a technical or management related field | Basic project management training course | 3 years |
| **Purchasing** | Basic computer competence; Knowledge of category and supply management concepts; Good communications; Data analysis and Negotiation competencies | Bachelor 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 nuclear power plant design, operations, maintenance, or other nuclear related activities; Experience in quality assurance programs and concepts; Senior Reactor Operator license 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 degree in a technical field | Government and/or NPP owner requirements for quality assurance reporting systems | 6 years |
| **Quality Control/Non-Destructive Exam** | Physical fitness; Basic computer competence; General knowledge of QC and NDE inspection and examination techniques | Secondary/High School Diploma or equivalent | ANSI qualification training program: 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; | Bachelor degree in Engineering | Nuclear plant reactor-specific | 2 years |

| Nuclear Work Function | Competencies/Experience Requirements | Educational Requirements | Training Requirements | Lead Time Required |
|---|---|---|---|---|
| | Advanced computer competence; Understanding of nuclear and reactor physics | | training (PWR, BWR, CANDU, AGR, VVER, etc.) | |
| **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 degree in Environmental Science, Engineering, Industrial Hygiene, Public Health or other physical science | Industrial safety training program; 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 degree in a technical field | NPP Owner provided training in plant scheduling systems | 8 years of nuclear plant experience in maintenance, operations, or engineering |
| **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 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 & controls) for maintenance training; Bachelor 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 |

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## APPENDIX IV.

## KNOWLEDGE MANAGEMENT

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

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

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

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

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

Other benefits of KM include improved decision-making, retaining organizational memory and organizational learning, improving morale. KM can be used on its own or in collaboration with other management disciplines and tools to establish an environmental that will enable the organisation to realise 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 support is 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 KM can be at different levels, applied to a whole organization or broader, or simply a small office or workgroup, depending on organisational needs or resources. Examples of knowledge management applications include: developing an organisation-wide knowledge strategy linked to human recourse development; incorporating KM into existing projects and processes, like NPP personnel training; and implementing projects with a specific knowledge goal.

For different KM applications or initiatives three phases of it implementation could be identified as below:

– Understanding the context for KM 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 strategic plan for knowledge management for the organisation. The aim of this phase is to develop an understanding of the internal and external environment of the organisation through examining strategy, organisational capability and culture, and drivers;

– Examining knowledge gaps. This phase encourages more investigation of "desired" knowledge environment. This desired situation should reflect the organisational strategy and the context of the organisation, and give a vision of the knowledge environment as it could be. A useful framework for analysis of knowledge environment is in terms of 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, lack of awareness of tacit knowledge, etc.;

– Facilitating knowledge in action. The aim of this phase to select and implement approaches, methods and tools to address the identified knowledge gaps. Examples of KM techniques related to human recourse development in nuclear organizations can be found in IAEA-TECDOC 1510 [INTERNATIONAL ATOMIC ENERGY AGENCY Knowledge Management for Nuclear Industry Operating Organizations, Vienna (2006)]. KM does not end with the implementation of an initiative. It is necessary to review and monitor the initiative, the environment and organisational strategy and continue working towards further improvement and alignment.

Effective KM should become part of the initiative itself. Explicit and tacit knowledge developed during the course of the initiative should be captures, 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 need 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 organisational learning process an organisational memory-loss occurs when key persons leave, which has often been the main reason for a project's failure. Organisational memory shapes an organisation's culture, its management approach, its decision making process, its communication strategies and last, but not least, the definition of its operating boundaries that is 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 being made by national bureaus of standards of various countries as well as professional societies and these also help in knowledge preservation. Nuclear industry has to submit



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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 organisational continuity, particularly within rapidly changing organisations 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 learnt 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 to the expected results to enable feedback for continuous improvement of the process.

- **Fostering a knowledge sharing culture**

  In the 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 an individual 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 programs 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 voluntarily together to share similar interests and learn from other's skills. 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 use 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 don't 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 as for countries with existing nuclear power programmes as for countries considering the introduction of nuclear power. There is a for the loss of a substantial amount of critical nuclear knowledge and corporate memory which have been accumulated or will be developed in nuclear organizations. The loss of such employees poses a clear internal threat to the continued development or operation of nuclear power facilities. In addition, the loss of this knowledge and expertice could impact future plans for the construction of new, advanced designed nuclear units.

IAEA has developed practical guidance on knowledge loss risk management [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:

- conducting 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;
- and to 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 should be 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 to the safety of plant personnel and the general public but also in improving public perception of the nuclear industry as well as enhancing the commercial performance of the 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 maximised and this should ultimately have a positive effect on company balance sheets.

A wide variety of activities were initiated by the IAEA relating 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, development of process flows and facilitating the development of regional safety networks such as the Asian Nuclear Safety Network.

# APPENDIX V.

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

## V.1. Introduction

This document presents the workforce and education planning 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, so mainly concerned the training of key Chinese staff for the operation of the units. Therefore, this study aims to describe practically some key elements related to the phase 3 of the Milestones document (i.e. after Milestone 2, when a commercial contract has been signed), resulting from France-China experience.

Some more general facts and figures are included for the workforce and training planning relating to the two first phases of the Milestones document, 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 turn key 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 program 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 electro-nuclear cooperation between the two countries was signed on May 5$^{th}$ 1983 at governmental level. It was planned that France could provide a 900 MWe nuclear Pressurized Water Reactor (PWR) to China, allowing some technology transfer.

On the Chinese side, a dedicated structure, GNPJVC (the Guangdong Nuclear Power Joint Venture Co., Ltd) was formed in February 1985 by 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 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 reference. For that first project, EDF was responsible for overall technical design, for manufacturing surveillance, supervision of the construction (direction and work control) as well as commissioning activities, while working completely integrated into the Chinese teams.

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

The safety of the plant has been under Chinese Nuclear Safety Authority supervision. Significant technical assistance was provided by the French IPSN (Institute de Protection et de Sûreté Nucléaire), which subsequently became an independent organization, the IRSN (radioprotection and nuclear safety Institute).

Of the electricity generated from Daya Bay plant, 70% goes to to Hong Kong and 30% to Guangdong province. Two dedicated high voltage transmission lines were built in the frame of the project: 400kV to Hong Kong and 500kV to increase capability of 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[3] 1 000 MWe 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 planning leading to a connection to the grid in 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 country of origin of the suppliers).

### V.4. Workforce Development Before The Bid

It is assumed that some nuclear expertise (research reactor, isotopes production, etc.) and theoretical courses in nuclear physics exists 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.

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[2] Investment in training is not significantly different for one or two units

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

Using a reverse planning as previously, the following steps have to be planned (see the summary Page 11):

- **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 program and procedures for choosing the supplier (**T0 – 120 months): the necessary skills for the role the operator needs to play as **'competent buyer'**[4], 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 license 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 program planning and supplier selection phase. Most of the personnel in the “project management” team will finish work when the power plant is commissioned. After that, the work they are allocated to 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 shown that a large-scale transfer of personnel between the project management team and the operator cannot be taken for granted: th**e operator must start its own skills training separately.**

<u>Total number of personnel to be trained</u> (as an example):

- For the overall project management, about **360 people** (see table 1 below) of whom approximately 180 should have a Master degree and 180 a bachelor degree;
- On the construction site, **qualified workers** should be recruited locally and shall require as a minimum, specific training about quality assurance and the use of quality procedures.

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[3] Similar to “Intelligent Customer” as defined in the main body of this report

TABLE 1: WORKFORCE NEEDED FOR PROJECT MANAGEMENT (APPROXIMATE FIGURES)

| | **Total** | **MSc**[5] | **BSc** |
|---|---|---|---|
| Project manager | 1 | 1 | |
| Project management team | 10 | 7 | 3 |
| Engineering and procurement | 40 | 40 | |
| Construction | 175 | 80 | 95 |
| Testing – start-up – commissioning | 95 | 55 | 40 |
| Contracting monitoring (MSc & BSc) | 30 | | |
| Quality assurance/surveillance (MSc & BSc) | 10 | | |

### V.5. Safety And Radiation Protection – Partnership With The IPSN[6]

Within the general framework of the agreement on analyzing nuclear safety, the IPSN and the Chinese NNSA (National Nuclear Safety Administration) 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;
- Feed water supply system for steam generators;
- Heat sink;
- Effluents;
- Accident analysis;
- Technical specification, emergency response plan, emergency operating procedure, surveillance tests, startup testing, maintenance;
- Quality assurance.

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[4] MSc = Master of Science; BSc = Bachelor of Science

[5] The Institute for Nuclear Safety and Protection (IPSN) being discussed here is now the Institute for Radioprotection and Nuclear Safety (IRSN), part of the French nuclear safety system.

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, whilst ensuring 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, based in Fontenay-aux-Roses (France). These **joint teams** involved both Chinese trainees coming to 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 year in 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 6 months** preceded by two months on an SAIS course (Safety Engineer Course) and specific training. A sufficient level of French was necessary for engineers to be integrated in this way.

In view of the 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 MWe 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, **about 10 experts (level: PhD) should be provided. Their training (**in reactor physics/fuel, metallurgy, thermal hydraulics, radiation protection) **should begin at**



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**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. Out 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**.

<u>Phases</u>

The industrial phase[7] lasted **approximately 84 months** that can be divided as follows, using reverse planning[8]:

- o Design from T0 - 84 months to T0 - 20 months,
- o Manufacture from T0 – 78 months to T0 -25 months,
- o Onsite construction from T0 - 60 months to T0- 10 months,
- o Commissioning tests from T0-14 months to T0,
- o Project Management, operation and maintenance

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

<u>Workforce for a nuclear site in operation (2 units):</u>

- 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:
  - o The management (10 people)
  - o The Operation shift teams: 6 teams of 20 to 25 people working on a 3 x 8 hours shifts roster, plus the daytime personnel.
  - o Chemistry and radio chemistry, for plant and environment monitoring (20 people)
  - o Test and performance (10 people)
  - o 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. They 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**

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

[8] The reverse planning runs from the choice of the supplier (T0 – 84 months) to the start up of the first reactor (T0)

- 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 maintenance activities can 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 to 7 week rota. It consists 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, fire fighters and information technology staff) require about **160 people**, some of whom can be contracted according to local policy.

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 to 650 people according to the operator sub-contracting policy, of whom approximately 110 to 150 will have, at least, a MSc degree**.

Acquisition of knowledge

A “project services contract” was signed between EDF and GNPJVC, planning the training of **118 Chinese engineers for the key operational functions**. This contract specified the formation of 5 groups of trainees depending on their future duties as well as the dates and the modalities of the training in Europe:

- G1: Site organisation  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 trainings were assured in China by a French teacher recruited by EDF, focused on scientific language for groups G3 and G4.

Some documents were elaborated in the frame 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.
- In addition the QA manuals of the Engineering and Operations departments of EDF covering the whole program.

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**:



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- Development of adequate behaviours (safety, security, respect of procedures, etc.)
- Improvement of theoretical and technological knowledge, 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 competences and know-how between each trainee and one EDF counterpart (who has, in an EDF plant, the job that the trainee is planned to do when back in China). These "shadow trainings" accounted for the most important part of the whole training program (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. 700 EDF employees assumed this "counterpart" role during more than a week, attracted mainly by the interest of 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. 220 tutor months were mobilized on the project.

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

Three types of audits were performed during the project:

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

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

<u>Pre-OSART</u>

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

**➔ Lessons learned**

- For the operator, an adequate number of e**xperts (PhD level) should be about 1% of the workforce** in order to enable it to:
    - o Fulfil its entire nuclear responsibility through a thorough knowledge and understanding of some phenomena (reactor physics, simulations, core calculations, material fatigue, thermal hydraulics)
    - o 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, deputy manager of the local training center, etc., raised a number of difficulties. Pre-selection criteria for Chinese trainees had to take into account the specifics of Chinese engineering degrees, which differ from the French system. 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 start-up phases** was therefore all the more important. However such difficulty can be solved through internship 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 authorisation to hold a specific position in a nuclear power station, which remains **Chinese authority responsibility and also requested by law** (Reactor operators and senior reactor operators have to be licensed on the simulator which represents the actual unit). An 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 **top management support** is 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 a linguistic training, rather that providing the training in English.

### V.7. Current Situation

Since then, the GNPJVC has developed its own training capacity in China and now has at its disposal:

- The "DNMC Nuclear Training Center" that can manage 2,500 man-months of training per year (40 full-time simulator instructors, manpower of around 200 persons, two "full-scope" simulators, one "basic principles" simulator, 22,000 m² of laboratories). At the end of 2008, this center has trained and licensed about 300 Operators for Daya Bay, Ling Ao, and trained all requested operation and maintenance engineers.

- An agreement signed between 3 Engineering Universities (located in Harbin, Xian, and Shanghai) and DNMC nuclear Training Center to develop nuclear engineering courses, in order to prepare future Operations and Maintenance personnel. They learn basic knowledge on operation and maintenance on PWR nuclear power plant. This national manpower represents 28 professors, 28 professors' assistants and 44 instructors.

### V.8. Conclusions

As a conclusion, a key success factor was to **integrate the main structure and organizations which were applied in France and to adapt them in the Chinese framework**. The main idea was to take a well known system and to adjust it to the



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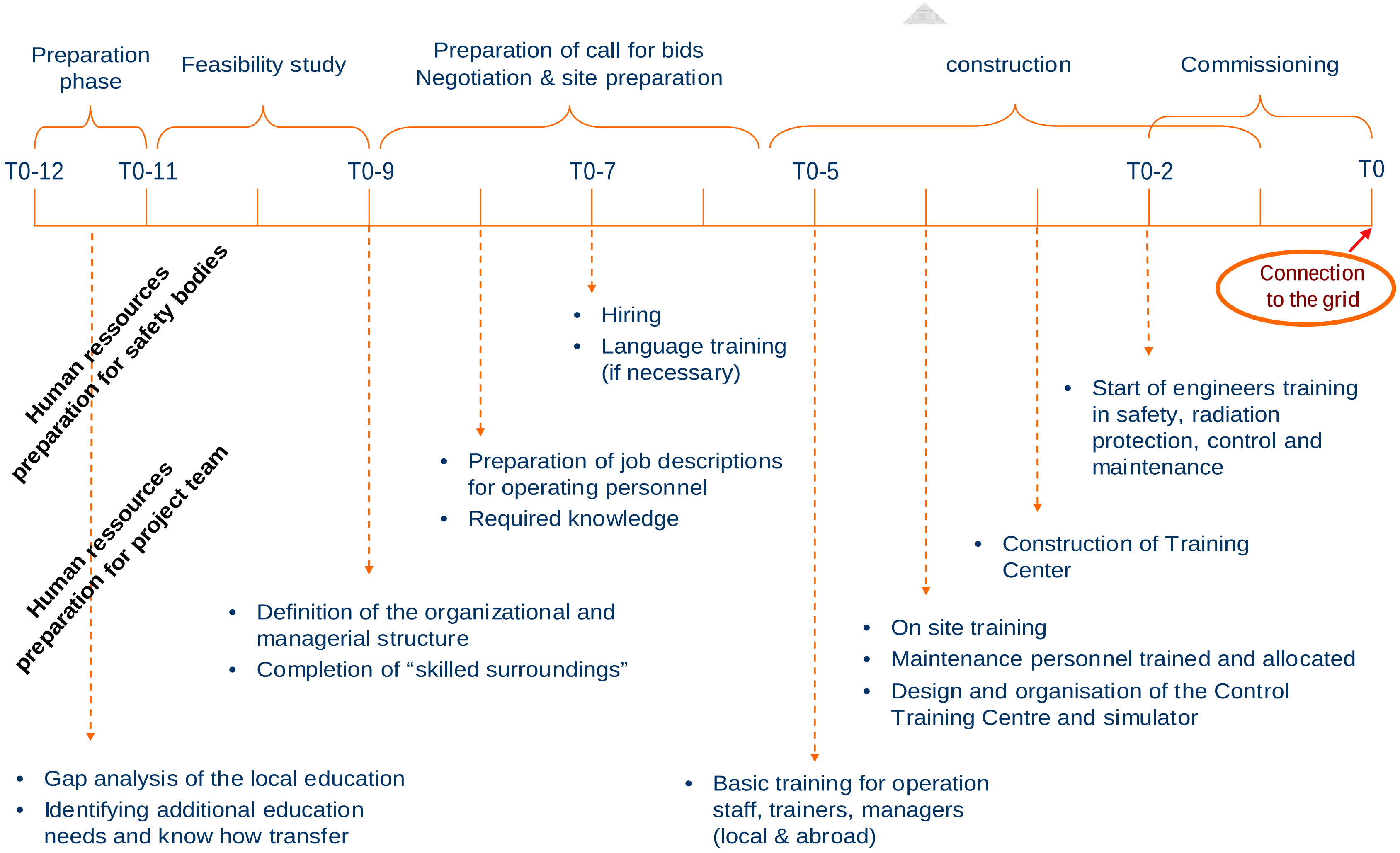
specifics of the recipient country in order to **give priority to experience** instead of the theory. This method required, from the recipient country, pragmatism and some important capacities of adaptation and, from the technology holder, to apply a way of doing and not a rigid structure.

Therefore, **the selection of the people involved was a very important step**. Hence, the Chinese trainees were selected not only on their current results but also on their high potential of integration.

### V.9. Summary: Human Resources Retro-Planning



## APPENDIX VI.

## LESSONS LEARNED FROM THE REPUBLIC OF KOREA NUCLEAR POWER PROGRAMME

### VI.1. Introduction

During the last forty years, thirty three countries have established large-scale commercial nuclear power programmes. All of their experiences can be valuable as lessons for prospective countries considering the first nuclear power as a part of their long-term energy supply. Major countries began their first nuclear power plant on the foundation of their strong industrial and financial standing. The Republic of Korea, however, began her 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 Koreans' successful nuclear power programmes for the sake of prospective developing countries.

As of 2006, Korea ranks as the world's 6$^{th}$ in total nuclear power generation using 20 units totaling 17,454 MWe, which supplied 38.6% of the total electricity demand. Korean NPPs have been successfully operated with the highest average availability factor (93.22%) and capacity factor (90.83%)[9] in the world between 2001 and 2006. Based on the positive experiences, the Korean government has recently decided to expand its nuclear power programme as a part of a long-range plan to further reduce energy import and greenhouse gases. [2] By 2030, nuclear power is expected to supply 59% of total electricity demand.

Upon the construction of the first three NPPs on a turnkey basis and the next 6 NPPs on a non-turnkey basis, the Korea's nuclear industry had successfully localized most technology to build NPPs with its own designs, namely OPR 1000 and APR 1400.[5] Therefore, the Korean 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 that are very useful for developing countries pursuing their first NPP project. On this ground, the history and processes of the Korean nuclear power programme are described in this report with highlights on the successes and mistakes.

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[9] The net capacity factor of a NPP is the ratio of the actual output of a 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 a NPP is the ratio of the amount of generation time over a period, to the time length of the entire period.

## VI.2. Essential Lessons – A Brief Overview

This chapter is intended to give a brief overview for readers who want to learn the essential lessons from the Korean nuclear power programme. However, it is recommended that those who are involved in the national nuclear programme development read the full information provided in chapter 3. This Appendix is extracted from *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. Authored by Sung Yeol Choi (choisys7@snu.ac.kr), Eunju Jun and Il Soon Hwang.*

### *VI.2.1. Integration of diverse knowledge and experience*

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

For the establishment of the NEPIO, not only scientists and engineers but economists, lawyers and psychologists are required. The Korean NEPIO established in 1960's 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, diplomacy and more. 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 collaborations with many domestic and international organizations. It was fortunate for Korea to stand on a strong national consensus and a firm governmental commitment to the programme. The Korean government has been determined to implement the nuclear energy as a vehicle for introducing advanced science and technology as well as for meeting the soaring demand on electricity. The first President of Korea, Sungman Rhee, moved to make agreements with the USA and the IAEA in an effort to obtain much needed international supports. The Atomic Energy Department was soon established in the Korea government directly under the President with the authority to plan and to promote the programme without major administrative obstacles. Because the utmost mandate of Korean nuclear power programme was to deliver safe, economical and stable electricity, the strong nation-wide commitment was maintained for approximately forty years since the establishment of NEPIO.

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

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, a NPP could not even start its operation without a commensurate basis of the 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 of heavy and chemical industry (HCI), a country may not succeed in the localization of the nuclear power technology.

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

### *VI.2.4. Strategies for securing manpower and establishing a self-reliant education system*

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

To immediately secure high-quality human resources, the government guaranteed high positions and salaries for qualified personals coming from other field 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 an up-to-date education and training could not be effectively provided in Korea and began overseas training for young talents.

To establish a long-term human resources development programme, the Korean government launched undergraduate nuclear engineering departments in universities from the early period. The brightest and most enthusiastic students rushed into this new, exciting field with strong government support. Moreover, the government provided grants to encourage nuclear research in 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 scientific and technology in modern Korea. With the return of the first wave of overseas trainees, Korean universities could 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 Korean government correctly assessed and concluded that domestic industries were not capable for meeting the requirements of nuclear quality assurance for the construction of NPPs. This was why Korea 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 the foreign contractors. KEPCO gradually increased the role of domestic industry but as sub-contractors to foreign main contractors. From this stage, the Korean technology transfer approach has started in an approach that can be best described by "On the Job Training (OJT)" and "On the Job Participation (OJP)" under the direction of foreign suppliers. KEPCO developed the NPP localization plan for the completion of Korea's 4$^{th}$ plant by starting a non-turnkey basis contract for the NPP. The plan was carried out in a close collaboration with foreign vendors for the development of a standardized NPP for Korea. With the growing experience of construction, operation and localization, KEPCO undertook the main contractor's role for the 10$^{th}$ NPP in 1987.

This localization policy contributed not only to saving foreign currency but to increasing the capacity factor with the faster supply of spare components from localized suppliers. Quality management responsibility at local suppliers also became a strong driving force to improve the quality of both nuclear and non-nuclear products; leading to Korea's trading competitiveness. This benefit of nuclear power technology transfer propagated into other industrial sectors including steel-making, ship-building as well as 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 vast amount of 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 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 a NPP. Korean news media closely followed this trend and reported important issues in the nuclear industry. Many intellectuals described, by writing in news media, about how Korea can 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. NEPIO effectively utilized the information network for the development of the Korean nuclear power programme. Whenever 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 the people from various organizations. The investigation team visited key organizations in advanced countries to collect information and check their policies and 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 experiences of NPPs, and the process of site selection, fuel cycle policy, strategy of securing nuclear fuel, and financing options for NPP.

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### *VI.2.7. Slow preparation of a safety regulatory system*

With the confirmation of the first NPP construction plan, the Korean 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 manpower shortage, most technical rules were borrowed from the countries of the reactor's origin, the USA. In parallel, Japan, an industrialized neighbor, was a model for Korea's government-driven economic development programme. As a consequence, the legal framework of the Japanese nuclear power programme was also introduced. Coexistence of different rules between USA and Japan caused conflicts and confusions 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 Korean experience highlights the importance of early development of a regulatory frame work 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) & Operational phase (until 1990) |
|---|---|---|
| **1956**<br>-Delegation to the First ICPUAE<br>-ROK-US Atomic Energy Agreement (the first international agreement)<br>-Establishing Atomic Energy Section<br>-First Exhibition for Atoms for Peace<br>**1957**<br>-Joined as a member of International Atomic Energy Agency<br>**1958**<br>-Enacted Atomic Energy Act<br>-Established Atomic Energy Departmen<br>-Established Department of Nuclear Engineering at Hanyang University<br>-Contracted for the First Research Reactor<br>**1959**<br>-Opened Atomic Energy Research Instit<br>-Established Department of Nuclear Engineering at Seoul National University | **1961**<br>-Established KEPCO (owner/operator)<br>-Promoted long-term plan for NPP<br>-Launched the First Five Year Economic Development Plan<br>**1962**<br>-Launched First Five Year Electric Power Development Plan<br>- Operation of the first Research Reactor<br>**1964**<br>-Started NPP Site Evaluation and Selection<br>**1966**<br>-Confirmed Site for NPP<br>**1967**<br>-Established Ministry of Science and Technology<br>-Established Office of Atomic Energy<br>**1968**<br>-Confirmed Long-term Plan for National Nuclear Power Programme<br>-Invited Bid for the first NPP<br>-Signed NPT | **1970**<br>-Signed the contract for the first NPP<br>**1971**<br>-Started the construction of Kori1, the first NPP, on turnkey basis<br>**1975**<br>-Entry into force of NPT<br>-Joined Comprehensive Safeguards Agreement (CSA)<br>**1976**<br>-Signed the contract of Kori 2<br>**1978**<br>-Started the operation of Kori 1, the first NPP<br>-Signed the contract of Kori 3, 4th NPP on component approach, non-turnkey basis<br>**1981**<br>-Established Nuclear Safety Center (regulatory body) under KAERI<br>**1986**<br>-Started seeking nuclear waste sites<br>**1987**<br>-Signed the contract for Yonggwang 3&4 NPP, with KEPCO as the prime contractor<br>**1989**<br>-Joined COCOM<br>**1990**<br>-Established Korea Institute for Nuclear Safety (regulatory body)<br>**2005**<br>-Acquired sites for LILW |

*FIG.1 Chronological Table of the Korean Nuclear Power Programme*[10]

[10] Please find ABBREVIATIONS on the last page of this document.

## VI.3. The History And Process Of Korean Nuclear Power Development And ITS 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 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 that it takes to pursue the full implementation of a nuclear power programme. [6]

The IAEA Milestones document 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 a difference stage 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

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

| Organization | | Role and Function in a Nuclear Power Programme |
|---|---|---|
| AED | AEC | Ultimate Decision Making Commission |
| | 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 Generating and Electric Grid Programme |
| Economic Planning Board | | Deciding Budget of Country and Support of Nuclear Power Programme with Economic Knowledge Base |
| University | | Human Resource Development and Basic Research |
| Industry | | Participating in a Nuclear Power Programme with Own Special Field |

**Human resources development**

Human resources development was one of the top priority tasks of the Korean government. With limited human resources on radiation protection and application strategy, it was difficult to launch domestic education systems on nuclear engineering. This was when the Korean 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 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 light from nuclear power 20 years later.”[11] [18]

With Cisler’s advice, the Korean government fully 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 who were drawn from informal study group. They were the only available human resources in 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 Korea hoped that education of young scientists and engineers is the most important task.

The government soon realized that up-to-date education and training could not be provided within Korea 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 human resources development plan mainly consisted of overseas training programme for 200 people. From 1955 to 1964, 237 persons were trained abroad. Among these, 127 persons were funded by the government and 80 persons were supported by the IAEA, 3 persons were on the Colombo plan and 27 persons were sent by other overseas aid. [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 Korean government also implemented a domestic system by launching undergraduate education. Nuclear Engineering Departments had been established in 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 in overseas universities or research institutes or domestic AERI after their graduation with a B.S. degree. It was about ten years later, upon the return of the first graduate students from their overseas studies, when engineering subjects, including nuclear reactor analysis, design, material, chemical, and waste disposal, could be taught at universities. [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 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 basic salary, research allowances and danger allowance in order to attract high-quality manpower working in universities and other domestic and overseas industries and research institutes. The location of the nuclear power programme institution also played

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[11] This is translated from Cisler’s speech written in Korea.



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an important role to attract human resources. Specifically, AERI was located near the Seoul National University campus to promote convenient collaboration with competent human resources in a reputable educational institution. Moreover, the government provided grants to encourage nuclear technology research in 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 nuclear power programme. [10]

The initial human resources development efforts are summarized below in Table 2. Also, Table 3 shows the history of the domestic education system, especially universities, over the entire period.

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

| Date | Activities for human resources development | Note |
|---|---|---|
| 9 April 1956 | 1st ISNSE | 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 Nuclear Engineering Department in 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 nuclear engineering department in Seoul National University | |
| 9 January 1959 | 9th ISNSE | 2 persons: France 2 |
| 1 March 1959 | The opening of AERI | |
| 15 July 1959 | 1st Nuclear Science Council | The predecessor of Korean Nuclear Society: one time per year |
| 6 August 1959 | 10th ISNSE | 22 persons |

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

TABLE 3. THE ESTALISHMENT OF THE DEPARTMENT OF NUCLEAR ENGINEERING[12] [20]

| Year | University which established the department of nuclear engineering |
|---|---|
| 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 |

**Stakeholder Involvement**

It is important to evaluate stakeholder involvement for defining and pursuing nuclear power programme goals. Since 1956, the UK and the USA began the first operation of commercial NPPs. This stimulated many countries into the development or planning of commercial NPPs. The Korean news media closely followed this trend of world nuclear energy. In the daily newspaper, journalists reported important advancements in nuclear energy and many intellectuals wrote editorials about how Korea would be changed and could advance in the world trend. Also, many magazines provided the public with a great deal of information about the internal and external situation through featured articles. Peaceful atomic energy became the focus of public interest. The Korea-U.S. Atomic Energy Agreement[13] further prepared the Korean public to expect the introduction of an NPP.

The government held an exhibition on the use of peaceful atomic energy to gain further support from the public. Photos and models provided by the US government were displayed for 6 days in 6 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 deadly atomic bomb and realizing how nuclear technology could be used in a peaceful manner. [12]

**Industrial Involvement**

Nuclear facilities require much higher quality assurance than other industrial systems. The NEPIO and industrial leaders exploring the involvement of domestic industry in a nuclear power programme had to fully examine accumulated experiences and abilities to meet the high quality standard Korea had virtually no industrial basis with high quality in the initial phase despite the fact many construction companies seriously wanted to obtain any opportunities in the emerging new business. Korea established a “learning by participating” strategy for helping domestic industry accumulate experiences by strictly-controlled participation.

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

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[12] This does not include specialized schools only for non-electric uses.

[13] The official name is 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.



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However, even with the restricted involvement, domestic industry participants were found to cause delays in schedule. The cost increased due to insufficient industry experiences handling a large and technically-demanding project. It was very difficult experience for NEPIO even though the construction of a research reactor is a very small project compared with that of a commercial nuclear power plant. 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 upon 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-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 Korea's programme. As a neighboring country many of Korean citizens were killed or injured in the first atomic bomb detonations in Japan. Nuclear power was associated with the dreadful image of atomic bomb which had the effect of naturally forming the safety culture for nuclear reactor facilities in Korea. However, the shortage of trained manpower did not allow the preparation of a dedicated organization for the nuclear safety regulation during phase 1.

With the widespread fear of radiation and atomic bomb, 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, supervising and penalties were explicitly defined as nuclear-specific provisions, distinguished from other provisions for general industrial activities.

***VI.3.2. Phase 2 (from 1961 to 1968): Preparatory work for the construction of a nuclear power plant after a policy decision has been taken***

**Human Resources Development**

In the early phase, with few domestic experts in the NPP, the development of human resources was trusted to two major activities; sending trainees abroad and inviting experts for lectures, reviews and research. The young talented trainees had been trained in the USA and Europe. The wide range of information, which they brought in, led to thoughtful decisions for selecting the first nuclear power plant and reactor types.

From 1955 to 1964, Korea sent 237 persons abroad, but only 150 persons returned to Korea. (Table 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, Korea's most preferred field, and decided to take better jobs overseas. To solve the problem, in 1961, the government imposed return obligations on all government scholarship students. [10] Students studying abroad on 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. [9]

TABLE 4. RETURN PEOPLE IN SENDING ABROAD FOR STUDYING NUCLEAR POWER [12]

| Sources / Year | Government | | IAEA | | ICA | | others | | The 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 |
| The Total | 129 | 81 | 135 | 101 | 10 | 9 | 36 | 13 | 310 | 204 |

When the first wave of trainees returned, Korea began domestic education by establishing nuclear engineering departments in universities and opening special lectures in government research institutes. International education experts were instrumental in establishing these domestic programs. For example, in 1960, the government invited an IAEA mobile laboratory for radioactive isotopes to operate in 4 cities for 4 weeks each. After the establishment of the Radiological Research Institute and Radiation Research Institute in Agriculture, the Korean government began domestic lecture programs on radiation for medicine and agriculture that were offered twice a year. [9] In 1968, when a detailed plan for nuclear power construction was confirmed, KEPCO assembled international and domestic experts to begin a specialized 6-week course titled “an elementary course on nuclear power plant operation” for training their staffs working in thermal power plant. From the end of phase 2 to the beginning of phase 3, many focused classes were held on nondestructive testing, quality evaluation of construction, systems and components of nuclear power plants, etc.

The initial university curriculum for nuclear engineering mostly consisted of atomic physics and radiation. Because of the shortage in professors, researchers from the 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 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 resource development since the first ICPUAE. [36] Many graduates of the new education programme entered national nuclear power programme organizations such as KEPCO to become today’s Korean 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 their advanced degrees in areas related to nuclear engineering. The government encouraged them to relocate to Korea by providing generous compensation for relocation.

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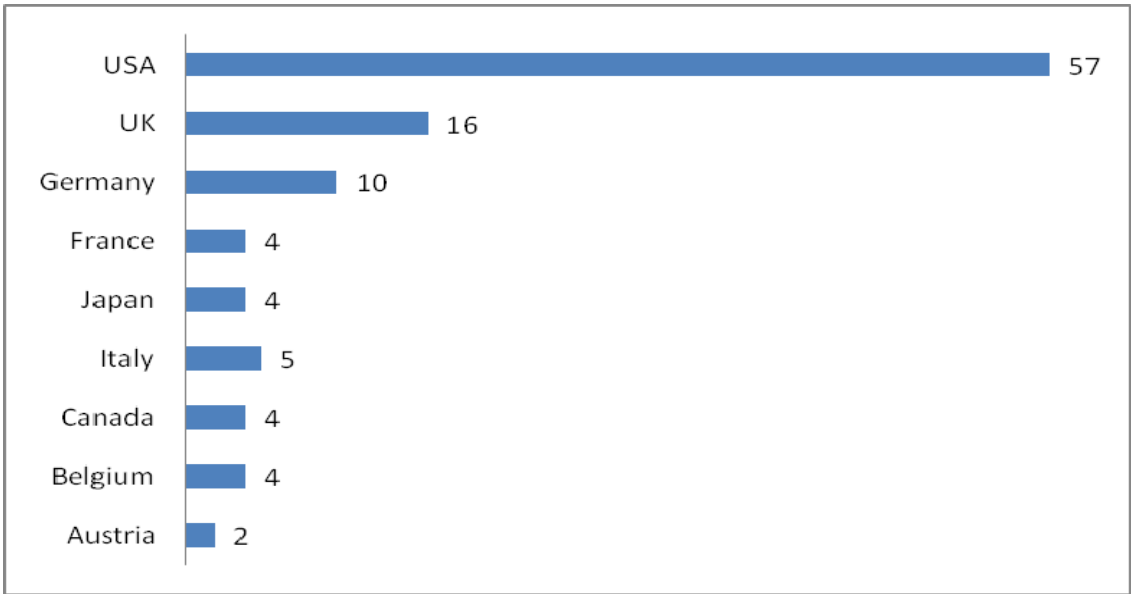


*FIG.1 The Geographical Distribution of People Studying Abroad in 1969*

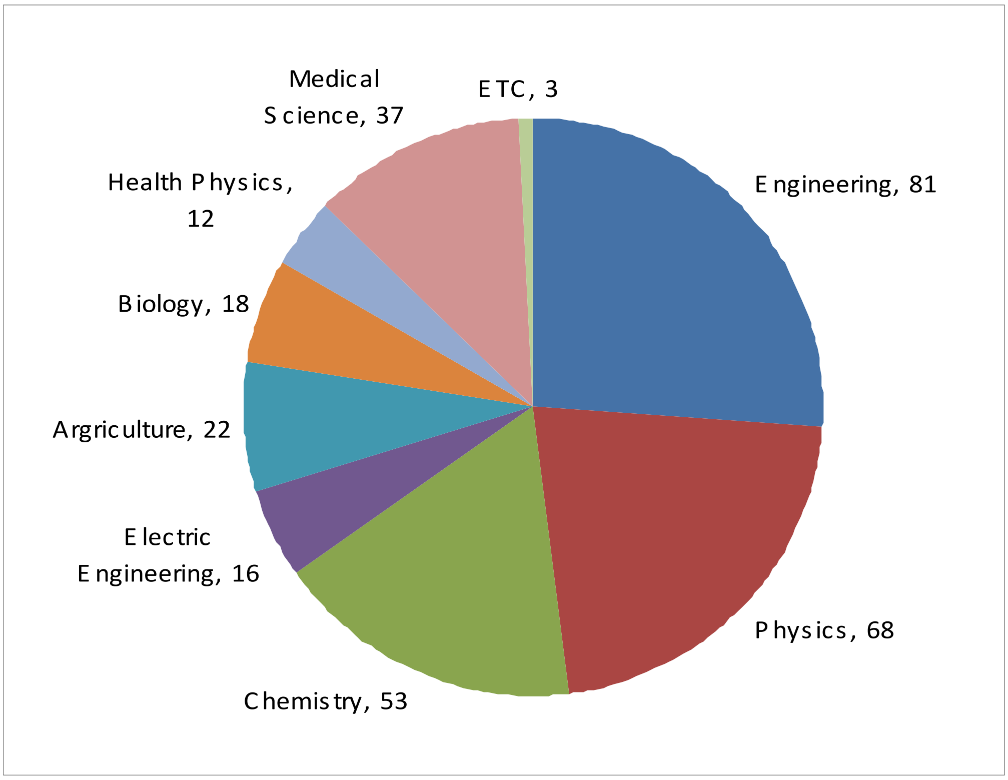


*FIG.3. Major Distribution of People Studying Abroad in 1969*

**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 of commercial, industrial, medical and agricultural use of nuclear power. In addition, a public lecture and a symposium were held in 3~4 cities a year starting in 1962. Through these efforts, the government wanted to remove the war-stained image of nuclear energy among the general public and industries and demonstrate the peaceful use atomic energy.

The government published easy introduction books for the public, “You and Atomic Energy”, “Atomic Energy Class”, and “Atomic Energy Story” and translated academic books for students and intellectuals and pamphlets which were published by the US Atomic Energy Commission for public enlightenment. 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 in domestic and foreign countries. In the 1960s, TV was not widely available. Hence, newspapers and books were the most important mass media used to inform the public. [9]

**Industrial Involvement**

In planning for nuclear power plant construction, the Korean 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 Korea decided on a turnkey contract for the first NPP. Under a turnkey basis bid specification, participation of the domestic industry was 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 enhancing the ability of HCI, the participation of domestic industries expanded from a peripheral role to core technology. Korea’s industry participation can be described simply as “Learning by Participating” as will be described in phase 3 under HCI development. [41]

**Procurement**

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

**Nuclear Safety**

Korea introduced provisions of licensing and supervision in the Atomic Energy Act and reflected the ICRP and other authorized international standards 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. [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. Korea 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 1969 to 1978) & Operational Phase (1979): 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 over the next 20 years. Based on the plan, the Nuclear Training Center was established in KAERI in 1967. This institute not only developed human resources but also helped technology transfer and cooperation



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among research institutes and industries. The KAERI Nuclear Training Center helped in human resource development of government and private industries at the various stages from elementary knowledge of nuclear power to regulation for domestic industry and government organization. [39] This human resources development role steadily expanded from research institute to private training programme, facilities, and courses of nuclear industries.

Moreover, in 1979, KAERI Nuclear Training Center invited IAEA experts for a lecture titled "Training Course on Safety Analysis and Review for Nuclear Power Plants". As well as the IAEA, many 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 1,511 students. There were Korean lecturers who provided course overviews and summaries to overcome the language barrier. Also, all foreign lecturers prepared presentation materials in a uniform context. Korean lecturers later localized the course by becoming post-lecturers to their own classes. [15] After the PWR was confirmed as the first NPP, KEPCO frequently sent staff to a PWR plant in Japan. In addition, Kori1 set up a sister plant relationship with the Genkai plant and made regular visits. [11]

With the expectation of commercial NPP operation in Korea, KEPCO estimated that about 170 people were needed for its operation but secured only 92 people by the end of 1972. KEPCO contracted with WEICO for training on operations and control to repair and 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 Kori1 site. Table 5 summarizes overseas training programmes during the construction period of Kori1. [8] [47]. Table 6 shows KEPCO training courses for new plant operators including domestic and overseas.

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 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 Korea regulation work. [43]

TABLE 5. OVERSEAS TRAINING PROGRAMME IN KORI1 CONSTRUCTION PERIODS FOR KEPCO STAFF

| Fields | Personnel | Period | Note |
|---|---|---|---|
| Planning | More than 2 persons a year | 1968.7- | |
| Executive | 21 | 1970.3-11 (9months) | Training with WEICO |
| Technical aids and components (spare) | 20 | 1971.3-11 (9months) | |
| Repair | 45 | 1971.3-11 (9months) | |
| Operation (Control) | 85 | 1972.8-1973.4 (9months) | |

TABLE 6. KEPCO TRAINING COURSES FOR NPP OPERATORS

| Steps | Contents | 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 | Start-up training in new NPP | 12 months |
| TR-6 | Supplementary education | 1 week ~ 3 months |

**Stakeholder Involvement**

After India developed nuclear weapons, the Nuclear Supplier Group (NSG) formed the London Club which limited sensitive technology transfer and requested international confidence of each country's nuclear power programme. Korea 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. [9] [15]

During the construction of Kori1, Korea and the USA closely cooperated and agreed to launch the Korea-US Joint Standing Committee on Nuclear and Other Energy Technologies in 1976. Also, Korea established the Joint Consultation Committee with France and Canada prior to the operation of the fuel fabrication facility and Wolsung1. [8]

**Industrial Involvement**

Only turn-key basis contracts were employed for the first three plants. As Kori1 was constructed on a turnkey basis, domestic industries and technicians participated in civil engineering, construction and nondestructive testing[14]. 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, Korea put architect engineering on the localization front and fostered its manpower. Korea established Korea Atomic Burns and Roe (KABAR) with Burns & Roe as a local architect engineering 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. [49] KNE began participation as a sub-contractor to the engineering design and construction of the fifth NPP.[15] KNE staff received training from Bechtel Corporation, the primary architectural engineering contractor, before participating in actual project. All of the contracted architectural engineering companies were required joint engineering work with

[14] Hyundai Engineering and Construction Co, Ltd.: Sub-contractor in the Reactor System, Dong Ah Construction: Sub-contractor in Turbine Generator, Yuyang Atomic Energy: Main Contractor in Nondestructive Testing.

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

KNE. In the 1980's, domestic companies became the main contractors with foreign companies as sub-contractors.

In addition, the government established the localization policy not only for engineering but also for NPP components. The government classified NPP components by localization feasibility per component, importance, and target schedule. Private enterprises were established for developing 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 positive impact also brought very positive influence in the steel-making industry and the ship building industry. [9]

Table 7 and Table 8 below indicate contract conditions and localization portions in Korea's NPP construction respectively. A "Learning by participating" strategy also applied in commercial NPP construction.

TABLE 7. THE CONTRACT CONDITIONS OF NUCLEAR POWER PLANTS IN KOREA[16] [50]

| Plant | Type (MWe) | NSSS (Sub) | TG (Sub) | AE (Sub) | Date Order | Construc-tion Start | Commi-ssioned |
|---|---|---|---|---|---|---|---|
| Kori1 (Turnkey) | PWR (587) | WEICO | GE | Gilbert | 1969 | November 1971 | April 1978 |
| Kori2 (Turnkey) | PWR (650) | WEICO | GE | Gilbert | 1974 | May 1977 | April 1983 |
| Wolsung1 (Turnkey) | PHWR (679) | AECL | NEI | Canatom | 1973 | May 1977 | April 1983 |
| Kori3 | PWR (950) | WEICO (KHIC) | GE (KHIC) | Bechtel (KOPEC) | 1978 | April 1979 | September 1985 |
| Kori4 | 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 |
| Ulchin1 | PWR (950) | Framatome (KHIC) | Alsthom (KHIC) | Framatome (KOPEC) | 1980 | March 1982 | September 1988 |
| Ulchin2 | 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 |

[16] Sub (Sub-contractor), NSSS (Nuclear Steam Supply System), TG (Turbine Generators), 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 8: LOCALIZATION PORTION OF NUCLEAR POWER PLANTS (%) [50] [17]

| Unit | NSSS | TG | BOP | CE | AE 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 |

**Procurement**

The first three NPPs were contracted on a turnkey basis which allowed limited domestic participation. From the 4th NPP, the contract terms were specified to ensure a certain level of localization with the approval of foreign contractors. The localization portion was increased with time. All of the localized components were required to pass inspection in accordance with the same standard as 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 sub-contractors.

From 4th to 9th NPP, these projects were contracted on the non-turnkey, component approach basis, which was defined that 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 sub-contractors under their supervision. This contract scheme had greatly stimulated not only to expand the localized portions but also to speed up the nuclear technology transfer.

From 10th NPP, Yonggwang 3 and 4, KEPCO decided to pursue an ambitious plant standardization programme based on the construction experiences of NPP with the same authorized power, 950MWe from third unit to ninth unit. Korea succeeded to construct Yonggwang unit 3, 4 as the reference plants of Korea Standard Nuclear Power Plant. Ultimate responsibility of NPP performance was placed on the main contractors, which promoted active participation of suppliers according to the localization policy. It allowed performing most design & engineering work, construction, and maintenance services by local companies, and further procuring most NPP components, from domestic suppliers.

**Nuclear Safety**

The IAEA Milestones document emphasizes 9 items for establishing nuclear safety infrastructure. They include operator skills and attitudes; management systems; safety culture; legal framework; regulatory independence, competence and authority; technical competence; financial stability; emergency preparedness; and international connectivity. These issues were already discussed other parts in this document.

[17] Localization portion is defined as the amount money of domestic suppliers' involvement to the amount of the total construction cost in NSSS, TG, BOP, and CE, and AE is defined as a man-hour of domestic manpower involvement in AE.



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## ABBREVIATIONS TO APPENDIX VII

| | |
|---|---|
| AE | Architectural Engineering |
| AEC | Atomic Energy Commission |
| AED | Atomic Energy Department (1958-1967) |
| AERI | Atomic Energy Research Institute |
| AES | Atomic Energy Section (1956-1958) |
| AFR | Away From Reactor Storage |
| AP | Additional Protocol |
| APR 1400 | Advanced Power Reactor 1400 |
| BO | Bureau Office |
| BOP | Balance of Plant |
| BWR | Boiling Water Reactor |
| CE | Civil Engineering |
| COCOM | Coordinating Committee for Multilateral Export Control |
| CP | Construction Permit |
| CSA | Comprehensive Safeguards Agreement |
| EIBUS | Export-Import Bank of the United States |
| FSAR | Final Safety Analysis Report |
| GA | General Atomic |
| GNP | Gross National Products |
| HCI | Heavy and Chemical Industry |
| HLW | High Level Waste |
| IAEA | International Atomic Energy Agency |
| ICA | International Cooperation Administration |
| ICNFD | Industrial Complex for Nuclear Fuel Development |
| ICPUAE | International Conference on the Peaceful Uses for Atomic Energy |
| ICRP | International Commission on Radiological Protection |
| INFCIRC | Information Circular |
| 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) |
| OAPEC | Organization of Arab Petroleum Exporting Countries |
| OP | Operational Permit |
| OPR 1000 | Optimized Power Reactor 1000 |
| PHWR | Pressurized Heavy Water Reactor |
| PSAR | Preliminary Safety Analysis Report |
| PWR | Pressurized Light Water Reactor |
| ROK | Republic of Korea |
| SSAC | State System of Accounting for and Control of Nuclear Material |
| SNF | Spent Nuclear Fuel |
| SOC | Social Overhead Capital |
| TCNC | Technology Center for Nuclear Control |
| TG | Turbine Generators |
| UKAEA | United Kingdom Atomic Energy Authority |
| USAEC | US Atomic Energy Commission |

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# APPENDIX VII. INDIAN CASE STUDY

# APPENDIX VIII. UNITED ARAB EMIRATES

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# APPENDIX IX. ARMENIAN CASE STUDY

## APPENDIX X.

## MODELING WORKFORCE DEVELOPMENT FOR NEW NUCLEAR POWER PROGRAMS

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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 help understanding and inform decisions on issues related to implementing a new program or setting the course for an existing program.

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

The nuclear power program model discussed below is constructed in the 'iThink' systems dynamics software by 'isee' systems.[18] 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 reflect 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.

### A Model Of A Nuclear Power Program

A viable plan for nuclear power requires power plants, workforce, and fuel services to be developed in a coordinated fashion, or the program runs the risk of failure to produce power as scheduled or costly actions to mitigate mismatches. The nuclear power program model discussed here consists of linked sub-models of workforce, infrastructure, and fuel cycle. These sub-models 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 program 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 lifecycle of nuclear power plants, namely design, licensing, and 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.

[18] See www.iseesystems.com



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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 labor and skilled labor. Craft labor categories included in the model are shown in Table 1 with the peak staffing required for a 1000 MWe power plant. Craft labor 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 labor is modeled 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 labor 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 aging demographics of the experienced workforce. The engineering workforce is thus modeled in greater detail, with educational pipelines, career paths, and retirement represented. The skilled labor workforce is limited by the educational capacity and retirement rates. The model has the ability to examine alternative approaches to workforce training, outsourcing, and sensitivity to retirement policy.

TABLE 1. PEAK CONSTRUCTION CRAFT LABOUR REQUIREMENTS [19].

| **Craft Description** | **Craft Percent** | **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** |

**Inputs to the model represent specific country cases**

The model represents a generic nuclear power program. To model the nuclear power program of a 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

[19] MPR, "DOE NP2010 Nuclear Power Plant Construction Infrastructure Assessment", MPR-2776 (2005).

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 2.

TABLE 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, 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, license 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 labor 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 |

**Running the model – Uncertainties and decisions in the nuclear program**

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 program. These controls were designed based on uncertainties that warrant evaluation, several key decisions in the U.S. power program, and key decisions for a new program.

Uncertainties that can be evaluated in the current model are:

Growth rate for electrical demand – the data includes 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 the 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 design of the plant, but also by delays due to weather and supply, or 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 the attrition during education from 20% to 70%.

Key options facing the U.S. nuclear program that are modeled are granting life extensions to the current fleet of reactors, replacing the current fleet as they reach the end of their lives (with or without an extension), and building the plants currently in the planning and licensing phase. For existing and for new programs, the decision to expand



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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 modeled provide a very flexible tool that can be used to examine a large range of potential programs.

### 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, workforce is generated to meet 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 lifecycle; applications, construction, operation, and decommissioned.

Workforce is determined in multiple categories and phases. The number of craft labor workers in the categories shown in Table 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, the model can generate the fraction of workers approaching retirement, new hires, and anticipated future needs.

### Examples from US case and new program 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.

Figure 1 and Figure 2 illustrate how a combination of different factors can lead to very different answers for questions regarding overall nuclear power program objectives. In the two figures, two cases are shown for the U.S. power industry, with the U.S. electrical demand shown in Figure 1 and the installed nuclear capacity in Figure 2. In the case illustrated with blue curves (marked 1), the growth rate for electrical power is the current projected rate of 1%[20], 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 behavior in the system starting in year 12 (year 1 being 2009). The implication of this difference is 50% more license 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 behavior is not seen in a representative new program, 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 program will drive the associated workforce requirements.

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[20] “Annual Energy Outlook 2008 with Projections to 2030, Electricity Demand”, Energy Information Administration, http://www.eia.doe.gov, 2008.

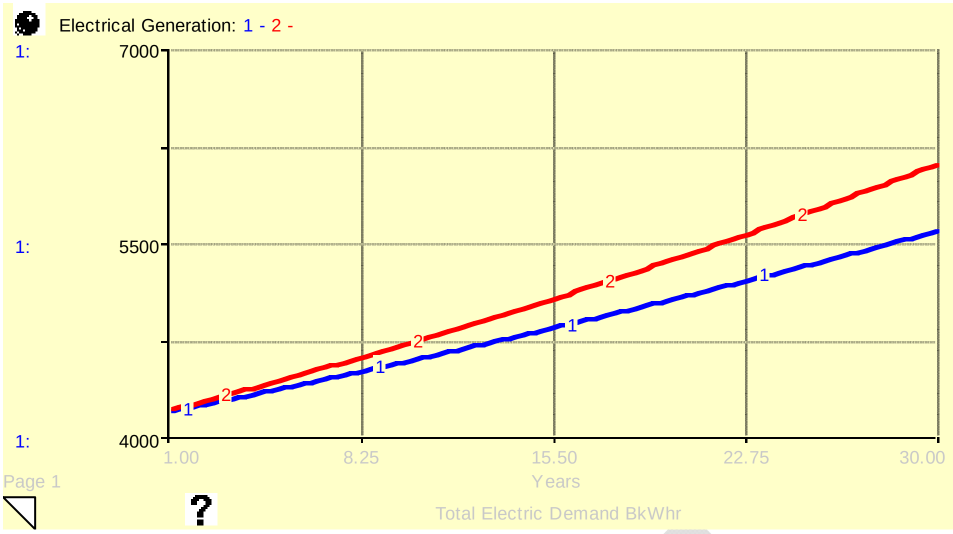


*FIG.1. Power demand for the U.S. with current projected electrical growth rate (blue curve, marked 1) and for a higher growth rate (red curve, marked 2).*

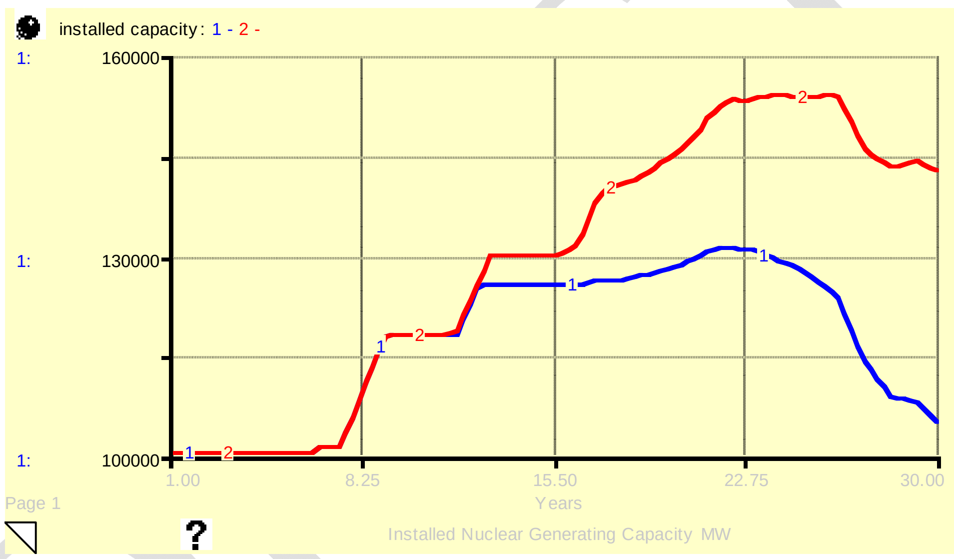


*FIG.2. Installed nuclear power capacity for the U.S. with varying electrical growth rate as in Figure 1 and nuclear market share of 20% (blue curve, marked 1) and with nuclear market share of 25% by 2030 (red curve, marked 2).*

Alternatively, given program objectives, the model can be used to examine the effects of technical decisions on human resource requirements. For example, Figure 3 shows the skilled workforce requirements for the U.S. program for 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 9 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 2020's 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, etc.) and require reduced staffing. As a result, the larger market share is achieved with the same or lower workforce demand as the baseline case, and a lower growth rate would be required in the educational pipeline.

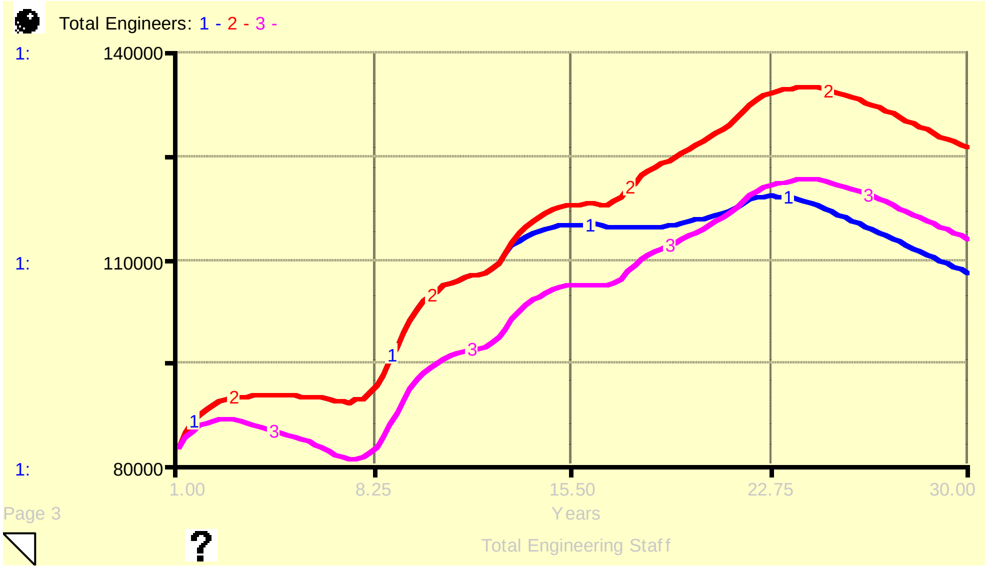


*FIG. 3. Skilled workforce requirements for the U.S. case under three scenarios.*

A related issue particular to new programs 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 lifecycle of the nuclear power plant. In Figure 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 program; if construction delays occur, a strategy is needed to retain the skilled workforce until the plant is ready.

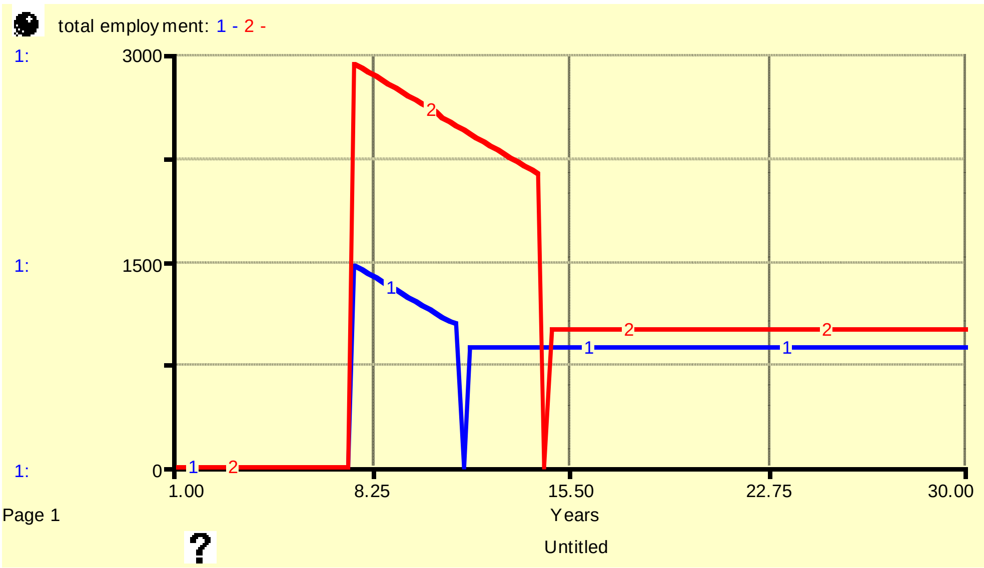


*FIG. 4. Total workforce required for a new program with and without a construction delay.*

A wide variety of other timing and staffing issues associated with the construction workforce may be examined using this model. For a new program a large craft labor 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 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 labor might be appropriate to consider – and the impact of those decisions fed back into the model.

**Conclusion**

Models are useful tools for investigating how a system might behave under various conditions. In this paper we have demonstrated a model of a nuclear power program 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.

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

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