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INTRODUCTION TO THE USE OF THE INPRO METHODOLOGY IN A NUCLEAR ENERGY SYSTEM ASSESSMENT

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IAEA NUCLEAR ENERGY SERIES No. NP-T-1.12

INTRODUCTION TO THE USE OF THE INPRO METHODOLOGY IN A NUCLEAR ENERGY SYSTEM ASSESSMENT

A Report of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

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FOREWORD

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was initiated in 2001 on the basis of an IAEA General Conference resolution in 2000 (GC(44)/RES/21). INPRO activities have since that time been continuously endorsed by resolutions of the IAEA General Conference and by the General Assembly of the United Nations.

The objectives of INPRO are to:

— Help ensure that nuclear energy is available to contribute, in a sustainable manner, to the goal of meeting energy needs in the 21st century;
— Bring together technology holders and users so that they can jointly consider the international and national actions required to ensure the sustainability of nuclear energy through innovations in technology and/or institutional arrangements.

To fulfil these objectives, INPRO developed a set of basic principles, user requirements and criteria, along with an assessment method, which are the basis of the INPRO methodology for evaluation of the sustainability of innovative nuclear energy systems. To provide additional guidance in using the INPRO methodology, the nine volume INPRO Manual was developed; it consists of an overview volume and eight volumes covering the areas of economics, institutional measures (infrastructure), waste management, proliferation resistance, physical protection, environment (including the impact of stressors and the availability of resources), reactor safety, and the safety of nuclear fuel cycle facilities.

To assist Member States in applying the INPRO methodology, the nuclear energy system assessment (NESA) support package is being developed. This includes a database (containing input data for assessment), provision of training courses in the INPRO methodology and examples of comprehensive assessments.

This publication provides guidance on how a variety of potential users, including nuclear technology developers, experienced users and prospective first time nuclear technology users (‘newcomers’) can apply the INPRO methodology for different purposes. Some information in this guide is of common interest and some is specific to different types of users. Thus, each section includes a statement on the target audience of the section.

Information on INPRO can be found on the following web site: www.iaea.org/INPRO.

The IAEA officer responsible for this publication was R. Beatty of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

This section is applicable to all prospective users of the INPRO methodology, including nuclear technology developers, experienced nuclear technology users and newcomers.

The IAEA offers many tools and services to assist Member States in developing and maintaining a nuclear power programme. Practically, each organizational unit within the IAEA has specific services in its area of expertise available to Member States in different ways, such as IAEA missions to countries, training sessions, comprehensive documents addressing specific issues, forums for discussion of important topics, etc. These IAEA tools and services can be accessed by different users, such as technology developers and experienced users of nuclear power, in accordance with their objectives. The INPRO methodology is one such tool. For newcomer countries, three different but complementary tool sets are of particular interest, namely: energy system planning tools; the tool provided through the 'Milestones' approach; and the INPRO methodology. The relationship among these three tools is discussed in more detail in Section 4.5 of this publication.

This publication provides guidance to different audiences on using the INPRO methodology for a nuclear energy system assessment (NESA). Such assessments can be tailored to the needs and objectives of different users. An outline of this INPRO report is presented in Section 1.6.

1.1. DEFINITION OF A NESA

A nuclear energy system assessment uses the INPRO methodology to evaluate a given nuclear energy system (NES) in a holistic manner in order to confirm its long term sustainability or to identify issues or gaps that need to be addressed (for example, by defining actions to be taken to move the NES towards a sustainable option of energy supply). Thus, NESA is a tool that helps users make decisions on how to implement, maintain or enlarge nuclear power programmes in a sustainable manner.

1.2. PROSPECTIVE USERS OF THE INPRO METHODOLOGY

This publication provides guidance on applying the INPRO methodology as set out in the INPRO Manual [1]. Given the different types of users potentially performing a NESA, and because a NESA can be performed for different purposes (Ref. [5]), guidance is provided for three different prototypical users:

— Nuclear technology developers, who are assumed to be using the INPRO methodology to guide technology development;
— Experienced nuclear technology users with a well established nuclear power programme, who are assumed to be using a NESA to assess the sustainability of their existing NES and/or assist with decision making concerning the expansion of a NES, through deployment of additional nuclear facilities;
— A country embarking on a new nuclear programme which can use the INPRO methodology to increase its awareness of the long term issues surrounding sustainable nuclear energy systems and to support its planning process.

Typical INPRO methodology users are assumed to be people working in academic societies, government organizations, universities, and research institutes. Based on awareness gained through using the INPRO methodology, they are able to provide advice to decision makers in a country regarding long term nuclear energy issues.

A country that adopts nuclear power makes a long term commitment spanning several generations and accepts consequences that could extend to over 100 years (see, for example, Ref. [2]). During this period, innovations in technology and institutions can be expected to be introduced that will impact a country's nuclear power programme and its options. For example, two, three, or more generations of reactor designs may be developed over such a time span, and a myriad of evolutionary changes can be expected to be introduced. A domestic nuclear power programme must also be able to cope with global changes, including for example the availability of uranium resources, the supply of nuclear services and components, multilateral cooperation in areas such as fuel cycle services, and other issues such as norms in non-proliferation, safety and security. Within the INPRO project, several collaborative projects[1] have been defined to cover such global aspects as well as to deal with future designs of nuclear power facilities.

1.3. THE HISTORY OF INPRO METHODOLOGY DEVELOPMENT

INPRO was set up in 2000 based on resolutions from an IAEA General Conference (GC(44)/RES/21). In its first phase, which ended in June 2006, INPRO developed a set of requirements and a method of assessment which together comprise the INPRO methodology, drawing from the input of over 300 experts in different disciplines, including reviews by the Generation IV International Forum (GIF). The methodology evolved over time:

— In 2003, the first set of INPRO methodology requirements was published [3].
— In 2004, a revised and validated set of requirements was published [4] based on 14 case studies.
— In 2007, the first seven volumes of the INPRO Manual [1] were published — covering economics, institutional measures (infrastructure), waste management, proliferation resistance, physical protection, environmental impact and availability of resources — to provide detailed guidance on performing a NESA.
— At the end of 2008, the INPRO Manual [1] was updated to include Volumes 8 and 9 covering the area of safety of nuclear reactors and fuel cycle facilities.

In its development and documentation, the INPRO methodology has brought together a large volume of information and has utilized a holistic approach, as discussed in Sections 1.4 and 2.2; this information should be of value to both developers and experienced users of nuclear technology, as well as to newcomers.

1.4. CHARACTERISTICS OF THE INPRO METHODOLOGY

The INPRO methodology was developed to address shortcomings in the past and public concerns that typically claim that nuclear power:

— Is too expensive;
— Is not safe;
— Provides no long term solution for nuclear waste;
— Contributes to proliferation;
— Is a target for terrorists;
— Is not environmentally sound nor sustainable.

Consequently, the INPRO methodology defines six assessment areas (explained in more detail in Section 2.3), each related to one of these concerns:

— Economics;
— Safety of nuclear reactors and fuel cycle facilities;
— Waste management;
— Proliferation resistance;
— Physical protection (security);
— Environment (impact of stressors, availability of resources).

[1] Information on INPRO collaborative projects is available at the INPRO web site: www.iaea.org/INPRO

The six assessment areas above define requirements mainly for designers of nuclear facilities. Additionally, an assessment area of the INPRO methodology was defined, covering aspects related to institutional measures or the infrastructure (such as legal framework) required for a nuclear power programme which must be established independently by a country, for example through its government, the operators of nuclear facilities and/or the national nuclear industry.

A NESA utilizes a holistic approach (discussed in more detail in Section 2.2), requiring the consideration of a complete nuclear energy system, comprised of reactors and front and back end fuel cycle facilities over the entire life cycle of a facility, from 'cradle to grave', and addressing all seven INPRO areas.

The INPRO methodology is a proven tool for performing a NESA. At the time this guide was written it had been used to perform six national NESAs and one international NESA, with the participation of eight countries (Ref. [5]).

1.5. NESA SUPPORT PACKAGE

Initial feedback [5] from users of the INPRO methodology identified the need for a NESA support package to assist users in applying the methodology. Elements of this support package include an input database, which is needed to perform a NESA, training workshops and/or modules, and examples of comprehensive assessments.

This report is one element of the NESA support package. Using the support package, the INPRO Secretariat can assist Member States in applying the INPRO methodology in a manner that best meets their needs.

1.6. STRUCTURE

In Section 2, a more detailed overview of the INPRO methodology is presented, including a brief discussion of the connection between the concept of sustainable development, energy system planning and the INPRO methodology.

In Section 3, the various types of NESA and a generalized procedure to perform a NESA are laid out.

Specific guidance directed at countries embarking on nuclear power programmes (also called 'newcomers') is presented in Section 4, guidance directed at experienced technology users is presented in Section 5, and guidance directed at technology developers is set out in Section 6.

Section 7 presents some concluding remarks.

In Annex I, some preliminary thoughts are presented on how to aggregate NESA results and compare different NES options.

2. OVERVIEW OF THE INPRO METHODOLOGY

This section is applicable to all prospective users of the INPRO methodology, including nuclear technology developers, experienced technology users and newcomers. It describes the relationship of the INPRO methodology to the concept of sustainable development, as well as the holistic nature of the INPRO methodology. Finally, a summary description is provided of the INPRO methodology requirements in all seven areas.

2.1. THE CONCEPT OF SUSTAINABLE DEVELOPMENT AND ITS RELATIONSHIP WITH ENERGY SYSTEM PLANNING AND THE INPRO METHODOLOGY

In 1987, the Brundtland Report [6], entitled Our Common Future, alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. The report defined sustainable development, as:

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The Brundtland Report recognized that to secure global equity would require economic growth and argued that such growth could only be sustained if it were accomplished simultaneously with environmental protection and conservation of non-renewable resources, in other words socially, environmentally, and economically sustainable development (called the three pillars of the concept). This concept of sustainable development has been further expanded through several United Nations related activities, such as Agenda 21, the Commission on Sustainable Development and the World Energy Assessment.

An important outcome of these activities is the insight that the availability of affordable energy is an important requirement for sustainable development. Various energy sources are available today, including fossil fuels, hydroelectricity, other renewable sources (wind, solar, etc.) as well as nuclear energy. An 'energy system planning' study can be used to select an optimal combination of available energy sources in a given country (as well as regionally or globally). Such a study can also be used to define the optimal role of nuclear power inside such an energy supply mix (see also Section 3.2).

Nuclear energy systems based on atomic fission have the potential to provide a sustainable source of energy with the capability of meeting any reasonable projection of global energy needs for hundreds of years using technologies (such as closed nuclear fuel cycles with recycling and fast breeder reactors) that have already been tested and demonstrated, at least at the pilot plant scale. But, as set out in the introduction (Section 1.4), diverse groups and individuals within the public, the media, the political realm, and the scientific community have concerns about the use of nuclear power, and challenge its sustainability. These include concerns about safety, radioactive waste and economic competitiveness; there is also a tendency to link the peaceful application of nuclear energy to proliferation of nuclear weapons, and concern about the potential of terrorist attacks (see, for example, Refs [7, 8]). The INPRO methodology addresses these concerns by setting out development goals and requirements for nuclear energy systems that, if completely met, would justify the claim that a given NES truly represents a sustainable energy supply system, and thus would help to ensure that nuclear energy is available to play a role in meeting energy needs in the 21st century in a sustainable manner.

Thus, from the outset, the INPRO methodology was linked to the concept of sustainable development. INPRO also considered innovation as a pathway to achieve the sustainability of nuclear energy systems from both the perspective of development and deployment. The linkage among energy system planning, NESAs using the INPRO methodology and the concept of sustainable development is illustrated schematically in Fig. 1.

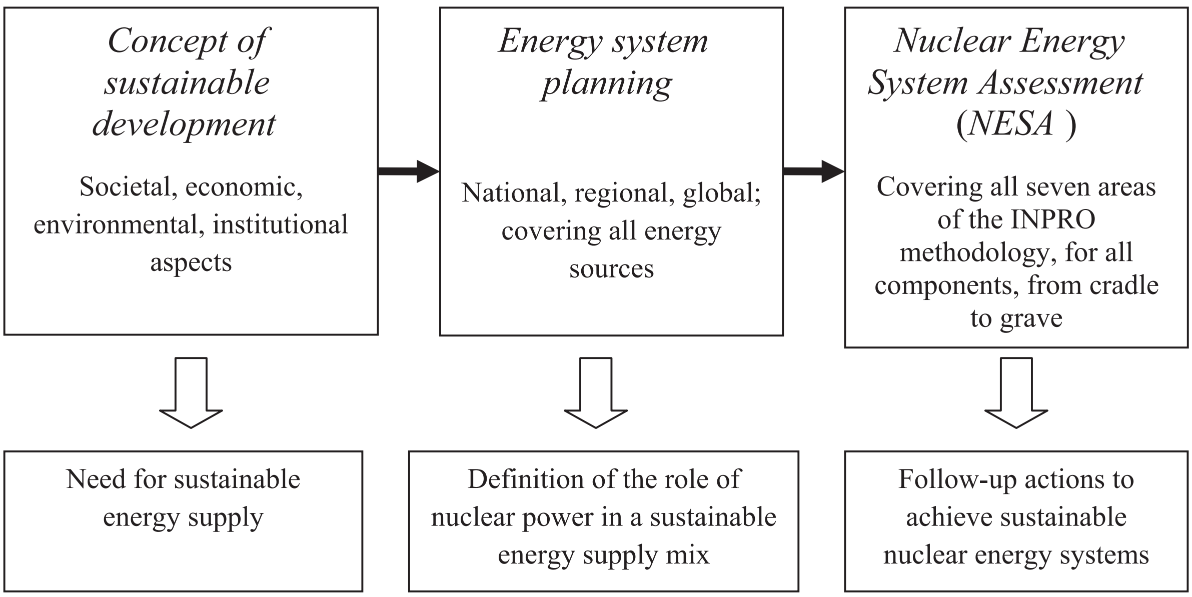

FIG. 1. The relationship among the concept of sustainable development, energy system planning and NESA.

As shown in Fig. 1, the concept of sustainable development establishes the need for a sustainable energy supply. Energy system planning then takes account of all available energy supply options — at national, regional and global levels — to define the role of nuclear power within a sustainable energy supply system. The IAEA makes several computer models available to its Member States to perform such energy system planning [9]. Finally, a NESA assesses a chosen nuclear energy system in all relevant areas to confirm its sustainability or to indentify the need for follow-up actions to achieve a sustainable NES. For example, a nuclear energy system that is not safe or which contributes to the proliferation of nuclear weapons — one, for example, that does not fulfil the requirements of safety or proliferation resistance defined in the INPRO methodology — will not be acceptable in the long term, and so does not represent a sustainable energy system.

2.2. THE HOLISTIC NATURE OF THE INPRO METHODOLOGY

As mentioned in the introduction, the INPRO methodology uses a holistic approach to assess the sustainability of a NES. The characteristics of this holistic approach are outlined in the following paragraphs.

A nuclear energy system (NES) as defined in the INPRO methodology consists of all elements of that NES, including the reactor, the front end of the fuel cycle, starting with mining, and milling, then conversion, enrichment, and fuel fabrication, as well as back end fuel cycle facilities, including reprocessing if applicable, waste management and decommissioning. The full life cycle of all these elements has to be evaluated from 'cradle to grave'. Within the INPRO methodology, a NES also includes infrastructure and institutional considerations such as legal frameworks, the electricity grid, industrial capacity and human resources.

The INPRO methodology, by definition, includes both innovative designs of nuclear facilities that represent a radical departure from existing plants, and evolutionary designs, such as those that evolve from existing (operating) plants. Thus, the INPRO methodology can be used to assess systems being considered for deployment in the near term as well as systems being developed for the longer term.

As outlined in more detail in the following section, requirements have been established in seven areas of the INPRO methodology — economics, institutional measures (infrastructure), waste management, proliferation resistance, physical protection, environment (impact of stressors and availability of resources), and safety requirements to achieve or maintain the sustainability of a NES. These requirements are meant to ensure that all issues related to the sustainability of a NES are considered.

To summarize, when using the holistic approach of the INPRO methodology, a complete nuclear energy system — the reactor together with the front and the back end of the nuclear fuel cycle including institutional measures (infrastructure) — is considered during its complete life cycle, taking into account all issues relevant to the sustainability of the nuclear energy system.

2.3. REQUIREMENTS OF THE INPRO METHODOLOGY

The INPRO methodology requirements are organized according to a hierarchy or architecture of basic principles (BP), user requirements (UR), and criteria (CR). The latter comprise indicators (IN) and acceptance limits (AL).

In a given area, such as economics, a 'basic principle' establishes a target or goal which needs to be achieved if a NES is to be a sustainable energy system in the long term. 'User requirements' define what should be done to meet the target or goal of the 'basic principle' and are directed at specific institutions involved in nuclear power development, deployment and operation, such as developers/designers, governments, facility operators, and support industries. The 'criteria' are used by an assessor to determine whether the 'user requirements' and hence the 'basic principles' have been met by the specific institutions participating in the nuclear power programme. The general features of INPRO methodology are presented in Volume 1 of the INPRO Manual [1].

INPRO has developed one basic principle in the area of economics, which states that nuclear energy and related products must be affordable and available, in principle, to all prospective users. Corresponding user requirements demand that to be sustainable within a country (or a region, or globally) electricity or heat generated by a NES should be able to compete with the cost of locally available alternative energy sources such as renewable energy sources (hydro, solar, wind, etc.) or fossil plants. As well, it is imperative that the total investment funds required to design, construct and commission a NES can be raised and that the risk of investment in a NES is acceptable compared with investments in other national energy projects. Finally, innovative nuclear energy systems should have the flexibility to meet the requirements of different (or changing) markets. In the area of economics, INPRO methodology requirements are directed primarily to the designer/developer of nuclear technology, but to some extent also to the government. Economics is considered in Volume 2 of the INPRO Manual [1].

INPRO has defined one basic principle in the area of institutional measures (or infrastructure), calling for a limitation of the effort necessary to establish (and maintain) adequate infrastructure in a country that intends to install (or maintain or enlarge) a NES. This should be achieved through regional and international arrangements, which should be made available to such countries. The corresponding user requirements recognize the need to:

— Establish and maintain an adequate national legal framework, including international obligations;
— Define the necessary industrial and economic infrastructure for a nuclear power programme;
— Lay out the appropriate measures required to secure public acceptance and political commitment;
— Address the availability of adequate human resources.

Regarding institutional measures, INPRO methodology requirements are directed primarily to the government, operators of nuclear facilities, and the national industry. Institutional measures are considered in Volume 3 of the INPRO Manual [1][2].

In the area of waste management, four basic principles have been derived from the nine IAEA fundamental Principles of Radioactive Waste Management[3]. Thus, to achieve a sustainable NES, the generation of nuclear waste must be kept, by design, to the practicable minimum, waste must be managed in a way that ensures an acceptable level of protection for human health and the environment, regardless of the time or place at which impacts may occur, waste must be managed in such a way that undue burdens are not imposed on future generations, and interdependencies among all waste generation and management steps shall be taken into account. These basic principles, in turn, lead to user requirements to:

— Minimize the generation of waste with emphasis on waste containing long-lived toxic components that would be mobile in a (final/end state) repository environment;
— Limit exposure to radiation and chemicals from waste;
— Specify a permanently safe end state for all wastes and move wastes to this end state as early as is practical;
— Classify wastes and ensure that intermediate steps do not inhibit or complicate the achievement of the end state;
— Accumulate assets for managing all wastes in the life cycle so that the accumulated liability at any stage of the life cycle is covered.

In the area of waste management, INPRO methodology requirements are directed not only at the designers and operators of nuclear facilities (including reactors, fuel fabrication facilities, etc.) and of waste management facilities (including waste storage, incineration, etc.) but also at governments. Waste management is considered in Volume 4 of the INPRO Manual [1].

In the area of proliferation resistance (PR), INPRO has produced one basic principle that requires intrinsic features to be always implemented together with extrinsic measures in a NES throughout its entire life cycle. Intrinsic features of a NES consist of technical design characteristics such as ease of inspection, while extrinsic measures comprise commitments by States, such as safeguard agreements. Corresponding user requirements ask that the State establish and maintain a sufficient legal framework, and that designers minimize the attractiveness of nuclear material (NM), make the diversion of NM difficult and easily detectable, incorporate multiple barriers against the diversion of NM, and implement cost effective safeguard measures. In the area of proliferation resistance, INPRO methodology requirements are directed primarily to governments and designers. Proliferation resistance is considered in Volume 5 of the INPRO Manual [1].

[2] The relationship between the INPRO methodology and the milestones approach is discussed in Section 4.5.
[3] These are set out in Ref. [10], and have since been superseded by the Fundamental Safety Principles [11], published in 2006.

One basic principle developed by INPRO in the area of physical protection (or security) stipulates the effective and efficient implementation of a physical protection regime for the full life cycle of a NES. Corresponding user requirements are based on the fundamental principles of the amended Convention on the Physical Protection of Nuclear Material. They cover the four general areas of the physical protection regime: (1) legislative and regulatory framework; (2) siting, layout and design of nuclear facilities, taking into account physical protection; (3) design of a physical protection system to defend against malicious actions; and (4) planning of contingencies and mitigation of consequences of malicious actions. The requirements for physical protection are intended primarily for the assessment of new nuclear facilities which will be installed in the future. In the area of physical protection, the INPRO methodology requirements are directed primarily at governments and at operators of nuclear facilities. Physical protection is considered in Volume 6 of the INPRO Manual [1].

In the INPRO methodology area of the environment, two aspects are considered, namely:

— Outputs from a NES released into the environment which represent environmental stressors, such as discharges of radionuclides or toxic chemicals;
— Inputs to a NES which may lead to the depletion of natural resources, such as uranium, zirconium, etc.

Consequently, INPRO has developed two basic principles in this area. The first basic principle calls for an acceptable level of environmental impact caused by nuclear facilities on humans and the environment and the second basic principle requires confirmation of the long term availability and optimal use of material resources required to operate a NES. The two user requirements corresponding to the first environmental basic principle seek to keep environmental stressors, such as the release and impact of radioactive substances from a nuclear facility, within relevant[4] standards (such as national regulatory limits) and, additionally to apply the ALARP concept[5]. The first user requirement related to the second environmental basic principle calls for the availability of fissile and fertile materials necessary for the fabrication of nuclear fuel and of materials required for the construction and operation of nuclear facilities for a period of at least 100 years, as well as improved utilization of such materials compared with nuclear systems operating in 2004. The second user requirement primarily calls for adequate energy output in relation to the energy needed to construct and operate a nuclear system. In the area of environment, INPRO methodology requirements are directed primarily to those who design NESs. Environment is addressed in Volume 7 of the INPRO Manual [1].

INPRO has developed four basic principles in the area of nuclear safety, based on the IAEA Fundamental Safety Principles [11], utility requirements such as EPRI Advanced Light Water Reactor Utility Requirements and on an extrapolation of current trends assuming a large increase of nuclear power in the 21st century. The first basic principle calls for the enhanced application of the defence in depth (DID) concept, with more independence for different levels of protection within the DID strategy. The corresponding user requirements are recommendations on how designers and developers can achieve a higher safety level compared to that of a reference design (in this case, the latest design of nuclear facilities operating at the end of 2004) through intensified use of the DID concept at each of its five levels. The second basic principle and the corresponding user requirements ask that designers — when appropriate — consider the increased use of passive systems and inherent safety features to minimize and, when possible, eliminate hazards. The third basic principle sets a high level goal by requesting that designers reduce nuclear facility risk levels regarding radiation exposure to workers and the public so that this risk is comparable to that arising from other industrial facilities with a similar purpose (such as coal fired plants or oil refineries). The fourth basic principle and its user requirements call for a sufficient level of R&D in relation to new nuclear designs in order to bring knowledge of plant characteristics and analytical tool capabilities up to at least the same confidence level as that for a reference plant (which is the latest design of a plant operating at the end of 2004).

The first, second and fourth basic principles are evaluated primarily by comparing the facility under assessment with a reference design, in this case a nuclear facility operating as of the end of 2004. In the area of safety, INPRO methodology requirements are directed almost exclusively to the designers of NESs. While the basic

[4] The term ‘relevant’ means at the time of installation of a new nuclear facility.

[5] ALARP means ‘as low as reasonably practicable’. This concept is described in more detail in Section 4.3.2 of Volume 1 of Ref. [1].

principles and user requirements in the area of safety can be applied to both reactors and fuel cycle facilities, differences between such facilities require different criteria. Thus, the area of safety is considered in two volumes of the INPRO Manual [1]: Volume 8 deals with the safety of reactors and Volume 9 deals with the safety of fuel cycle facilities.

For each user requirement of the INPRO methodology briefly described above, at least one criterion has been developed to enable an assessor applying the methodology to check whether the relevant participant(s), such as designers, operators, governments and national industries, have met the user requirements. If all the user requirements of a basic principle have been met, the NES assessed will achieve the target/goal of the corresponding basic principle.

If, for a given NES, and for a given reference energy system plan, all INPRO criteria are met in all areas when assessed in a holistic and comprehensive manner, that NES represents a sustainable energy system (see Fig. 1). The energy system plan can relate to a national plan, a regional energy scenario or a global energy scenario.

It should be noted that even if all INPRO methodology requirements are not met, a given NES may still represent an excellent energy supply system for a period of time. However, action should be taken in due course to move the NES towards sustainability, more or less in accordance with the concept of continuous improvement. NESA results do not specify the details of desired actions, but rather indicate the need for action and clarify specific issues that need to be addressed.

It is important to note that the INPRO methodology requirements do not represent an IAEA standard. Rather, they provide a means of assessing the sustainability of a NES within the context of a reference energy system plan.

3. APPLICATIONS OF THE INPRO METHODOLOGY

This section is applicable to all prospective users of the INPRO methodology, including technology developers, experienced technology users and newcomers. It presents guidance on how to use the INPRO methodology and a generalized procedure is put forward on how to perform a full scope NESA.

3.1. LEVEL OF SCOPE AND DEPTH OF STUDIES USING THE INPRO METHODOLOGY

In principle, the INPRO methodology can be applied with different levels of depth and scope. For example, it can be applied to:

- Studying the INPRO methodology across all areas, focusing on key messages of basic principles and user requirements (but not performing an assessment), in other words using the methodology as a learning tool to ‘increase awareness of the long term issues of sustainable nuclear energy systems’;
- Performing a ‘NESA with limited scope’, for example, an in-depth assessment of a NES, or a single component (facility) thereof in selected areas of the INPRO methodology at the criterion level, together with a review of all other areas;
- Performing an in-depth ‘full scope comprehensive NESA’ covering all components of a NES, and all areas of the methodology at the criterion level.

The prospective users of the INPRO methodology were presented in Section 1.2, and include nuclear technology developers, experienced technology users and newcomers. For newcomer countries, all three applications of the INPRO methodology presented above could be used at different stages of development within a new nuclear power programme (discussed further in Section 4). For experienced users and designers of nuclear technology, the second and third applications of the INPRO methodology presented above are more useful.

In the following, these different applications of the INPRO methodology are presented in more detail taking into account feedback from countries which have already performed such studies [5].

Because of the holistic nature of the INPRO methodology (Section 2.2), studying the INPRO documentation could be a useful activity for newcomer countries to build awareness at an early stage of the multitude of long term issues that need to be considered to build a sustainable nuclear energy system. This does not, of course, provide a judgment regarding the long term sustainability of a national nuclear programme, but it could provide input for decision making and national energy policy formulation (discussed further in Section 4).

Performing a 'NESA with limited scope', is foreseen to be primarily helpful to developers of nuclear technology who are only interested in one component (facility) of a NES, such as a reactor design under development, and/or selected areas. Such an assessor may wish to research the restricted area of interest to find out whether there are gaps or issues to be addressed. For example, one might assess a reactor design in the area of economics to determine its economic competitiveness, making certain assumptions about fuel costs, waste management costs, etc. In performing such a limited scope NESA, other INPRO areas and components of the NES should also be checked to ensure that proposed innovations do not negatively impact other INPRO areas or components and to ensure a balanced and holistic view is maintained. A limited scope NESA could also be useful for a newcomer country at an advanced stage of nuclear power programme development (discussed further in Section 4.3).

The third type of NESA, a 'full scope comprehensive NESA', consists of assessing all INPRO areas (economics, waste, safety, etc.) at the criterion level, and is meant to determine the sustainability of a chosen NES, including its options. Should such a NESA identify gaps in a nuclear power programme, follow-up actions should be defined that would move the NES in the direction of a sustainable nuclear energy system.

3.2. PERFORMING A FULL SCOPE COMPREHENSIVE NESA

In general, performing a full scope NESA requires the following pre-requisites:

- An energy system planning study has been carried out that defines the role or contribution of nuclear power in meeting the projected energy needs of a country (or of a region, or globally);
- An assessment team has been assembled;
- The NES has been specified based on the role of nuclear power set out in energy system planning;
- The scope and purpose of the NESA have been decided.

3.2.1. Energy system planning

Energy system planning is not part of a NESA per se but is a prerequisite that should be in place before undertaking a NESA. Moreover, the most recent energy plan available should be used, since projections of energy demand and available supply options will change with time. Energy system planning determines the future role or potential contribution of nuclear power to satisfy the predicted growth of energy demand in a country [9].

As shown in Fig. 2, the results of a full scope NESA may impact on energy system planning and necessitate revision of an energy plan. For example, if an energy plan assumes that nuclear power will be introduced at some date but the NESA leads to a conclusion that establishing the necessary infrastructure will require more time, the energy plan would have to be modified. Energy system planning is discussed in more detail in Ref. [1] (Chapter 5 of Volume 1 of the INPRO Manual) and Ref. [9]. Assistance with energy system planning can be provided by the IAEA.

3.2.2. Assessment team

The starting point for performing a NESA is assembling and training the necessary assessment team. As noted, the original intention of the INPRO methodology is to perform a comprehensive and holistic assessment of a NES, considering all INPRO areas, including institutional measures (infrastructure) and all components of the NES from 'cradle to grave', including the reactor, the front end of the fuel cycle, starting with mining, and the back end, including waste management and decommissioning.

To perform such a full scope comprehensive NESA requires the participation of a number of individuals with expertise in different INPRO methodology areas and some knowledge of the nuclear facilities that comprise the

NES; an assessment team is required so that all criteria in all areas can be considered. Typically, such individuals would be experts from government organizations and universities, academic societies and research institutes. Some experts may be assessment team members while others may contribute to the NESA from time to time, on an as-needed basis. But, within the assessment team itself, individuals must be assigned responsibility for one or more INPRO methodology areas so that all areas are covered. As well, a team leader or project manager will need to be assigned to assume overall responsibility for the NESA. The assessment team needs to develop a common understanding of the INPRO methodology, of the NES being assessed, of the scope of the NESA, and of the NESA itself to achieve a consistent and comprehensive assessment.

Effective communication is very important to the success of a NESA, including internal communication among team members, as well as external communication between the team and the IAEA/INPRO Secretariat[6], the team and the energy planner, and the team and other experts who participate in or supply information to the study from time to time.

3.2.3. Specification of the NES

As stated, a NESA requires that the NES be specified. The NES may be an existing system or it might be a planned system. In principle, it should include all facilities that are needed for the production of nuclear power regardless of whether they are located inside or outside of the country. One reason for doing so is to be able to address concerns that a domestic programme that utilizes facilities in other countries, such as those which supply fuel or uranium, might be contributing to harm in the supplier country in the form of environmental damage, for example. The NES would include a number of nuclear power plants (NPPs), some of which may already be in operation, and a number that are scheduled to enter into operation according to a time frame set out in the reference energy plan, and an associated fuel cycle. NES options to be considered could include different types of reactors and fuel cycles. The assessment team itself could specify the NES or it could be supplied by an energy planning study.

3.2.4. Scope of the NESA

The different possible scopes of a NESA have been discussed in Section 3.1. A full scope, comprehensive NESA in principle requires a complete NES with all fuel cycle facilities, from cradle to grave, and all INPRO areas at full depth (criterion level) should be considered.

3.3. PERFORMANCE OF A NESA

Assuming that energy system planning has been undertaken to the extent necessary to define a NES (see Fig. 2), the scope of the accompanying NESA has been defined, at least in a preliminary manner, and an assessment team has been identified, the team should start by familiarizing itself with the INPRO methodology. All team members should read all relevant sections of this publication and Volume 1 of the INPRO Manual [1]. The individuals with responsibility in a given INPRO methodology area should study the relevant volume of the INPRO Manual [1] dealing with that area.

The team should participate, as a group, in training sessions offered by the IAEA/INPRO secretariat as part of the NESA support package (see Section 1.5). As part of this training, questions identified by team members as a result of their self study should be posed to the trainers. Training should lead to a common understanding of issues. Sources of information required for a NESA should also be identified in the training, including a review of IAEA information data banks. As the team proceeds with the NESA, contact should be maintained with the IAEA/INPRO group[7], in particular to resolve questions and discuss issues as they arise.

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[6] The IAEA/INPRO Secretariat manages the IAEA/INPRO group.

[7] The IAEA/INPRO group is located at the IAEA offices in Vienna, Austria. It consists of experts familiar with the INPRO methodology.

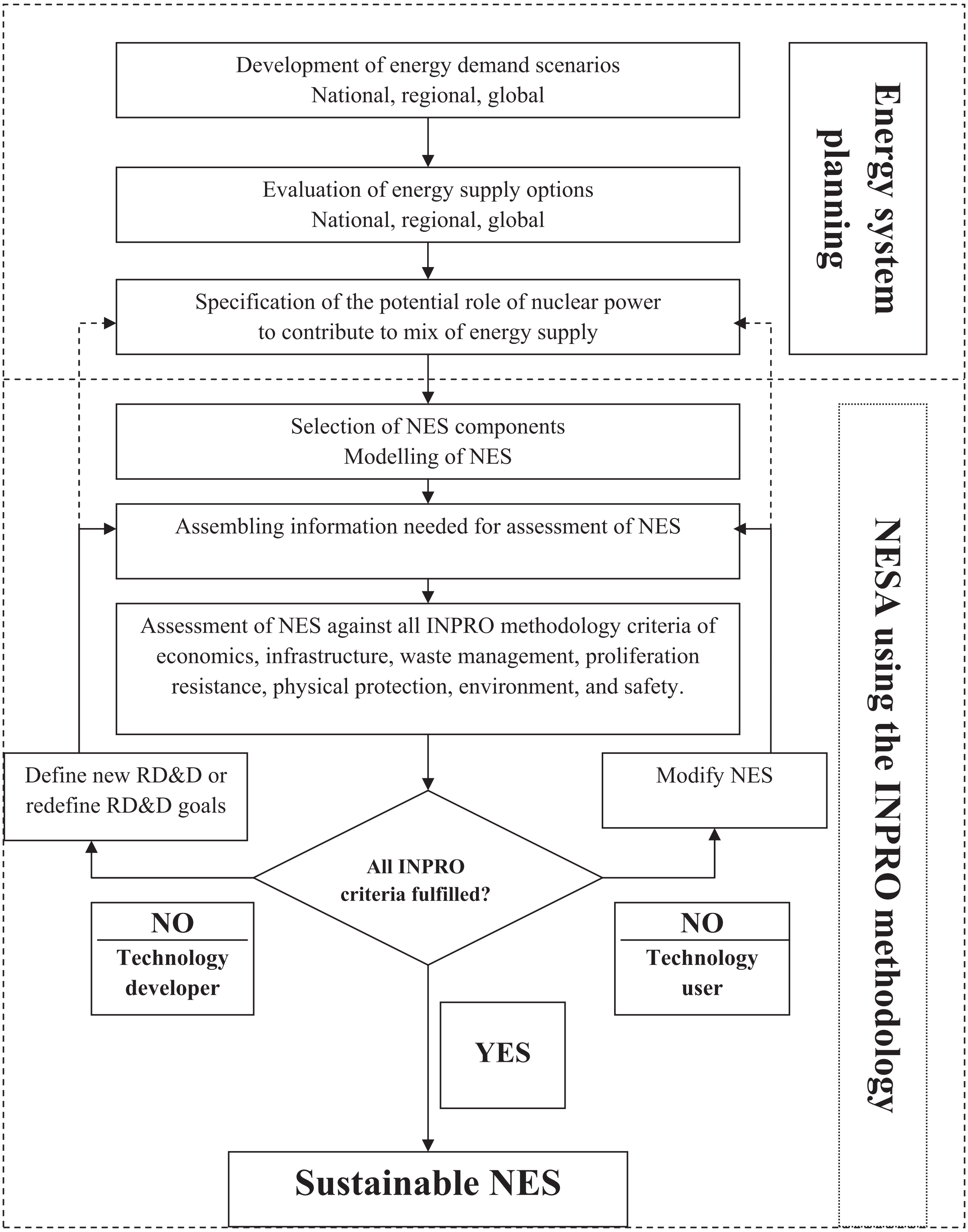

FIG. 2. Steps of energy system planning and a full scope NESA using the INPRO methodology (Volume 1 of Ref. [1]).

3.4. FOLLOW-UP ACTIONS AFTER A NESA

The output of a full scope NESA is a confirmation that either all INPRO methodology criteria have been met by the NES assessed, in which case the assessed NES is sustainable, or the determination that all criteria have not been met, in which case follow-up actions should be specified to address the gaps that have been identified. In the latter case, and depending on whether or not the assessor is a technology developer or a technology user/adopter, there are several possible courses of action.

In the case of a technology developer, actions could include the reformulation of R&D goals or definition of additional necessary RD&D[8] for the NES (or components thereof) to meet all INPRO methodology criteria, assuming that the NES (or component) is otherwise attractive.

If certain information about the design needed for the assessment of INPRO methodology criterion were not available due to the early stage of development, the procurement of such data should be defined as a follow-up action to be performed in due course. This situation is further discussed in Section 6.

The dotted line on the left side of Fig. 2 (between the boxes 'Define RD&D' and 'Specification of the potential role of nuclear') indicates that as the result of successful RD&D, the role of nuclear in an energy mix can be redefined, for example resulting in a larger contribution by nuclear energy.

In the case of a technology user, follow-up actions could include the following:

- Choosing an alternative NES (or alternative nuclear facility) that is capable of meeting all INPRO methodology requirements, for example a smaller (more compact) unit with better economics;
- Adjusting the nuclear energy plan, for example, to delay the introduction of new NPPs;
- Accepting the NES as a satisfactory interim energy supply source while advocating innovation on the part of technology developers to improve the performance of components which could be added to or substituted in the NES in the future.

Lack of data availability required for evaluation of an INPRO methodology criterion should not automatically result in a judgement of non-compliance with that criterion; in such a case the IAEA/INPRO secretariat should be consulted for support (see Section 5 for a more detailed discussion).

The dotted line on the right side of Fig. 2 relates to the second bullet above regarding adjustment of the role of nuclear power in an energy system plan.

3.5. DOCUMENTATION OF A NESA

The results of a NESA need to be documented in a report that sets out information on at least the following:

- The objective of a NESA, and it scope;
- The reference energy plan under consideration and the projected role of nuclear power;
- The nuclear energy system selected for assessment;
- The general approach followed by the assessment team;
- The sources of information for each INPRO methodology area included in the study;
- Overall conclusions reached for each INPRO methodology area included in the study at the level of user requirements and basic principles, and the rationale for these conclusions;
- Details of the judgments reached about each criterion evaluated and the rationale for these judgements, possibly set out in an appendix;
- Recommendations, including recommendations for actions in the event that gaps are identified;
- Feedback to the IAEA/INPRO group on the assessment process and recommendations for improving the INPRO methodology and the INPRO NESA support package.

[8] RD&D means research, development and demonstration.

3.6. REVIEW OF THE NESA

Once a study has been completed, the assessment team may wish to submit its report for a review by the IAEA/INPRO group. In such a case, it is recommended that the table of contents and the information to be included in the report be discussed at an early stage with the IAEA/INPRO group and that a draft of the report be submitted for review before it is finalized.

4. USE OF THE INPRO METHODOLOGY BY A NEWCOMER COUNTRY

This section is applicable to newcomer countries. It provides guidance on applying a graded approach to using the INPRO methodology as a learning tool for building awareness of long term nuclear issues as well as when performing a NESA.

Any country that is interested in a sustainable national nuclear programme would benefit from monitoring global nuclear trends to consider their domestic implications. Countries may use advisors drawn from governmental organizations, universities, academic societies and research institutes, as well as experienced nuclear consultants to support high level decision making. The INPRO methodology can be used by such advisors as a tool for assessing the sustainability of a nuclear energy system 50 to 100+ years in the future. It may also be used as an educational tool at universities and technical schools with nuclear power programmes, as is already being done in a number of INPRO member states.

Building awareness by applying the INPRO methodology could also provide input to feasibility type studies performed during the formulation of a national energy policy. Such a policy should justify the inclusion of nuclear power in the national energy supply system and explain both the benefits and associated risks of all energy supply options. Considering the long term aspects of nuclear power, such as waste management, is essential for such a policy and is recommended to achieve long term public acceptance of nuclear power.

In INPRO methodology documentation, Ref. [1] (Section 3.4.1 in Volume 3 of the INPRO Manual) the main features of such a policy are briefly described. In addition, within the input tables that are a part of the NESA support package (see Section 1.5) several links to web sites are given that provide the text of national nuclear energy policies considered to be examples of good practice in several languages.

4.1. USING A GRADED APPROACH

It has been recognized that the application of the INPRO methodology in a full scope NESA represents a large effort for newcomer countries because they are focused on establishing their national nuclear infrastructures. Therefore, a ‘graded approach’ is proposed regarding the application of the INPRO methodology. A graded approach to applying the INPRO methodology can be defined as selecting for evaluation certain INPRO basic principles, user requirements and criteria, both horizontally (focusing on selected INPRO methodology areas) and vertically (choosing the depth of assessment of requirements), commensurate with the information available for a NES, the number of INPRO requirements that a user wishes to evaluate, and the level of detail desired in results and conclusions. This will determine the level of effort required to be expended.

The proposed grading is linked primarily to the development status of the national nuclear power programme in a newcomer country. At the very beginning of a nuclear power programme becoming familiar with the INPRO methodology essence (expressed in key messages and in the background of its basic principles as well as in user requirements in all INPRO areas), should be sufficient to provide an overview of nuclear power’s long term issues. Such an activity could be part of ‘awareness building’ in a country. With time, an increasing level of detail from the INPRO methodology criteria can be taken into account. If the necessary human resources are available in a country, a NESA with limited scope can be undertaken. Then, as a nuclear programme continues to mature, a full scope

NESA could be initiated. This level of maturity normally develops as a country gains experience with planning for, acquiring and operating a nuclear power plant. Once a country has experience with all these activities, it is no longer considered a newcomer. Such applications of the INPRO methodology apply the philosophy of 'learning by doing'.

The depth to which INPRO methodology can be used depends on the type of organization involved. Academic societies, universities and research organizations should develop the underlying information used to support recommendations presented to decision makers and thus require more detailed knowledge of those nuclear issues addressed in the INPRO methodology. For decision makers and their senior advisors, it is important to appreciate the holistic aspect of the INPRO methodology, which emphasizes the need to meet goals set out in the basic principles of all INPRO methodology areas to ensure the sustainability of a nuclear power programme.

4.2. INCREASING AWARENESS OF SUSTAINABLE NUCLEAR ENERGY ISSUES

One of the most important activities for a country starting a national nuclear power programme is to increase awareness of the relevant long term issues surrounding a sustainable nuclear energy system. Because of its comprehensive and holistic approach, the INPRO methodology can be used for this purpose.

Each of the nine volumes of the INPRO Manual [1] contains a significant amount of background information[9] which can serve to introduce the reader to specific topics within each area of the INPRO methodology. Additionally, references are provided to supporting documentation. As part of a graded approach, people at an appropriate level within national (primarily academic) organizations involved in a nuclear power programme can familiarize themselves with the INPRO methodology for the areas in which they have responsibilities. At this early stage of the programme, understanding the basic principles in each area should be sufficient. In time, details associated with user requirements, and, finally, criterion levels of the INPRO methodology would need to be considered. It is to be noted that it is not necessary to conduct an actual assessment for awareness building to take place; studying background information should be sufficient. The development of a formal document or report is not required to be issued as part of this awareness building effort, but this is left up to individual Member States.

4.2.1. Team makeup

The team could consist of a group of individuals from academia and governmental organizations with some basic background relevant to each of the INPRO methodology areas, including economics, institutional measures (infrastructure), waste management, proliferation resistance, physical protection, environment and safety. Although no detailed knowledge of nuclear power technology is necessary, a country should make use of its existing knowledge base. Thus, if a country has existing nuclear experience, including, for example, operation of a research reactor, it would be helpful to include individuals from such programmes.

4.2.2. NES to be specified

For such an activity no country specific NES has to be defined, as it is supposed that all nuclear issues are studied without examining the specific design of nuclear facilities.

4.2.3. Support provided by the IAEA/INPRO secretariat

As mentioned in Section 1.5, the IAEA/INPRO secretariat offers training in the INPRO methodology as part of the NESA support package. Workshops can be held in a country to provide an overview and explanation of the INPRO methodology and an introduction to the background information presented in the INPRO Manual [1].

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[9] Preparation of a separate, new publication containing only background information is being planned (Ref. [1]).

4.3. NESA WITH LIMITED SCOPE

Depending on the evolution of the national nuclear programme and availability of appropriate national resources and technical capabilities, a country could perform a NESA of limited scope. As mentioned in Section 2.3, the seven INPRO methodology areas provide requirements directed at different types of stakeholders in a nuclear power programme. In some areas, such as safety, the requirements of the INPRO methodology are primarily directed at the designers of nuclear facilities. Other areas, however, such as the those dealing with institutional measures, waste management and economics, are applicable to all countries because they are directed at the institutions involved in developing the nuclear power programme (including the government, the operator, and national industry). Thus, it is recommended that a newcomer country undertake an in-depth assessment of these three specific areas, using Volumes 2, 3 and 4 of the INPRO Manual [1], respectively. All other areas of the INPRO methodology should be covered at a limited depth to ensure a balanced view.

4.3.1. NES specifications

A NES should be specified to the level of detail that is desired for an assessment. Guidance on defining a NES is provided in the INPRO Manual (Section 5.3 of Volume 1 of Ref. [1]). The NES specification should consider whether an entire NES and waste management facilities will be located within the country under study, as well as which fuel cycle will be used. For example, if a country is considering a once through nuclear fuel cycle, the following assumptions can be made:

- Only reactors and related and necessary waste management facilities will be located in the country.
- Fuel will be purchased from abroad, but spent fuel and other radioactive waste will be managed within the country.
- Only the NES facilities located within the country are considered.

4.3.2. Benefits of a NESA with limited scope to a newcomer country

A country will be able to confirm the long term sustainability of its nuclear power programme within its energy supply system when specific boundary conditions are taken into account, such as economics, the need for security of supply, the availability of alternative energy sources, etc. By considering long term issues related to institutional measures (infrastructure[10]), such as legal framework, human resources, the role of national industry, political commitment and public acceptance, a country can develop an enhanced understanding of the actions required to maintain a sustainable nuclear power programme. Dealing with the issue of nuclear waste as defined in the INPRO methodology enables a country to develop a better understanding of the long term commitment associated with its waste management obligations and the options that might be available to reduce the burden on future generations.

By performing a NESA, the individuals contributing to the study will increase their knowledge about relevant nuclear topics. Thus, a NESA provides the opportunity for ‘learning by doing’.

4.3.3. Assessment team required for a NESA with limited scope

In order to perform a limited scope NESA, a country must have the analytical capability and human resources necessary to gather, analyse, and manage the required data. These are usually located in academic or research institutions. By limiting the in-depth scope of a NESA to the INPRO methodology areas of economics, institutional measures (infrastructure), and waste management, an assessment team would initially consist of a team leader and individuals with expertise in these three areas.

As discussed in Section 3, a country should normally have carried out an energy system planning study which would have defined the role of nuclear power in meeting its projected energy demand. Experts who participated in

[10] The topic of infrastructure is documented in Volume 3 of Ref. [1]. Additionally, Volumes 5 and 6 of Ref. [1] contain specific requirements on institutional measures for proliferation resistance and security.

this planning study could be included in the assessment team. They would have the appropriate expertise and knowledge of economics of the country, as well as an understanding of its industrial capacity. As well, the information assembled for an energy planning study and the output from such a study can be expected to be used as input for a NESA, particularly in the areas of economics and institutional measures.

4.3.4. Support of a NESA team by the IAEA/INPRO group

To start a NESA of limited scope, an assessment team should participate in training sessions tailored to the INPRO methodology areas of economics, institutional measures (infrastructure) and waste management offered by the IAEA/INPRO secretariat as part of the NESA support package (see Section 1.5). During these training sessions, questions identified by team members as a result of their self-study of the INPRO Manual [1] could be posed to the trainers. Training should lead to a common understanding of issues. Sources of information required for a NESA should also be identified in training. As the team proceeds with a NESA, contact should be maintained with the IAEA/INPRO group, in particular to resolve questions and discuss issues as they arise.

After the training phase, the team should identify the national government agency responsible for energy planning and contact that agency for information on the energy plan and on the potential role of nuclear power. Representatives of that national agency might also be members of the team, but if not they should at least be available to assist the team on an as-needed basis.

4.3.5. Performance of a NESA with limited scope

An assessment team could start by studying an overview of INPRO methodology (Volume 1 of the INPRO Manual [1]) focusing on the assessment method as set out in Chapters 4 and 5 of that publication. As already stated, the country should only consider three INPRO methodology areas in-depth — economics (laid out in Volume 2 of Ref. [1]), institutional measures (laid out mainly in Volume 3 and partly in Volumes 5 and 6 of Ref. [1]), and waste management (laid out in Volume 4 of Ref. [1]). In these three areas, INPRO methodology requirements are primarily directed toward domestic organizations, to the government, the operator and the national industry involved in a nuclear power programme.

For the three INPRO areas of economics, waste management and infrastructure, algorithmic tables have already been developed[11], as part of the NESA support package, which provide examples of input data required for assessment.

To assist with performing an economic assessment, an EXCEL sheet based programme (called NEST, NESA Economic Support Tool) is available which contains all equations used to calculate economic parameters such as levelized unit electricity costs (LUEC), and financial figures of merit such as the internal rate of return (IRR), used in the economic analysis described in Ref. [1] (Annex A of Volume 2 of the INPRO Manual).

Additionally, the NESA support package includes electronic tables with a description of the necessary input values and examples of such data (mainly links to relevant web sites). Using these support tools, an assessor can perform a parametric study to identify the long term economic prerequisites for a sustainable nuclear power system in the country. Some examples are the production costs of electricity (and heat) from a NES to be compared with the costs of available alternative energy sources in the country, the attractiveness of long term investment in nuclear installations and the acceptability of the associated risk. By screening the data available from suppliers (such as prices of nuclear installations, construction schedules, etc.), an assessor can confirm the viability of a NES option to supply energy in a country. If data from country specific energy system planning were not available, one could also use the cost data applied in energy planning studies referenced in Volume 2 of the INPRO Manual [1], and/or the cost data presented in the example presented in Chapter 4 of Volume 2 of the INPRO Manual. Alternately, one could consider data from comprehensive economic studies available in literature such as the MIT study [12] or various studies published by the OECD/NEA (Refs [13, 14]) and WNA [15].

If a country is examining several options regarding suppliers for nuclear facilities, it can be expected that prospective technology suppliers are interested in supplying representative economic information. In this context,

[11] Similar input tables are under development for all other INPRO areas as part of the NESA support package.

one should be careful to ensure that disposal costs are adequately represented in the economic analysis, taking into account the number of power plants that a country is expecting to deploy.

Assessment of the INPRO methodology area of institutional measures (infrastructure) consists of determining whether institutions within a country are adequate to ensure that the NES is sustainable and can adapt to future global trends. Thus, an assessment team would be expected to contact various government departments (or nuclear agencies if they exist) to determine the current state of affairs in relevant areas. As part of the NESA support package, electronic input tables are available (from the IAEA/INPRO secretariat) which provide links to examples of well established nuclear infrastructures. A study of these examples will contribute to knowledge building in the country. This activity should not be confused with the Milestones approach [16], which lays out a roadmap for developing the necessary infrastructure for a country's first nuclear power plant and a method to formally assess its progress towards this goal.

In the area of waste management, an assessment team, broadly speaking, is also asked to assess the state of affairs in the country. Some INPRO methodology requirements in this area relate to the status of operating waste management facilities, while other requirements are more concerned with the status of planning. Since a newcomer country would not be expected to have significant waste management facilities in operation, an assessment team must concern itself with the status of planning in a first assessment; an assessment team is expected to contact various government departments to determine this. In the area of waste management, electronic input tables exist similar to those described above for the area of economics and institutional measures (infrastructure). An assessment in the area of waste management will increase awareness of the need to consider long term sustainability issues in order to minimize the burden passed to future generations.

4.3.6. Documentation of a NESA

Documentation of a NESA with limited scope should follow the general guidelines provided in Section 3.2. This documentation focuses on areas which would have been assessed in depth, but should also examine the other INPRO areas to ensure that a holistic and balanced view is obtained.

4.4. FUTURE APPLICATIONS OF A NESA

After a country has gained experience with planning for, acquiring and operating a nuclear power plant, its decision makers may decide that it has acquired a sufficient level of knowledge about nuclear power to perform a full scope comprehensive NESA. This is described in general terms in Section 3.2 and in more detail in Section 5.

4.5. RELATIONSHIP AMONG THE TOOLS FOR ENERGY SYSTEM PLANNING, THE INPRO METHODOLOGY AND THE MILESTONES APPROACH FOR A NEWCOMER COUNTRY

In this section, the relationship among energy system planning [9], the INPRO methodology [1], and the Milestones approach [16] is presented. Energy system planning and NESA are tools for long term nuclear power considerations, whereas the Milestones approach relates to near term activities.

4.5.1. Energy system planning

The first step for any new nuclear power programme should be the performance of an energy system planning study [9]. If such a study points to a clear (future) role for nuclear power in the country's energy supply system, the next logical step is to familiarize a team of advisers to the country's decision makers about the main issues regarding nuclear power. Such advisors (presumably from academic societies and research institutions) would then need to ensure that decision makers are adequately briefed on these issues, their implications, and on the need for future adjustments to the national programme.

4.5.2. INPRO methodology for newcomers

As a basis for the above mentioned briefing, advisers may use the INPRO methodology documented in Ref. [1] to build up awareness of long term nuclear power issues, as discussed in Sections 4.1 and 4.2. Performing such an awareness building activity can provide insight into the actions required to prepare for global trends in the nuclear fuel cycle, such as building as much flexibility as possible into the infrastructure to assist in adaptation to these future trends.

After a newcomer country is well advanced in its programme and has thus accumulated sufficient knowledge of nuclear issues, performing a limited scope NESA could be of additional benefit. This would certainly be the case after the first nuclear power plant has successfully started up. Performing a limited scope NESA is dependent on available human resources and expertise in a country.

After a country has gained experience planning for, acquiring and operating a nuclear power plant, it is considered knowledgeable and could perform a full scope, comprehensive NESA.

4.5.3. The Milestones approach

In order to introduce the first nuclear power plant into a country, a wide range of infrastructure issues must be addressed. A systematic approach — called the 'Milestones approach' — describing how to establish adequate infrastructure for a first nuclear power plant is presented in Refs [16, 17]. The Milestones approach provides practical guidance to decision makers in the development of national nuclear power programmes in the near term (within the upcoming 15–20 years). According to the Milestones approach, a first nuclear power plant should be installed in three phases, each ending with a milestone. The first milestone is reached when a country is ready to make a knowledgeable commitment to a nuclear power programme, the second when it is ready to invite bids for its first nuclear power plant, and the third when it is ready to commission and operate its first nuclear plant. Inside of these three phases, 19 issues have been identified which should be considered (see Table 1) by a newcomer country. For each of these 19 issues, specific conditions are provided for countries to help them determine how they can reach each of the three milestones (see Fig. 3).

The Integrated Nuclear Infrastructure Group (INIG) coordinates the IAEA's support to Member States in the area of nuclear infrastructure development (http://www.iaea.org/NuclearPower/Infrastructure/). Support is offered primarily via:

— Development of guideline documents;
— Assistance in performing self-assessments;
— Performing Integrated Nuclear Infrastructure Review missions;
— The IAEA technical cooperation programme;
— Regional and international workshops on infrastructure development related issues.

TABLE 1. ISSUES INVOLVED IN THE DEVELOPMENT OF A NATIONAL INFRASTRUCTURE FOR NUCLEAR POWER

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

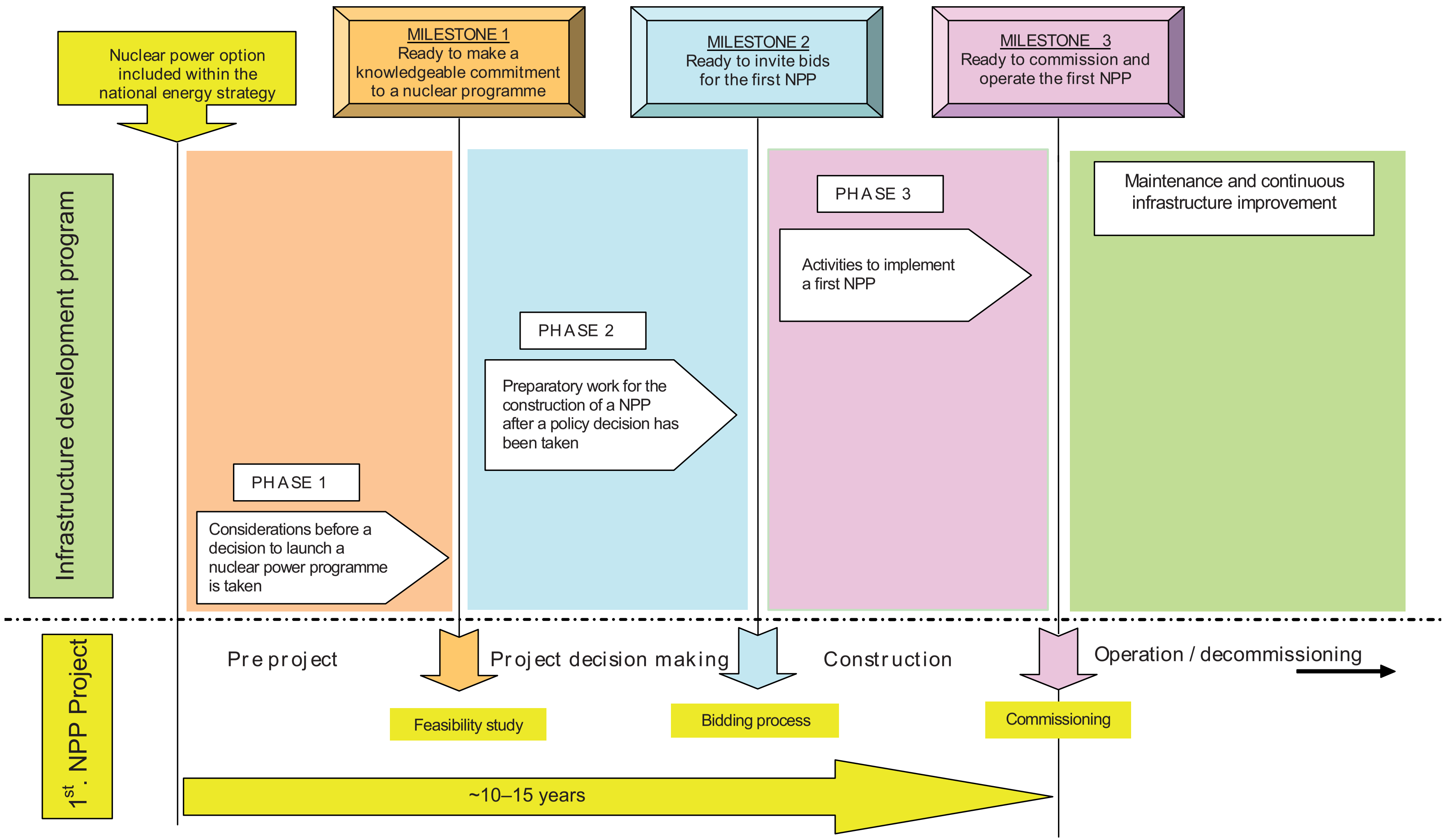

FIG. 3. Milestones in the development of a national infrastructure for nuclear power.

Integrated Nuclear Infrastructure Review (INIR) missions are coordinated external IAEA peer reviews conducted by a team of international experts upon Member State request. These INIR missions can be used to evaluate the status of a country's progress towards implementation of their nuclear power programme by utilizing the milestones approach.

4.5.4. Conclusions

Figure 4 illustrates in a simplified form the relationship among the tools for energy system planning, a NESA, and the Milestones approach in relation to newcomer countries. It shows that energy system planning and the INPRO methodology are tools for long term considerations related to the sustainability of a NES. The Milestones approach involves near term activities which are required to implement a first nuclear power plant and provides a systematic methodology for a country to assess how well prepared it is to implement peaceful nuclear power safely, securely, and efficiently. The figure also shows that energy system planning provides the necessary input to both the INPRO methodology and the Milestones approach.

It should be emphasized that the time horizons considered in these three tools are different. The Milestones approach primarily considers the time period from a decision to explore the possibility of including nuclear power into a national grid until the start up of a first nuclear power plant, a process that may take up to 20 years. Energy system planning — a continuous activity — typically looks up to 30 years into the future. A NESA should cover the role of nuclear power and associated nuclear activities 50 to 100 year into the future, or at least until the end of the 21st century, and may be undertaken on a periodic basis after a first nuclear power plant has been built and commissioned.

5. A NESA CARRIED OUT BY AN EXPERIENCED TECHNOLOGY USER

This section is applicable to countries which are experienced technology users.

5.1. BENEFITS OF PERFORMING A NESA FOR AN EXPERIENCED USER

An experienced technology user (a country with a well established nuclear power programme) can use the INPRO methodology to screen a NES when considering whether to maintain or expand an existing NES, for example by replacing retired plants or deploying more nuclear power plants, to identify gaps with respect to long term sustainability. If gaps have been identified, a user might propose follow-up actions to address such gaps; actions that can either be taken by the user or which may need to be addressed by the technology supplier.

An experienced technology user can also use the INPRO methodology to assess the readiness (maturity) of a given NES or of a component that might be considered for deployment at a future date. It is also possible to use the INPRO methodology to compare technology options and identify the relative pros and cons of different options in assisting with selection of a preferred option.

The benefits for an experienced technology user of utilizing the INPRO methodology include the following:

- It provides a systematic and comprehensive basis for evaluating options;
- It ensures, through consideration of all components and all areas, that all significant issues are considered, thus avoiding pitfalls;
- It identifies gaps that need to be addressed over time to move a NES towards sustainability;
- It identifies potential synergies among different NES combinations.

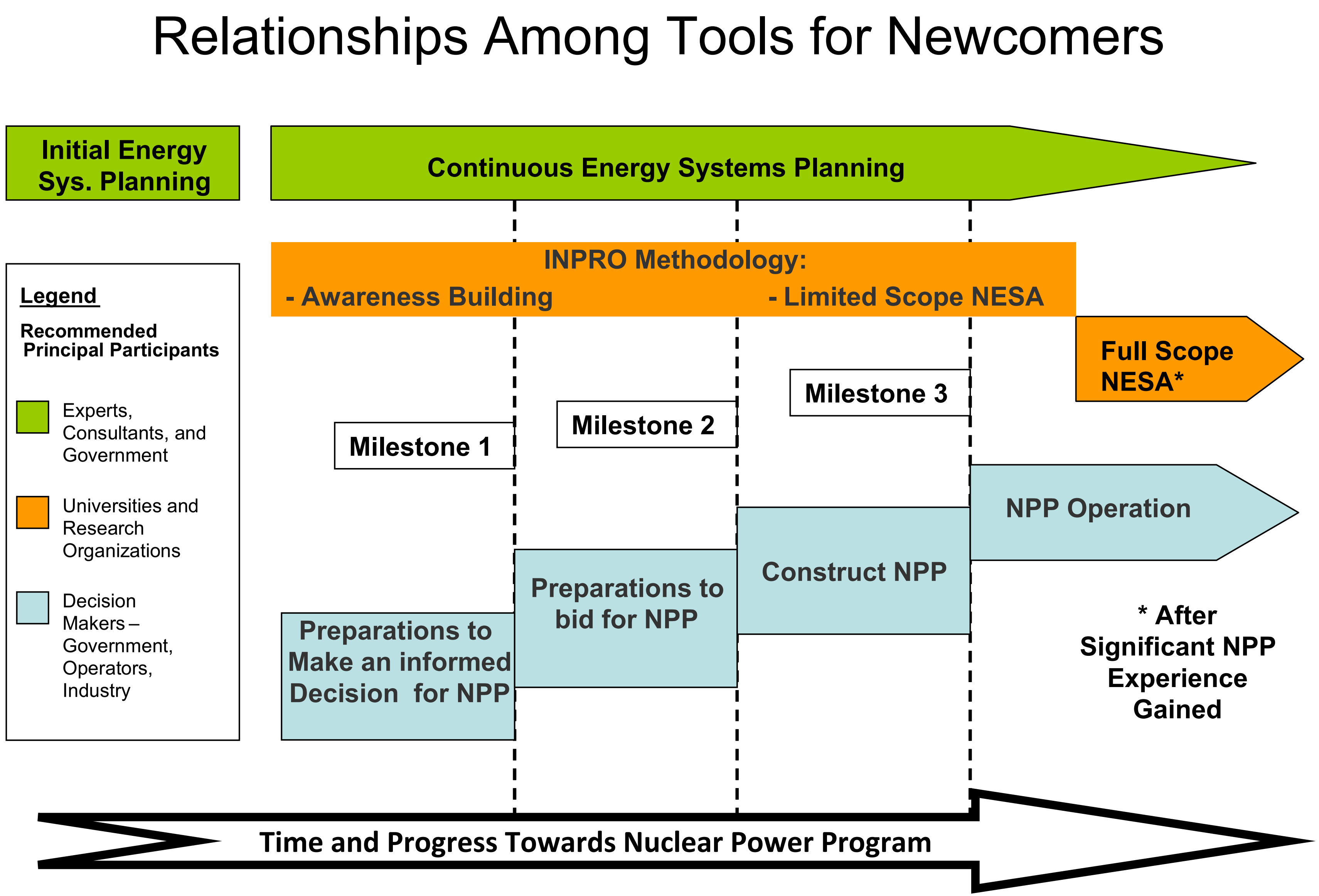

FIG. 4. Relationship among the tools for energy system planning, NESA and the Milestones approach for newcomer countries.

5.2. NES SPECIFICATIONS, SCOPE OF A NESA AND THE ASSESSMENT TEAM

It is assumed that an experienced technology user country wishes to carry out a NESA for a well defined purpose. The purpose will dictate the scope of the NESA, for example the INPRO methodology areas to be covered and the definition of the NES components and facilities to be included in the NES. By definition, an experienced technology user country is one that has:

— Acquired and operated at least one nuclear power plant for a considerable period of time, and probably several plants;
— An ongoing programme, and considerable depth of experience in the areas of operations, fuel purchasing and possibly manufacturing, waste management and licensing.

By definition, such a country is not a developer of nuclear power technology, although it may or may not have some capability in the front end of the fuel cycle, and it certainly would have some relevant experience with nuclear waste management. It would also have a well developed infrastructure and would be expected to meet most INPRO methodology requirements in the area of institutional measures (infrastructure).

For example, the user country might have a number of operating nuclear plants, as well as other power plants (hydro, fossil) and it may want to perform a NESA of the existing NES within the country to assess the sustainability of the current system to, for example, be in a position to provide input into policy discussions on sustainable energy options for the country. In this case, the national NES would consist of a limited number of components, namely the reactors and waste management facilities in a country, plus any front end components within the country, such as uranium mining and fuel manufacturing. For completeness, a NESA should address all areas including institutional measures (infrastructure), even if, a priori, there seems to be particular concern about some other specific INPRO methodology area for one reason or another. Given that the prime interest is the question of sustainability, it can be expected that the assessment would include any front end and back end facilities and operations that are located outside the country so that a complete picture can be obtained.

Another example could be a country that is considering deployment of additional nuclear units. In such a case, a user's prime interest might focus on issues associated with deploying additional units, including, for example, economic considerations, environmental considerations, waste management implications, and implications regarding the front end of the fuel cycle. Therefore, such a country may include all INPRO methodology areas within the scope of a NESA and might include existing and proposed new reactors, front end facilities and waste management facilities needed to manage wastes produced by the NES. An assessment of institutional measures (infrastructure) also includes a review of the current status of the national nuclear infrastructure, and so would address issues such as the need for additional trained staff to operate the new reactors and to provide oversight by the regulatory authority.

In either case, it can be assumed that the country would have access to domestic expertise in all INPRO methodology areas, and thus could assemble an assessment team with the necessary expertise to consider all INPRO methodology areas. As well, such a country should be familiar with international nuclear organizations, such as the IAEA, and would have access to their publications.

In the remainder of this section we assume, for the sake of guidance, a specific set of circumstances based on the second example discussed above. Thus, the experienced technology user is assumed to be a country with one or more utilities operating a number of nuclear units, some of which will be reaching the end of their operating lifetimes within the planning period. A NESA is to be carried out to provide input into policy discussions about whether the country should support the continued and increased use of nuclear power.

Because some currently operating plants are nearing the end of their lives, a NESA would examine the issue of replacement by and addition of new plants. An assessment is meant to cover all INPRO methodology areas and a NES which comprises nuclear power plants, front end facilities (mining, conversion, enrichment, and fuel manufacturing) and all related waste management facilities. Also, by way of example, it is assumed that mining, conversion and enrichment facilities are located out of the user's country (offshore) and that utilities purchase about 50% of their fuel from domestic fuel manufacturers on the basis of long term supply contracts and about 50% from off shore under short term supply contracts. The country and its utilities have resident expertise in planning, economics, regulatory affairs and licensing, environmental assessment, purchasing, operations, interim processing and storage of radioactive wastes, as well as interim storage for spent fuel, etc. In other words there is a wide base of experience which can be called upon in performing a NESA.

The assessment should look at all INPRO methodology areas. Even though such a country already has a well defined infrastructure, the corresponding INPRO methodology area should also be included to ensure there are no outstanding issues, as well as to examine the implications of a possible expansion of its nuclear fleet on national infrastructure, including human resources, training, etc.

To perform an assessment, a team comprised of a team leader and members with expertise in each INPRO methodology area needs to be established. There are a variety approaches that might be followed in setting up such a team. For example, it might consist of some combination of senior staff from government departments, academia, and representatives of relevant professional societies. These staff might be supported by more junior staff that would have the task of assembling the necessary information for review by the assessment team itself. However, the team would require a strong chair to act as project manager, working close to full time, and within the team at least one individual would need to be assigned lead responsibility for each INPRO area.

5.3. PERFORMING A NESA

As noted in Section 3.2, the beginning point for a NESA is an energy system plan that sets out the role of nuclear energy and which, in turn, is used to define the NES to be assessed.

The assessment team could operate in a variety of ways. For example, if it consisted of full time members with dedicated support staff it might take the lead in assembling the information needed to perform an assessment. In doing so, it would need information from the various organizations that comprise the domestic nuclear community, such as the utilities, the regulator, the fuel manufacturer, appropriate government departments, etc. Another approach would be for the team to request the various organizations that comprise the domestic nuclear community submit assessment studies in specific areas. For example, it could ask the utilities to assess the economic competitiveness of nuclear energy using the criteria and user requirements in the INPRO methodology area of economics. Regardless of the approach adopted, input from external organizations would be required, including support from the off shore organizations that supply enrichment, conversion and fuel manufacturing services to the utilities, and from the IAEA.

To get started, once the assessment team had been created, the team would have to decide on its modus operandi and it would have to familiarize itself with the INPRO methodology by reading this document and Volume 1 of the INPRO Manual [1]. Each team member with responsibility for a given INPRO methodology area would also need to study the relevant Manual volume [1] for which he or she has responsibility. As mentioned in Section 1.5, it is foreseen that in due course a NESA support package will become available. This will include examples of full scope NESAs. At the present time, sufficient detailed documentation of examples is not available, but once such examples become available, they should also be reviewed by the team.

Early in the process the team needs to meet several times to ensure that it has a common understanding of the INPRO methodology, to agree on its approach for performing an assessment, to identify contact points within the domestic nuclear community, etc. Contact with the IAEA/INPRO group should also be established at the beginning and should be maintained while an assessment is being carried out to address issues and questions and, if necessary, to secure assistance in obtaining information from foreign organizations.

Once the team has familiarized itself with the INPRO methodology and its tasks, it will have to decide whether it should participate in a training exercise with the IAEA/INPRO group. Regardless of this decision, the team leader should establish contact with the IAEA/INPRO secretariat and confirm that the assessment team is using the best information available, namely the most recent revision of the INPRO Manual [1], the most up to date INPRO methodology database, etc. As noted in Section 7 of this publication, the INPRO Manual [1] will be revised in due course. The assessment team should take this updated information into account in their NESA.

As a NESA proceeds, it is important that the assessment team maintains ongoing communication among team members, for example by holding regular review meetings, to develop a consistent and integrated understanding of the review process itself and of the results being obtained. The assessment team is responsible for the quality of the assessment and its documentation.

5.4. SOURCES OF INFORMATION

As discussed in Section 5.2, it is assumed that the assessment is about a NES that includes facilities that are currently in operation, as well as new nuclear power plants to be installed and operated in the country. For existing facilities, be they in the country itself or in another country (mining, conversion, enrichment, and some fuel manufacturing are assumed to be done outside), a good deal of information required for an assessment should already be available.

For example, domestic utilities would have information — needed in an assessment — regarding levelized costs for existing nuclear power plants and other types of plants they currently operate, discount rates used in their economic analyses, etc. Information should also be available from the utilities and domestic fuel manufacturers about releases and environmental performance, etc. The waste management practices currently in place should be well known and waste management plans should be available from the utilities. If such waste management plans do not exist, a clear gap would be identified.

A regulator should be able to supply information concerning safety culture, and operating facilities should have information available about operational peer reviews, etc.

Information should be available from off shore organizations on mining, conversion, enrichment, and fuel manufacturing, as well as about environmental performance, waste management plans, national infrastructure, etc. from the companies themselves or from national regulatory authorities in the countries in which such facilities are located. If an assessment team has difficulty accessing such information directly, the utilities should be able to obtain it on behalf of the assessment team, since they are the customers of these foreign suppliers. Thus, for currently operating facilities the information needed for an assessment should not be overly difficult to obtain.

For new nuclear power plants, vendors will have to be contacted to obtain relevant information, either directly or through the utilities, in the areas of economics, safety, and environment. In the area of safety, for example, new plants are expected to exhibit improvements compared with existing plants and potential vendors should be able to supply information to demonstrate improved safety. In the area of waste management, vendors are expected to have information available regarding waste minimization efforts, but for the most part information in the area of waste management should be obtained from domestic sources, the utilities, the regulator, and any national waste management organizations. It is assumed that existing plants are subject to IAEA safeguards and that the IAEA itself can be contacted concerning the proliferation resistance of currently operating facilities and proposed new power plants under consideration. The IAEA may also be able to assist in other specific areas, such as supplying information about whether peer reviews have been held regarding safety culture.

It is obvious that any new nuclear plants would have to conform to national regulatory requirements regarding safety, environment, physical protection, proliferation resistance, and waste management, and that a national regulator can be contacted concerning these INPRO methodology areas. In the area of infrastructure, domestic organizations such as the utilities, the regulator, the national nuclear society, educational institutes, etc., should be able to assist. Finally, the database of information being compiled as part of the NESA support package will be helpful once it is available.

Feedback from assessment studies performed to date has indicated that an experienced technology user would benefit from guidance on some specific topics, including using the INPRO methodology to compare options. These topics are briefly discussed below in Sections 5.5 to 5.8.

5.5. COMPARING NES OPTIONS

Ideas for comparing NESA results are discussed in Ref. [1] (Section 4.4.4 and Annex B of Volume 1 of the INPRO Manual). No additional work has been done in this area, since the text of the INPRO Manual was frozen in 2008. However, in preparing this guide some additional ideas have arisen and these are presented below.

Regarding the example introduced in Section 5.1 above, let us assume that one of the rationales is to compare reactor options of proven technology to select a preferred reference option. Thus, a NESA with different reactor options should be carried out to determine if all reactor options being considered lead to a sustainable energy system. For simplicity, let us assume that only two options are being considered. Three results of a NESA can be foreseen:

— Case 1: One option is sustainable and a second option is not;
— Case 2: Neither option is sustainable;
— Case 3: Both options are sustainable.

These three cases are discussed below.

5.5.1. Case 1

If one option were sustainable (meaning it fulfils all INPRO methodology criteria) and another option were not, preference for the sustainable option would be normally expected. But, as noted in Section 2.3 of this report, a given NESA might represent an excellent interim energy system, provided that actions can be taken to move it towards a sustainable energy system in the longer term. Therefore, when comparing two reactor options, one which is consistent with sustainability and one that is not, an assessment team should consider the INPRO methodology area where gaps exist and what actions would need to be taken to close the gaps and move the unsustainable option towards sustainability. If the actions represent a significant challenge then the sustainable option would be preferred. If the required actions were not onerous, the non-conforming option might be considered acceptable as an interim option, thus both options would remain in contention, in which case discussion about Case 3, presented below, should be taken into account.

5.5.2. Case 2

If neither option were sustainable, actions required to close gaps and move the options to sustainability should be identified. If these actions represent a significant challenge for one option and not for the other, the latter option would be preferred. For example, one can ask whether there are large differences between options in one or another of the INPRO methodology areas and whether greater uncertainties have been encountered in performing an assessment for one option compared to another. If so, it should be relatively easy to differentiate. But if there do not appear to be large differences, comparing options may be more problematic, and it may not be possible to discriminate on the basis of actions required to move each of the two options towards sustainability. In such a situation, the discussions in Case 3 should be taken into account.

5.5.3. Case 3

In this case, both options are judged to be sustainable (or cannot be differentiated on the basis of sustainability, as in Cases 1 and 2), thus the issue of sustainability cannot be used to discriminate. In this case, factors other than sustainability need to be considered. A NESA may or may not bring these factors into focus, since the INPRO methodology has been developed to date to assess the sustainability of a NES. Once a sustainability determination has been made, the utility of the INPRO methodology may be problematic.

To try to discriminate between options using the results of a NESA requires that an assessment team decide on the factors it would use to differentiate options. In general, some INPRO methodology areas may not be amenable to differentiation of choices. Safety may be one such INPRO methodology area, since all reactors are expected to meet international standards. In any case, the recommendation is to consider at first only a few INPRO methodology areas for comparing options. The areas to be chosen depend on the assessor, but economics, institutional measures (infrastructure) and possibly waste management are likely candidate areas.

In the area of economics it is important to ask questions such as: Which option has the lowest LUEC? Which option represents the lowest investment risk? Are there clear differences or are the differences within the uncertainties associated with data provided by potential suppliers, especially information provided that is not part of a firm bid?

In the area of institutional measures (infrastructure) required questions include: Does one option require a significant incremental investment in, say, training or support infrastructure because it represents a major change in technology? Does one option offer greater scope for domestic participation?

In the area of waste management questions to ask include: Does one option present more challenges for defining end states and putting in place the domestic capability to move wastes to the end state?

Technology suppliers, of course, will offer information to demonstrate superior performance in one or another area and an assessor will need to take such information into account. Through performing a NESA, an assessor may be able to form a judgment on the validity of such claims, as well as whether some offsetting factors need to be considered.

To conclude, to date the INPRO methodology has been developed primarily to assess NESs on the basis of sustainability. Thus, using a NESA to discriminate between options on some other basis may be problematic.

5.6. MATURITY OF NES OPTIONS

An experienced technology user country, which by definition in not a technology developer country, and which uses INPRO methodology to compare options, is expected to be concerned about the maturity of options under consideration. It is obvious that a technology user country will, at some time, have to adopt technology that has not yet been deployed in the country. For example, once a given reactor reaches the end of its life, it is highly unlikely that it will be replaced by an identical reactor.

If an option is to be adopted for deployment in the near term, say within the next 5–10 years, an assessment team should give strong preference to proven technology — meaning technology that is already licensed and operating in the country of origin. Thus an option that is not proven, that is one which is not already in operation in the country of origin, should normally be excluded from consideration.

In some circumstances, an experienced technology user might consider a first of a kind (FOAK) plant, but only if it promised very favourable performance compared with other options, for example in the area of economics. In such circumstances, an assessment team would need to ensure that the risks of building a FOAK plant were clearly understood by all those concerned, that any risks had been taken into account in the assessment[12], and further that risk could be limited in one way or another, for example, through appropriate contractual terms.

If a user were considering technology that might be adopted in the longer term future, for example, to be considered for deployment in 20 years, uncertainty associated with immaturity of design may not be as important, but it is nonetheless an issue. In such circumstances, a technology supplier should be able to provide information to an assessor demonstrating that by the time a decision is to be made whether to actually deploy a technology, that the technology will have been proven commercially (see Section 4.3.3 of Volume 1 of the INPRO Manual [1], and in particular, Table 4.3 in that volume). If a supplier's development schedule were not consistent with a technology user's plan for deployment, then such an option would normally be dropped from consideration because the technology could not be proven by the planned deployment time.

When a country is adopting proven technology which is new to that country, for example a new reactor or fuel cycle facility, a plan should exist to develop the requisite domestic capability, drawing from international experience and especially the experience of the supplier country. The plan should be credible to an assessor, and if no such plan is available, follow-up actions would need to be identified.

5.7. AGGREGATING AND SUMMARIZING NESA RESULTS

Some thoughts about aggregating NESA results are discussed in Ref. [1] (Section 4.4.4 and Annex B of Volume 1 of the INPRO Manual). Aggregated results may be most useful when trying to summarize NESA results for decision makers. No significant development work has taken place to date on aggregation. The results from NESAs carried out to date [5] indicate that numerical aggregation is problematic.

Thus, it is recommended that technology users should not try for now to use numerical aggregation as a tool for comparing options. Rather, options can be compared simply by summarizing major differences in the INPRO methodology areas of prime interest. As already noted, it may be problematic using a NESA based on INPRO methodology to discriminate among options.

[12] See Ref. [1], for example, Section 3.4 of Volume 2 of the INPRO Manual, and in particular, the discussion of INPRO methodology criteria CR3.1, CR3.2 and CR3.3 in Volume 2, and Section 4.4.3 of Volume 1 of the INPRO Manual.

Some preliminary ideas for aggregation and comparison of NES option assessment results are presented in Annex I.

5.8. DEALING WITH NON-DOMESTIC FACILITIES OF A NES

When performing a complete NESA to confirm its sustainability, all components (facilities) of a NES should be considered. In many NESAs, it is not unusual for some components to be located outside of the country. For example, if a country is using a NESA as a decision making tool in relation to deployment of a nuclear power plant, perhaps only the nuclear power plant and related waste management facilities are located in the country, and the fuel supply components of the fuel cycle's front end (mining, conversion, enrichment, and fuel fabrication facilities) are located outside the country. However, to come to a conclusion about the sustainability of a NES, all NES components must be included in the assessment. The information needed for an assessment would have to be obtained from the countries in which the various facilities are located.

Ideally, supplier countries would evaluate INPRO methodology criteria for facilities in their countries and supply a domestic assessment team with the results, including supporting documentation. Today, signatories to the Joint Safety Convention and to the Convention on the Safety of Radioactive Waste and Spent Fuel assemble much of the information that would be needed for a NESA to comply with the peer review requirements of these conventions. Supplying such information to an assessment team in another country should not represent much of a burden on the information supplier, though some effort would still be required since, at the very least, the formats for presenting information are different. The IAEA/INPRO secretariat may be able to assist in obtaining relevant information. As well, many nuclear organizations now post relevant information on their web sites. In addition, and as noted in Section 5.4 of the report, commercial suppliers should be willing to provide information needed for a NESA to potential customers.

If the nuclear facility of a nuclear fuel cycle to be built in a country were compared to the same kind of facility to be built outside of the country — both to be constructed in the future — it is recommended that identical results of assessments for both facilities be defined for all design related INPRO requirements in the relevant INPRO methodology areas of safety, proliferation resistance, physical protection, environment, and waste management. This means that the final location of a facility, whether inside or outside a country, should not influence assessment results. For INPRO methodology requirements that are either site specific, for example in the area of physical protection, or addressed to the country itself, such as economics and institutional measures (infrastructure), different assessment results for facilities located inside and outside a country are expected.

6. A NESA CARRIED OUT BY A TECHNOLOGY DEVELOPER

This section is applicable to a technology developer. The guidance in this section is rather general. Technology developers have their own processes and tools they use in planning and monitoring technology development. It is expected that as the INPRO methodology is used, developers will provide examples of good practices that can be used to improve the INPRO Manual [1] and this guide (and vice versa).

6.1. INTRODUCTION

This section discusses the use of the INPRO methodology in the context of technology development. INPRO methodology requirements are tied to the objective of a sustainable energy supply. If, for a given NES, all criteria are met in all methodology areas, it is a sustainable NES. If all criteria are not met, then actions need to be defined to move the NES towards sustainability.

A technology developer can use INPRO methodology to assess the sustainability of a given NES in a slightly different way than a technology user would. Independent of the INPRO methodology, a developer will have identified development objectives to improve the performance of a given NES, or of some parts of the NES, in a given area. Unlike a technology user, a developer can only compare development targets with INPRO methodology requirements to determine whether a proposed development is consistent with the objective of sustainable energy development. Strictly speaking, an assessor could check each and every INPRO criterion to ascertain whether a given development target meets the corresponding INPRO methodology acceptance limit. If development targets meet or exceed all INPRO acceptance limits, the NES is judged to be sustainable, within the boundary conditions used in the assessment. If the assessor concludes that some INPRO acceptance limits are either not met or not covered by development targets — that some gaps have been identified in the development programme — the developer should reformulate the targets, adding new ones if necessary.

Further, by assessing a NES in all INPRO methodology areas that would utilize a proposed development, a developer can determine whether development objectives set in one area can have potentially adverse consequences in another INPRO methodology area. In the latter case, such development objectives and plans would presumably be modified so that development would be consistent with the objective of achieving a sustainable energy system.

6.2. SCOPE OF A NESA AND THE ASSESSMENT TEAM

As is the case of an experienced technology user, the scope of an assessment carried out by a technology developer will be determined by the anticipated use of assessment results. It is assumed that a technology developer would want to assess, at some developmental stage, a proposed NES to determine if, once developed, the NES would represent a sustainable energy system. This is the primary purpose of performing a NES assessment using the INPRO methodology. An assessment should address all INPRO methodology areas and consider all components of the NES.

By way of example, one could assume a technology developer is interested in the evolutionary development of a reactor. To ensure that such a reactor could be a component of a sustainable energy system, the developer would need to assess the sustainability of a reference NES in which the reactor is used, considering all components, all INPRO methodology areas, and a reference energy plan. For such a developer, the reference energy plan should be representative of the market in which the developer expects to compete.

The criteria set out in the INPRO Manual [1] define what is needed for a NES to be sustainable. Thus, a developer should ensure that development targets set for a reactor are consistent with INPRO methodology criteria. For example, development targets in economics could be essentially the same as INPRO methodology acceptance limits as defined for a target market. The prime target market could be the developer's domestic market. In this market, the developer would have to identify competing energy sources, and use the competing energy sources to establish economic acceptance limits. If development goals at least meet these limits, the INPRO methodology criteria would be satisfied. Development goals might exceed acceptance limits but should not fall short. However, in reactor development all INPRO methodology areas need to be considered, not only economics. Thus, as various proposals are brought forward for consideration — proposals for enhancing safety, enhancing environmental performance, etc. — the impact of implementing a proposal would be reviewed to estimate its impact on other INPRO methodology areas, in particular economic performance. Thus, INPRO, and in particular the INPRO methodology criteria, would be used to test specific development proposals to ensure that a reactor, once developed, could be part of a sustainable energy system.

In this example, the 'assessment' would be used to guide development so that a balanced design is achieved which embraces all seven INPRO methodology areas. Thus, the assessment team would presumably consist of senior advisers and managers who would provide ongoing oversight and review of reactor development using the INPRO methodology criteria and user requirements as guide posts.

As noted above, to assess sustainability, a developer should use a reference energy plan. For development purposes, a reference plan should be representative of the energy demand expected in a target market, and representative of what nuclear power could contribute if development goals were fully met. This means it should be a plan that reflects what might be possible as opposed to a reference plan that has been adopted. An important consideration in such a plan is the anticipated demand on uranium resources, and hence on the need to adopt advanced fuel cycles to extend such resources. The question of uranium resources is discussed briefly in Ref. [1] (Section 5.4 of Volume 1 of the INPRO Manual) and any developer of reactor technology should bear in mind that, in due course, extending uranium resources may become an important consideration.

In another example, a developer might contemplate the use of advanced fuel cycles based on the assumption that such fuel cycles and associated reactors will be needed in due course. In such a case, a developer could use INPRO methodology criteria to set development targets so that once fully developed, a NES based on an advanced fuel cycle, as well as its associated reactors, would be sustainable. Thus, the same overall development targets would be used, but presumably with different boundary conditions. In both examples, economic criteria require that the cost of energy from a NES be competitive with available alternatives; in both cases waste management criteria would have to be satisfied, etc.

Therefore, from a development perspective, INPRO methodology requirements as set out in the INPRO Manual [1] are the principal contribution to the development process. It is then up to the developer to decide how to meet those requirements.

Having said that, it has been acknowledged in NESAs carried out to date [5] that some additional comments on specific topics could be helpful to technology developers. These topics are discussed, to a limited extent, below.

6.3. DISCRIMINATION AND MATURITY OF DEVELOPMENT

At present, the INPRO methodology has been developed primarily to assess NESs on the basis of sustainability. Therefore, using a NESA to discriminate among NES options on some other basis may be problematic. In addition, as noted above, if INPRO methodology requirements are used to set development goals for a given system, or conversely if development goals are fully compatible with INPRO requirements, all such systems can be considered equivalent. However, experience shows that setting a goal is not the same as meeting a goal. The real challenge for a technology developer is not setting development goals that reflect and are consistent with the INPRO methodology requirements, rather the challenge lies in meeting all INPRO methodology requirements simultaneously.

At an early stage of development, there is considerable uncertainty about whether a given target can be met. The greater the uncertainty, the more likely it is that development objectives will, in fact, not be fully met. These issues are discussed in Sections 4.4 and 4.5 of Volume 1 of the INPRO Manual [1].

Development processes can be viewed as methods to reduce uncertainty. At the beginning of development, targets are established. These should be realistic targets, which are expected to be met through a given development effort as set out in a development plan. Therefore, the initial expectation or judgment is that all targets will be met. If, as discussed above, the targets are consistent with INPRO methodology requirements in all areas, a NES will, once developed, be a sustainable energy system.

As development proceeds and uncertainty is reduced, it is important to review the judgments and expectations around meeting development targets based on the current state of knowledge. If, as development proceeds, it appears that some targets will not be met, though they have been set at the acceptance limits of the related criteria, it is equivalent to identifying gaps. If more and more gaps are identified as development proceeds, the more problematic is the expected outcome of the development from the view point of sustainability. If, on the other hand, judgments about meeting goals based on currently available information remain positive as development proceeds, the likelihood of the ultimate success of a development programme from the view point of sustainability rises.

If two innovations have similar development targets and one is much further along the development path than the other, development targets will likely be reached first by the more mature innovation. This means that for similar development targets, more mature technological innovations would in general be considered less risky.

When comparing options for development, consideration must be taken of the cost of a proposed development programme and the risk that this development will not be fully successful. In general, the greater the risk of a proposed development and the greater the development costs, the greater should be the expected benefit of an innovation. Thus, if two development options are expected to lead to comparable benefits but one option is at an earlier stage of development and/or the development is more costly, the more mature and less costly option would normally be preferred.

However, it must also be recognized that some development projects may be justified using a range of strategic considerations that may dominate other considerations, like those presented above. For example, development activities may be carried out to preserve national capabilities or to keep an option available as a form of insurance. Such considerations are legitimate, but are not directly reflected within INPRO methodology requirements.

6.4. AGGREGATION OF NESA RESULTS FOR COMPARISON OF NES OPTIONS

To date, a preferred approach to aggregation has not been developed but, as noted in Section 5.7 of this report, some ideas are presented in Ref. [1] (Section 4.4.4 and Annex B of Volume 1 of the INPRO Manual) and in Annex I of this report. Based on the discussion presented in Section 6.3, a technology developer should be cautious about trying to numerically aggregate results to arrive at an integral figure of merit that can be used to differentiate options. The main benefit of performing a NESA is in the detailed insight that is achieved through performing a holistic assessment of all INPRO methodology areas. The process of performing and documenting an assessment may provide as much insight as the results themselves.

7. CONCLUDING REMARKS

The INPRO methodology was developed over a period of six years. To date, it has been used in a limited number of NESAs [5]. Feedback from these NESAs indicates that the INPRO methodology is a useful tool and that results obtained by assessment teams justify the time invested by teams in performing their assessments. Feedback has also indicated the need for a NESA support package to assist assessors. This publication represents one part of this support package.

As more experience is gained using INPRO methodology to perform assessments of nuclear energy systems, feedback from such studies is expected to lead to improvements in the methodology and its documentation, including this guide. At present, it is foreseen that a new version of the INPRO Manual [1], revised to take into account feedback from the first set of studies, will be issued in due course, perhaps as early as 2011 or 2012. Subsequent revisions of the INPRO Manual [1] and this publication will take into account and benefit from future applications of the methodology, and from the production of sample or reference case studies, which are also to be included in the NESA support package. The formation of an INPRO users group to guide further development of the methodology has also been proposed.

Annex I

HOW TO COMPARE NES OPTIONS

A.1. ASSESSING NES DEVELOPMENT OPTIONS (BY TECHNOLOGY DEVELOPERS)

The following steps are proposed to evaluate NES options (or components thereof) under development, to aggregate relevant assessment results, such as different judgements on the potential of NES options, and to identify optimal options:

- Look for each NES option at each criterion; compare the judgement of each criterion of each option in all or in preferred INPRO areas.
- For those criteria where agreement is found, such as compliance with the acceptance limit (AL), determine if one NES option is superior in fulfilling the ALs than other options. Try to rate the importance, for example 'significant' or 'not important', of such a criterion with different levels of compliance found in the NES options. Try to rate the superiority of NES options like 'a little better' or 'much better'.
- For criteria judged to be non-compliant, for example either 'non-potential' based on available information, or 'non-potential' because of (at that point) non-availability of data, rate each individually as a gap. Ratings could represent a gap that is 'easy to close', with little effort (if possible, quantify the costs) and certain success (estimate the probability of success), or 'difficult to close', costing a lot of effort and with an uncertain outcome.
- Neglect all criteria that show no difference between options, and concentrate on criteria providing different judgements for NES options.
- List all criteria in which one NES option is superior to other options, if possible with different ratings, for example regarding levels of importance and superiority, as well as existing gaps, including rating the effort involved in closure and probability of success.
- Summarize the results of compared NES options, for example by defining the necessary total effort to close all gaps in each option and by discussing the rated superiorities of each option.

A.2. ASSESSING COMMERCIALLY AVAILABLE NES OPTIONS (BY TECHNOLOGY USERS):

The following steps are proposed to evaluate different NES options (or components thereof) consisting of proven technology and aggregate relevant assessment results, such as different judgements on the potential of NES options, and how to identify the optimal option.

- Decide on a ranking of importance for INPRO methodology areas and select the most important or preferred areas.
- Look for each NES option at each criterion (in the most important areas) and compare the judgement of each criterion of each option in the preferred INPRO areas.
- For criteria where agreement is found, that is compliance with acceptance limits (ALs), determine which option is superior in fulfilling those ALs. Again you could introduce a rating of importance for the criterion and of superiority regarding the judgement (as proposed above for technology development).
- If non-compliance is uncovered for an INPRO criterion due to lack of available data, for example design information of a nuclear facility, contact the IAEA/INPRO secretariat to obtain these data. Ideally, all data should be available to the INPRO assessor to perform a judgement on the potential of a NES to meet INPRO methodology requirements. If, however during the performance of a NESA these data are not available, try to define the importance of the criterion; if the criterion is weighted as not important eliminate it in the comparison; if it is found to be important try to define the probability for the NES option of non-compliance with such a criterion. In any case a follow-up action should be defined to get the needed data.

- If non-compliance exists, that means a gap based on a 'non potential' judgement, define the effort required and the probability of closing it (as proposed above for technology development). If the estimated effort is excessive, eliminate the option.
- Neglect all criteria that show no difference between options, concentrate on criteria that show different judgements for NES options.
- List all criteria in which one NES option is superior to other options, including a rating on superiority and importance of criteria, criteria with gaps based on a non-potential judgement including a rating regarding efforts required to close and the probability of success, and finally criteria for which data were not available.
- Summarize comparison results for NES options, by discussing rated superiorities of each option, by defining the total necessary effort to close gaps in each option, and by discussing the criteria for which data were not available.

GLOSSARY

acceptance limit. A criterion (see the definition of 'criterion') of the INPRO methodology consists of an 'indicator' (see definition of 'indicator' — IN) and an acceptance limit' (AL). The AL is a target, either qualitative or quantitative, against which the value of an IN is to be compared by an INPRO assessor, leading to a judgement of acceptability (pass/fail, good/bad, better/poorer).

analysis. An 'analysis' is a process of using qualitative or quantitative tools, such as computer models, to produce primarily numerical results which can be used as input in an INPRO 'assessment' (see the definition of 'assessment'). A typical example of 'analysis' is the deterministic and/or probabilistic safety analysis of nuclear facilities from which results are needed as input for the INPRO safety assessment described in Ref. [1] (Volumes 8 and 9 of the INPRO Manual).

area of INPRO methodology. Within an assessment using INPRO methodology, the following 'areas' are to be covered: economics, institutional measures (infrastructure), waste management, proliferation resistance, physical protection, environment (impact of stressors and availability of resources), and safety of nuclear reactors and of nuclear fuel cycle facilities.

assessment. An 'assessment' of a nuclear energy system (see definition of 'nuclear energy system') is defined as the process performed by an INPRO assessor of collecting the necessary information from analyses reports and other relevant documents, such as design descriptions, and checking whether the INPRO criteria (see definition of 'criterion') are met.

back end of the nuclear fuel cycle. This includes the handling, reprocessing and disposition of used (spent) nuclear fuel after its discharge from a reactor. In a closed nuclear fuel cycle (see definition of 'closed nuclear fuel cycle') this leads to the refabrication of new fuel. In all types of fuel cycles, the back end includes the ultimate disposition of high level radioactive waste.

basic principle. Within the INPRO methodology, a 'basic principle' defines a goal or target for each area (see definition of 'area') which needs to be achieved if the nuclear energy system is to be a sustainable (see definition of 'sustainability') energy system in the long term, meaning it can operate until at least the end of the 21st century.

breeder reactor. A 'breeder reactor' is a nuclear reactor in which energy is released in the fuel by fission of fissile material (i.e. ^{235}U, ^{233}U, Pu) while at the same time more fissile material is produced (than consumed) by capturing neutrons in fertile material (i.e. ^{238}U, ^{232}Th). The ratio of fissile material produced to the fissile material consumed is called the breeding ratio and must be greater than one in a 'breeder reactor' (if it is smaller than one it would be called a converter).

case study. Within Phase 1 of the INPRO project, several 'case studies' were performed by INPRO members to validate the INPRO methodology. Within a 'case study', typically an exemplary nuclear energy system was selected and an assessment performed, thereby checking the usefulness of the basic principles, user requirements and criteria of the INPRO methodology.

closed nuclear fuel cycle. This is a fuel cycle in which used (spent) fuel is reprocessed to recover residual fissionable (and fertile) material which is then reconstituted into new fuel that is reintroduced into a reactor (see also the definition of 'open nuclear fuel cycle').

criterion. A 'criterion' enables the assessor to check whether the addressee of the corresponding user requirement (see definition of 'user requirement') has done what was requested. It consists of an indicator and an acceptance limit.

defence in depth. Defence in depth (DiD) provides a strategy for safety measures and features of nuclear installations to prevent accidents and, if prevention fails, to limit and mitigate their potential consequences. DiD is characterized by five levels of protection: level 1 deals with prevention of abnormal occurrences and accidents; level 2 with control of abnormal operation and detection of failures; level 3 with control of accidents within the design basis; level 4 with control of severe plant conditions, including prevention and mitigation of consequences of severe accidents; and level 5 with mitigation of radiological consequences of significant releases of radioactive material.

evolutionary design. An ‘evolutionary design’ of a nuclear facility is an advanced design that has been improved over existing designs (within the INPRO methodology ‘existing design’ means the design of a plant operating as of the end of 2004) through small to moderate modifications, with a strong emphasis on maintaining design ‘proveness’ to minimize technological risks (see also the definition of ‘innovative design’).

front end of the nuclear fuel cycle. The front end of a nuclear fuel cycle includes the facilities for mining/milling of uranium (or thorium), conversion, enrichment and fuel element fabrication.

Generation IV International Forum. This forum was founded in 2001 by the US Department of Energy together with Argentina, Brazil, Canada, France, Japan, the Republic of Korea, and the UK. Later South Africa, Switzerland, the European Union, the Russian Federation and China joined. An international team of experts selected six types of advanced nuclear reactors (called Generation IV reactors) and their fuel cycle technology to be developed jointly over the next to 15 to 25 years: A gas cooled fast reactor, a sodium fast reactor, a lead cooled fast reactor, a molten salt reactor, a super critical water cooled reactor, and a very high temperature reactor.

holistic. Within the INPRO methodology the term ‘holistic’ requires an assessor to look at a complete nuclear energy system, including all nuclear facilities from mining and milling to final depositories of nuclear waste, as well as to consider the complete life time of all these facilities, and assess all areas of the INPRO methodology.

indicator. An indicator is part of the criterion (see the definition of ‘criterion’). Two types of ‘indicators’ are used within the INPRO methodology: Numerical and logical indicators. A logical ‘indicator’ is usually presented in the form of a question to be answered either positively (yes) or negatively (no) in the assessment. A numerical ‘indicator’ is usually based on a measured or calculated value that reflects a property of a nuclear energy system, such as the probability of severe core damage after an accident.

inherent safety. A nuclear facility has an inherently safe characteristic against a potential hazard if the hazard is rendered physically impossible by design. As an example, a room without burnable material is inherently safe against fire.

innovative design. An ‘innovative design’ of a nuclear facility is an advanced design, which incorporates radical conceptual changes in design approaches or system configuration in comparison with existing designs (within the INPRO methodology ‘existing design’ means the design of a plant operating at the end of 2004).

INPRO methodology. The INPRO methodology was developed in Phase 1 of INPRO. It consists of a hierarchy of demands (basic principles, user requirements and criteria) directed at different stakeholders in a nuclear power programme: designers/developers of nuclear technology, operators of nuclear facilities, governments with a nuclear power programme, and national industries involved in such programmes.

nuclear energy system. A ‘nuclear energy system’ consists of all the nuclear facilities of the front end and back end of the fuel cycle, such as mining and milling, conversion, enrichment, fuel fabrication, reactor, waste management facilities, reprocessing and final depositories of nuclear waste. It can contain evolutionary and innovatively designed nuclear facilities.

nuclear energy system assessment. A nuclear energy system assessment (NESA) using the INPRO methodology checks the sustainability of a nuclear energy system, and, if gaps are found, defines the need for follow-up actions to be taken to achieve sustainability.

open nuclear fuel cycle. An 'open fuel cycle' (or once through fuel cycle) is a fuel cycle in which the fuel is not recycled following its use in a reactor. The used (or spent) fuel is kept in temporary storage before being loaded into a final depository.

passive system. A 'passive system' is a reactor (safety) system that consists of passive components (for example driven by gravity) which require no external input or active components (pumps or motor operated valves) to operate.

safety culture. The term 'safety culture' was introduced in 1986 by the International Nuclear Safety Group (INSAG). It is the assembly of characteristics and attitudes in organizations and individuals which establish that, as an overriding priority, protection and safety issues receive the attention warranted by their significance.

sustainability. In 1987, the Brundtland commission defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". A sustainable energy supply is an important requisite for a country to obtain sustainable development. Nuclear energy is one option for a sustainable energy supply system. The main objective of INPRO is to help to ensure that nuclear energy is available to contribute to fulfilling energy needs in the 21st century in a sustainable manner. To check the sustainability of a nuclear energy system, the INPRO methodology was developed. A nuclear energy system is sustainable; for example, it will operate at least until the end of the 21st century if it fulfils all INPRO criteria in all INPRO methodology areas.

user requirement. Within the INPRO methodology a 'user requirement' defines what a specific stakeholder (or user), such as designers, operators, governments or national industries, in a nuclear energy programme has to do to achieve sustainability of the programme. The fulfilment of user requirements is checked by an assessor via the evaluation of corresponding criteria.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual, IAEA-TECDOC-1575, Rev. 1, IAEA, Vienna (2008).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Choosing the Nuclear Power Option: Factors to be Considered, STI/PUB/1050, IAEA, Vienna (1998).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles, Report of Phase 1A of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1362, IAEA, Vienna (2003).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Methodology for the Assessment of Innovative Nuclear Reactors and Fuel Cycles, Report of Phase 1B (first part) of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1434, IAEA, Vienna (2004).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from Nuclear Energy Systems Assessment (NESA) using the INPRO Methodology, IAEA-TECDOC-1636, IAEA, Vienna (2009).

[6] BRUNDTLAND COMMISSION, "Our Common Future", World Commission on Environment and Development, Oxford University Press, Oxford (1987).

[7] Nuclear power: The critical issue of safety, The Economist, March 21–27 (2009) 65.

[8] Proliferation and nuclear power: Food for thought, The Economist, March 21–27 (2009) 66.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Sustainable Energy for the 21st Century, IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessments, IAEA, Vienna (2009). www.iaea.org/INPRO

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Principles of Radioactive Waste Management, IAEA Safety Series No. 111-F, IAEA, Vienna (1995).

[11] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[12] MASSACHUSETTS INSTITUTE OF TECHNOLOGY, The Future of Nuclear Power, An Interdisciplinary MIT Study, MIT (2003).

[13] OECD NUCLEAR ENERGY AGENCY, The Economics of the Nuclear Fuel Cycle, Nuclear Energy Agency, OECD, Paris (1994).

[14] OECD NUCLEAR ENERGY AGENCY, Projected Costs of Generating Electricity (2010), Nuclear Energy Agency, OECD, Paris (2010).

[15] WORLD NUCLEAR ASSOCIATION, The Economics of Nuclear Power, www.world-nuclear.com/info/inf02.html (2009).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Milestones in the Development of a National Infrastructure for Nuclear Power, IAEA Nuclear Energy Series No. NG-G-3.1, IAEA, Vienna (2007).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Evaluation of the Status of National Nuclear Infrastructure Development, IAEA Nuclear Energy Series No. NG-T-3.2, IAEA, Vienna (2008).

ACRONYMS

AL	acceptance limit (INPRO)
ALARP	as low as reasonably practical, social and economic factors taken into account
BP	basic principle (INPRO)
BWR	boiling water reactor
CANDU	Canada deuterium-uranium reactor
CR	criterion (INPRO)
DID	defence in depth
EPRI	Electric Power Research Institute (USA)
FCF	fuel cycle facility
FOAK	first of a kind
GC	IAEA General Conference
GIF	Generation IV International Forum
HTR	high temperature reactor (GIF)
HWR	heavy water reactor
I&C	instrumentation and control
IEA	International Energy Agency (OECD)
ICRP	International Commission on Radiological Protection
IN	indicator (INPRO)
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles (IAEA)
INSAG	International Nuclear Safety Group (IAEA)
IPCC	Intergovernmental Panel on Climate Change
LUEC	levelized unit electricity cost
LWR	light water reactor
MIT	Massachusetts Institute of Technology (USA)
MSR	molten salt reactor (GIF)

NEA	Nuclear Energy Agency (OECD)
NES	nuclear energy system
NESA	nuclear energy system assessment (INPRO)
NM	nuclear material
NPP	nuclear power plant
OECD	Organisation for Economic Co-operation and Development
P&T	partitioning and transmutation
PHWR	pressurized heavy water reactor
PSA	probabilistic safety assessment
PWR	pressurized water reactor
RD&D	research, development and demonstration
SCPR	supercritical water cooled power reactor (GIF)
UR	user requirement (INPRO)
WWER	water cooled water moderated power reactor
WNA	World Nuclear Association

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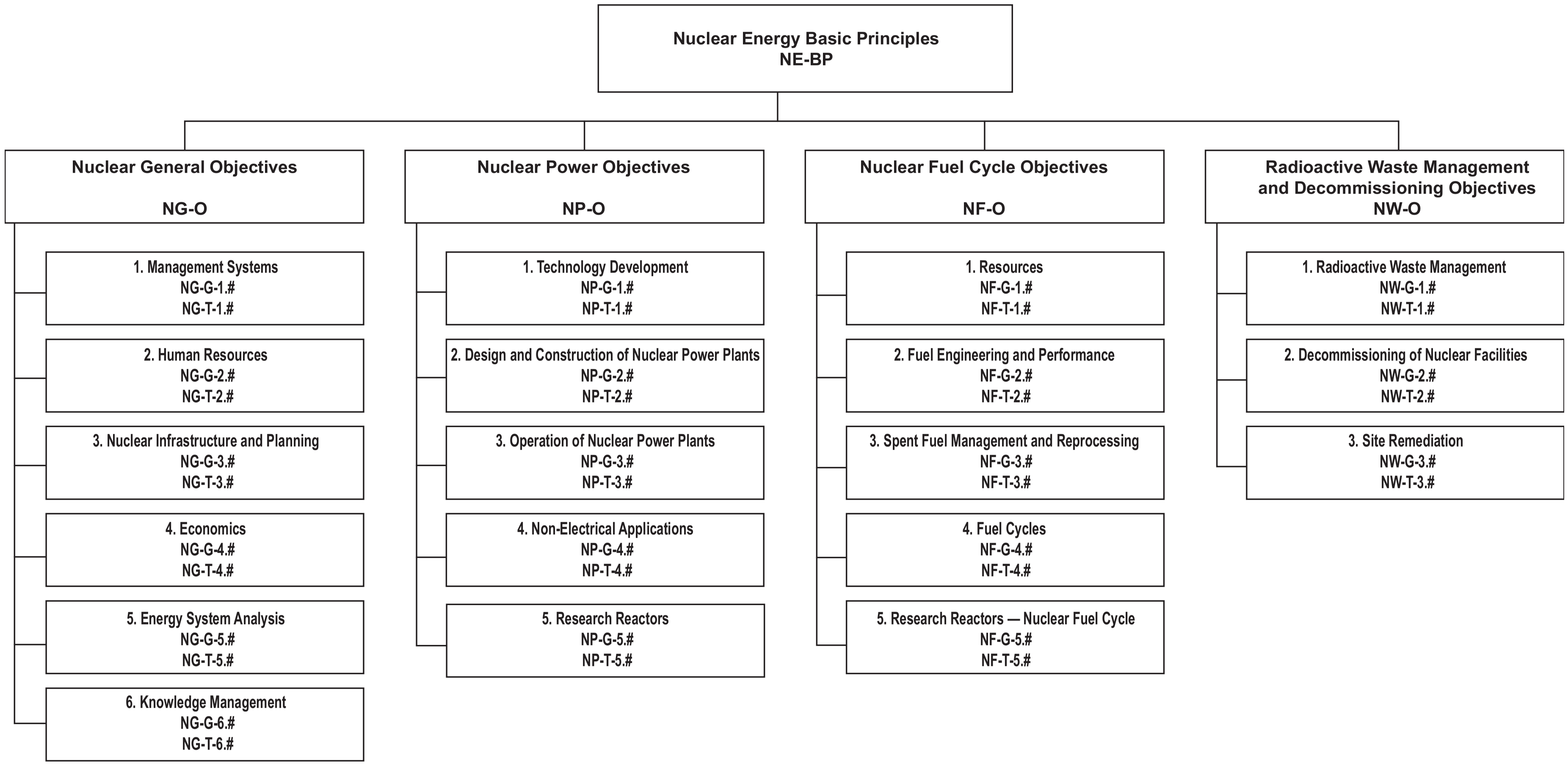

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