The Role of Research Reactors in Introducing Nuclear Power

A. Introduction

Throughout the second half of the twentieth century, many countries saw research reactors as an essential step towards building their first nuclear power plants (NPPs). Times have changed; industrial experience and globalization now significantly facilitate the exchange of information and collaborative resource development. Nonetheless, in certain situations and provided that additional applications of the research reactor are well planned, a research reactor can still be a useful step towards nuclear power. This annex describes situations where a research reactor programme might contribute to the introduction of nuclear power, and how its utilization can be well planned.

Research reactors fulfil diverse needs, including medical and industrial isotope production, elemental analysis, silicon doping, neutron beam based science and applications, education and training, scientific research, and technology development (this includes support for existing and advanced nuclear power technologies). While a research reactor is not a prerequisite for nuclear power, the infrastructure developed to support the construction, regulatory approval, operation, maintenance and eventual decommissioning of a research reactor can help a country to introduce nuclear power.[1] The infrastructure necessary for a research reactor is similar to that required for an NPP but often differs in scale. In addition, certain research reactor capabilities directly or indirectly support the development and implementation of nuclear power. Experience from managing nuclear material at research reactors promotes a better understanding of the infrastructure and issues that need to be addressed in the field of nuclear power.

Because the countries that now have nuclear power had access to operating research reactors before commissioning their first NPPs, several countries currently seeking to embark on nuclear power programmes for the first time are also considering either building their own research reactors or joining an existing research reactor coalition as a stepping stone towards nuclear power. In Morocco, for example, staff with experience from a project to build a new research reactor are now directly involved in their country's nuclear power planning. In contrast, the United Arab Emirates has taken a different approach and has contracted for its first NPPs without having previously operated a research reactor.

Countries considering the introduction of nuclear power may find that the experience gained from running a research reactor and managing nuclear material helps to facilitate studies that will allow them to make a knowledgeable decision about the long-term commitments required for nuclear power. The Agency's 'Milestones approach'[2] identifies 19 distinct national infrastructure issues to be addressed by countries considering the introduction of nuclear power programmes (Ref. V-1). Having a research reactor or other facility with nuclear material may mean that a country has already made progress on some of these issues, for example safeguards accountancy, nuclear security and regulatory oversight.

In particular, an existing research reactor programme and supporting infrastructure, when managed in accordance with international standards and accepted practices, can help in developing the

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[1] The same is true in the case of building a first nuclear reactor for seawater desalination, heat energy production or other non-power purpose. The observations in this annex also apply to those applications.

[2] The publication *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA Nuclear Energy Series No. NG-G-3.1, Vienna, 2007) identifies three phases of infrastructure development, each with its own 'milestone'. Milestone 1 represents sufficient analysis of those 19 issues to enable a country to consider itself ready to make a knowledgeable commitment to a nuclear energy programme. Milestone 2 represents the necessary accomplishments in the areas to which each issue relates prior to inviting bids for an NPP. Milestone 3 represents the necessary accomplishments in all of these areas to be ready to commission and operate a first NPP.

infrastructure, experience and expertise of interest to a country's nuclear energy programme implementing organization (NEPIO). Treaties, legal frameworks, emergency response preparedness, and waste management policies and plans are examples of research reactor programme infrastructure of potential interest to a NEPIO. Similarly, experience derived from operating and regulating a research reactor, managing its fuel cycle, training its staff, assuring safety, continuously improving programmes, and managing a large capital project provides the NEPIO with an important reserve of domestic knowledge to draw on. The pool of experienced staff within the research reactor operating organization, regulatory authority and associated government agencies is a source of beneficial domestic expertise as a country begins to form a NEPIO. In Slovenia, for example, practically all nuclear professionals in the country began their career or attended practical training courses at the research reactor at Podgorica, Montenegro. In Malaysia, technical staff from an electric utility are being trained by research reactor operators in preparation for introducing nuclear power.

Conversely, countries with underutilized or shut down research reactors that are not managed in accordance with international standards and accepted practices may have legacy issues to overcome before they can introduce nuclear power. Dysfunctional infrastructure, institutional inertia and laws, practices, policies and protocols unsuitable for commercial nuclear power may have to be revised to match the needs of a nuclear power programme. In this case, a prior research reactor programme might turn out to be a burden for the NEPIO, albeit one that must be addressed in any case.

The NEPIO will complete comprehensive reviews of all the issues to be covered before each milestone can be attained. The infrastructure, experience and expertise gained from one or more research reactors that have been safely and reliably operated, heavily utilized and well maintained could help in attaining milestones for several of the 19 issues specified by the Agency.

B. Selected issues for which research reactor programmes can pave the way for nuclear power

B.1. National position

The foundations of a country's national position on nuclear power are significantly different to those on which a national research reactor programme might rest. Government support may (and does) exist for research reactor programmes in countries politically opposed to nuclear power. For example, in Australia a new research reactor called the Open Pool Australian Light Water (OPAL) Reactor started operation in 2007, even though national policy there excludes nuclear power. Similarly in Germany, which established a nuclear power phase-out policy in 2000, the FRM-II research reactor at the Technical University in Munich was subsequently commissioned in 2005.

However, despite the apparent lack of linkage, many key infrastructure requirements related to Milestone 1 for a country's national position on nuclear power will have typically already been considered within the scope of a research reactor programme. This experience could help develop an understanding within a NEPIO, energy ministry or a public utility of:

- The need to ensure the safety, security and non-proliferation of nuclear material;
- The need to adhere to appropriate international legal instruments;
- The need to develop a comprehensive legal framework covering all aspects of nuclear law, which includes safety, security, safeguards and nuclear liability and other legislative, regulatory and commercial aspects;
- The need to have an effective, independent, competent regulatory body;
- The need to develop and maintain national human resource capabilities within both government and industry to successfully manage, operate, maintain and regulate nuclear facilities and nuclear material as well as preserve knowledge and expertise.

Similarly, in implementing the actions recommended for Milestone 2 for a country's national position on nuclear power, governments will benefit from the experience of a research reactor programme, but any measures adopted as part of the latter will likely have to be revised to support nuclear power. Examples include:

- The expansion of an existing regulatory body;
- The establishment and maintenance of an effective State system of accounting for and control of nuclear material to facilitate the implementation of the State's safeguards commitments;
- An established policy for the nuclear fuel cycle, including arrangements for secure supplies of fuel, safe and secure transportation and storage of new and spent fuel, and long term waste management;
- Established legal, organizational and financial arrangements for decommissioning and radioactive waste management;
- Programmes for the security of nuclear materials and facilities;
- Programmes for radiation protection and emergency preparedness and response;
- Adopted international standards for environmental protection.

B.2. Nuclear Safety

The operator's prime responsibility for safety is as important for a research reactor as it is for an NPP, as is the need for the government and all other stakeholders to appreciate what this means in practice. In particular, similarly stringent safety requirements must be implemented by both research reactor staff and nuclear power staff. The need for an effective regulatory body is just as important in both cases and is considered in a later section of this annex.

In most cases, countries with heavily utilized, well maintained and reliable research reactors will be able to easily demonstrate that programmes are implemented consistently with fundamental safety principles and other internationally recognized safety standards. Nuclear power newcomer countries with established research reactor programmes that are operated and maintained in accordance with such standards will generally already be participating in the global nuclear safety regime.

With respect to Milestone 1 for nuclear safety, relevant aspects of a research reactor programme may help a NEPIO achieve specific objectives. Examples include domestic expertise and experience in fostering and maintaining a nuclear safety culture, stakeholder involvement and participation in the global nuclear safety regime. The NEPIO will have to ensure that the safety culture is adequate for introducing nuclear power and take any necessary actions to instil a safety culture in stakeholders not normally involved with research reactors, e.g. utilities, industrial organizations and energy related government agencies (as opposed to those agencies involved in science and research).

With respect to Milestone 2, the requirements relate more specifically to nuclear power and the need to ensure that the relevant stakeholders adopt the proper practices and culture. However, expertise and experience from government organizations responsible for research reactors, from the research reactor regulator and from operating organizations could be used by the NEPIO to help ensure that all nuclear safety related objectives are satisfied.

B.3. Legislative Framework

Countries with an active research reactor programme are likely to have an existing legislative framework that may provide an adequate basis for the legislative framework needed to support nuclear power. Many international legal instruments that are necessary for nuclear power are also necessary for a research reactor programme. In any case, national legislation should comprehensively cover nuclear safety, security, safeguards and liability for nuclear damage.

A number of elements related to Milestone 1 will typically already exist for a research rector programme, but must still be reviewed by the NEPIO for possible revision to support nuclear power. Examples include:

- Established and effectively independent regulatory authorities and legislation dealing with

  - a system of licensing, inspection and enforcement,
  - radioactive material and radiation sources,
  - the safety of nuclear installations,
  - emergency preparedness and response,
  - nuclear related transport of nuclear material,
  - radioactive waste and spent fuel,
  - nuclear liability and coverage,
  - safeguards,
  - export and import controls, and
  - physical protection;
- Legislation dealing with the roles of the national government, local government authorities, the public and other stakeholders;
- Legislation dealing with fuel cycle issues in general and the ownership of nuclear material;
- Provision for the development of human resources to ensure the continued integrity of the nuclear programme;
- The commitment to use nuclear technology and techniques for peaceful purposes.

Likewise, for Milestone 2, elements of the required legislation for nuclear power will have been developed to support research reactors but will likely have to be revised. Examples include:

- Appropriate national legislation pursuant to the relevant non-proliferation undertakings of the State;
- Legislation that specifies the allowed ownership of nuclear facilities and nuclear materials; the legislation establishes clear responsibilities and liabilities for the operation of nuclear facilities and safeguarding of nuclear material;
- Legislation that establishes an effectively independent regulatory body with full authority to implement the functions assigned to it by the enabling legislation.

B.4. Regulatory Framework

A country embarking on a nuclear power programme will consider how to efficiently build on the national infrastructure already in place for radiation, waste and transport safety. Expanding the existing regulatory body for a research reactor so that it can also act as the regulator for an NPP may be the best way to utilize existing facilities and human resources that are likely to be limited in many countries.

With respect to Milestone 1, many fundamental elements of a regulatory framework will be in place to support an existing research reactor programme but must still be reviewed by the NEPIO for possible revision to support nuclear power. Examples include:

- Designation of an effectively independent regulatory body, with clear authority and adequate human and financial resources;
- Regulations for licensing, review and assessment, inspection, enforcement and public information;
- Authority to obtain technical support as needed;
- Authority to implement international obligations, including IAEA safeguards;
- Provisions for stakeholder and public information and interactions;
- Compatibility with the existing regulatory framework for radiation, waste and transport safety.

Similarly for Milestone 2, a number of important issues would be familiar to a regulatory body established for research reactors, but will also likely have to be revisited for nuclear power. Examples include:

- Safeguards;
- Nuclear and radioactive materials transportation, handling and storage;
- Radiation protection;
- Waste management, including disposal;
- Codes and standards developed or adopted for:
  - The import/export, transportation, storage and handling of nuclear and other radioactive material;
  - Radiation protection;
  - Waste management;
  - Emergency preparedness and response.

B.5. Security and Physical Protection

Nuclear security requires the concerted effort and commitment of all organizations involved in the planning, design, construction and operation of a nuclear research or power reactor. It is critical that these organizations acknowledge the importance of nuclear security and embrace a nuclear security culture. With respect to Milestone 1, an existing research reactor programme should demonstrate a country's commitment to a strong nuclear security culture. The NEPIO will work to ensure that the existing security culture is adequate for the introduction of nuclear power and take any necessary actions to instil a security culture in stakeholders not normally involved with research reactors, e.g. utilities, industrial organizations and energy related government agencies (as opposed to those agencies involved in science and research).

With regard to Milestone 2, several conditions should already exist in countries with a well managed research reactor programme. As is the case above, existing programmes will likely have to be revised to support nuclear power. Examples include:

- Legislation providing appropriate authorities for security and physical protection;
- Protocols and programmes for local and national law enforcement;
- Programmes for the definition of sensitive information, protection requirements and associated penalties;
- Laws providing for penalties for malicious acts, illegal possession and trafficking of materials, as described in international legal instruments;
- Programmes for the careful selection and qualification of nuclear programme staff with access to facilities or sensitive information.

C. Utilization Planning

Careful consideration is essential before committing to start a new research reactor programme to avoid unnecessary burdens, underutilization and the significant legacy issues currently faced by many research reactors worldwide. While a new research reactor programme can, over time, serve to facilitate the introduction of nuclear power just like an existing research reactor programme, experience suggests that the support provided by a new or existing nuclear power programme is inadequate on its own to sustain long-term research reactor operation. Most nuclear utilities develop customized training programmes, and nuclear engineers make up only a minor proportion of the workforce at an NPP (Ref. V-2).

The decision to embark on a research reactor programme and the decision to introduce nuclear power are similar in that both involve long-term commitments related to facility construction, operation, decommissioning and the ultimate disposition of all waste. A major important difference between the two, however, is the funding of operation, maintenance, waste management and decommissioning. Nuclear power plant financing and funding requirements are typically at least an order of magnitude greater than those of a research reactor. Even more important is the fact that NPPs generate revenues to cover these costs, while most research reactors are funded and operated with government funds. Most are not financially self-sustaining and require continuing government financial support throughout the entire period of operation and decommissioning.

The utilization plan for an NPP is straightforward. It should operate as consistently as possible with safe and secure programmes and procedures. For research reactors, utilization planning is less straightforward. A robust utilization plan is needed from the very beginning of the planning. Underutilized research reactors may struggle to justify and secure adequate funding to be properly maintained. This makes it harder to ensure adequate safety, security and environmental stewardship. A robust utilization programme and strategic plan can help to ensure sustainable funding to fulfil a country's or region's long-term needs in terms of research, education and training, isotope production and other related aspects. A research reactor constructed without a thorough utilization analysis could be faced with reduced utilization and funding cuts.

A research reactor constructed mainly or solely to support the introduction of nuclear power may lose its principal value after the first NPPs are commissioned because a nuclear power programme can be sustained without national research reactors. For example, nuclear power continues in Spain and Sweden although all their research reactors have been shut down. Also, following the breakup of the former Soviet Union and the division of Czechoslovakia, Armenia, Slovakia and (until 2009) Lithuania have maintained nuclear power without domestic research reactors.

On the other hand, some countries with nuclear power are reconsidering the role of their research reactors. For example, plans to shut down a research reactor at Imperial College, London, have been reversed at least in part to support human resource development for an expected expansion of nuclear power. Also, construction of a new training reactor is being considered in Sweden.

Figure V-1 illustrates that practical or vocational training is an important component of nuclear education and infrastructure development for nuclear power. In addition, formal training and education programmes must be established for people throughout the full range of a country's nuclear power infrastructure, i.e. students, engineers, operators, inspectors, regulators, managers and even the general public. Access to research reactors — particularly those designed to support training programmes — can help satisfy both formal and vocational education needs. Such access could be through a domestic research reactor or partnership in a research reactor coalition.

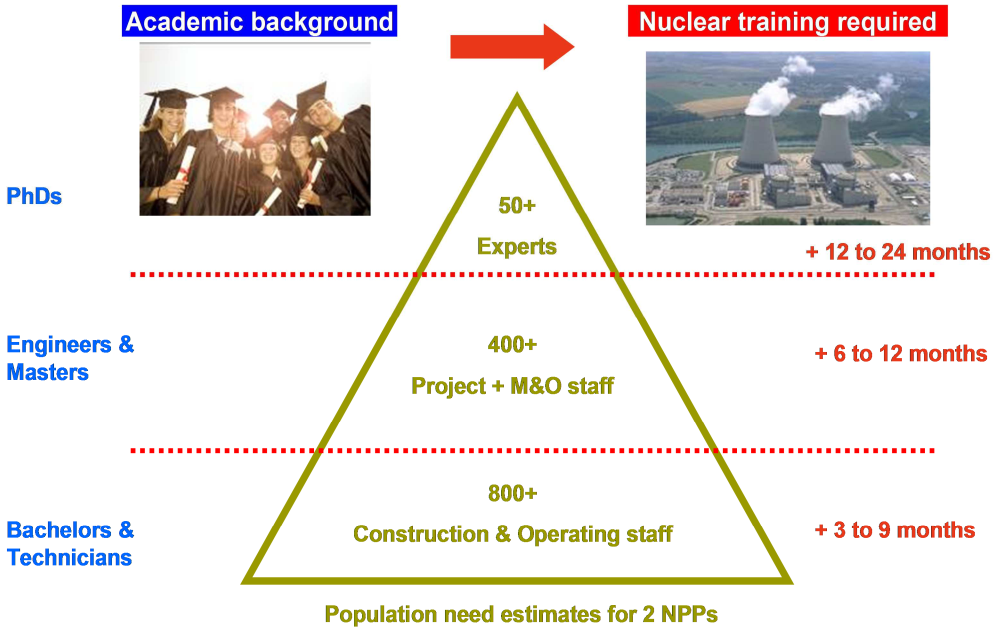

FIG. V-1: The need for basic academic qualifications (on the left) and supplemental specialized nuclear training (on the right) for staff at all required levels for building, operating and managing a first NPP with two reactor units. (M&O = operation and maintenance) Source: AREVA, France.

An example of a country using domestic research reactors in support of nuclear power is France. France uses a range of training methods that includes software applications, training research reactors and dedicated simulators. The combination of these different tools provides a comprehensive understanding of reactor design, physics phenomena, operation and safety principles. In this context, the ISIS research reactor of the French Alternative Energies and Atomic Energy Commission (CEA)'s National Institute for Nuclear Sciences and Technology (INSTN) in Saclay has been refurbished and adapted to be used for nuclear training. It now provides more than 100 hands-on training courses annually for nuclear and non-nuclear engineering students, reactor operators, safety authorities and nuclear industry specialists both from France and other countries. The Czech Republic uses a similar approach. Figure V-2 illustrates training courses at the VR-1 training research reactor of the Czech Technical University (CTU) in Prague.

Research reactor coalitions help countries that would like to support their nuclear power programmes with training at research reactors but are unable to justify operating domestic research reactors. Coalitions allow access to existing research reactors in other countries to help develop the necessary human resources and skills with little delay (see Ref. V-2). Such shared access can allow countries without research reactors of their own to take advantage of other countries' established infrastructure, including their competence in nuclear technology and their mature safety and security cultures.

FIG.V-2: Training courses at the VR-1 training research reactor of the Czech Technical University (CTU) in Prague.

Research reactors are well suited to this role. Many have utilization programmes specifically developed for nuclear related training and education and are often very willing to accommodate the needs of other countries. Austria, for example, has no nuclear power programme, but the research reactor in Vienna is a founding member of the East European Research Reactor Initiative (EERRI) and supports the nuclear education and training programmes of other countries. These include training NPP operators from other countries. Another example is in Jordan, where the Jordan University of Science and Technology is using a web-based video system to permit its nuclear engineering students to complete exercises and experiments as if they were present in the control room of a research reactor at the North Carolina State University in the USA.

Other examples include:

- The TRIGA Mark II reactor located at the University of Mainz, Germany. Here, a broad range of courses are offered related to nuclear engineering, including reactor operation and reactor physics, nuclear chemistry and radiation protection.
- The AGN-201K reactor at the Kyung Hee University, Republic of Korea. Between January 2009 and December 2010, 12 courses were completed at this reactor for 128 nuclear engineering students from 7 universities.
- The IPR-R1, TRIGA Mark I reactor at the Nuclear Technology Development Centre in Belo Horizonte, Brazil. Most of Brazil's NPP operators and other technical staff have been trained at the IPR-R1 reactor. As of December 2010, more than 250 nuclear energy workers were certified by an operator training course on research reactors. This course was designed as part of the first phase of the power reactor operator training programme.

Additional data for selected research reactor training programmes that support existing nuclear power programmes are provided in Table V-1.

Table V-1. Role of research reactors in education and training for nuclear power utilities, support industry and safety authorities

Country – Research Reactor	Number of staff trained			
	2008	2009	2010	2011
Austria*, TRIGA Mark II, 250 kW	15	15	15	8
Brazil, IPEN/MB-01, 0.1 kW	0	23	0	37
Czech Republic**, VR-1, 5 kW	13	31	51	33
France, ISIS reactor***, pool, 700 kW	290 (i=11%)	310 (i=17%)	350 (i=32%)	400 (i=30%)
France, MINERVE, critical facility	40	40	40	60
Germany****, AKR-2	41	50	44	25
Italy, TRIGA Mark II, 250 kW	0	47	47	24
Malaysia, TRIGA Mark II, 1000 kW	20 +	-	10 ++	-
Slovenia, TRIGA Mark II, 250 kW	51	41	32	70

* *For utilities in Slovakia*

** *For utilities in the Czech Republic and Slovakia*

*** *Depending on the specific objectives, training course durations range from 3 to 24 hours (i = percentage of international students)*

**** *For 9 other countries*

\+ *17 engineers from a utility, 3 lecturers from a university*

\++ *All lecturers from a university*

D. Conclusion

The support infrastructure, experience and expertise fostered by an existing, well utilized and effectively managed research reactor programme can contribute to the understanding which a country needs in order to make knowledgeable decisions regarding nuclear power. In particular, a competently managed research reactor programme will be backed up by national laws, international legal instruments and organizational infrastructure with features similar to those required for sustaining nuclear power. Research reactors can foster domestic safety and security cultures that are difficult to achieve in the absence of active programmes and the day to day hands-on experience that these entail. In addition, research reactors can support an existing or beginning nuclear power programme, particularly with regard to training, research and technical support.

On the other hand, a poorly managed research reactor programme can add a significant burden to the efforts of a NEPIO. In some cases, existing infrastructure will have to be significantly revised to address the needs of a nuclear power programme. Thorough assessments by the NEPIO and other national oversight organizations will determine the best path forward.

Countries have benefited in the past from starting research reactors before launching nuclear power programmes. Today they can benefit from the research reactor capabilities offered through partnerships with others, through either a regional research reactor facility or a coalition. In these cases, the capabilities of the existing reactor, the approach to nuclear safety and security, and the value and relevance of its training programmes can be assessed in advance.

For those countries which choose to construct a new research reactor as a stepping stone towards nuclear power, identifying other uses for the facility will help to ensure its long-term viability. A robust utilization plan, developed with input from a broad community of potential users and customers, will be reflected in high levels of utilization, the availability of necessary funding, and long-term safe, sustainable and environmentally responsible operation of the facility.

REFERENCES

[V-1] *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA Nuclear Energy Series No. NG-G-3.1, Vienna, 2007).

[V-2] *Human Resources for Nuclear Power Expansion* (Supplement to Nuclear Technology Review 2010 (IAEA document GC(54)/INF/3 issued on 10 August 2010)).