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VENDOR AND USER REQUIREMENTS AND RESPONSIBILITIES IN NUCLEAR COGENERATION PROJECTS

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IAEA NUCLEAR ENERGY SERIES No. NR-T-2.17

VENDOR AND USER REQUIREMENTS AND RESPONSIBILITIES IN NUCLEAR COGENERATION PROJECTS

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
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FOREWORD

The IAEA's statutory role is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". Among other functions, the IAEA is authorized to "foster the exchange of scientific and technical information on peaceful uses of atomic energy". One way this is achieved is through a range of technical publications including the IAEA Nuclear Energy Series.

The IAEA Nuclear Energy Series comprises publications designed to further the use of nuclear technologies in support of sustainable development, to advance nuclear science and technology, catalyse innovation and build capacity to support the existing and expanded use of nuclear power and nuclear science applications. The publications include information covering all policy, technological and management aspects of the definition and implementation of activities involving the peaceful use of nuclear technology. While the guidance provided in IAEA Nuclear Energy Series publications does not constitute Member States' consensus, it has undergone internal peer review and been made available to Member States for comment prior to publication.

The IAEA safety standards establish fundamental principles, requirements and recommendations to ensure nuclear safety and serve as a global reference for protecting people and the environment from harmful effects of ionizing radiation.

When IAEA Nuclear Energy Series publications address safety, it is ensured that the IAEA safety standards are referred to as the current boundary conditions for the application of nuclear technology.

Climate warming concerns have increased in many areas of society in recent years. These concerns have great potential to affect many areas of energy production and consumption. Some areas that currently consume large quantities of fossil fuels are process heat for industry, the production of hydrogen, residential heating and the desalination of seawater. Energy consumption is also likely to grow with increasing global population, in a world that aims for expanded access to energy and sustainable economic development. Continued or expanded use of fossil based energy sources for these activities would lead to increased emissions of carbon dioxide and other climate change agents. This path is unsustainable if the catastrophic effects of climate change are to be avoided.

Nuclear energy is essential in its ability to provide large amounts of clean and reliable energy. It is therefore well positioned to be the energy source of choice for a wide range of activities beyond electric power generation. Many concepts under current research and development involve cogeneration, with a nuclear power plant both generating electricity and transferring a portion of the heat directly to another energy demanding activity. Some operating experience already exists for such installations. Challenges to widespread application of nuclear cogeneration remain, but a compelling case is being made in various countries for its contribution to mitigating climate change, while also reducing air pollution and providing an increase in the efficiency of energy conversion.

Any project involving nuclear energy will have certain unique considerations and will call for careful project planning, management and execution. Vendors of nuclear power plants and equipment should work closely with users of cogeneration facilities and their associated equipment, who may have little knowledge of nuclear power plants. Nuclear cogeneration projects are inherently complex and require careful adherence to nuclear safety and security principles and practices. They require expertise in a wide range of subjects. This publication is intended to provide general information, perspectives, background and key references to assist both vendors and users in making decisions regarding nuclear cogeneration facilities and in designing successful nuclear cogeneration projects.

This publication was compiled based on evaluations of officially issued reports and published papers as well as contributions provided by national experts. The IAEA wishes to thank the contributors to the drafting and review of this publication. The IAEA officers responsible for this publication were A. Constantin and I. Khamis of the Division of Nuclear Power.

EDITORIAL NOTE:

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1. INTRODUCTION

1.1. BACKGROUND

The delivery of nuclear cogeneration projects (to produce electricity and process heat for non-electric applications such as desalination, district heating or cooling, hydrogen production, etc.) requires clear understanding of tasks that are the responsibility of various stakeholders during the design, operation and management phases. Cogeneration projects are inherently complex, regardless of the energy source, because there are diverse energy outputs. The use of nuclear energy adds further complexity.

At a high level, project management principles are common to any multifaceted project. However, detailed project management considerations for nuclear cogeneration reflect the complexity and uniqueness of such projects, as discussed in this publication. To facilitate effective implementation of such projects, there should be a preliminary exchange of information among the involved parties, especially concerning siting and potential sharing of resources, the envisaged utilization of the cogenerated commodity, the status and selection of the technologies for the coupled industrial plant, financial constraints and considerations, etc. For example, during the deployment stage, various elements should be made clear to all parties involved, including licensing issues and procedures; responsibilities for the project management of tasks and sub-tasks; the business model and the stakeholders' relationships, especially those between vendors and users of the nuclear cogeneration projects (i.e. the vendors and users for the nuclear power plant and the vendors and users for the cogeneration's applications, e.g. process heat, desalination, etc.); and the overall management of the coordination of nuclear cogeneration projects related to the suppliers, contractors and end users.

Nuclear cogeneration projects are implicitly nuclear power infrastructure projects and there are many similarities in the implementation of such projects. Hence, in addition to addressing the specifics of nuclear cogeneration projects, this publication aims to capture the high level aspects of nuclear power infrastructure projects to offer a more comprehensive perspective to readers. These were addressed in-depth in a series of other IAEA publications and resources that are referenced in this publication with the purpose of establishing the grounds for understanding nuclear cogeneration projects.

Several business models have been developed for nuclear cogeneration projects. As a result, additional user and vendor requirements and responsibilities are involved, depending on the extent of integration among the stakeholders (owner, operators, users, etc.). In the non-integrated project model, for example, each core activity (energy contract management, energy distribution, plant operation, etc.) is the business of a specific company whose responsibilities are limited to the scope of the work of that company. In the user owned model, as another example, one of the users (usually the largest industrial application of the business cluster) owns the nuclear power plant (NPP[1]) and cogeneration plant. This may result from the business consideration of securing the supply of heat and power and enabling the industrial plant to operate continuously. Depending on the qualification, the main user may manage all cash flows, operate the nuclear cogeneration plant, and own and/or operate the distributing system. In all business models, an energy manager is a key stakeholder whose role between the plant and the users is crucial to managing the risks and creating economic value for the project. These aspects are covered thoroughly in Alternative Contracting and Ownership Approaches for New Nuclear Power Plants (IAEA-TECDOC-1750) [1], which was under revision at the time of writing.

This publication focuses on analysing the requirements and responsibilities of users and vendors and the correspondence between them through the life cycle of a nuclear cogeneration project, and highlighting the experience and lessons learned from retrofit and new build projects, given the significant potential of and new interest concerning both types of projects worldwide.

This publication has been prepared in response to the 12th resolution of the 60th General Conference (GC(60)/RES/12/4.4.b) of the IAEA on Strengthening the Agency's Activities Related to Nuclear Science,

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[1] A list of the abbreviations used in the text is given at the end of the publication.

Technology and Applications, requesting the Director General to “Issue a technical report addressing responsibilities of vendors and users involved in nuclear desalination projects, and assessing different scenarios for cogeneration”.

1.2. OBJECTIVE

The objective of this publication is to provide information, perspectives and background to assist actual or potential vendors and users involved in the planning, execution and life cycle management of a nuclear cogeneration project. It accomplishes this by discussion of the general principles involved, reference to key guidance documents, reference to operating experience from past cogeneration projects and perspectives from major current developing projects. The subject matter addressed includes economics, technology, nuclear and non-nuclear safety, environmental and regulatory considerations, and communication with stakeholders.

This publication references and builds upon the direction provided in Guidance on Nuclear Energy Cogeneration (IAEA Nuclear Energy Series No. NP-T-1.17) [2], which provides generic guidance on the merits of cogeneration, steps during implementation and information for Member States embarking on cogeneration with nuclear energy. As stated above, this publication focuses specifically on guidance for vendors and users.

As discussed in this publication, ‘vendors’ are the designers, manufacturers and providers of equipment for the nuclear cogeneration projects. Some of this equipment will be related to the nuclear power plant that supports cogeneration, while other equipment will be related to the non-nuclear Part of the cogeneration project. The boundary between the nuclear and non-nuclear sides is important, because the applicable requirements are typically much less stringent for non-nuclear structures, systems and components (SSCs), as compared to nuclear SSCs. Vendors are companies and entities providing goods and services, including plant engineering, equipment manufacturing, civil construction and site installation, operation and maintenance services, and other technical support and services for the nuclear reactor and associated cogeneration facilities.

In this publication, ‘users’ are owner/operators of cogeneration facilities for whom the vendors provide energy generation and transmission products. There may or may not be more than one user for a cogeneration project, depending on how the project is structured. (Typically, however, only one entity will hold the licence to operate the nuclear power plant.) Users provide energy generated in the cogeneration project to ‘end users’, the customers for the energy, whose role is discussed in limited detail in this publication (and for whom guidance is not directly provided herein). Users may include developers, owners and operators typically responsible for assessing energy demand, selecting the technology for providing the energy, evaluating the feasibility of potential technologies, preparing vendor services and negotiating contracts, and obtaining regulatory licences via safety and environmental assessments. They also manage construction, operation and maintenance, and decommissioning of the cogeneration facility. The responsibilities and capabilities of owners and operators in initiating nuclear power programmes are covered in detail in Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators (IAEA Nuclear Energy Series No. NG-T-3.1) (Rev. 1) [3].

This publication focuses on the requirements and responsibilities applicable to users and vendors. As used herein, ‘requirements’ refer to the expectations of the vendor and user with respect to each other or mandates imposed by a third party (usually a government, especially a regulator) on the user and/or vendor, with the latter being covered in the second revision (in preparation at the time of writing) of Milestones in the Development of a National Infrastructure for Nuclear Power (IAEA Nuclear Energy Series No. NG-G-3.1) (Rev. 1) [4]. ‘Responsibilities’ are corresponding acts (or necessary inactions) by the user or vendor to meet requirements and thereby to support project success.

A nuclear cogeneration plant consists essentially of a nuclear (fission) reactor that will usually be designed to be coupled with steam turbines to generate electricity, along with additional equipment enabling simultaneous supply of heat produced by the same nuclear reactor to another process cogenerating (regulated heat extraction turbine) for non-electricity products.

Wind and solar renewable energy sources, which are currently gaining increased momentum for deployment in the context of achieving climate goals, are not well suited as cogeneration sources because they are not dispatchable. In other words, they are by nature intermittent power sources and cannot be counted upon to provide energy on demand. That can be a significant impediment to end users who want energy to be available continuously or at their convenience. Nuclear energy has the ability to provide energy on demand or continuously. It also has the important advantage of high energy concentration, requiring a much smaller footprint for the cogeneration facility or a larger energy production capability as compared to a renewable source. Generation of nuclear energy does not contribute to greenhouse gas emissions, a major advantage over the use of fossil fuels in cogeneration. Nuclear cogeneration projects, in particular district heating using nuclear energy, can also be driven by reducing air pollution (e.g. the Haiyang Nuclear Energy Heating Project in China, which includes a heating network using steam from Haiyang's two AP1000 nuclear reactors, is expected to avoid, in its first phase, the use of 23 200 t of coal annually and the emission of 60 000 t of CO_2). Although nuclear power has seen little penetration of the non-electric energy market to date, these advantages could result in a large demand for non-electric nuclear energy for cogeneration in the short to mid term.

The nuclear reactor typically uses a steam turbine or gas turbine, or a combination of both (referred to as 'combined cycle'), to convert nuclear heat into electric power. This power conversion results in a large amount of waste heat (this is for all steam Rankine cycle applications, used in the current fleet of water cooled reactors), typically significantly more than 50% of the reactor fission power, a portion of which may be recovered for uses such as desalination and district heating. High temperature energy may also be extracted from the top or intermediate section of the power conversion cycle for uses such as industrial steam and hydrogen production using thermal processes. A nuclear cogeneration plant project could be entirely new, it could be retrofitted onto an existing nuclear power plant, or it could be a retrofit/conversion of a cogeneration facility from another (typically fossil powered) energy source if the parameters of extracted steam are suitable for cogeneration. Most of the currently operating nuclear power plants use saturated steam, which is not as favourable as an energy source for some cogeneration applications as compared to superheated steam. In any case, such a project requires the establishment of a corresponding organizational and physical infrastructure to execute all phases of the project throughout the plant life cycle from pre-project activities to project development, and from licensing and financing construction through to operation and decommissioning of the plant. This publication seeks to assist vendors and users in understanding, at a high level, the considerations that they will need to address to make decisions and be successful in such projects.

Guidance and recommendations provided here in relation to identified good practices represent experts' opinions but are not made on the basis of a consensus of all Member States.

1.3. SCOPE

The scope of this publication includes both new build as well as potentially retrofit projects in terms of technical and managerial requirements within the context of the national, vendor and user requirements that may be established for nuclear cogeneration projects. It analyses the responsibilities and requirements of project parties, such as users and vendors, involved in nuclear cogeneration projects, taking into consideration the different aspects of implementation, including economic, technical, safety, environmental, communication, regulatory and contractual issues. It also provides an insight into issues and lessons learned from previous experiences in the planning and deployment of such projects.

1.4. STRUCTURE

The publication contains an overview of nuclear cogeneration systems and considers stakeholder involvement in nuclear cogeneration projects, the roles of users and vendors, and their requirements and responsibilities in terms of economics, safety, environment, regulations, and technical and contractual matters. A dedicated section contains additional highlights related to market mapping, understanding end user needs, feasibility, selection of vendors and the various stages of project implementation. Four case studies of nuclear cogeneration projects are included, highlighting the requirements and responsibilities of, and the lessons learned by, users and vendors in each of these specific projects. Finally, the main findings are summarized and suggestions are presented.

2. NUCLEAR COGENERATION SYSTEMS

Section 2 provides background on nuclear cogeneration systems and concepts, as well as applicable project management considerations. Specific requirements and information for users and vendors for the projects and concepts discussed in this section are provided in Sections 4–7.

2.1. EXAMPLES OF NUCLEAR COGENERATION SYSTEMS

This subsection describes some examples of nuclear cogeneration facilities and applications. This is by no means an exhaustive discussion of possible applications. Some of these concepts are well developed, and some have seen actual application. Others are in an early stage of development or are conceptual.

Depending on the design of a nuclear power plant, the generated heat may be used for a wide range of applications, such as desalination, heating and cooling, industrial and agricultural process heat, and hydrogen and synthetic fuel production.

For desalination, heating and cooling, and some industrial and agricultural processes, relatively low temperatures (100–250°C) are required, compatible with the existing water cooled NPPs producing saturated or slightly superheated steam that dominate the current nuclear electricity generation fleet. For some applications (e.g. metallurgy, synthetic fuel, chemistry) either a high temperature reactor (such as a high temperature gas cooled reactor) or a combination of preheating by nuclear heat and superheat from other sources of heating (e.g. fossil) is required.

Hybrid energy systems (HESs) represent a sophisticated use of cogeneration in a complex structure with other sources of energy. In such systems, disparate generation, storage and consumption technologies are brought together in a single system, improving the overall benefits compared to a system that depends on a single source. One or more nuclear cogeneration facilities could be a component of such systems. HESs are not discussed further in this publication, but cogeneration in nuclear–renewable HESs is discussed in Nuclear–Renewable Hybrid Energy Systems for Decarbonized Energy Production and Cogeneration (IAEA-TECDOC-1885) [5].

2.1.1. Desalination

Increasing water demand in combination with reduced water supply have made desalination of unconventional water resources such as seawater or brackish water essential in many arid and water scarce areas of the world. Desalination plants may supply drinking quality water and/or water for industrial uses.

Development of a variety of desalination technologies started in the early 1960s with worldwide research efforts. Commercial thermal approaches such as multistage flash (MSF) or multiple effect distillation (MED) for desalting water were common, with capacities up to 8000 m^3/d being achieved.

In the 1970s, commercial scale membrane processes such as reverse osmosis (RO) and electrodialysis were introduced and used more extensively. Today's desalination capacity worldwide is ~100 million m^3/d distributed over some 21 000 plants. RO technologies using electricity are currently dominant, with ~70% market share, while thermal desalination technologies come next, with 25%, and other desalination technologies play a marginal role, with ~5% [6].

Desalination technologies such as MSF, MED and RO have strengths and weaknesses in terms of energy requirements, pretreatment, capital cost and water purity; MSF and MED are thermally driven processes that require relatively low temperature steam/heat (< 200°C), while RO is pressure driven, almost exclusively requiring electric energy for water pumping. MSF is the preferred technology for large capacity requirements; however, the use of RO is increasing, especially where feed is provided by brackish and wastewater. Hybrid technology has advantages in that it can provide redundancy, utilization of streams from one to another, and production of two qualities of water for best utilization. The water produced from MSF is of distilled quality, which is sufficient for industrial use. The water produced from RO is of potable quality.

The contribution of desalination to worldwide energy consumption is ~0.2%. High level estimates place the equivalent electric energy consumption of the current online capacity at ~200 TWh/year, or an average power demand of ~23 GWe; and one estimate suggests that desalination results in direct carbon emissions of ~120 million t annually. Approximately 41% of this energy is consumed as electricity; the remainder is heat used to drive thermal desalination plants, typically in the form of steam at temperatures between 65–130°C, depending upon the technology [7].

The specific energy required for desalination varies between 3–25 kWh/m^3 water produced, depending on the technology used as well as the salinity and characteristics of the raw water to be desalinated. The local carbon footprint of a desalination plant depends on the source of energy that drives it and the efficiency of the plant. An opportunity exists to guide future developments in ways that minimize energy use and greenhouse gas emissions.

Interest in using nuclear energy for seawater desalination is growing worldwide, motivated by the potential economic competitiveness of nuclear energy, price stability and predictability, the desire to conserve limited fossil fuel resources and concern about reducing or limiting the carbon footprint of a desalination facility. The nuclear desalination process involves coupling nuclear reactor technology with desalination technology. Normally, any type of nuclear reactor can be used to provide the electrical and/or low temperature thermal energy needed. Although existing light water reactors (LWRs) may be preferred for this application due to their advanced state of development and deployment, as well as their use of readily available low enriched nuclear fuel, other reactor types requiring less use of water may also be competitive in the arid regions likely to see construction of new desalination facilities.

A cogeneration plant producing both electricity and heat for desalinated water has several economic advantages over single purpose plants. It has inherent design strategies to optimize thermodynamic efficiency and economic benefit. Due to the fact that facilities and staff can be shared in a configuration with on-site coupling of a desalination plant with a nuclear power plant, the operation and maintenance costs for the desalination plant might be reduced compared with the case of a single purpose desalination plant. However, a cogeneration plant also has disadvantages, such as less overall operational flexibility in system designs where the production of electricity and heat is interdependent or technically constrained.

If the cogeneration option is chosen, careful consideration should be given to the power to water ratio, defined as power required per m^3/d of fresh water produced. This parameter can be intrinsically limited by the reactor plant design and could thus affect the reactor plant selection. The required power to water ratio varies from country to country and also during the seasons of the year.

The approach to coupling of the nuclear and non-nuclear portions of the cogeneration facility has a significant technoeconomic impact on the overall system, particularly in the case where thermal coupling with a nuclear reactor or a nuclear steam turbine is used to supply steam for seawater desalination, rather than electrical generation powering a desalination process. It has to be ensured that any variation in steam demand from the desalination system is included in the NPP safety case and will not adversely affect the safety of the nuclear installation. In addition, adequate safety measures have to be provided to prevent accidental release of radioactivity into the water product. Suitable design features will likely make use of multiple barriers and pressure differentials to block the transport of radioactive materials to the desalination plant reliably and to shut down the process rapidly in the case of an emergency. A pressurized water reactor (PWR) provides a steam generator as an in situ barrier for turbine coupling while a boiling water reactor (BWR) lacks it.

Experience with nuclear desalination in India, Pakistan and Japan has exceeded 100 reactor-years. No incidents of safety concern associated with nuclear desalination have been reported so far. A nuclear desalination plant based on hybrid technology was developed by the Bhabha Atomic Research Centre (BARC) and is operational at Kalpakkam in India, powered by the Madras Atomic Power Station, a pressurized heavy water reactor plant. It is a hybrid system that produces 4500 m^3/d of water through MSF and 1800 m^3/d through RO, and is the largest capacity operating nuclear desalination plant based on hybrid technology in the world. It produces distilled water and potable water. Another nuclear cogenerating plant is in operation in Pakistan. An MED unit was retrofitted to the Karachi Nuclear Power Plant (KANUPP), a 125 MW(e) pressurized heavy water reactor plant. The desalination plant produces 1600 m^3/d.

While nuclear desalination is a proven technology, there is opportunity for further development in areas such as increasing energy efficiency and waste heat utilization, optimizing coupling and integration systems, and improving brine management. Besides these technical aspects, economics is an important consideration in establishing whether nuclear energy is competitive against other energy sources for desalination projects.

2.1.2. District heating

A district heating system (DHS) is a system for distributing heat generated in a centralized location through a system of insulated pipes for residential and commercial heating requirements such as space heating or cooling, and water heating. Heat is transported as either steam (as in almost all district heating systems established up to 1930 in the United States of America (USA) and Europe, where some remain in use today) [8] or hot water (as in newer systems, including nearly all nuclear district heating systems) in the temperature range of 80–150°C. Given current concerns regarding human induced climate change, decarbonization of heating and cooling is a high priority for many Member States. Multiple resources may be mobilized to reduce the emissions in the sector, including potential nuclear cogeneration.

The size of a DHS may be in the range of 600–1200 MWt in larger cities, and ~10–50 MWt in smaller communities. Urban areas or conurbations (aggregations or continuous networks of urban communities) in climatic zones with relatively cold winters have excellent potential for district heating. Other essential factors are the availability of heat sources, economics and enabling national legislation. As heat delivery has to be reliable, backup capacity is required. Most district heating systems are fossil powered, so there is substantial opportunity to reduce greenhouse gases by replacing such facilities with nuclear cogeneration.

Combined heat and power (CHP) district heating plants may have either a flexible or a fixed power to heat ratio. CHP plants with a flexible power to heat ratio include condensing steam turbines (typical for current NPPs in operation). Plants designed with little flexibility and a fixed power to heat ratio include backpressure machines (used for process heat, not district heating) or regulated heat extraction turbines, CHP plants or gas turbines with heat recovery boilers. The flexibility of both designs can be improved by using auxiliary coolers and heat storage facilities. Naturally such systems have in the past primarily been preferred in less flexible CHPs with a fixed power to heat ratio, as they enable these plants (which otherwise have little flexibility) to optimize their use on the electricity market.

Nuclear DHS is a valuable option, taking into consideration the urgency of decarbonization in the sector and potentially favourable economics. Nuclear district heating has been used in several countries (Bulgaria, China, the Czech Republic, Hungary, Romania, the Russian Federation, Slovakia, Switzerland, Ukraine), making some significant contributions, such as in Switzerland and Slovakia, where the share of nuclear in total heating is 6.6% (as of 2019) [9] and 5% (as of 2018), respectively [10].

The latest examples of nuclear district heating cogeneration are found in Chinese commercial nuclear power plants. The Haiyang AP1000 pressurized water reactor NPP provides steam from the secondary circuits of both units to a multistage heat exchanger before going off-site to a heat exchange station run by a local thermal company to deliver heat to 700 000 m^2 of housing. In addition, the Qinshan NPP is the site of a district heating demonstration project that began its first Phase of operation in 2021. Furthermore, China has developed several design concepts for nuclear reactors for district heating purposes, such as the pool type light water district heating reactor, DHR-400 (400 MWt), and the heating reactor, HAPPY200 (200 MWt). In Finland, nuclear energy was considered a viable option for district heating in the 1970s and 1980s, and a recent study considering small modular reactors (SMRs) indicated that nuclear energy is an economically viable option for district heating under certain conditions [11].

Nuclear reactors can be used for cogeneration without major technological modifications. However, designing a reactor specifically for district heating can have certain advantages, such as small unit size (almost 100% efficiency), no turbine cycle and reaching operating temperature at a pressure below 10^6 Pa (in comparison to $1.2–1.5\times10^7$ Pa in PWRs), which can lead to a simplified manufacturing process and passive safety design. For such reasons, VTT Technical Research Centre of Finland is developing a small modular reactor for district heating to serve the Finnish market.

Nuclear district heating is a topic that has been investigated seriously in the past but there was a loss of interest and further development ceased following the Chornobyl nuclear power plant accident in 1986. For example, the district heating projects comprising AST-500 nuclear heating reactors were planned to provide heat to the cities of Gorky and Voronezh in the former Soviet Union. France also developed the THERMOS project in the 1980s to use nuclear energy for district heating purposes, but the project was cancelled.

A comprehensive review of all district heating applications of nuclear power as of 2020, both built and planned, is presented in Ref. [12], highlighting that the potential for using nuclear energy for district heating has been demonstrated, although only to a limited extent. A major drawback of older nuclear systems for district heating is that they are usually insufficiently economical, but there is a new opportunity with new nuclear power plants that are being built or are planned, including small modular reactors that can provide optimized designs for cogeneration. In the case of medium to large nuclear reactors, due to the limited power requirements of the heat market and the relatively low load factors, electricity has been the main product, with district heating accounting for only a small fraction of the overall energy produced.

2.1.3. Industrial process heat

Most industries that require process heat operate in a competitive global market where energy consumption plays an essential role in cost management. More recently, emission of greenhouse gases has become a concern. Most industrial heat is currently generated by burning fossil fuels. High temperature applications benefit from proximity of the heat source to the consuming site to minimize thermal losses during transmission. These process heat systems require high reliability and load factors, as well as backup capacity.

Industries with substantial energy consumption include the petroleum and coal processing, chemical, primary metals and paper products industries. The chemical and petroleum industries consume more than 30% of the total industrial energy consumption worldwide. Many processes are highly energy intensive, such as product separation or the generation of synthesis gas through steam reforming of natural gas or other high temperature processes. Individual industrial applications may have a demand for energy in the range of 100–1000 MWt.

All types of nuclear reactors can, in principle, provide process heat/steam and/or electricity to industrial processes. In cases where the required temperature levels are not reached by a given reactor design, processes can be supported by conventional heating (such as electric reheating of the steam). Some advanced reactor technologies promise coolant outlet temperatures greater than 600°C, which could support a wide spectrum of industrial applications. High temperature reactors (HTRs) delivering helium gas at up to 950°C could be prime candidates for nuclear assisted processes such as methanol synthesis, ammonia production, coal gasification or hydrogen production, resulting in a significant reduction in greenhouse gas emissions as compared to fossil fuelled sources.

The technologies needed for the extraction of heat or steam from a nuclear plant already exist. However, penetration of the industrial heat market by nuclear energy has been very limited to date. Some experience on nuclear industrial process heating — aPart from district heating and desalination — has been accumulated in Canada, Germany, Norway, Switzerland and the United Kingdom, with the delivery of low temperature process steam to nearby industrial companies. Detailed feasibility studies, especially for higher temperature reactors, and business case development are necessary for large industrial platforms.

2.1.4. Hydrogen production

A major hydrogen economy already exists and it is expected to grow further. Commercial use at a large scale is already occurring in the fertilizer industry with the manufacture of anhydrous ammonia. Likely near term markets will be petrochemical industries requiring massive amounts of hydrogen for the conversion of heavy oils, tar sands and other low grade hydrocarbons, and for the refining of petroleum products. In the last few years hydrogen has been seen as a valuable asset in the decarbonization of some chemical processes, especially ammonia production, replacing fossil fuels as a transportation fuel and natural gas consumption.

Current production of hydrogen is mainly via extraction from fossil fuels. However, the pressure to reduce emissions of greenhouse gases experienced by other industries is also impacting on hydrogen production. In principle, all kinds of primary energy can be utilized to generate hydrogen, for example through electrolysis. Nuclear energy and hydro power (which can provide cheap and low carbon electricity) are capable of large scale hydrogen production. A better economic outlook is expected if electrolysis is conducted at higher temperatures (reducing electricity consumption), which could be provided by an HTR. Additionally, the energy requirements for high temperature electrolysis can be also provided by LWRs (in connection with heat recuperators). Unlike conventional electrolysis, this option requires that the chemical plant be located in the vicinity of the nuclear reactor, for an efficient heat transfer.

Nuclear-assisted hydrogen production at existing nuclear power plants currently undergoes demonstration. In March 2023, the clean hydrogen generation system at the Nine Mile Point Nuclear Station in the United States started production. Experience in nuclear assisted hydrogen production exists alsoin the form of experimental devices in Germany and Japan, which have simulated the HTR heat source with electrically heated helium to test the chemical reactions. The splitting of natural gas was successfully demonstrated, but that process is considered to be a transitional technology, as it uses fossil feedstock. The focus is therefore on water splitting processes. Thermochemical (hybrid) cycles that also operate at higher temperatures (> 600°C) have been and are being researched in various Member States (Canada, China, France, Germany, Japan, the Republic of Korea and the USA), but are still at the research level and remain to be demonstrated at a larger scale.

2.1.5. Other applications

A wide range of additional applications could exist for nuclear cogeneration, including:

- Synthetic fuel manufacture;
- Nuclear ship propulsion;
- Nuclear space propulsion;
- Chemical synthesis;
- Primary metal manufacture (e.g. hydrogen for iron and steel making);
- Cement production;
- Direct air capture of carbon dioxide (e.g. chemical liquid solvent and chemical solid sorbent technologies);

— Cogeneration capability that includes isotope production (e.g. ^{99}Mo, ^{60}Co, ^{14}C).

These concepts are not discussed in detail here, but they are discussed in Opportunities for Cogeneration with Nuclear Energy (IAEA Nuclear Energy Series No. NP-T-4.1) [13] and Industrial Applications of Nuclear Energy (IAEA Nuclear Energy Series No. NP-T-4.3) [14], as well as the trade and scientific literature.

2.1.6. Extracting heat from the turbine for cogeneration

This subsection introduces some considerations related to the way that heat is extracted from the turbine, with an emphasis on the particular features encountered in nuclear cogeneration projects.

Nuclear cogeneration projects can emerge from retrofitting of nuclear power plants that have initially been designed with the single purpose of serving electricity generation or from the optimization of new designs (e.g. small modular reactors designed for multipurpose use).

The parameters of the steam (i.e. temperature, pressure, flow) that enters the turbine are directly related to the parameters of the reactor coolant. The pressure inside the reactor vessel is determined by the manufacturer's ability to produce pressure resistant equipment (especially the required thickness of the wall of the reactor pressure vessel) and by the neutronic parameters of the reactor's core. For PWRs that operate with three separate loops of water the water coolant pressure is ~16 MPa (in order to have one Phase liquid flow) and for BWRs that operate on two separate loops the water coolant pressure is two times lower, as the water coolant is required to boil. Both type of design provides saturated steam for the coupled turbine.

To have one Phase coolant in the PWR's core, the inlet and outlet coolant temperatures should be regulated. The 'cold' feedwater in the secondary circuit Part of the steam generator (SG) exchanges heat with the coolant (the primary circuit Part of the SG), which allows feedwater to achieve saturation temperature (boiling temperature), and for each pressure this temperature is different. The liquid water changes to steam and goes to the steam turbine. As in the secondary Part of the SG, water boils in order to produce steam — the pressure is lower than that of the primary circuit.

The steam generated in the SG is saturated (the humidity is higher and the temperature and pressure are lower than in traditional fossil fuelled thermal power plants). This is because of the limitations on the maximum temperature of the coolant in the reactor core. There are special separation devices in the SG, but this is not enough to separate all of the moisture. Additional separation is provided between the turbine cylinders.

For BWRs, there are some differences. In the case of NPPs with BWRs, there is no SG. The coolant in the reactor boils and saturated steam is generated directly in the reactor. There are also special separation devices at the top of the reactor, but in the same way as in PWRs, steam that is wet enough enters the steam turbine.

Hence, in both cases saturated steam enters the first Part of the steam turbine, the high pressure cylinder (HPC), where the steam expands and the pressure decreases, but the amount of moisture increases again as the condensation process starts — the amount of steam remains constant, the volume increases, the pressure and temperature decrease, and the moisture increases. Then the steam enters the special moisture separators and reheaters (MSRs) and becomes dry. After that, the steam enters the intermediate pressure cylinder (IPC) or goes directly to the low pressure cylinder (LPC), as in some cases the steam turbine is composed solely of HPCs and LPCs. Due to the erosion process that might affect the turbine blades in the case of increased steam moisture, the steam needs to be dried out, despite the fact that this decreases the efficiency coefficient of the NPP (i.e. it leads to greater thermal losses).

The water steam properties are used to determine the turbine inlet temperature. These data are found in specific tables of water properties and dedicated thermodynamic programs allow us to calculate the temperature of the water in all the phases (liquid, vapour, steam), if the pressure is known, and vice versa. Usually, for PWRs the inlet vapour parameters are 6 MPa and 270°C. They are slightly lower than those of the outlet SG due to thermal losses.

The steam flows from the SG to the low pressure end of the turbine as follows:

(a) As an outlet flow from the SG (secondary circuit), the saturated steam travels to a high pressure cylinder (HPC);
(b) From the HPC, wet steam is moved to MSRs and becomes drier;
(c) From the MSRs, dried steam enters either an intermediate pressure cylinder (IPC) or the LPC directly;
(d) Finally, the steam moves to the LPC.

Depending on the type of nuclear cogeneration project (i.e. district heating, desalination, use of heat for industrial processes or hydrogen production), the type of reactor technology and the temperature needed for cogeneration purposes, the heat from the turbine can be extracted from different parts and there are specific codes that assess optimal extraction.

Usually, the number of extractions and their location are determined by technical and economic optimization: the more extractions and regenerative heaters there are, the higher the efficiency coefficient is, but at the same time the steam turbine price will be much higher. As a consequence, there is a certain number of steam extractions that cannot be exceeded in an existing steam turbine for cogeneration projects.

There is a certain number of turbine stages in each cylinder, and between each stage the steam pressure is different. For example, the inlet steam pressure to an HPC (in the case of a steam turbine for a PWR, 1000 MWe) is ~6 MPa and the outlet HPC pressure is ~1 MPa. The amount of work that is produced in each stage is not constant and different pressure drops are achieved. Hence, if there is steam extraction with a pressure of 2–3 MPa, this suits a particular condition for a cogeneration project. If greater steam pressure is required, then the extraction should be performed from the head of the steam turbine (with higher pressure). Ideally, if cogeneration is to be included in a nuclear power plant project, the steam turbine should be redesigned to ensure steam extractions with the required parameters.

In the case of a thermal desalination process that requires low temperatures, the steam required for heating and boiling the seawater feed can be extracted from an LPC or low pressure preheater.

For district heating, extraction of steam requires turbine system modification. For example, in Ref. [15] the modification of an existing French 1300 MW NPP by changing the LPC to expand the steam to an outlet temperature of 120°C and a pressure of 0.2 MPa is demonstrated.

In a high temperature gas cooled reactor (HTGR), the following coupling will be implemented: the high temperature helium coolant transfers its heat from the reactor plant to the intermediate heat exchanger (IHX) and further to the hydrogen plant [16]. In the Japanese Gas Turbine High Temperature Reactor 300 Cogeneration (GTHTR300C) design, the IHX can transfer 170 MWt of the total 600 MWt reactor thermal power to the hydrogen production process.

2.2. OVERVIEW OF NUCLEAR COGENERATION PROJECTS

A nuclear cogeneration project will take one of two general forms. It will either be a completely new project, or it will be a backfit of cogeneration capability onto an existing operating nuclear power plant. This subsection provides an overview and project management considerations for both cases.

2.2.1. New projects

For countries embarking on a nuclear energy programme (including a nuclear cogeneration project), the IAEA suggests a milestones approach to develop the infrastructure required for the whole life cycle of a nuclear plant [4]. This type of project structure also applies for a new cogeneration project in a country that has existing nuclear power infrastructure. However, in such cases many of the aspects of the project implementation will either have already been accomplished or will require less development (and time) than for a country that is beginning the cogeneration project with no prior nuclear infrastructure. Even if the nuclear infrastructure is present, additional planning for the respective heat demand is needed. As the nature of heat demand is local or regional, this demand assessment should be made at the project level and not at the national level, as in the case of electricity demand.

Programme development is divided into three phases, each ending with the completion of a milestone (Fig. 1); that is, fulfilment of the conditions necessary to demonstrate that the Phase has been successfully completed. Each Phase addresses a list of 19 issues[2] pertaining not only to material infrastructure, such as power grids and sites, but also institutional infrastructure, such as nuclear law, regulations, financial resources and human resource development. Phase 3 is particularly focused on project contracting, construction and commissioning.

As inferred based on experience gathered from Member States, the IAEA suggests allowing at least 10–15 years to complete these three phases of programme development, depending on the level of national interest in, and commitment to, the programme, and the scale of resources that can be invested. Only then can the fourth (operational) Phase begin, comprising a substantially longer period, usually several decades, that includes operation and maintenance, followed by decommissioning of the plant.

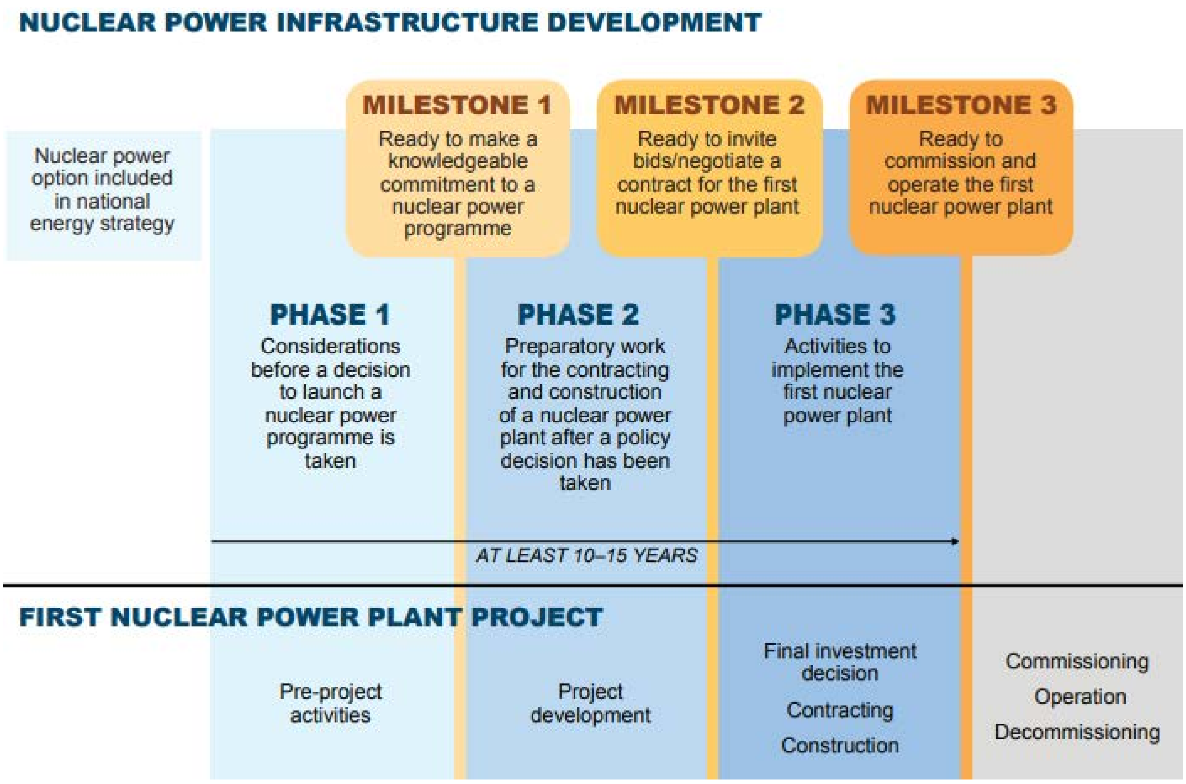

FIG. 1. Development of the infrastructure for a national nuclear programme (reproduced from Milestones in the Development of a National Infrastructure for Nuclear Power (Rev. 1) (IAEA Nuclear Energy Series No. NG-G-3.1) [4]).

[2] The 19 infrastructure issues, as introduced in Milestones in the Development of a National Infrastructure for Nuclear Power (Rev. 1) (IAEA Nuclear Energy Series No. NG-G-3.1), are as follows: national position, nuclear safety, management, funding and financing, legal framework, safeguards, regulatory framework, radiation protection, electrical grid, human resource development, stakeholder involvement, site and supporting facilities, environmental protection, emergency planning, nuclear security, nuclear fuel cycle, radioactive waste management, industrial involvement and procurement.

The project will have, as with any large project, different interested parties, or stakeholders[3] — persons and organizations who are affected by, have an interest in, or have concerns about the project. Some of the more important stakeholders are: the government (and by extension the public), which plays a crucial role in creating and enabling the environment for introduction of the nuclear power programme, an independent nuclear safety regulator, the owner/operator and the vendors of the plant SSCs. The obligations of these key stakeholders derive from the international legal regime in place governing the peaceful use of nuclear power and its applications globally. Other stakeholders include academia, with different nuclear science programmes to educate and sustain a skilled work force, research institutions to develop and update technologies, and professional associations for codes and standards, to name a few.

Human resource management is treated in detail in Human Resource Management for New Nuclear Power Programmes (IAEA Nuclear Energy Series No. NG-T-3.10) (Rev.1) [17], Resource Requirements for Nuclear Power Infrastructure Development (IAEA Nuclear Energy Series No. NG-T-3.22) [18] and Recruitment, Qualification and Training of Personnel for Nuclear Power Plants (IAEA Safety Standards Series No. NS-G-2.8) [19] (in relation to nuclear power programmes and nuclear infrastructure development), Managing Regulatory Body Competence (IAEA Safety Report Series No. 79) [20] and Organization, Management and Staffing of the Regulatory Body for Safety (IAEA Safety Standards Series No. GSG-12) [21] (in relation to the regulatory body).

It is important not to underestimate the importance of the government and the public in nuclear projects, as their support or acquiescence will be essential and cannot be taken for granted.

Milestones in the Development of a National Infrastructure for Nuclear Power (IAEA Nuclear Energy Series No. NG-G-3.1) (Rev. 1) [4] briefly references the following considerations for nuclear cogeneration:

— In the demand planning stage: “Essentially, the same infrastructure is needed whether the programme is planned for the production of electricity, for seawater desalination or for any other peaceful purpose”;
— In the national position: “While nuclear energy is most often used to generate electricity, if there is an intention to develop nuclear powered desalination or process heat production, this should also be addressed in the statement”.

2.2.1.1. Phase 1

Phase 1 supports the policy decision to commit to a new nuclear power programme. Significant progress on a specific nuclear project is unlikely until this milestone has been met. It is a preparatory step that involves gathering information on (and as necessary developing) relevant national policy, and also gaining understanding of local and private sector decision making processes, prior to the commitment of the investing stakeholders to the project considered. This holds even for countries that have already operated nuclear power reactors and that intend to initiate a new nuclear cogeneration project. Considerations may include national energy supply and demand outlook, the role of nuclear power in long term energy supply and economic planning for cogeneration products, among others.

Based on global experience on nuclear plant projects, preparatory work will likely include development/determination (or verification) of:

— The ownership and management structure of the project (ownership roles of vendors, users, the government and investors or other project owners);
— Research activities needed to support the policy decision;

[3] As introduced in Stakeholder Engagement in Nuclear Programmes (IAEA Nuclear Energy Series NG-G-5.1), “Stakeholders include legislators, media, government agencies and decision makers, the owner/operator, the regulatory body, suppliers, workers, communities near actual or potential sites, neighbouring countries, non-governmental organizations, and the public.”

- Government commitment to participation, coordination, funding, or other involvement;
- Consultation with potential users (owners/operators) of power, heat and other non-electric applications, including regarding the merits and benefits for them of the proposed project; the procurement process; and arrangements to assist in operation, maintenance and financing of the nuclear plant;
- Consultation with vendors to select the appropriate reactor technology and develop the plant conceptual design in order to explore supply chain and contractual arrangements for goods and services, including from offshore companies;
- Financial models and investment schemes exploring public, private, user and vendor resources;
- Plans for comprehensive workforce development, including education and training to meet staff demand and ensure the competence of the institutional and industrial sectors;
- A legal and regulatory framework, and culture, for nuclear safety, security and safeguards; and for compliance with international IAEA standards;
- A framework for nuclear liability and damage compensation;
- National energy policy;
- Relevant economic policies, at the national, regional and international levels, as applicable;
- Relevant environmental policies, at the national, regional and international levels, as applicable;
- Communication plans, to promote acceptance by the public, local communities, and the power and heat industries;
- Plans for commitment to standards and requirements for site characterization and emergency preparedness; for occupational health, safety and environmental impact; and for waste management (e.g. ISO14001);
- Plans for new or strengthened existing infrastructure, for example adjusting the power transmission network or improving the interface with end users;
- Integration of all the above considerations into a policy decision to proceed with a nuclear power programme or project.

To the extent feasible, cost sharing or funding grant arrangements should be explored with the government, based on the precept that exploration of a possible nuclear cogeneration project could lead to benefits for stakeholders at national and local levels who are constituents of the government.

2.2.1.2. Phase 2

Phase 2, following the policy decision made to proceed, comprises the establishment of major institutions and legal/regulatory frameworks, and the preliminary or basic project design. It likely includes additional research and development, design of new technology, and other work (e.g. inviting bidding and contract negotiations prior to commitment to construction). The typical activities of Phase 2 toward making the business case or demonstrating feasibility include (Fig. 2):

- Development of detailed ownership, financing models and schemes for the cogeneration project, building on those envisioned in the first phase;
- Specification of a qualified user (owner/operator) of the nuclear plant;
- Clear specification of engineering, procurement and construction (EPC) terms;
- Definition of off-takers for electricity and cogenerating products;
- Development of a risk management plan;
- Development of an operation and maintenance (O&M) scheme;
- Selection of nuclear fuel and cycle options;
- Development of terms for technology transfer.

Figure 2 depicts, in a general way, the nominal relationships among the expected project participants. Variations in the project participants and their relationships with each other are likely, depending on

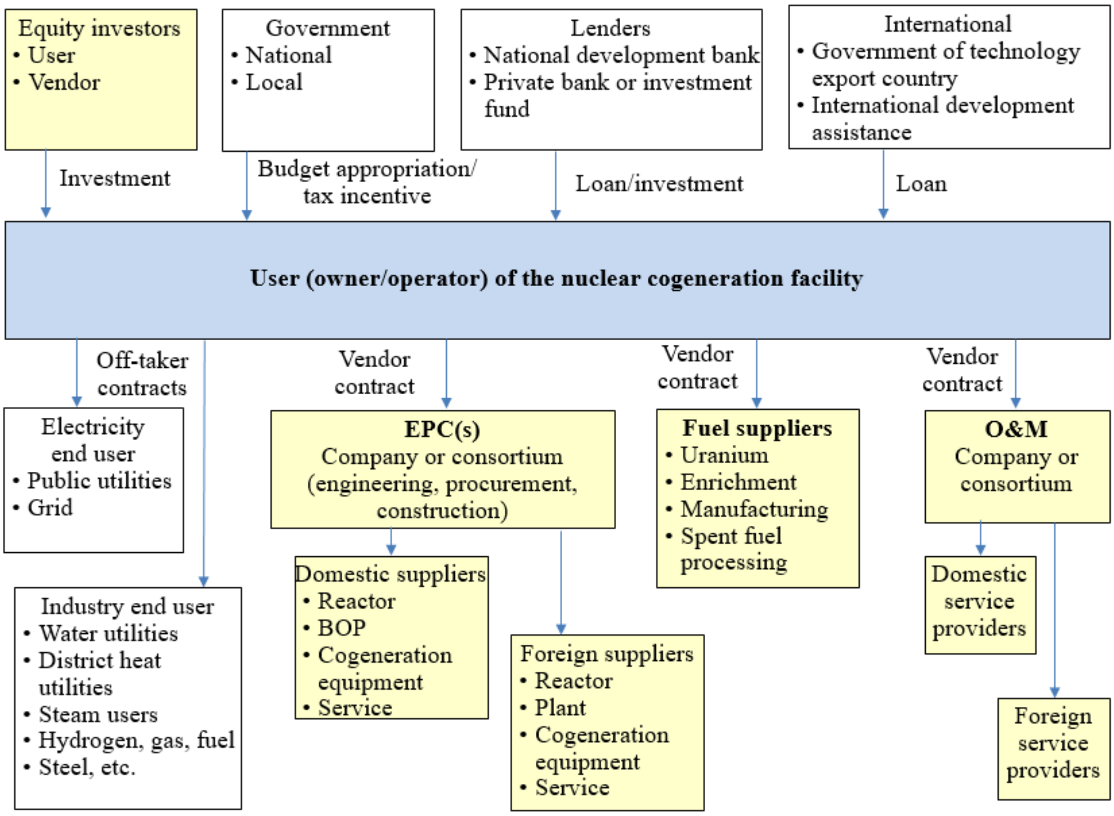

FIG. 2. Typical business model for a nuclear cogeneration plant project.

factors such as the participation of the government, the laws to which business entities are subject, the specific terms of contracts among the user and its vendors and suppliers, etc. The primary value of Fig. 2 is to assist the project participants in considering the relationships among them that apply to their specific situation. The figure can readily be adapted to the specifics of each project.

Additional government support for the project should be pursued, in particular first of a kind work in areas such as conceptual design, research and development for technology readiness, licence applications, plant construction and fuel production. A sliding ratio of governmental to private financing during the project cycle is often practised, starting with 4:0 for Phase 1, 3:1 for Phase 2, 2:2 or less for Phase 3 and 0:4 for Phase 4. Such government support may take many forms, for example government grants or ownership participation, or loans from a national development or investment bank. Such involvement helps reduce private sector business risk and improve the confidence of the owner in its ability to secure additional private lending. As an example of government support, in the USA, the Government may provide a loan guarantee of up to 80% of the total project cost for a new NPP construction project, as well as a long term tax deduction after the start of operation.

If the user (owner/operator) is familiar with the EPC functions, as is the case with most electric utilities, the user may, but need not, assume responsibility for EPC, managing the project construction, including:

— Selection of equipment suppliers;
— Bidding and contracting for equipment;
— The integrated management system;
— The quality assurance programme;
— The procurement department;
— Site management and technical support.

However, if the user company has little experience with NPP construction or wants a more experienced company to reduce risk or fix the cost of the project, it may contract with an EPC company to develop and manage the whole construction project (or perhaps just the nuclear Part of it), and have the plant turned over to it once it has been completed, licensed and commissioned. This is commonly known as a turnkey plant. More details on this are provided in Alternative Contracting and Ownership Approaches for New Nuclear Power Plants (IAEA-TECDOC-1750) [1].

This turnkey scheme may be most practical for a user in an embarking Member State. It may also be preferred for an established user to have the cogeneration system built and connected to the nuclear reactor as a turnkey plant. The scheme is also suitable for most independent power producers.

A qualified EPC project should be undertaken by a company with comprehensive experience and capabilities regarding a particular nuclear technology. EPC for a cogeneration system such as desalination or hydrogen production and the construction of the nuclear plant in general should be contracted independently. Another possibility is that the EPC entity may be formed by a consortium of vendor companies including offshore vendors, each experienced with Part of the technology. In the latter case, a major company of the consortium would likely be contracted as the lead, with the responsibility for interfacing the parts of the technology provided by the companies of the consortium and scheduling the delivery of equipment, as well as the installation and final commissioning of the plant, etc.

It is important for the user of a turnkey project to exert significant oversight over the EPC contractor and its subcontractors to ensure that nuclear quality and standards are being maintained and implemented, regulatory requirements are being met and the project is being well and efficiently managed. Lack of such oversight has led to project failures in the past.

Off-takers are the end users of the electricity and cogenerating products from the plant gate. Examples of off-takers are utilities or transmission companies, and gas and steel businesses that purchase the heat and hydrogen produced by the nuclear cogeneration plant. For a captive plant, the off-taker is also the user of the plant. More details concerning and insights into these aspects are provided in Alternative Contracting and Ownership Approaches for New Nuclear Power Plants (IAEA-TECDOC-1750) [1].

A risk management plan is usually required for a complex long term project such as a nuclear cogeneration project. Such a plan defines the execution method for various project tasks, major examples of which are shown in Table 1 for Phases 2 and 3 of a project. The risk events/factors are identified and assessed for probability of occurrence, degree of impact, response plan, etc. Stakeholders responsible for risk factors or most suited to mitigate them are identified, and a risk management plan is developed to eliminate or mitigate each risk as deemed necessary and prudent. It is important to estimate the cost of countermeasures for a risk management plan and secure a budget in advance.

The stakeholders listed in Table 1 should be considered to be potentially responsible for, and potentially able to mitigate or partially mitigate, some aspect or portion of the risks noted. The specifics applicable to a given project will vary by project and State. For example, government financing may or may not be applicable or available to a given project. If it is not, the government is not necessarily a 'responsible stakeholder', though it could choose to step in, if needed, and if the government in question believes it to be advantageous to do so.

Further, the role of given stakeholders in a specific risk is not the same. The regulator is responsible for licensing and regulation. But the competence of the user and vendor in executing their roles in the regulatory process impacts on the licensing risk of the project. Therefore, Table 1 is useful in thinking broadly about project risks and the potential role of different stakeholders in mitigating such risks.

An in-depth perspective on managing financial risk associated with new nuclear power plants can be found in Refs [22, 23].

Similar to conventional electric power and industrial plants, the user (owner/operator) of a nuclear plant often relies by contract on a company to be responsible for actual O&M. The intention is to engage an experienced company or consortium to concentrate on the O&M business in order to ensure long term and stable operation and maintenance of the plant. For embarking nuclear energy countries, such an O&M company may be (or be partnered with) a foreign company or a foreign utility with abundant knowledge and experience. Having management responsibility and a financial interest in ensuring smooth

TABLE 1. RISK MANAGEMENT FOR PROJECT PHASES 2 AND 3

Risk categories	Risk events and factors	Responsible stakeholders
Politics	— Instability of government, laws or policy — International relations (treaty, war, etc.)	— National and local governments — Foreign governments
Financing	— Government budget authorization and appropriation — Private company bankruptcy or default — Financial or foreign exchange crisis	— Government — Investors, owners and equity lenders — Financial stakeholders
Design	— Design delay and design rework/modification — Technology development delay and failure	— EPC vendor and its subcontractors
Permitting, licensing and regulation	— Delay in application — Delay in licensing — Changing regulations requiring project changes	— Users (owner/operator) — Vendors — Regulators
Construction management	— Schedule delays in procurement — Cost overruns	— EPC vendor — Vendor suppliers
Off-takers	— Demand and market changes due to economic recession/industry regulations — Off-taker defaults	— End users (power utilities) — End users (industrial users: water, district heat, steam, hydrogen, etc.)
Fuel supplier	— Delayed start of operation due to delay in building fuel procurement supply chain — Policy shift for spent fuel treatment — Policy shift for waste disposal	— Vendor (fuel): uranium procurement, fuel enrichment, processing, manufacture
Radioactive waste treatment/disposal and disposal of spent fuel	— Final disposal site for radioactive waste and spent fuel not selected and implemented	— National/public disposal site, etc. — Vendor for fuel processing and disposal

operation and production over the lifetime of the plant itself, such foreign utilities are also often willing to invest financially in the construction of the plant.

Technology transfer may be a contractual Part of the project. It may take the form of transfer or licensing of tangible technology (equipment) and/or intangible (technical and management skill) know-how. The kind of transfer technology may vary. It could be a transfer of technology ownership, or it could be a limited licence agreement that only grants the right to use the technology with a clearly defined or restricted scope and without transferring ownership of the technology. In addition to benefitting the licensee, the licence agreement may benefit the licensor by granting it the right to use any improvement made by the licensee through its use of the technology.

2.2.1.3. Phase 3

Phase 3 is the final investment decision and construction of the nuclear power plant (and the cogeneration facility in this case), ending with the milestone of readiness for commission and operation of the first nuclear plant and cogeneration facility. It involves activities such as:

— Finalizing contracts;
— Detailed design and engineering;
— Construction licensing;

— Construction.

The user (owner/operator) of a turnkey plant will begin by contracting with the EPC company or consortium. The EPC will then launch bidding and subsequent negotiation of the contracts to select suppliers to provide the design, equipment manufacturing, plant assembly and commissioning of the NPP and cogeneration facility — any and all aspects of the project construction that the EPC vendor will not handle itself. For a non-turnkey plant, the user will act as its own EPC and proceed directly with the bidding and negotiation of the contracts to choose the suppliers.

The EPC vendor will perform design and engineering to produce a site specific design while assisting the user in site characterization, development of the environmental impact assessment and development of the preliminary safety analysis report. These activities will support the user in submitting an application for construction licensing.

A competent national regulatory authority that is as independent of political and economic considerations as possible should exist or be established by law prior to Phase 3. Furthermore, the project should be committed to appropriate codes and standards and the human resources needed to perform safety and security reviews and oversight for the proposed nuclear programme or project should be in place. The regulatory authority will then be ready to conduct safety and security reviews of the application, interact with the licensee and mandate necessary design changes, and finally issue a construction permit.

The EPC vendor will then conduct all procurement and construction activities. Many such activities will be subject to continual regulatory oversight of compliance with the licence during the construction. More than one regulatory authority will likely have oversight (e.g. nuclear regulator, environmental protection regulator, industrial safety regulator), and the EPC vendor has to ensure that all requirements are met throughout the construction period. At the end of construction, the EPC vendor will hand over the plant to the user (owner/operator), who will apply for and obtain an operating licence in compliance with the regulatory requirements for safe and secure operation of the plant.

2.2.2. Retrofit projects

Various considerations may lead to the conclusion that it may be wise to consider the retrofitting of a nuclear power plant designed, constructed and operated for a single purpose (usually generation of electricity) to serve additional purposes through cogeneration. Such considerations may include:

— Favourable cost of cogenerated energy as compared to alternative sources;
— Lower project risk as compared to new nuclear construction;
— More intensive use of fuel energy, namely reduction of waste heat;
— Reduction of CO2 footprint compared to otherwise fossil fired plant operation;
— Reduction of cost for thermal energy through cogeneration;
— Changing demands for utility products, for example hydrogen production in an enhanced hydrogen economy;
— Diversification of revenue streams for the operator;
— Advancement of technologies, for example enhanced ability to transport heat over large distances economically.

The demand for new (cogenerated) products has to be sufficiently large to be economical, and the costs of nuclear assisted production likely need to be lower than costs from competitive fossil (or other) heat sources — unless environmental considerations such as reducing greenhouse gas emissions compensate for nuclear being somewhat more expensive. The new system to be connected to the NPP may take advantage of otherwise wasted residual heat exhausted from the main turbine. It may also make economic sense, in the presence of demand for higher quality heat, to divert some amount of heat before the power plant turbine for use in cogeneration at the cost of lower electrical output from the turbine generator.

The stakeholders are, in principle, similar to those for the above described cogeneration case. The role of the EPC vendor will be different in many ways, especially because the nuclear power plant will presumably already be licensed and constructed. A complex licence amendment will be needed, but it will surely be a much less challenging task than licensing and constructing a new nuclear power plant. Because transients on the secondary (balance of plant) side of an NPP can and occasionally have led to issues on the primary (safety related) side, such potential impacts will need to be assessed carefully and addressed in the licence amendment. EPC vendor companies familiar with NPP licensing and construction but specializing in analysing the as-is (nuclear) plant and determining and designing plant modifications to support cogeneration will likely be engaged.

The essential Part of the nuclear plant to be retrofitted is the main steam system in the conventional section of the NPP, as well as the turbine–generator system. Furthermore, there may be a need — for cogeneration safety reasons — to install a tertiary circuit with another heat exchanger (and operating at a higher pressure than the system tapped into the NPP) to virtually exclude the possibility of transport of radioactive contamination to the cogeneration product stream. Sufficient space has to be available for installation of the required equipment.

The largest capital costs would likely involve the new system to be added, for example the transport system for hot water or steam in the case of district heating.

2.2.3. Specific cogeneration infrastructure

2.2.3.1. Acceptance of nuclear power by conventional industries

Globally, there are numerous industrial sites with large market potential for nuclear process heat utilization encompassing a wide range from low to high process temperatures. High temperature applications of nuclear energy, particularly for production of new fuels like hydrogen on a CO_2 emission free basis, may have great potential for the future. Low temperature heat for industrial drying or preheating processes represents a way of saving enormous quantities of conventional fuel.

From an economic and thermal efficiency point of view, the coupling of the nuclear plant to process heat applications such as topping or bottoming cycles for power conversion promises a significant improvement in efficiency. Since in principle all types of nuclear reactors can be operated in the CHP mode, with any heat to electricity ratio possible, CHP nuclear plants can be readily integrated into an electrical grid system of sufficient size and with sufficient alternative generation sources to be compatible with the nuclear cogeneration plant electricity generation capability and intended generation mode (e.g. rated power capability and variable or stable electrical output).

Nuclear cogeneration is ideally suited for nearby consumers with a need for a reliable, larger scale baseload supply of power, as well as for process heat/steam to support provision of other products, such as hydrogen, to industrial consumers. The process heat/steam utilization system connected to a cogeneration NPP will not be designed as a nuclear grade system. It will rather be designed as a conventional industrial plant that receives energy products from the nuclear plant. Its nuclear regulatory footprint will presumably be limited to evaluation and control of any potential safety impacts the process heat system could have on the NPP, as well as prevention of release of unacceptable amounts of radioactive materials to the cogeneration stream.

2.2.3.2. Development of a safety concept

Superior safety features and high reliability are considered to be prerequisite for the introduction of nuclear process heat and nuclear combined heat and power. The complexity of the combined system requires the development of advanced safety concepts and techniques to ensure proper control of the system. Therefore, it is useful to divide the safety evaluation into the areas of the nuclear heat supply system, the process heat application system, and the interface and interaction between the two systems.

Potential hazardous or off-normal events in connection with the combined nuclear–industrial systems include:

- — Transients imposed on the nuclear system by expected or unexpected conditions or transients in the product stream;
- — Radionuclide transportation or leakage into the product process stream (e.g. tritium transportation from the core to the product hydrogen);
- — Thermal turbulence induced by problems in the chemical system;
- — Fire and/or explosion of flammable mixtures with process gases present in the system;
- — Release of toxic material.

A principal requirement and expectation for the nuclear power plant is that radioactivity be retained inside the plant even in the unlikely event of accidents (including those considered highly unlikely and beyond the design basis of the nuclear plant), with no consequences posing a threat to public health and safety off-site. No measurable radioactive materials should be capable of migrating to the industrial circuits and contaminating the end products delivered to the consumers. Potential contamination refers in particular to highly mobile tritium and the possibility of permeation from its origin in the primary system through heat exchanging systems or the gas purification plant; this issue, however, is largely diminished with the introduction of a tertiary circuit. Degradation in heat exchangers could also lead to direct leakage of a wide range of radionuclides that can be found in the primary nuclear circuit. The existence of the tertiary circuit, and maintenance of higher pressure on the secondary and/or tertiary sides as compared to the primary loop, minimize the likelihood of this leakage occurring. Additional safety measures include radiation or contamination detection systems that result in rapid automatic system shutdowns and isolations if unexpected leakage into the secondary circuit occurs.

An abnormal loss of the heat sink on the industrial side should not force the nuclear reactor to scram/trip, but rather should lead to an orderly transition of the reactor to idle (standby) running conditions. A safety related issue is the operability of the production process system during a sudden loss of the heat source (i.e. a nuclear reactor scram). Nuclear safety regulations require that the ultimate heat sink of a nuclear power plant always be available to remove decay heat. Such heat sinks are usually limited to water and/or air and cannot be electricity or chemical energy as the result of a conversion process. Therefore, a separate ultimate heat sink from the normal cogeneration process stream will likely be required.

2.2.3.3. Nuclear safety

The general subject of nuclear safety is outside the scope of this publication. However, the owner/user and vendor of a nuclear cogeneration facility will need to bear in mind the overarching requirement that the nuclear power plant be designed and operated such that public health and safety, and the environment, are protected against hazards associated with the use of radioactive materials in the nuclear plant. In addition to the hazards particular to any nuclear power plant, potential hazards associated with the use of cogeneration that might impact on the safety of the nuclear power plant (and hence the potential for release of radioactive materials as a result of a nuclear accident or incident) have to be considered and addressed. This is separate from consideration of the potential for release of radioactive materials to the cogeneration system and heat application (discussed in Section 2.2.3.4. on coupling technology). The safety analysis report developed and submitted to the nuclear regulator by the facility owner/user will need to thoroughly address potential impacts and hazards associated with the cogeneration Part of the facility on the nuclear safety related structures, systems and components of the nuclear plant. The analysis will need to include consideration of scenarios where off-normal conditions occur in both the cogeneration facility and the electric power generation portion of the facility as a result of a given initiator, and the impacts of such conditions on the nuclear safety related portions (i.e. the nuclear reactor and its supporting and emergency response systems).

2.2.3.4. *Coupling technology*

In early nuclear process heat concepts, the intermediate heat exchanger (IHX) linking the primary with the secondary circuit provided the separation between the nuclear plant cooling medium and the heat application. In contrast, some current concepts include an additional circuit. For example, a gas reactor providing process heat via a gas medium could have another heat exchanger transferring heat from (secondary) helium to the (cogeneration feed) process gases to further reduce the risk of process or product gases being contaminated with radioactive materials. In this example there could be a temperature reduction of ~50°C in the cogeneration stream due to temperature drop across the intermediate loop. The physical separation allows for the heat application facility to be designed conventionally, and for repair work to be conducted without the need for adherence to nuclear standards. Experience with the IHX component has been gained in Germany with two 10 MW test components where nuclear conditions (950°C helium) were simulated, and in Japan with the 30 MW IHX components in the High-Temperature Test Reactor (HTTR) experimental reactor.

For process steam production, a tertiary cycle will typically be employed, with heat transfer via a steam to steam heat exchanger providing an additional barrier against tritium migration to the process system.

Conditions for the IHX may be challenging, since it will often be subjected to high temperatures, large pressure differences and a corrosive environment on the process side. A design that allows easy in-service inspection is desirable.

A significant materials challenge is susceptibility to corrosion as a result of contact with acids at high temperatures and pressures. Screening tests have been conducted in various institutions to identify corrosion resistant materials in environments typical of the operation conditions of the sulfur–iodine cycle that is a candidate to produce hydrogen. Ceramic and quartz have excellent corrosion resistance, but they exhibit manufacturing challenges due to their brittleness, particularly if exposed to thermal stress. Work to better define suitable materials and fabrication technologies continues.

Experience has accumulated in Member States on particular aspects of heat exchangers to be used in connection with a hydrogen production facility. For example, Germany has tested a pilot plant scale immersion heat exchanger to connect the nuclear side with a steam–coal gasification furnace. Both Germany and Japan have investigated helium heated steam reforming heat exchangers. More recent efforts concentrating on hydrogen production through the sulfur–iodine cycle evaluated heat exchangers for the decomposition of sulfuric acid at high temperatures, with major testing conducted in Japan and the Republic of Korea.

Another essential coupling component is the use of high temperature isolation valves, whose function is to shut off both the supply lines and the product gas lines quickly in the case of off-normal conditions. The shutoff system comprises multiple different valves (redundance), some of which shut quickly on demand or based on a process signal. Proof of concept for such a component has been demonstrated in Germany [24, 25] and Japan [26] in testing under simulated nuclear conditions.

2.2.3.5. *Plant size and configuration for nuclear cogeneration*

A modular arrangement of several smaller scale nuclear plants could be sized to optimize support for the intended industrial use. The use of several small nuclear units potentially enhances the redundancy, reliability and reserve capacity of the provided energy product. The arrangement could consist of multiple identical reactor modules or multiple reactor modules of differing ratings and configurations. Smaller unit sizes allow for simplicity and potentially for higher safety margins. The small power size of modular reactors is also favourable for operation in less developed electrical grids, which are often not compatible with larger unit outputs. Such a configuration could also make it easier to expand capacity by adding additional small reactors as market demand warrants. Many small modular reactors are either being marketed worldwide or are in developmental stages to support marketing in the near to mid term.

2.2.3.6. *Lifetimes of nuclear plant versus cogeneration facility*

The expected lifetime of the nuclear plant is likely to be at least twice that of the cogeneration distribution infrastructure. For example, if cogeneration supports natural resource extraction, the natural resources are likely to be depleted well before the end of the nuclear power plant design lifetime. This creates challenges and opportunities for the nuclear power plant owner. The owner should structure the project's finances and contracts in such a way that investors can expect to see an adequate return on funds invested. Given the relatively high construction costs for a nuclear power plant, it is unlikely that a nuclear cogeneration project would be proposed with a shortened nuclear power plant lifetime to match a relatively short lived cogeneration facility. The project as designed should reflect a vision for the entire projected lifetime of the nuclear and non-nuclear portions. An example could be to at least conceptually plan for a follow-on cogeneration facility of the same or a different type, and/or modify the project to result in additional electric power at the end of life of the cogeneration facility. Section 7 discusses the contractual implications of these different lifetimes.

2.2.3.7. *Extension of codes and standards*

The realization of nuclear cogeneration systems connected to conventional industrial processes requires intensive partnership of nuclear organizations and end user industries, but also the early and close involvement of national regulators to develop or validate a protective but not unduly burdensome regulatory framework. IAEA guidance to Member States in areas such as safety evaluations and emergency planning is also essential. Such guidance will help bring about a reasonably consistent regulatory and safety environment worldwide that will assist vendors and users to invest in the new technology with confidence, while also helping to ensure the protection of public health and safety. The requirements and acceptance criteria to deal with the risk of any contamination of end user products or installations (in case of accidents) will be subject to discussions with safety authorities.

An important parameter that needs to be determined is the physical separation distance to protect the nuclear side from any accidental occurrences on the industrial side (essentially fire and explosions). This separation is usually determined as a function of the quantity of a flammable material involved ('quantity–distance relationship'). It may be fixed on the basis of credible events, taking account of — if referring to hydrogen — the evolving flammable atmosphere, as well as the heat and pressure wave resulting from a possible ignition. The separation distance can then be defined according to physically defined criteria, for example an acceptable threshold for peak overpressure or thermal energy pulse. A particular aspect is the risk of projectiles, which may be thrown much further away than the safety distance if based solely on blast pressure. Safety distance guideline approaches are often simplified. They may, however, not be applicable in situations where confinement or congestion may lead to flame acceleration. Further, non-quantifiable leakages (e.g. from cracks in welding seams) cannot be applied to simplified guidelines.

3. STAKEHOLDER INVOLVEMENT IN NUCLEAR COGENERATION PROJECTS

Information about topics, concepts and research related to nuclear cogeneration is available today, but specific guidance for vendors and users on the process of planning for, constructing and operating a nuclear cogeneration facility has not been laid out in a public domain publication. This publication seeks to provide this information at a summary level. This section provides information for vendors and users to consider as they begin the planning and decision making process regarding a possible nuclear cogeneration project, while details on contracting and ownership approaches for nuclear power projects are provided in Alternative Contracting and Ownership Approaches for New Nuclear Power Plants (IAEA-TECDOC-1750) [1].

This section begins with a discussion of the stakeholders for such a project and continues with specific planning information for vendors and users. Several IAEA publications expand on stakeholder engagement in nuclear programmes: Stakeholder Engagement in Nuclear Programmes (IAEA Nuclear Energy Series No. NG-G-5.1) [27], Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities (IAEA Nuclear Energy Series No. NG-T-1.4) [28] and Communication and Consultation with Interested Parties by the Regulatory Body (IAEA Safety Standards Series No. GSG-6) [29].

Although a limited practice, 71 large nuclear reactors were operating in cogeneration mode at the end of 2021. Some countries, even with wide experience of operating nuclear power reactors, have reduced the number of or have no existing nuclear cogeneration projects. For example, in the USA there are 93 operating nuclear power units (as of March 2022, according to the IAEA Power Reactor Information System (PRIS)), but there has been only 1 example of a nuclear cogeneration facility: the Diablo Canyon Nuclear Power Plant with a water desalination facilityRecently, in March 2023, the nuclear hydrogen demonstration project at Nine Mile Point Generating Station started to become operational. Few other nuclear hydrogen demonstration projects using the current nuclear power fleet are on-going demonstration in the United States.

Support from all stakeholders, as well as careful planning and execution, are needed for a nuclear cogeneration project to succeed. The information that follows is intended to provide planning concepts to help project owners develop a business and stakeholder engagement plan. Success will result from careful planning.

The state of knowledge on next generation nuclear reactors and on nuclear cogeneration is evolving rapidly. The IAEA will therefore continuously collect Member State feedback to support updating of the guidelines in the future as appropriate to optimize their usefulness.

3.1. STAKEHOLDERS FOR A NUCLEAR COGENERATION PROJECT

Discussions around nuclear power involve considerations of nuclear safety, environmental impacts, energy management, public health and safety, climate change, the role of government, etc. These discussions are often fraught with emotion, miscommunication and misinformation. It is extremely important for the success of the project that stakeholders be fully identified, and that a plan for interacting with stakeholders be developed and implemented. The purpose of such involvement is to enable all stakeholders to make their views known and to work together to ensure that these views are addressed/considered. At the same time, it should be recognized that the aim of an effective stakeholder involvement programme is not necessarily to gain consensus or 100% agreement, but rather for stakeholders to understand the basis for a decision and thus have greater trust that the decision was appropriate.

Decisions regarding any type of nuclear facility have typically received considerable attention among the public and other stakeholders. Regardless of the stage in the life cycle of the nuclear programme — initial consideration, operation, expansion or decommissioning —addressing stakeholder needs and concerns properly improves the probability of programme success. Engaging stakeholders as early as possible and with ongoing attention is essential, including helping stakeholders understand the extent of their involvement in decision making processes regarding these nuclear facilities/programmes.

Finding mutually acceptable agreement for all the parties obviously requires the participation of a wide range of stakeholders. Political, cultural, governmental and legal authorities vary significantly from country to country. For instance, private organizations are directly responsible for designing, building and operating nuclear power plants in the USA. In other countries the government may take on a large owner or sponsor role. As another example, the role of national versus local government in emergency planning varies significantly from country to country. Although decision making processes vary considerably by country, depending on culture, history and governmental structure, it is always advisable that all entities primarily responsible for nuclear programmes create plans for stakeholder involvement. There is no one ideal model for this. Stakeholder involvement strategies and approaches depend on the nature of the nuclear facility, the point in its life cycle, cultural and legal norms, and other factors. Therefore, this guideline is principally useful in establishing the thought process in developing a project specific plan for identifying and involving stakeholders.

3.1.1. Identifying stakeholders

Many stakeholders for a proposed activity have roles defined in national or local laws and regulations that inherently make them participants in the process. Examples include regulators. Other participants may not have a direct statutory role but are still important for the outcome of the project.

Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities (IAEA Nuclear Energy Series No. NG-T-1.4) [28] and the new publication Stakeholder Engagement in Nuclear Programmes (IAEA Nuclear Energy Series No. NG-G-5.1) [27] are excellent sources of guidance on stakeholder involvement. Reference [28] states that:

"stakeholders have typically included the following: the regulated industry or professionals; scientific bodies; governmental agencies (local, regional and national) whose responsibilities arguably cover, or 'overlap' nuclear energy; the media; the public (individuals, community groups and interest groups); and other States (especially neighbouring States that have entered into agreements providing for an exchange of information concerning possible trans-boundary impacts, or States involved in the export or import of certain technologies or material)."

The same publication cites a definition of a stakeholder as "any actor-institution, group or individual with an interest in or a role to play in the societal decision making process".

Another reasonable definition of a stakeholder for a given activity is a person or organization that believes they are impacted on by the activity. Legal proceedings may ultimately determine the validity of assertions of impacts. However, regardless of such determinations, those who believe they are impacted on may have the ability and the motivation to participate meaningfully in public discussions and/or legal proceedings that could impact on the ultimate success of the project. Many stakeholders are also intrinsically bound to the project (e.g. users, vendors, suppliers, their respective staffs, and related companies). Table 2 lists typical categories of stakeholders and example stakeholder types within the categories.

TABLE 2. REPRESENTATIVE STAKEHOLDERS

Stakeholder category	Example stakeholders within categories
Users (owners/utilities)	— Full scope electric utilities — Electricity generating companies — Water agencies
Vendors (engineering, procurement and construction vendors and their supply contractors)	— Firms involved in design and construction of the physical plant — Suppliers — Manufacturers
Consumers (grid operators, industries, etc.)	— Firms that operate the electrical grid — Government agencies that manage grid reliability — Industrial end users of cogenerated products (hydrogen, steam, desalination, district heating, etc.)

TABLE 2. REPRESENTATIVE STAKEHOLDERS (cont.)

Stakeholder category	Example stakeholders within categories
Owner (operator) and/or vendor (service providers)	— Plant operators — Maintenance crews — Administrative staff — Engineers — Labour unions
Financial community/lenders	— Banks — Creditors
National government	— Executive (president/prime minister) — Legislature — Judiciary — Government regulatory agencies
Provincial/state government	— Executive — Legislature — Judiciary — Regulatory agencies — State/provincial police
Local government	— Mayor — City council — Local police
Project financial participants	— Investors — Shareholders
Public	— Local communities — Concerned citizens — Affinity groups — Advocacy groups — Public interest groups
Scientific community	— Research centres — Professional societies — Universities — College students — Academics — Analysts
Media	— News media — Social media
Medical professionals	— Physicians

Table 2 is not comprehensive, and a comprehensive list will vary by Member State, depending on many factors, for example government structure, the role of private industry in the economy and cultural values. It is primarily of use to indicate that there are many potential stakeholders, and that project owners have to consider carefully who their stakeholders may be.

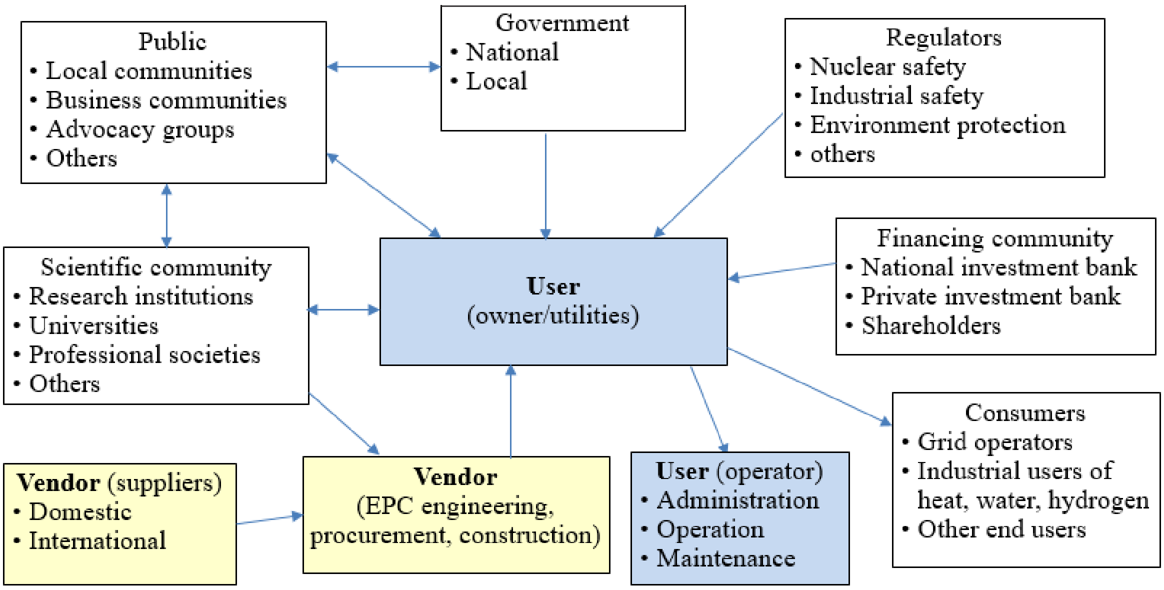

FIG. 3. Typical relationships of users/vendors among other stakeholders.

3.1.2. Developing a business plan and involving stakeholders

To identify stakeholders and then develop plans for working and interacting with them, as applicable, it is important to understand the relationships among the stakeholders. Figure 3 depicts typical relationships of users and vendors among other major stakeholders identified in Table 2. The complexity of the relationships varies with the demand of a project. The IAEA guidance publication, Industrial Involvement to Support a National Nuclear Power Programme (IAEA Nuclear Energy Series No. NG-T-3.4) [30], identifies an example of simpler relationships.

A business plan is essential for the success of a complex project such as a nuclear cogeneration facility. This plan will establish the role and involvement of each stakeholder/participant, and will identify how best to coordinate and manage these roles to achieve project success. The business case is discussed briefly here in the context of stakeholder involvement. It is discussed in more detail in Section 4.

In Ref. [31] the key components within a business plan identified are the following: partners, activities, resources, value proposition, customer relationships, communication channels, cost structure and revenue streams. Each of these key components would have to be thoroughly examined for the planning of a nuclear cogeneration project. Some of the considerations for these components are the following:

(a) Key partners. Who are the partner organizations who will be producing and providing the necessary components to bring the power plant to fruition? Who are those in charge of each organization? What responsibilities are they given? Who do they answer to?
(b) Key activities. What are some key goals that have to occur in order for the project to be counted as a success? What are the deadlines for each of these objectives? Who is assigned to each objective, and how much freedom do they have in completing it?
(c) Key resources. What are the essential supplies necessary to construct the power plant? Who will supply these materials? How much will it cost, and is there a more prudent way to reach the project's goals in a less expensive manner?
(d) Value proposition. How will the nuclear cogeneration facility be attractive to its investors and owners, local citizens and governments? Will the power plant use the latest technology to ensure

safety and efficiency? What steps will the plant take to set a positive tone in the community about its presence and service?

(e) Customer relationships. How are relationships with local stakeholders formulated? Does the plant provide career opportunities for local people to be involved within the project? Does the plant have user friendly means for stakeholders to communicate concerns or ask questions? Are their opinions and requests taken seriously?

(f) Communication channels. Does the cogeneration project and facility have various means of contact? Does it have a mailing list and a website? Does it have a valid email address and phone number?

(g) Cost structure. What are the various costs involved in building the cogeneration facility? The costs involve a variety of categories, ranging from labour, building expenses, waste removal, construction equipment, etc.

(h) Revenue streams. What are the specific revenue streams by which the project/facility will be made profitable?

A successful business plan also identifies risks to maximize the probability of project success. Figure 4 presents an example of a risk matrix [32].

It is important for project success that the owner/operator engage a reputable risk management firm to develop a comprehensive risk management plan.

The business plan will also need to consider financing for the project. This is especially key for any nuclear project, for which capital coasts will be a major portion of the total life cycle expenses as compared to other fuel sources, for which fuel cost is a much larger contributor. Potential finance options for nuclear cogeneration projects include direct investment by owners such as utilities, loans from banks/commercial financial institutions, bonds, equity investors (through sale of stock) and government funding. The best specific funding package depends on the national and business context and cannot be specified here. The important point is that detailed planning is needed for financing, including how cost overruns (especially likely for first of a kind projects) will be handled.

Another aspect of the business plan is interactions with, and involvement of, the government. The project owners have to clearly understand the regulatory framework and the level of support for the project within all levels of the government (national to local). The regulatory framework to support review and approval of the project before, during and after construction has to be in place. Depending on the national and project context, active government support may be required. In any event, experience has shown that widespread opposition within the government to a nuclear project will make the project very difficult to complete successfully.

The details of the regulatory framework will differ among Member States, but the principles are the same or very similar. The owner/operator of the nuclear power plant will be required to obtain a licence or licences to construct and operate the plant. A separate environmental impact permit will also likely be needed, as will other permits. In order to receive the operating licence, the operator will need to demonstrate the completion of hundreds of tests and inspections, and it will have to license operators to run the plant. Throughout construction and plant operation, the plant will be subject to regulatory inspection, and the operator will need to show constant adherence to, and recognition of, the principles of a nuclear safety culture. An example of regulator expectations for safety culture is found on the US Nuclear Regulatory Commission web site [33]. The owner/operator has to clearly understand the regulatory process and adhere to it closely.

The aspect of the business plan regarding engagement with the public is also very important. It is particularly important for any nuclear project because of the scepticism and potential opposition some fraction of the public in the vicinity of the project may have toward the project because of antipathy toward nuclear power in general. It is vital that the project owner/user establish a positive relationship with the community to garner positive public opinion, encourage dialogue and avoid opposition to the extent feasible. A fairly recent poll shows that informing the public about nuclear technologies has a strong effect on their views on a nuclear project [34]. Just as with government opposition, widespread public opposition to a nuclear project will make the project very difficult to complete successfully.

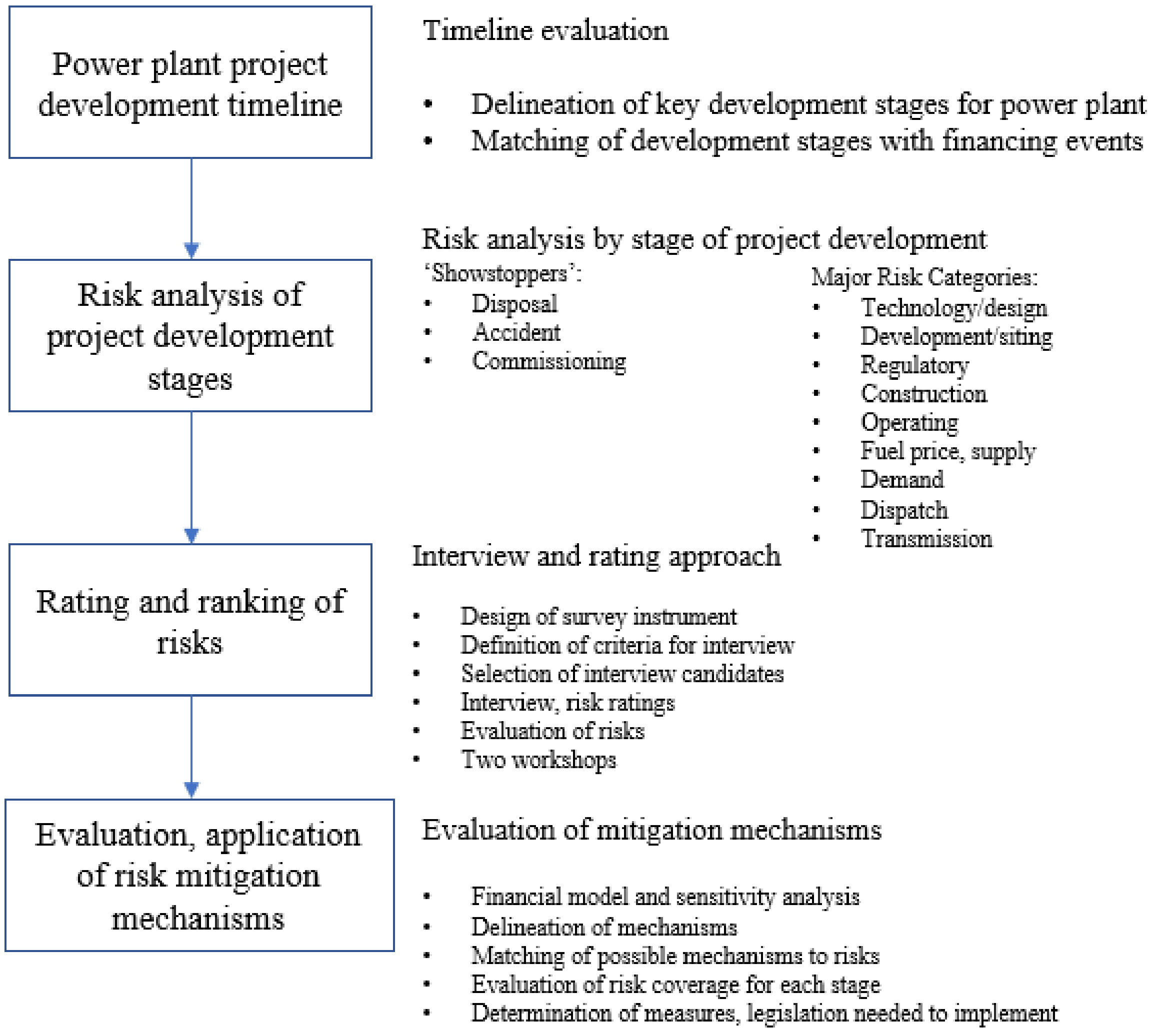

FIG. 4. Example risk management framework: logic flow and approach to risk analysis.

The scientific community, as a stakeholder, will provide expert advice and will likely contribute research and development resources to help provide the technological underpinning for the project and resolve technical issues that may emerge at any stage of construction or operation. For example, if an unexpected corrosion mechanism should emerge, the scientific community may help identify the path to mitigation or correction of the issue.

3.2. STAKEHOLDER INVOLVEMENT PRINCIPLES FOR USERS AND VENDORS

3.2.1. Stakeholder involvement principles

To be successful in stakeholder involvement, users and vendors contemplating a nuclear cogeneration project should bear in mind the unique nature of the facility. Some stakeholders will be particular to the cogeneration project, regardless of its power source. Others will be concerned or involved with the nuclear Part of the facility, and many will view it in a similar way to how they would view a standalone nuclear power plant. There is likely to be overlap — that is, some stakeholders will be concerned about both the nuclear and cogeneration aspects, or about the project as a whole. Successful users and owners will need to carefully consider the complexities this uniqueness brings, and they will need to tailor a stakeholder involvement plan to meet the needs of all stakeholders.

This subsection provides information on and references for stakeholder involvement, many of which were originally developed to support nuclear power projects. The principles in these guidance documents are applicable to a nuclear cogeneration facility. Users and vendors should apply the principles to involvement of both stakeholders related to the nuclear power source and stakeholders related to the cogeneration Part of the facility, bearing in mind that many of the latter will not necessarily have the same concerns and involvement as those on the nuclear side. For example, there may be fewer safety concerns, and environmental and economic concerns will likely be different. The stakeholders themselves will be different, and successful approaches to involvement may differ for nuclear and non-nuclear stakeholders. Hence, the guidance principles should be applied with care.

Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities (IAEA Nuclear Energy Series No. NG-T-1.4) [28] identifies six general principles for stakeholder involvement:

(a) Exhibit accountability;
(b) Recognize the purpose of stakeholder involvement;
(c) Understand stakeholder issues and concerns from the beginning;
(d) Build trust;
(e) Practice openness and transparency;
(f) Recognize the evolving role of and methods for stakeholder involvement.

All stakeholders with a vested interest in project success should understand and have a role in implementing these principles. They are not written specifically for vendors and users, but vendors and users have perhaps the most to gain or lose, depending on their implementation of the principles.

The user is responsible for every aspect of the nuclear cogeneration facility, and it therefore has to publicly and privately accept its accountability for issues and errors. Users should demonstrate clearly in communication that they accept accountability and will avoid obfuscation. The user is likely the owner/operator of the nuclear cogeneration plant and the project lead. It therefore falls to the user to ensure success of all aspects of stakeholder involvement and communication; blaming another party for project failure is not project success.

Users and vendors should recognize that the purpose of stakeholder involvement is to enable all stakeholders to make their views known and work together to ensure that these views are addressed/considered. This does not mean that each stakeholder sees every decision go the way they desire; rather, the goal is that stakeholders understand the basis for decisions made and conclusions reached.

Users and their vendor partners should understand stakeholder issues and concerns from the beginning. This starts with the development of an appropriate strategy and a plan for implementing it, as discussed below. Having identified concerns and sensitivities among the various stakeholder groups, users and vendors can develop processes to ensure that, throughout the life of the project, stakeholder involvement is timely for all issues of potential concern to the stakeholders.

Building trust is particularly challenging for nuclear facilities, because nuclear power has been a controversial subject with some fraction of the public essentially from its beginning. This requires that emphasis be placed on trust. Such trust is facilitated by exhibiting integrity, forthrightness, accountability and fairness. Establishing trust is fostered through implementation of effective stakeholder involvement from project inception. However, trust should never be taken for granted, as it can quickly be destroyed by a single failure to exhibit the principles that foster trust, especially in the presence of a high visibility event or issue. The existence of a cogeneration facility adjoined to the nuclear power plant does not negate or diminish potential concerns about the nuclear facility or the need to establish trust and overcome concerns about the nuclear power plant Part of the cogeneration facility.

There is also likely to be a separate set of stakeholders and concerns about the cogeneration facility unrelated to its nuclear energy source. There could be concerns about the environmental impact of the cogeneration facility and its safety, cost, etc. The stakeholder involvement plan also needs to identify these potential stakeholders and address their concerns proactively.

Openness and transparency are implemented through consistent and timely interaction with stakeholders. Users should focus on openness with stakeholders affected by a given issue, but they should also recognize that they need to be open with all stakeholders. This means implementation of broad communication measures as a consistent practice. Where full openness is not feasible (e.g. for security issues), users and vendors should explain as much as circumstances permit and explain why they cannot share more.

Stakeholder involvement practices need to evolve as technology and cultural conditions change. A primary example of this is the decline of the audience for newspapers and traditional broadcast media, related to the rise of social media. Social media presents a particular challenge to successful stakeholder communication, both because of its susceptibility to misinformation and the ability of social media users to publish messages virtually instantaneously. Users and vendors should ensure that they have highly knowledgeable staff monitoring social media at all times, such that the project's message and accurate information concerning it are also promulgated quickly, both proactively and reactively.

3.2.2. Stakeholder involvement strategy

The successful path to stakeholder involvement begins with developing a stakeholder involvement strategy for the project, with goals and objectives for stakeholder involvement. Different goals likely apply to different stakeholders. For example, one obvious goal for interaction with the public is to ensure that it understands the benefits of the project to the community. A goal for communication with the regulator is to establish the regulator's confidence in the user's/licensee's/applicant's integrity and competence. The user may or may not have sufficient knowledgeable resources in-house to develop the strategy. If it does not, it will need to engage a reputable firm capable of developing a strong stakeholder involvement strategy.

The EPC vendor is the user's partner in developing and implementing the strategy. The vendor has a large stake in project success, and it may have more experience in such strategies from lessons learned in past projects. The first step toward a successful strategy is communication between the user and vendor, and recognition of their shared goal in project success. The user and vendor will need to ensure that messaging is consistent at all levels of the project, and they will therefore need to involve suppliers and other project participants in implementation of the strategy. While involvement of, and communication with, stakeholders external to the project is very important, vendors and users should not neglect strategy for communication with internal stakeholders such as subcontractors and suppliers.

3.2.3. Stakeholder involvement plan

With the strategy developed, Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities (IAEA Nuclear Energy Series No. NG-T-1.4) [28] notes that the next action is to prepare the plan for implementing the strategy, with the following steps:

— Identify and prioritize stakeholder groups to be considered;
— Identify the issues and means of engagement that are considered most important for each stakeholder group;
— Identify the tools and approaches that will be used;
— Design an evaluation component;
— Assign ownership of plan elements;
— Allocate sufficient resources to accomplish the actions;
— Identify the competencies that will be needed by those who will be responsible and how these competencies will be developed and ensured.

Users and their vendor partners need to identify all significant stakeholders, as previously discussed, for both the nuclear and cogeneration side of the facility. The plan will need to be tailored to each stakeholder type or group, and potentially to specific stakeholders within groups. The plan also needs to recognize that the importance of various stakeholders will change as the project progresses. After developing a complete list of potential stakeholders, it can also be valuable to map how various stakeholder groups interact with or influence one another. There are various ways of identifying and prioritizing stakeholders, and competent communication and engagement specialists can provide advice on the subject, tailored to the project and its stage. While consistency in messaging is essential, the emphasis on or the level of detail concerning certain aspects of the message may vary among groups.

Various tools and engagement techniques may be used, each of which has a unique set of advantages and disadvantages. Approaches may include press conferences, print or broadcast media interviews, social media posts, etc. As previously noted, social media is becoming increasingly important. It presents an opportunity for two way communication, which can be an advantage or disadvantage. In any case, involvement in social media is essential, not an option.

The stakeholder involvement plan should include an evaluation component to validate success of the plan and make adjustments as needed. The component should be in place early in plan implementation and should include periodic reviews at regular intervals. Approaches might include interviews with opinion leaders and focus groups.

The user, with leadership of the stakeholder involvement plan, will need to determine responsibilities for all aspects of the plan. It is very important to assign the right resources for each aspect of the plan. For example, messages developed by technical staff will need to be reviewed by communications staff to ensure that the messaging conveys the intended meaning. Technical staff with potential to interact with external stakeholders should be trained in public communication techniques and risk communication.

The resource needs for a stakeholder involvement programme depend on its goals and objectives, as well as its complexity and the project specific communications challenges. Resourcing for such plans will compete with resource needs for unrelated aspects of the project, but the user needs to recognize the importance of effective implementation of the programme for the project's success, and ensure that it is adequately resourced with fully trained and competent staff.

4. USER AND VENDOR ROLES IN NUCLEAR COGENERATION PROJECTS

This section discusses the specific roles of users and vendors in a nuclear cogeneration project, as well as the interfaces between the two.

4.1. RELATIONSHIP BETWEEN USER AND VENDOR

The IAEA publication Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators (IAEA Nuclear Energy Series No. NG-T-3.1) (Rev. 1) [3] provides in-depth coverage of the responsibilities and capabilities of owners and operators in developing the infrastructure for a nuclear power programme. Users and vendors for a nuclear cogeneration project should follow these principles, with additional considerations identified in this section that result from the inclusion of the cogeneration facility.

Figure 5 depicts a simplified relationship among the user (owner/operator), the EPC vendor (which may be a consortium) and the project suppliers. The architect–engineer is the lead firm for the facility

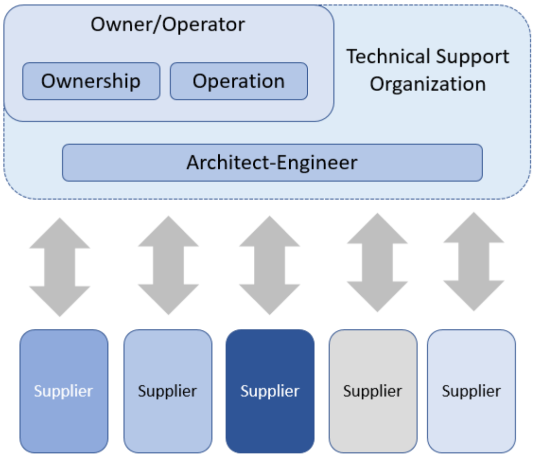

FIG. 5. Responsibilities and capabilities of owners and operators (users or end users) (reproduced from Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators (IAEA Nuclear Energy Series No. NG-T-3.1) (Rev. 1) [3]).

design. For a cogeneration facility, there could be an architect–engineer for the entire project, or separate ones for the nuclear and cogeneration sides.

There are several types of possible business contractual arrangements between the user and vendor for a nuclear power plant project. One common option is a turnkey EPC contract, under which the principal contractor leads the construction of the facility, with management responsibility for construction — from site preparation to commissioning of the cogeneration facility — and finally hands the plant over to the user, the owner/operator, after satisfactory demonstration of its operation at rated capacity. In many cases, the EPC continues to provide goods and services through contracts for activities such as engineering, inspection and maintenance during the operating lifetime of the plant. It is possible that there may be a different EPC contractor for the nuclear and cogeneration sides of a nuclear cogeneration facility.

Another possible type of arrangement, called an engineering, procurement and construction management (EPCM) contract, under which the user (utility owner/operator) manages the whole project, with more involvement in, or control over, the design and construction of the nuclear power plant and connected cogeneration facility, and procurement of equipment and suppliers. If necessary, the user may be supported by partnering with a firm that is experienced with the type of plant technology, and/or with cogeneration. The EPC contractor (or contractors) still designs and constructs the plant, but with greater management control by the owner/operator.

As for the EPC arrangement discussed previously, there may be a different EPC contractor for the nuclear and cogeneration sides of the facility. Thus, the owner/user may have more than one EPCM contract and may need to use different project management and control approaches for each. For example, construction methods and controls need to be implemented carefully for a nuclear power plant. There is little tolerance for error in such projects; errors may result in rework and major cost overruns, or in the worst case could threaten project viability. On the cogeneration side, nuclear safety construction codes and standards generally do not apply. Quality still matters, and non-nuclear construction codes and standards will apply, but design changes and fact of life adjustments during construction will likely be much easier. The level of oversight by the user will differ from that required for the nuclear side, so the user will need to customize its approach accordingly.

Regardless of the arrangement, the user (owner/operator) holds the ultimate responsibility for the success and safety of the project. Therefore, the owner/operator oversees the project and needs to be knowledgeable and capable of ensuring that the vendors and all subcontractors and suppliers meet the established quality standards and regulatory requirements for the manufacture and installation of SSCs associated with reactor safety, as well as the codes and standards applicable to the cogeneration side.

While the penalties for mismanagement on the non-nuclear side differ from those on the nuclear side, competence in design and construction is still required to provide assurance of safe and reliable operation of the combined facility, also thereby ensuring that the facility can and will be licensed by respective regulators. In addition, once the plant is operational, the owner/operator will have responsibility for the sustainability of the supply chains for long term operation. This applies to goods and services provided by national and local suppliers, as well as those procured from foreign suppliers.

The relationship between users and vendors strongly influences the risks and potential for success of the investment. In the EPC case, the owner relies more heavily on the competence of the EPC contractor(s). In the EPCM case, the owner both more closely controls all aspects of the project and more directly assumes the role of managing for success. Of course, even in the EPC arrangement the owner needs to exert effective oversight over the EPC vendor and its subcontractors and suppliers, with regard to quality, adherence to nuclear safety requirements, and project plan and schedule adherence. Failure to do so constitutes a major, and unnecessary, project risk.

Considering the long duration of any nuclear construction project (including a nuclear cogeneration project), establishing a long term relationship between the user and vendor(s) based on trust and mutual benefit is crucial. Such a relationship can begin at the initiative of the vendor. who approaches the user, demonstrates an understanding of the user's requirements needs and proposes a project to meet those needs. Or the negotiation may begin at the initiative of the user, who is trying to find the best way, and the best vendor, to implement a project. Discussion and negotiations leading up to contract award have to be detailed and forthright; the user has to ensure that competent staff or advisors perform a thorough review of the proposal, as well as the vendor's capabilities and demonstrated competence in the type of work being proposed — taking nothing for granted. Many owners and/or vendors rush to contract award, not paying enough attention to developing a relationship and ensuring that vendors are a good fit for users' needs.

From the user's perspective, four elements are of greatest importance:

(a) Satisfaction. The user needs the vendor to fulfil all requirements (including quality, schedule and cost).
(b) Competitiveness. The chosen vendor provides the best value for price proposition and continues to do so during the project's course.
(c) Innovation. The vendor demonstrates value added to meet user needs through innovative approaches and solutions.
(d) Financing. The vendor provides helpful and compelling financing terms and assistance.

From the perspective of the vendor, there are some crucial conditions to a successful business relationship with the user:

(1) Payment. The vendor always expects timely payment in accordance with the contract.
(2) Flexibility. The user should formulate project contractual requirements that are sufficiently flexible to avoid unreasonable expectations, deadlines, etc., and allow for the contingencies that are inevitable in complex projects.
(3) Continuous relationship. The user should communicate frequently with the vendor, not only when necessary because an issue has arisen.
(4) Information exchange. The vendor expects a two way information exchange with the user, for example the user is to promptly communicate changes in project conditions or other matters affecting the vendor's interests.
(5) Correct assessment. The exigencies of the user should not affect a fair and correct assessment of the vendor's performance. The vendor expects to receive clearly formulated requests and realistic user evaluations of the status of the project.

4.2. ROLES OF USER AND VENDOR

There are three possible conditions under which a nuclear cogeneration project may be implemented:

(a) Countries building their first nuclear plant — the nuclear cogeneration facility[4];
(b) Countries with an ongoing nuclear programme, retrofitting an existing nuclear plant for cogeneration;
(c) Countries with an ongoing nuclear programme, building a new nuclear unit in cogeneration mode.

Regardless of the scenario, some basic principles in the project, and the involvement of the user and vendor, will apply. This subsection discusses the detailed guidance available for nuclear power plant projects. The following subsection discusses the application of such guidance to a nuclear cogeneration project.

Figure 6 (adapted from Milestones in the Development of a National Infrastructure for Nuclear Power (IAEA Nuclear Energy Series No. NG-G-3.1) (Rev. 1) [4]) illustrates the process, where Ms 1 refers to "Milestone 1: Ready to make a knowledgeable commitment to a nuclear power programme", Ms 2 refers to "Milestone 2: Ready to invite bids/negotiate a contract for the first nuclear power plant" and Ms 3 refers to "Milestone 3: Ready to commission and operate the first nuclear power plant" in Ref. [4].

While Ref. [4] focuses on national capabilities (and is therefore a good reference for the owner/operator), the steps below are focused on the owner/operator itself, and on the vendor who partners with the owner/operator. It focuses on three key milestones:

(1) Commitment to the project. The potential owner/operator considering the nuclear cogeneration project should assume overall coordination, ensure the engagement of all important parties, compile the information and studies necessary for a knowledgeable policy decision on whether to proceed with the project and provide a comprehensive report that defines and justifies for stakeholders a decision to move forward on the proposed project.
(2) Readiness to solicit vendor bids. The owner/operator will carry out the work required to prepare for the contracting, financing and construction of the facility. It should verify the necessary infrastructure (see Ref. [4]) has been developed to support readiness to invite bids/negotiate a commercial contract, including ensuring that it has developed the organizational competence to manage a nuclear power project, meet regulatory requirements and be a knowledgeable customer.
(3) Commissioning and operation. The greatest capital expenditure for the facility will occur leading up to the commissioning of the facility. Work will include development of the site specific design and the preliminary and final safety analysis reports. It also includes obtaining all required licensing and planning approvals. Work will further include procurement and construction activities, under appropriate management arrangements, as well as regulatory oversight and approvals.

The user will be closely involved in the steps that lead to each milestone accomplishment, while the vendor's involvement in each step will be variable. For example, candidate vendors will be involved in the pre-project activities, providing expertise and explaining capabilities to support user decision making. Vendors will by definition not be involved in vendor selection. During operation the role of the vendor may be limited to consultancy or specified services.

For the period from project inception to commissioning in particular, the path to project success lies with the user and vendor viewing each other as closely connected partners. Joint project status reviews, user oversight of the vendor's work, and vendor oversight of its subcontractors and suppliers are all necessary for the success of a complex project such as nuclear cogeneration.

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[4] For countries embarking on nuclear power, the typical approach might be the following: (1) use of a reference plant design with operational feedback; (2) contracting one integrator EPC contractor with experience (turnkey approach) to manage the project interfaces; (3) use of architect–engineers and/or owner–engineers to support the user to oversee the EPC contractor when experience is absent.

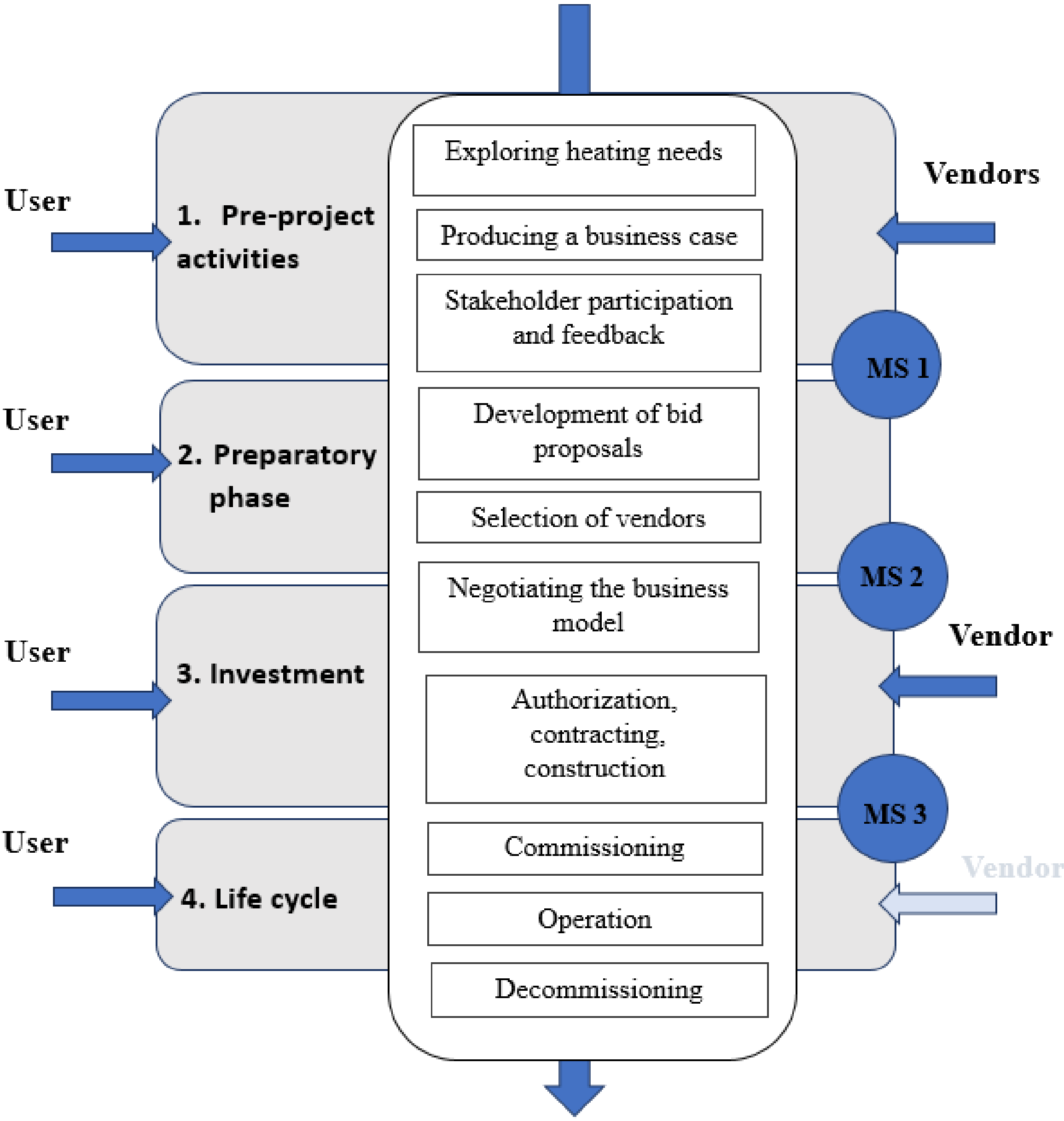

FIG. 6. Users and vendors in the IAEA milestone approach for developing a national infrastructure for nuclear power. Ms 1, "Milestone 1: Ready to make a knowledgeable commitment to a nuclear power programme"; Ms 2, "Milestone 2: Ready to invite bids/negotiate a contract for the first nuclear power plant"; Ms 3, "Milestone 3: Ready to commission and operate the first nuclear power plant".

In some circumstances, the vendor may additionally play the role of the technology owner/developer and, in this case, other steps involving research and development (laboratory scale, demonstration, first of a kind) will need to be added for the vendor to accomplish.

Both users and vendors need to be characterized by certain attributes to support project success, as stated in IAEA guidance publication, Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators (IAEA Nuclear Energy Series No. NG-T-3.1) (Rev. 1) [3]:

— *Leadership and an appropriate organizational culture*. "Since the owner/operator has prime responsibility for the safety and security of the nuclear power plant, it should develop an organizational culture that promotes the appropriate attitudes, values, standards, morals and norms of acceptable behaviour that are necessary in a nuclear facility” [3].

- *Ability to manage growth and change*. “The owner/operator will start as a core group of decision makers, managers and experts brought together to start the first nuclear power plant project. As the project progresses, the owner/operator organization will grow in size” [3]. “The management system developed for the organization should support the changes in size and scope” [3].
- *Effective communication*. “The owner/operator should establish clear lines and procedures for internal communication and reporting. Communications should be clear and concise, and the procedures should cover both the provision of correct and complete information and the receipt and dissemination of information” [3].
- *Technical competence*. The owner/operator needs to have the technical expertise to manage the nuclear cogeneration project from development to operation, and to ensure an informed decision making process. If the required expertise is not available in the host country, as might be the case for early phases of the project and for countries that do not have operating nuclear power plants, external support might be needed for some activities. This can include various areas where the need to outsource expertise has been identified (such as technical areas, e.g. nuclear safety and security, radiation protection, waste management), as well as areas related to contracting and procurement. Note that the owner/operator should have sufficient knowledge to identify the areas of work to be outsourced and have a good understanding of the results presented by the subcontractors.

Additional detail on these attributes can be found in Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators (IAEA Nuclear Energy Series No. NG-T-3.1) (Rev. 1) [3].

Additional relevant IAEA publications on management aspects at nuclear power plants include:

- Preparation of a Feasibility Study for New Nuclear Power Projects (IAEA Nuclear Energy Series No. NG-T-3.3) [35];
- Commissioning Guidelines for Nuclear Power Plants (IAEA Nuclear Energy Series No. NP-T-2.10) [36] (mainly for Phase 3);
- Project Management in Nuclear Power Plant Construction: Guidelines and Experience (IAEA Nuclear Energy Series No. NP-T-2.7) [37];
- Invitation and Evaluation of Bids for Nuclear Power Plants (IAEA Nuclear Energy Series No. NG-T-3.9) [38];
- The Management System for Nuclear Installations (IAEA Safety Standards Series No. GS-G-3.5) [39];
- Leadership and Management for Safety (IAEA Safety Standards Series No. GSR Part 2) [40];
- Application of the Management System for Facilities and Activities (IAEA Safety Standards Series No. GS-G-3.1) [41];
- Development and Implementation of a Process Based Management System (IAEA Nuclear Energy Series No. NG-T-1.3) [42];
- Use of a Graded Approach in the Application of the Management System Requirements for Facilities and Activities (IAEA-TECDOC-1740) [43].

While the references focus primarily on owner responsibilities, the vendor needs to exhibit the same or very similar strengths and characteristics to support project success. The owner/user engages a vendor without such characteristics at its peril.

4.3. CONSIDERATIONS SPECIFIC TO NUCLEAR COGENERATION PROJECTS

As previously noted, many aspects of the relationship between the user and vendor that apply to a nuclear power plant project, as discussed in Section 4.2, apply equally to a nuclear cogeneration project. To succeed, the vendor and user of the cogeneration facility need a sound nuclear construction project, and cogeneration in no way lessens the requirements applicable to management of a nuclear power plant construction project. The user and vendor(s) for the cogeneration facility have to manage the joint construction projects effectively, each of which influences the other(s), but each of which is also subject to very different requirements. This is similar to the different requirements applicable to the primary (nuclear) side of a nuclear power plant and those applicable to the secondary (balance of plant) side. In essence, the cogeneration project constitutes a portion of the balance of plant, with the remainder being the generation of electric power.

One additional consideration is that the cogeneration facility may take a reactor plant fluid product (steam from the non-nuclear Part of the facility) and send it off-site. There will likely be requirements applicable to that configuration that go beyond those applicable to the balance of plant for a nuclear power plant, since process fluids for those plants do not run off-site, with the exception of cooling water systems.

Most of the principles set forth in the publications referenced in Section 4.2 are valid for any complex project for which tolerance of error or mismanagement is small. This is particularly the case for a nuclear power plant project, but it is also true for a joint cogeneration project. Users and vendors would be well advised to start with guidance applicable to nuclear project management, but to modify the application of those principles to recognize that the cogeneration side is not subject to the same requirements as the nuclear side. This is a similar principle to management of the balance of plant side of a nuclear power plant construction project. Attempting to impose nuclear level management controls on the cogeneration side will result in unnecessary project costs. Hence, the user and vendor should develop project management processes that ensure quality and efficiency but avoid unnecessary bureaucracy.

Unlike the case for nuclear power plant project management, specific guidance for cogeneration facility project management in the public domain is limited. One good source of top level guidance on the subject of management of combined heat and power projects is the United States Environmental Protection Agency [44]. This information does not address nuclear power as a potential energy source for a combined heat and power project. However, it provides useful guidance and background on project management for users and vendors for the cogeneration side of the facility.

5. REQUIREMENTS FOR USERS AND VENDORS

Important aspects of the introduction of a nuclear energy project to provide power and other products include the development of nuclear policies and regulations, feasibility studies, market studies, public consultations, technology evaluation, requests for proposals and proposal evaluation, project and contract development, financing, safety and risk assessment studies and environmental impact assessments, and then eventually construction, commissioning and operation, and finally decommissioning and dismantling. The user and the vendor should partner to complete these activities successfully.

If a country wants to develop and operate a nuclear cogeneration system, a range of conditions and requirements need to be fulfilled. They comprise areas such as the nuclear policy of a country and its established sets of codes and standards, as well as its regulatory framework. While the user of the project is not directly responsible for these national level concerns, the user cannot complete the project before the required national infrastructure is in place. It is therefore essential for the user to work with and support the government and other stakeholders to develop any missing infrastructure.

This section focuses on requirements applicable to users and vendors.

As defined in Section 1, requirements are the expectations of the vendor and user with respect to each other or mandates placed by a third party (usually government, especially a regulator) on the user and/or vendor. Examples include but are not limited to: design or retrofit requirements (technology, standard, performance, economics, etc.), usually falling on the vendor; safety, environmental and licensing requirements, usually falling on the user; end user (consumer) product requirements, usually falling on the user; and project (project structure, management, contract, procurement, etc.) requirements, usually falling on the vendor as well as the user.

5.1. ECONOMIC ASPECTS

5.1.1. Business case

For a sound long term investment case, confidence in the technology on both the nuclear and industrial sides is required, although these industries have very different cultures. The owner/operator will need to develop a cogent business case that makes a convincing argument to stakeholders that the nuclear cogeneration facility is the best approach to meeting an identified energy need or needs.

The owner/operator is the project developer in Phase 2.[5] It owns the assets of the nuclear power plant and will eventually benefit from the income from the sale of the electricity generated and cogeneration products provided. In Phase 3[6], the owner/operator is required to submit licence applications, oversee construction and prepare for commissioning and future operation.

To develop and submit its business case to decision makers who will decide whether the project advances, the owner/user will need to complete a comprehensive analysis that comprises both monetary and non-monetary considerations, including:

- A statement of energy needs the proposed facility will meet;
- A description of the proposed facility, including the cogeneration aspects;
- A description of the operation of the facility (electrical and cogeneration heat capability over time);
- Analysis of current and future fuel costs, as well as utility rates;
- Evaluation of power reliability at the site;
- Assessment of the owner/user organizational culture (its goals, decision making, funding scheme, openness to new approaches);
- Assessment of environmental impacts;
- Analysis of costs for construction, operation and maintenance, fuel cycle and decommissioning;
- Comparison with alternative energy sources to meet stated needs;
- Contingencies and controls to minimize, monitor and respond to deviations from project plans and schedules;
- Project risk assessment.

There will likely be more than one decision point, and more than one decision maker, along the path to project approval. The owner will usually make the case with the involvement of the selected vendor, although the point in time where the vendor is selected may or may not precede the point at which the owner makes the business case to a given stakeholder/approver.

The vendor, as the lead company managing EPC for the project, might also be the vendor for the cogeneration facility — or it may interface with a separate company in that role. In any case, the EPC vendor will support the owner in its development of the business case for the project. The vendor will add specifics on the design and the cost, and it will work with the owner’s staff to develop the complete financial and technical package to be submitted.

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[5] Phase 2 in the IAEA Milestones approach [4].

[6] Phase 3 in the IAEA Milestones approach [4].

The development of taxonomies for sustainable activities, such as the one set up by the European Union (EU) in order to meet its climate and energy targets for 2030 and reach the objectives of the European Green Deal [45], can have a significant impact on the attractiveness of certain investments, including for cogeneration projects, as in the energy sector the taxonomy can also cover the goods produced by certain types of sustainable energy. For example, the Complementary Climate Delegated Act [46] of the EU taxonomy, approved in principle by the European Commission in February 2022, mentions hydrogen as a product of nuclear falling under the proposed taxonomy.

5.1.2. Financing

The high capital cost and relatively long construction times involved in nuclear construction projects entails significant financial risks, including interest rate risks, construction cost overruns and delays, uncertainties in energy prices at project completion and political risks. Prudent investors or lenders for such a project will consider all these risks in determining whether to participate in financing a project and under what terms.

Corporate financing (investment by public or private companies financed from the corporate balance sheet, which can include debt and equity) was formerly the main financing vehicle for nuclear projects [47]. In this model, the corporation takes on the full risk of the project. However, the high cost and risk of a new NPP creates challenges for all but the largest companies (or groups of companies) with strong balance sheets.

Given the high capital costs involved, government funding assistance may be needed. Such arrangements could include issuance of government loan guarantees or direct government equity ownership in the project.

Vendor financing is another possibility. In this model, there are a number of options, including corporate financing via equity or loans provided from the balance sheet of the NPP vendor. Users may require vendors to take an equity position in the project. The vendor may also arrange credit from associated banks and export credit agencies.

These financing options can be coupled with other mechanisms to guarantee revenues and redistribute some of the risks away from investors and lenders. Examples include long term contracts such as power purchase agreements to guarantee future revenue, and ‘contracts for difference’, through which the user is paid the difference between the contract price and the market price. Similar agreements may be negotiated with the end users for the cogneration facility. Governments have other options to reduce financing risks for the cogeneration facility, so a good working relationship with the host government to support fiancing negotiations is essential.

Another option that may help to reduce risk in a first of a kind project is to build a smaller scale prototype. Typically, such a project will span the development of a programme, the development of a project, the deployment of a prototype plant and the deployment of a commercial plant. It may be the case that only the prototype project is approved initially. The decision to go straight to a commercial scale project without a protoype could also be made. However, unless prototyping and commercial development of the proposed plant have already occurred, going straight to commercial is very risky financially.

Financing a nuclear project is a complex endeavor, and early in the development of the business case the user and vendor will need to engage with governments and financial proessionals to find the best financing approach for the specific project — and country — in question.

Comprehensive details on funding and financing in relation to nuclear power infrastructure can be found in the IAEA Nuclear Infrastructure Bibliography [48], under Section 4:

- Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects (IAEA Nuclear Energy Series No. NG-T-4.6) [22];
- Financing of New Nuclear Power Plants (IAEA Nuclear Energy Series No. NG-T-4.2) [23];
- Nuclear New Build: Insights into Financing and Project Management (NEA No. 7195) [49];
- Nuclear Power Economics and Project Structuring (WNA Report No. 2017/001) [50].

5.1.3. Project management

A nuclear power (including a nuclear cogeneration) project is among the most complex and demanding construction projects possible. It is very multidisciplinary and requires multiple years for completion. Most importantly, it requires unceasing focus on ensuring that the project complies with a large number of exacting standards and requirements in place for the protection of public health and safety. Industry experience has shown that leadership in both the owner and the vendor teams is a strong determinant of whether the project succeeds.

If the nuclear cogeneration project involves the complete construction of a nuclear power plant (and not just retrofit an existing nuclear power plant), all of the project management requirements for constructing a new nuclear power plant also apply to the nuclear cogeneration project, with the addition of requirements applicable to the cogeneration side. Many of these requirements may be handled similarly to how the non-safety (balance of plant) construction is managed in a typical nuclear power plant. If the project is a backfit, many of the project management principles apply, but the overall complexity will be substantially lower.

The IAEA has issued a guidance publication on the subject of nuclear construction project management — Project Management in Nuclear Power Plant Construction: Guidelines and Experience (IAEA Nuclear Energy Series No. NP-T-2.7) [37]. This publication states that its purpose is to:

"address all relevant issues related to construction management of nuclear power plants and to introduce good management practices drawn from international experience which will allow commissioning to proceed promptly, safely and to high quality standards."

The publication is written in large Part for the information of IAEA Member States contemplating a new nuclear power plant construction programme. However, much of the information presented is also applicable and useful to users and vendors.

It divides its guidance into phases that are similar but not identical to the three Phase structure presented earlier in this publication. Many of these requirements will be met during more than one Phase of the project. Some highlights follow, while substantial additional detail is found in the publication itself. It is important to note that a given aspect of project management necessary to support a given project Phase will often need to be fully in place at the beginning of that phase, particularly in the case of construction and commissioning activities.

While the allocation of work to address these requirements between the owner/user and vendor will vary depending on the contractual relationship between the two parties, the owner/user should always 'own' each and every aspect, because the success of the entire endeavour ultimately depends on that ownership. The owner/user should both maintain big picture oversight and get involved in detailed oversight. The vendor should itself take responsibility for project success and support the owner/user, because the vendor also has a vested interest in project success.

During the preparatory phase, as discussed in Ref. [37] (prior to pouring first concrete), the significant requirements are as follows:

- — Evaluating existing civil infrastructure at the proposed project site for adequacy and strengthening it, if necessary, in a timely manner to allow an immediate start as soon as the project is launched;
- — Commissioning a scrutinized environmental assessment, which should include a natural environmental impact assessment, a biological impact assessment and a socioeconomic impact assessment;
- — Putting the project management and leadership team, and the entire project organization, in place to be ready before the project begins;
- — Implementing management controls and procedures;
- — Making certain that realistic preliminary plans and schedules have been developed;
- — Setting priorities and resolving all conflicts in accordance with project goals, objectives and commitments;
- — Developing and approving a detailed project budget based on the best available estimates and keeping it up to date during the duration of the project;

— Issuing project procedures, project numbering schemes and budget codes;
— Defining the project requirements, in particular the applicable codes and regulations;
— Setting up the work breakdown structure, authorization and assignment of work activities;
— Setting up and implementing a process to govern, harmonize and integrate resource allocation, negotiation of tradeoffs, selection of methodologies and alternatives, and management of interdependences among processes;
— Setting up a communication plan for internal and external stakeholders;
— Setting up a rigorous information management system (e.g. technical and project information, project management and schedule information, human resources information, etc.);
— Managing engineering activities, including determination of project specific conditions; designing systems, building and site layouts; civil and architectural design; and component design;
— Implementing a rigorous change management and control process for the plant design and configuration;
— Setting up and implementing contracts;
— Implementing a quality assurance and management system;
— Applying for, obtaining and maintaining construction and operating licences;
— Setting up a risk management process to improve project management and limit the financial and schedule exposure of project participants;
— Developing project infrastructure, including levelling land, constructing warehouses and offices, developing water and sewer capabilities, hiring and training support staff, etc.;
— Implementing a security system, including physical protection, imaging and alarms, access control and nuclear materials accountability.

During (or before, in some cases) the construction phase, as discussed in Ref. [37], the significant requirements are:

(a) Identifying and minimizing risks of manufacturing and construction delays.
(b) Selecting or approving subcontractors.
(c) Measuring progress (e.g. engineering, procurement, installation) and costs against schedule and cost budgets.
(d) Regularly holding project status meetings focused on assessing progress and resolving conflicts, challenges, and delays — not on resolving technical issues, which are resolved outside these meetings.
(e) Coordinating construction, with owner and vendor roles consistent with the terms of the contracts.
(f) Managing work through use of an established work package system:
    — Dividing work into manageable segments (work breakdown structure);
    — Assigning work within the structure.
(g) Developing and maintaining a detailed multilevel project schedule:
    — Summary or overview level;
    — Master schedule showing major activities and interfaces;
    — Integrated project schedule showing project elements;
    — Detailed schedule showing detailed tasks.
(h) Monitoring costs and investigating cost overruns.
(i) Ensuring adherence to quality standards through the quality management system.
(j) Implementing a construction inspection and testing process to ascertain that SSCs have been manufactured, installed, modified, or repaired, and quality control implemented in accordance with an approved construction plan and procedures.
(k) Establishing, maintaining and monitoring a safety culture among all participants.
(l) Maintaining and ensuring industrial and occupational safety.
(m) Complying with environmental standards and minimizing impacts on the environment.
(n) Developing and implementing a human resources plan.

To support commissioning, project management requirements include:

(1) Implementing a project completion organization with responsibility for completion of construction and system turnover.
(2) Conducting turnover activities:
    — Turnover of systems and components from construction to commissioning;
    — Turnover of systems and components from commissioning to operations;
    — Turnover of rooms from construction to operations.
(3) Maintaining and preserving construction records.

The proper management of the wide scope of project activities during this period represents a major challenge for the governmental, utility, regulatory, supplier and other support organizations involved. The main focus is to ensure that the project is implemented successfully from a commercial point of view while remaining in compliance and accordance with the appropriate regulatory, engineering and quality requirements, safety standards and security guides.

The complexities associated with the timing and integration of cogeneration systems will require the involvement of participants and/or advisors with expertise in such systems. Undertaking the nuclear cogeneration project will entail some additional requirements for the user, including:

— Preparing a technoeconomic feasibility report based on field studies and the existing multidisciplinary experience for similar plants;
— Selecting a CHP plant of appropriate rating and type;
— Assessing operating costs/savings;
— Placing the CHP contract(s);
— Defining performance guarantees and sanctions, if the intention is to pass responsibility for and control of key components, facilities or other site activities to a third party.

Major CHP specific requirements for the vendor include:

— Converting findings of a positive feasibility study into an operational plant;
— Defining specifications focused on the outputs to be delivered rather than on how delivery of those outputs will be achieved;
— Determining where and how the CHP unit will be installed and connected to fuel, heat and power systems;
— Assessing the capital costs of installation or energy supply costs if an energy supply contract is being considered;
— Assessing economic, energy and environmental benefits of installation.

Comprehensive details on project management for NPP owner/ operator in relation to nuclear power infrastructure can be found in the IAEA Nuclear Infrastructure bibliography [48], under Section 3:

— Responsibilities and Capabilities of Owner/Operators in the Development of a National Infrastructure for Nuclear Power (IAEA Nuclear Energy Series No. NG-T-3.1) (Rev.1) [51];
— Preparation of a Feasibility Study for New Nuclear Power Projects (IAEA Nuclear Energy Series No. NG-T-3.3) [35];
— Commissioning Guidelines for Nuclear Power Plants (IAEA Nuclear Energy Series No. NP-T-2.10) (mainly for Phase 3) [36];
— Project Management in Nuclear Power Plant Construction: Guidelines and Experience (IAEA Nuclear Energy Series No. NP-T-2.7) [37];
— Invitation and Evaluation of Bids for Nuclear Power Plants (IAEA Nuclear Energy Series No. NG-T-3.9) [38].

5.2. TECHNICAL REQUIREMENTS

A nuclear cogeneration project entails a number of specific technical requirements, as discussed in this section.

5.2.1. Siting

The location of the plant is to be decided by the user(s). Essential requirements for site selection include:

- Sufficient space (with potential extension of establishment in future);
- Accessibility by road and rail;
- Proximity to end users;
- Proximity of residential areas;
- Availability of power, auxiliary power, water and other raw materials;
- Accessibility and quality of feedstock supply;
- Local environmental requirements (e.g. protected nature reserves);
- Identification of factors that could prevent CHP (e.g. existing contracts, local policies);
- Factors affecting nuclear power plant siting (e.g. seismic activity, volcanic activity, potential for site flooding, availability of reliable off-site power, etc.);
- Capability for management of (radioactive and non-radioactive) waste streams;
- Ability to provide security of the site with regard to the nuclear reactor, nuclear materials and storage of cogenerated products (e.g. hydrogen).

The IAEA has issued a publication, Managing Siting Activities for Nuclear Power Plants (IAEA Nuclear Energy Series No. NG-T-3.7) [52], that provides information on management of both safety and non-safety aspects to be considered in the siting and site evaluation processes for a NPP and its supporting facilities. It includes important factors, such as considerations regarding nuclear safety and nuclear security, technology and engineering, economics and cost, land use planning and preparation, availability of water, non-radiological environmental impacts, emergency planning, socioeconomic impacts and involvement of stakeholders. These requirements are applicable to a nuclear cogeneration project to the extent that it is not a backfit onto an existing NPP (for which siting has obviously already been addressed).

Comprehensive details on site and supporting facilities in relation to nuclear power infrastructure can be found in the IAEA Nuclear Infrastructure Bibliography [48], under Section 12:

- Site Survey and Site Selection for Nuclear Installations (IAEA Safety Standards Series No. SSG-35) [53];
- Managing Siting Activities for Nuclear Power Plants (IAEA Nuclear Energy Series No. NG-T-3.7) (Rev.1) [54];
- Site Evaluation for Nuclear Installations (IAEA Safety Standards Series No. SSR-1) [55].

Details on environment protection can be found in the IAEA Nuclear Infrastructure Bibliography [48], under Section 13:

- Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes (IAEA Nuclear Energy Series No. NG-T-3.11) [56];
- Regulatory Control of Radioactive Discharges to the Environment (IAEA Safety Standards Series No. GSG-9) [57];
- Strategic Environmental Assessment for Nuclear Power Programmes: Guidelines (IAEA Nuclear Energy Series No. NG-T-3.17) [58].

5.2.2. Selection of reactor technology

An extremely important decision to be made regards selection of the appropriate nuclear technology for the cogeneration project. Considerations include the following:

(a) In principle, any type of nuclear reactor can be coupled with a system to cogenerate products. Conventional LWRs can be employed to deliver electricity for the conventional electrolysis process in the case of hydrogen production; electricity and hydrogen production are not directly linked and can be deployed at different locations. Low temperature heat can be connected to district heating or desalination. Typically, the heat supply for district heating is steam extracted from a selected stage of the turbine. Selection of the extraction point is a design decision based on considerations about the necessary temperature and energy to supply the district heating system, the equipment cost of the heat supply system and the impact on the thermal efficiency of the power plant. Other types of reactor designs with higher coolant outlet temperatures may allow the recovery of the waste heat rejected from the reactor advanced power conversion cycle [59] or the direct transfer of energy from the hot medium to the cogeneration (e.g. chemical) process.

(b) The selected reactor design has to support the performance goals defined for the project. The reactor also has to be designed to achieve a high safety level (e.g. through passive safety systems) to meet licensing requirements and public and government expectations. Specific design parameters to be defined are thermal power level, fuel concept, moderator material, coolant temperatures, overall efficiency and plant lifetime.

(c) Selection of a different reactor type from that already deployed in the user's country may pose additional requirements. For example, a new type of reactor has to be compatible with the existing regulatory framework, or that framework will need to be updated. Revision of such frameworks is challenging to accomplish and will likely require a period of years to accomplish, assuming that a valid need is identified, as well as the willingness of the government and the regulator. Research may be necessary to support such a revision, which could further lengthen the time required.

(d) The reactor design should demonstrably meet goals and objectives for high reliability, availability, maintainability and ability to host inspections. This demonstration will preferably have occurred through prior construction and operation of at least a prototype (and ideally a full scale commercial application) of the reactor design.

(e) The design has to be licensable in the country siting the reactor. As an example, a Canada deuterium–uranium (CANDU) heavy water reactor is readily licensable in Canada, but much less so in the USA — not because it is unsafe, but because the regulator in the USA is unfamiliar with CANDU reactors and the current regulatory framework is focused on light water reactors (although that may change to accommodate next generation reactors).

Industrial demand for heat may usefully be divided into three temperature ranges:

— 150–600°C, where heat is mainly transported in form of steam;
— 600–900°C, where the heat is used to run chemical reactions (e.g. steam reforming);
— >900°C, where the heat is used for melting minerals or causing reactions between solids.

The reactor coolant material and its maximum temperature are essential criteria for determining which nuclear concepts are appropriate for coupling with high temperature processes such as direct hydrogen production. Advanced reactor designs meet a wide range of heat requirements, between 550–1000°C, allowing nuclear to be considered for a variety of energy missions.

Coolant exit temperatures of the reactor at full load will likely need to be maintained at all levels of partial load to support reliable cogeneration. The reactor coolant outlet temperature needed for chemical processes will be ~50°C above the bulk process temperature. A reactor outlet temperature of 900°C is well suited for steam reforming applications. A value of 950°C, however, would significantly reduce the heat transfer area and improve efficiency. Attaining higher coolant exit temperatures (e.g. 1000°C) leads to challenges to both the reactor fuel and the metallic materials (reactor pressure vessel, thermal barriers, etc.). Temperature requirements for process heat applications are generally lower (250–300°C) than in gas turbine applications (450–550°C), which is advantageous for reactor pressure vessel design and material choices.

Nuclear power plants should be capable of following variations in the energy demand of the industrial processes on time scales ranging from months (maintenance periods, seasonal variations of the market) to days (demand variation) to minutes (peak demand, inadvertent process plant shutdowns). They should be capable of:

— Operating without scram/trip in the event of full load rejection from loss of steam, electrical or high temperature gas demand;
— Stable operation at zero steam flow demand, zero power demand and/or zero high temperature gas demand;
— Operating with high coincident demand from steam, electrical and high temperature gas.

Backup power/process heat production capability is necessary, despite its economic impact. The source could be another nuclear plant, a dedicated fossil fired boiler, or a previously operated fossil fired CHP installation used as a reserve. An alternative might be a heat storage facility. The choice of medium depends in Part on the operating temperature of the thermal power plant and the scale of storage required.

5.2.3. Coupling

Process heat implies the supply of heat required for industrial processes from several centralized heat generation sites through a steam transportation network. Transporting heat without excessive energy loss is difficult and expensive. The need for a pipeline, thermal insulation and pumping, and the corresponding investment, heat losses, maintenance and pumping energy requirements make it impractical to transport heat beyond a certain distance.

State of the art industrial heat transport technologies available in the range of conditions relevant for nuclear industrial applications should be considered based on the experience obtained from existing technologies on industrial sites.

The primary circuit and the heat utilization system will need to be decoupled for the following reasons:

(a) Separation of the nuclear island for safety reasons;
(b) Limitation/exclusion of radioactive contamination of the product (e.g. tritium);
(c) Exclusion of ingress of corrosive process media into the primary circuit;
(d) Enables the design of the heat utilization system to be nearly conventional;
(e) Ease of maintenance and repair for the heat utilization system;
(f) Further reduces the possibility of contamination of high value industrial investments from a highly unlikely severe event at the nuclear plant.

A decision has to be made concerning the type of heat carrier and its characteristic parameters, such as maximum temperature, pressure and flow rate. A helium IHX is suitable for high temperature gas to gas heat transfer. High temperature heat can also be transferred from gas to a molten salt or a liquid metal, promising higher efficiencies but posing corrosion and freezing risks. Another heat transfer technology, for which substantial operating experience is available, is a steam-–team heat exchanger in the lower temperature range, for example from a LWR linked to a nuclear district heating system.

In the cogeneration mode, a gas turbine can be operated in parallel to the IHX. The turbine could also be installed on the tertiary circuit and, depending on the temperature required for the heat process, it could be in a bottoming or a topping cycle configuration. It makes the system more complex, but also more flexible, while the simpler direct coupling may not be acceptable for safety reasons.

The options for a nuclear cogeneration strategy are either to match the thermal demand, meaning that any excess/deficit power is to be exported/imported, or to match the power demand, meaning that any excess/deficit thermal energy is wasted/has to be made up by conventional heating. In any case, reactor design needs to allow for safe operation in all stages between all electric production and all thermal energy production. To achieve sufficient flexibility, the technical requirements to be assumed are:

(1) A system capable of operating with only one reactor module;
(2) No reactor shutdown in case of loss of steam or electricity demand from the industrial site;
(3) Satisfactory system performance with scheduled power variation by adjusting nuclear power.

5.3. SAFETY CONSIDERATIONS

5.3.1. Design

The IAEA has issued numerous publications that convey requirements and/or guidance regarding nuclear safety related to facility design. This section discusses a few of the more notable publications.

The IAEA publication, Safety of Nuclear Power Plants: Design (IAEA Safety Standards Series No. SSR-2/1) (Rev. 1) [60], establishes requirements applicable to the design of nuclear power plants and elaborates on the safety objectives, safety principles and concepts that provide the basis for deriving the safety requirements that have to be met for the design of a nuclear power plant. It will be useful for organizations involved in the design, manufacture, construction, modification, maintenance, operation and decommissioning of nuclear power plants (including nuclear cogeneration facilities), as well as regulatory bodies. It establishes design requirements for the SSCs of a nuclear power plant, as well as for procedures and organizational processes important to safety that are required to be met for safe operation and to prevent events that could compromise safety, or for mitigating the consequences of such events, were they to occur.

A lower tier IAEA publication, Technical Support to Nuclear Power Plants and Programmes (IAEA Nuclear Energy Series No. NP-T-3.28), addresses relevant aspects of requesting and obtaining effective technical support and its adequate utilization in decision making on nuclear power programmes, projects and plants. It describes the technical support functions and associated organizational activities and skills involved in providing technical and scientific input to the decisions on plant safety and performance throughout the plant’s life cycle and establishing and sustaining technical support capability and capacity in Member States embarking on nuclear power programmes or already operating nuclear power plants. The publication also presents observations, lessons learned, and conclusions drawn from good practices for defining and maintaining roles, responsibilities and interfacing requirements for technical support organizations, nuclear power project/plant entities and other stakeholders. As such, it provides a set of descriptive and practised processes that integrate technical and scientific information for safety, performance and economic aspects in support of sound and timely decisions on the safe, reliable and efficient operation of nuclear power plants. As with Safety of Nuclear Power Plants: Design (IAEA Safety Standards Series No. SSR-2/1) (Rev. 1) [60], most or all of the concepts discussed in this publication apply to a nuclear cogeneration project as much as to a conventional nuclear power plant.

The development and implementation of an appropriate infrastructure to support the successful introduction of nuclear power and its safe, secure, peaceful and sustainable application is an issue of central focus, especially for countries that are considering and planning their first nuclear power plant. In preparing the necessary nuclear infrastructure, there are several activities that need to be completed. These activities can be split into three progressive phases of development. The IAEA publication Milestones in the Development of a National Infrastructure for Nuclear Power (Rev. 1) (IAEA Nuclear Energy Series No. NG-G-3.1) [4] provides a description of the conditions expected to be achieved by the end of each Phase to assist with the best use of resources.

The IAEA safety standards require an organization with responsibility for nuclear safety to establish and maintain a management system that fosters a strong safety culture. Leadership and Management for Safety (IAEA Safety Standards Series No. GSR Part 2) [40] emphasizes the importance of leadership in achieving this. In the same way, the IAEA guidance publication, Objectives and Essential Elements of a State's Nuclear Security Regime (IAEA Nuclear Security Series No. 20) [61], states that "prime responsibility for the security of *nuclear material*, *other radioactive material*, *associated facilities*, *associated activities*, *sensitive information* and *sensitive information assets* rests with the *authorized persons*" (i.e. the owner/operator), who contribute by "Demonstrating leadership in nuclear security matters at the highest levels".

Nuclear Security Culture (IAEA Nuclear Security Series No. 7) [62] states that an "effective nuclear security culture can result in a significant increase in the effectiveness of the security of radioactive material and associated facilities and transport." It further states that "nuclear security culture refers to the personal dedication and accountability and understanding of all individuals engaged in any activity which has a bearing on the security of nuclear activities."

Establishing a System for Control of Nuclear Material for Nuclear Security Purposes at a Facility during Use, Storage and Movement (IAEA Nuclear Security Series No. 32-T) [63] notes that the owner/operator should establish procedures to carry out functions necessary to account for and control nuclear material, and will be expected to prepare reports on the subject for submission to the regulatory body.

A corresponding safety culture is needed for the industrial application connected to the nuclear energy source. Processes on a chemical industrial site usually involve toxic and flammable substances and other hazardous materials being handled at high temperatures and high pressures. Safety and risk analyses have to consider conceivable scenarios such as loss of containment followed by the propagation of released materials in environment/atmosphere to assess minimum safety requirements and distances, and to assess the consequences of overpressures, thermal radiation and toxic effects.

Initiating Nuclear Power Programmes: Responsibilities and Capabilities of Owners and Operators (Rev. 1) (IAEA Nuclear Energy Series No. NG-T-3.1) [3] states that the owner/operator should establish clear lines and procedures for internal communication and reporting. Communications should be clear and concise, and the procedures should cover both the provision of correct and complete information and the receipt and dissemination of information. The owner/operator will also need to communicate with a wide range of stakeholders connected with the implementation of the nuclear power programme, in particular with the vendor organization and the regulatory body. The necessary interfaces and communications with external organizations are discussed in Section 6 of this publication.

Industrial Involvement to Support a National Nuclear Power Programme (IAEA Nuclear Energy Series No. NG-T-3.4) [30] describes the roles of various companies involved in nuclear plant design and supporting licensing, including owners, engineering companies, manufacturers and service providers.

Comprehensive details on the regulatory framework in relation to nuclear power infrastructure can be found in the IAEA Nuclear Infrastructure Bibliography [48], under Section 7:

— Establishing the Safety Infrastructure for a Nuclear Power Programme (IAEA Safety Standards Series No. SSG-16) [64];
— Managing Regulatory Body Competence (IAEA Safety Report Series No. 79) [20];
— Governmental, Legal and Regulatory Framework for Safety (IAEA Safety Standards Series No. GSR Part 1) (Rev. 1) [65];
— Organization, Management and Staffing of the Regulatory Body for Safety (IAEA Safety Standards Series No. GSG-12) [21];
— Technical and Scientific Support Organizations Providing Support to Regulatory Functions (IAEA-TECDOC-1835) [66];
— Independence in Regulatory Decision Making (INSAG Series No. 17) [67];
— Functions and Processes of the Regulatory Body for Safety (IAEA Safety Standards Series No. GSG-13) [68];

— Licensing Process for Nuclear Installations (IAEA Safety Standards Series No. SSG-12) [69];
— Licensing the First Nuclear Power Plant (INSAG Series No. 26) [70];
— Experiences of Member States in Building a Regulatory Framework for the Oversight of New Nuclear Power Plants: Country Case Studies (IAEA-TECDOC-1948) [71].

5.3.2. Construction and commissioning

Ensuring nuclear safety for a new nuclear plant, including a cogeneration facility, requires attention to nuclear safety principles throughout the period from project inception to final decommissioning. Attention to safety principles during design (discussed in the preceding subsection) and construction are two of the building blocks that provide operators with a safe plant.

As discussed in this publication, Project Management in Nuclear Power Plant Construction: Guidelines and Experience (IAEA Nuclear Energy Series No. NP-T-2.7) [37] contains substantial guidance for 'building in' safety during construction. Its stated purpose is to address all relevant issues related to construction management of nuclear power plants and to introduce good management practices drawn from international experience that will allow commissioning to proceed promptly, safely and to a high standard. The discussion in that subsection will not be repeated here.

Construction for Nuclear Installations (IAEA Safety Standards Series No. SSG-38) [72] points out that "even if the design and commissioning are fully compliant with all safety requirements, a high level of safety can only be achieved when the construction is carried out with high quality and care, since commissioning cannot test all aspects of the design. Therefore, all construction activities have a potential impact on safety, even though there may be no nuclear material present during the construction." The publication provides guidance on prerequisites for beginning construction. It discusses in detail the management system required to support construction so that safety requirements will be met in the constructed facility, including the following aspects:

— Safety culture;
— Application of a graded approach;
— Responsibilities of the licensee;
— Activities of the construction organization;
— Project management;
— Control of design information;
— Management of interfaces;
— Transfer of responsibility;
— Resources for construction;
— Control and supervision of contractors;
— Measurement, assessment and improvement.

Commissioning, the transition from construction to operation, is equally important in helping to ensure nuclear safety during plant operation. Safety of Nuclear Power Plants: Commissioning and Operation (IAEA Safety Standards Series No. SSR-2/2) (Rev. 1) [73] provides safety requirements for the commissioning phase. Section 6 of this publication contains 15 overarching safety requirements for commissioning, extracted below:

— "The commissioning programme for the plant shall cover the full range of plant conditions required in the design and the safety case…ensuring that no commissioning tests are performed that might place the plant in an unanalysed condition."
— "The commissioning programme shall provide the operating organization and the regulatory body with the means of identifying the hold points in the commissioning process at which approval may be required prior to continuing to the next stage."

- “A review of the test results for each stage shall be completed before commissioning is continued to the next stage.”
- “The commissioning programme shall include all the tests necessary to demonstrate that the plant as built and as installed meets the requirements of the safety analysis report and satisfies the design intent”.
- “Operating and maintenance procedures shall be validated to the extent practicable as Part of the commissioning programme, with the participation of future operating personnel.”
- “Suitably qualified operations personnel shall be directly involved in the commissioning process.”
- “The commissioning programme shall be sufficiently comprehensive as to provide reference data to characterize structures, systems and components.”
- “All the functions of the operating organization [e.g. management, training of personnel, the radiation protection programme, waste management, management of records, fire safety, physical protection and the emergency plan] shall be performed at the appropriate stages during commissioning.”
- “Operating procedures and test procedures shall be verified to ensure their technical accuracy and shall be validated to ensure their usability with the installed equipment and control systems.”
- “From the commencement of commissioning, reviewed and approved arrangements for work control, modification control and plant configuration control shall be in place to meet the conditions of the commissioning tests.”
- “Initial fuel loading shall not be authorized until all relevant pre-operational tests have been performed and the results have been accepted by the operating organization and the regulatory body. Reactor criticality and initial power increase shall not be authorized until all necessary tests have been performed and the results have been accepted by the operating organization and the regulatory body, as appropriate. The tests of the commissioning programme shall be successfully completed as a necessary condition for authorization, as appropriate, for normal operation of the plant to be commenced.”
- “The operating organization shall ensure that the interfaces and the communication lines between different groups (i.e. groups for design, groups for construction, contractors, groups for commissioning and groups for operations) shall be clearly specified and controlled.”
- “Authorities and responsibilities shall be clearly specified and shall be delegated to the individuals and groups performing the commissioning activities. The operating organization shall be responsible for ensuring that construction activities are of appropriate quality and that completion data on commissioning activities and comprehensive baseline data, documentation or information are provided. The operating organization shall also be responsible for ensuring that the equipment supplied is manufactured under a quality assurance programme that includes inspection for proper fabrication, cleanliness, calibration and verification of operability.”
- “During construction and commissioning, the plant shall be monitored, preserved and maintained so as to protect plant equipment, to support the testing stage and to maintain consistency with the safety analysis report.”
- “During construction and commissioning, a comparison shall be carried out between the as built plant and its design parameters…resolutions to correct differences from the initial design and non-conformances shall be documented.”

Nuclear safety requirements during construction of a cogeneration facility backfit onto an existing nuclear power plant will focus on ensuring that the construction does not have an adverse impact on the safety of the existing facility. Some portion of the construction will likely occur while the power plant is operating. Such construction would not involve direct interaction with plant systems, but it could involve work such as heavy lifting or use of heavy equipment nearby. That proximity poses a hazard of inadvertently affecting a plant system and causing damage with perhaps a plant transient. Nuclear power plants all have processes and procedures for plant modifications that will require safety reviews prior to construction or installation of any Part of the modification; such reviews are intended to identify potential hazards and ensure that they do not result in safety impacts. Construction will also require modification to existing plant systems, such as pipe cutting; potential impacts include inadvertent introduction of foreign material into plant systems. Existing plant modification control processes and procedures should also address and prevent these types of issues. Commissioning of the backfit cogeneration system will follow similar principles to commissioning of an entirely new facility, although the scope will be much reduced.

Construction and commissioning are covered by the following specific IAEA publications:

- Commissioning Guidelines for Nuclear Power Plants (IAEA Nuclear Energy Series No. NP-T-2.10) (mainly for Phase 3) [36];
- Project Management in Nuclear Power Plant Construction: Guidelines and Experience (IAEA Nuclear Energy Series No. NP-T-2.7) [37].

5.3.3. Operation and maintenance

Many requirements and guidance publications exist for operation of a nuclear power plant, and essentially all of them apply to operation of a nuclear cogeneration facility. For example, Safety of Nuclear Power Plants: Commissioning and Operation (IAEA Safety Standards Series No. SSR-2/2) (Rev. 1) [73], cited in the previous subsection, contains requirements for safe operation. Many other requirements and safety guides exist. The fundamental requirements of Ref. [73] highlight crucial aspects of ensuring safety during plant operation — as well as ensuring safety during maintenance that occurs during the operation (including shutdown periods) of the facility. Some of these aspects at first glance appear to be obvious or administrative in nature. However, many of them have arisen from lessons learned during the operation of commercial nuclear reactors. In addition, the fundamental organizational underpinnings have to ensure safety. As used here, 'operating organization' is synonymous with 'user/owner'. It is the organization that owns the facility and that employs staff, including operators, maintenance technicians, engineers, radiation protection technicians and administrative personnel. (Some work will also be performed by contractors, but the owner/user retains responsibility for their competence and adherence to plant procedures.) The aspects of operational safety cited in Ref. [73] include, but are not limited to:

- "The operating organization shall have the prime responsibility for safety in the operation of a nuclear power plant."
- "The operating organization shall establish, implement, assess and continually improve an integrated management system."
- "The structure of the operating organization and the functions, roles and responsibilities of its personnel shall be established and documented."
- "The operating organization shall be staffed with competent managers and sufficient qualified personnel for the safe operation of the plant."
- "The operating organization shall establish and implement operational policies that give safety the highest priority."
- "The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons."
- "The operating organization shall ensure that safety related activities are adequately analysed and controlled to ensure that the risks associated with harmful effects of ionizing radiation are kept as low as reasonably achievable."
- "The operating organization shall establish a system for continuous monitoring and periodic review of the safety of the plant and of the performance of the operating organization."
- "The operating organization shall establish and implement a system for plant configuration management to ensure consistency between design requirements, physical configuration and plant documentation."
- "The operating organization shall establish and implement a programme to manage modifications."
- "Systematic safety assessments of the plant, in accordance with the regulatory requirements, shall be performed by the operating organization throughout the plant's operating lifetime, with due account

taken of operating experience and significant new safety related information from all relevant sources.”
- “The operating organization shall ensure that a systematic assessment is carried out to provide reliable confirmation that safety related items are capable of the required performance for all operational states and for accident conditions.”
- “The operating organization shall ensure that an effective ageing management programme is implemented to ensure that required safety functions of systems, structures and components are fulfilled over the entire operating lifetime of the plant.”
- “The operating organization shall establish and maintain a system for the control of records and reports.”
- “The operating organization shall ensure that the implementation of safety requirements and security requirements satisfies both safety objectives and security objectives.”
- “The operating organization shall prepare an emergency plan for preparedness for, and response to, a nuclear or radiological emergency.”
- “The operating organization shall establish, and shall periodically review and as necessary revise, an accident management programme.”
- “The operating organization shall establish and implement a radiation protection programme.”
- “The operating organization shall establish and implement a programme for the management of radioactive waste” (including spent nuclear fuel and other contaminated solids and liquids).
- “The operating organization shall make arrangements for ensuring fire safety.”
- “The operating organization shall establish an operating experience programme to learn from events at the plant and events in the nuclear industry and other industries worldwide.”

In addition to the many safety requirements applicable to any nuclear power plant, the nuclear cogeneration facility has to ensure that unacceptable levels of radioactivity do not occur in the product stream. Means for so doing have already been discussed in general terms in this publication. Radioactivity in the intermediate system and tertiary process stream has to be monitored continuously, with automatic isolation features if an off-normal or unacceptable amount of leakage is detected. Further, transients, off-normal conditions and events in the cogeneration facility have to be demonstrably prevented from having an adverse affect on safety in the nuclear plant. Depending on the end cogeneration product and use, proximity to population centres may be an advantage, whereas isolation from population centres is preferable for nuclear plant safety, in the highly unlikely event of a severe accident. Balancing these two competing factors is an essential element in the design and location of the facility.

5.3.4. Decommissioning

A decommissioning plan has to be developed and established in the design phase, to include evaluation and discussion of:

(a) Estimation of quantities of contaminated/activated materials and total activity contents;
(b) Determination of areas of different radiation levels in the plant as decommissioning proceeds;
(c) Choice of decommissioning strategy (e.g. immediate dismantling, deferred dismantling, entombment);
(d) Management of spent fuel;
(e) Disposal of contaminated materials;
(f) Overall cost estimation and expected funding sources;
(g) Potential future use of site and facilities remaining after decommissioning.

Identifying these aspects in the design Phase helps to ensure that the decommissioning implications of design choices are considered in a timely manner. It also demonstrates to decision makers and other stakeholders that the user and vendor have considered decommissioning as Part of the overall facility plan and design, and that the facility will not simply be abandoned at the end of operation without decommissioning being performed in a safe and appropriate manner.

Policies and Strategies for the Decommissioning of Nuclear and Radiological Facilities (IAEA Nuclear Energy Series No. NW-G-2.1) [74] provides guidance on developing a decommissioning plan.

5.4. ENVIRONMENTAL PROTECTION

5.4.1. Environmental impact assessment

Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes (IAEA Nuclear Energy Series No. NG-T-3.11) [56] provides a holistic approach to environmental protection in new nuclear power programmes. It describes the environmental impact assessment (EIA) process, the subsequent utilization of the EIA and the necessary infrastructure for such processes. The assumption is that a Member State embarking on such a programme already has an environmental regulatory framework in place, which may not be developed for nuclear power but instead for industrial projects; therefore, the emphasis is on the environmental aspects that are unique to a nuclear power plant project. The publication is addressed to senior managers, project managers or coordinators and technical specialists of government authorities and agencies, including the regulatory body, and operating organizations (users) and supporting industries (vendors) and other organizations involved in environmental issues. It describes actions for each Phase of the nuclear power programme dealing with environmental issues, following the approach suggested by Milestones in the Development of a National Infrastructure for Nuclear Power (Rev. 1) (IAEA Nuclear Energy Series No. NG-G-3.1) [4]. It also explains the process of developing a structured series of environmental reports, which provide information to all stakeholders and contribute to an open and transparent approach to nuclear power programme implementation. Where possible, it describes flexible approaches that allow Member States to adjust the guidance to fit their existing legislative framework or policy.

The following IAEA publications are also relevant for environmental protection aspects:

— Regulatory Control of Radioactive Discharges to the Environment (IAEA Safety Standards Series No. GSG-9) [57];
— Strategic Environmental Assessment for Nuclear Power Programmes: Guidelines (IAEA Nuclear Energy Series No. NG-T-3.17) [58].

Additional relevant IAEA publications related to emergency planning are:

— Considerations in Emergency Preparedness and Response for a State Embarking on a Nuclear Power Programme (EPR-Embarking 2012) [75];
— Preparedness and Response for a Nuclear or Radiological Emergency (IAEA Safety Standards Series No. GSR Part 7) [76];
— Arrangements for Preparedness for a Nuclear or Radiological Emergency (IAEA Safety Standards Series No. GS-G-2.1) [77].

5.4.2. Assessment of alternatives

Environmental law in many countries requires such assessment of alternatives. Specifically, the user and their vendor partner will be required to demonstrate that there are no obviously superior alternatives to the proposed facility in terms of environmental impacts, or that the proposed facility is environmentally preferable. The nuclear cogeneration facility will likely have many advantages over reasonable or feasible alternatives (e.g. avoided emissions). However, environmental law can be complex, so the user and vendor will be well advised to engage organizations with expertise in the field to prepare environmental documentation, and to help assess and potentially mitigate environmental impacts that would or could result from construction, operation and decommissioning of the facility.

Strategic Environmental Assessment for Nuclear Power Programmes: Guidelines (IAEA Nuclear Energy Series No. NG-T-3.17) [58] provides guidelines for strategic environmental assessment for nuclear power programmes.

5.5. REGULATORY REQUIREMENTS

5.5.1. The role of a national regulatory authority

A strong and technically competent regulator of nuclear safety is essential for the protection of people and the environment in countries with nuclear installations. Although the user of a nuclear cogeneration facility is of course not required (nor should it be allowed) to set the parameters for its regulator, it is in the interest of the user that a visible, credible, competent and independent regulator be established before a nuclear project is implemented. Most countries use nuclear materials, even if they do not operate nuclear power plants. Typical uses include sources for medical procedures and radiography of materials. Thus, the regulator in all likelihood is already present, though for embarking countries its capabilities will need to be augmented significantly to ensure capable regulation of nuclear power plant safety. The existence of a strong and competent regulator should be viewed as a prerequisite for project start.

Governmental, Legal and Regulatory Framework for Safety (IAEA Safety Standards Series No. GSR Part 1) (Rev. 1) [65] provides requirements for the governmental, legal and regulatory framework for safety. These requirements are not legally binding on any country, and the regulatory framework will vary from country to country. However, the principles in Ref. [65], if followed, provide a strong and predictable regulatory framework within which a licence applicant and licensee will be able to understand their own roles. For example, Requirement 24 of Ref. [65] addresses the expectations of an applicant regarding submission of an application containing a demonstration of the safety of a proposed facility.

A strong and credible regulator is essential to ensure nuclear safety in a country. It is also essential for providing assurance to all stakeholders, including the public and the government in particular, that safety is being placed above all other priorities and considerations. The United States Nuclear Regulatory Commission has published its Principles of Good Regulation[7]:

— Independence;
— Openness;
— Efficiency;
— Clarity;
— Reliability.

A regulator that does not commit and adhere to principles such as these should be viewed as a potential risk to the success of a nuclear project.

The user and vendor will need to ensure that they thoroughly understand the regulatory framework, including all regulators and their authorities. Some of the authorities may overlap (e.g. nuclear and environmental), and the applicant/licensee will need to fully understand and address the overlaps. Communication with the respective regulators is essential to resolve any challenges in meeting the regulations to avoid project delay or other jeopardies. The applicant/licensee will also need to clearly understand the difference between a regulatory requirement — with which the applicant/licensee has to strictly comply — and regulatory guidance. Typically, the regulator will expect the intention of guidance to be met, but it may be open to alternative approaches from those specified in the guidance.

[7] For more information: https://www.nrc.gov/docs/ML1413/ML14135A076.pdf

Comprehensive details on regulatory framework in relation to nuclear power infrastructure can be found in the IAEA Nuclear Infrastructure Bibliography [48], under Section 7:

— Establishing the Safety Infrastructure for a Nuclear Power Programme (IAEA Safety Standards Series No. SSG-16) [64];
— Managing Regulatory Body Competence (IAEA Safety Report Series No. 79) [20];
— Governmental, Legal and Regulatory Framework for Safety (IAEA Safety Standards Series No. GSR Part 1) (Rev. 1) [65];
— Organization, Management and Staffing of the Regulatory Body for Safety (IAEA Safety Standards Series No. GSG-12) [21];
— Technical and Scientific Support Organizations Providing Support to Regulatory Functions (IAEA-TECDOC-1835) [66];
— Independence in Regulatory Decision Making (INSAG Series No. 17) [67];
— Functions and Processes of the Regulatory Body for Safety (IAEA Safety Standards Series No. GSG-13) [68];
— Licensing Process for Nuclear Installations (IAEA Safety Standards Series No. SSG-12) [69];
— Licensing the First Nuclear Power Plant (INSAG Series No. 26) [70];
— Experiences of Member States in Building a Regulatory Framework for the Oversight of New Nuclear Power Plants: Country Case Studies (IAEA-TECDOC-1948) [71].

5.5.2. Licensing requirements

For project success, the user and vendor need to have a clear understanding of the applicable licensing requirements. Clarity in the requirements, and clarity in how to meet the requirements, should be viewed as essential early in the project. Licensing Process for Nuclear Installations (IAEA Safety Standards Series No. SSG-12) [69] provides guidance for participants in the nuclear licensing process, including the owner/user, who will hold the necessary licences to construct and operate the nuclear cogeneration facility.

The documents submitted to the regulator should be incorporated as Part of the licence, as necessary. The set of documents to be submitted, and their content, will depend on national regulations, regulatory regimes and practices. A generic list of such documents is included in the Appendix to Ref. [69].

As indicated in Ref. [69]:

“The applicant or licensee should prepare and submit a comprehensive application to the regulatory body that demonstrates that priority is given to safety; that is, that the level of safety is as high as reasonably achievable and that safety will be maintained at the site for the entire lifetime of the nuclear installation.”

The applicant or licensee has to continue to demonstrate that safety is being maintained in all aspects of plant operation until the decommissioned facility is released from regulatory control by the regulatory body. Some of the principal requirements detailed in Ref. [69] include:

— “The applicant or licensee should have the capability within its own organization (either on-site or within the organization as a whole) to understand the design basis and safety analyses for the nuclear installation, and the limits and conditions under which it must be operated.”
— “The applicant or licensee should exercise control over the work of contractors, understand the safety significance of this work (‘intelligent customer’ capability) and take responsibility for its implementation.”
— The applicant or licensee should have a clear control process for reviewing, approving, and documenting modifications, which under specified circumstances may need to be approved by the regulatory body, either before or after the fact as required by applicable regulations.
— “The applicant or licensee should have a design capability and a formal and effective external relationship with the original design organization or an acceptable alternative.”
— “The applicant or licensee should assess safety in a systematic manner and on a regular basis.”

— “The applicant or licensee should ensure physical protection and security at the nuclear installation.”
— “The applicant or licensee should demonstrate in its application for a licence that it has and will continue to maintain:
  (i) Adequate financial resources (e.g. depending on national legislation and regulation, for regulatory fees and liability insurance, and for funding of the construction, operation and decommissioning stages and of maintenance);
  (ii) Adequate human resources” (including nuclear liability insurance).

The key licensing document required to support the applicant’s safety demonstration is the safety analysis report (SAR). Format and Content of the Safety Analysis Report for Nuclear Power Plants (IAEA Safety Standards Series No. SSG-61) [78] provides guidance intended to ensure that the information provided in the SAR is comprehensive and sufficient to demonstrate compliance with the relevant IAEA safety requirements and recommendations. It contains general recommendations, as well as recommendations for the structure and content of the SAR — recognizing that content will depend in Part on regulatory requirements and the specific facility design.

Reference [78] notes that the SAR is:

> “developed by the operating organization and used by the regulatory body in assessing the adequacy of plant safety in all stages of the lifetime of a nuclear power plant to determine the suitability of the licensing basis. The safety analysis report, compiled either as a single document or as an integrated set of documents that collectively constitute the licensing basis of the plant, should provide an adequate demonstration that the nuclear power plant meets all applicable safety requirements.”

The document should be updated during the lifetime of the plant at the intervals required by the regulator to show current plant configuration and safety analysis.

The SAR is required to document that design changes have been properly justified and reviewed, and that the safety aspects of interactions between technical, human and organizational factors have been duly considered. It has to demonstrate that the plant will be operated safely, and as necessary should reference related materials that support its conclusions.

5.5.3. Codes and standards

Codes and standards are technical positions on specific subjects, such as fabrication or welding. They are typically developed by non-governmental standards development organizations (SDOs), often professional organizations such as the International Organization for Standardization (ISO). They are subjected to rigorous peer review consistent with the SDO’s practices. As issued, they may be guidance for operators of facilities.

The nuclear cogeneration facility will fall within the scope of many nuclear and non-nuclear codes and standards. Regulators may make use of specified standards mandatory. They may allow licensees to use an alternative approach to demonstrate a particular aspect of safety. However, such a demonstration will often be much more difficult than complying with the code or standard already accepted by the regulator. Even if a code or standard is not required, demonstrated compliance with an appropriate code or standard provides a high level presumption that the activity is being conducted safely. Thus, codes and standards are highly supportive of the owner’s and vendor’s safety and compliance demonstration. If compliance with a code or standard is required by the regulator, an exemption from the requirement will likely be required, which will require approval from the regulator.

The vendor will need to determine codes and standards with which its design and construction will comply. In so doing, it will need to fully understand the regulatory framework regarding codes and standards in the country in which the nuclear cogeneration facility will be licensed, constructed and operated. Use of different sets of standards in the same technical area can lead to confusion and error. It is therefore important to manage the standards selected for a project by adopting standards thar are identical to those of the supplier or by using existing national standards.

5.6. CONTRACTUAL ASPECTS

5.6.1. Procurement

Procurement should be managed effectively to ensure the availability of design functions throughout a nuclear facility's service life, and to ensure that construction schedules can be met. Ineffective control of procurement process can jeopardize facility safety, reduce reliability, or result in increased costs to operating organizations.

Procurement Engineering and Supply Chain Guidelines in Support of Operation and Maintenance of Nuclear Facilities (IAEA Nuclear Energy Series No. NP-T-3.21) [79] provides an overview of nuclear procurement processes, discusses issues of special concern and provides guidance for good practices to set up and manage a high quality procurement organization. Lessons learned for organizations considering new build nuclear projects are also included.

5.6.2. National and local industrial involvement

The user and vendor, in designing and developing the plan for the nuclear cogeneration project, will likely encounter expectations from the host country regarding involvement of its industry and workforce in the project. Industrial Involvement to Support a National Nuclear Power Programme (IAEA Nuclear Energy Series No. NG-T-3.4) [30] discusses these expectations and potential requirements. It notes that many goods and services are required to construct a nuclear power plant and to support its operation, and that most countries have an objective to increase national and local participation in providing these goods and services. Host countries will expect that participation to increase over time as the capabilities in the host country increase through training and experience.

6. USER AND VENDOR RESPONSIBILITIES

Whereas Section 4 of this publication addresses requirements placed on users and vendors by third parties or each other, this section focuses on responsibilities — corresponding actions (or necessary inactions) by the user or vendor to meet requirements and thereby support project success.

6.1. ECONOMIC ASPECTS

6.1.1. Business case

The user and vendor are responsible to a number of stakeholders for the financial success of the project. These include, as applicable:

— Stockholders in the respective companies;
— Bondholders;
— National and local governments, to the extent that they provide financial assistance and/or incentives;
— Employees (who may also be shareholders).

The business case, to be effective, needs to be comprehensive, credible and convincing to these stakeholders. For these criteria to be met, certain points should be addressed in the business case.

Stakeholders will likely be aware of the financial challenges and risks associated with any nuclear construction project. The successful business case will address these concerns, demonstrating the competence of the user/vendor team and its capability to bring the project to completion on or near budget. The business case should also focus on the advantages of nuclear. Among these are the concentration of most of the financial risk in the construction period, whereas fossil powered cogeneration will be highly exposed to fuel cost risk throughout facility operation due to fuel (typically natural gas) price volatility. Nuclear fuel is a much smaller portion of overall facility cost as compared to fossil fuel.

The owner and vendor will need to successfully make the case that safety and economic benefits from their proposed project outweigh concerns or disadvantages. Such arguments may be easier to make for a backfit cogeneration project because the benefits from an existing reactor are tangible, not just conceptual as they are during initial facility deliberations. Lack of acceptable waste disposal facilities has the potential to cause elevated concerns, given that it may be necessary to implement interim management solutions such as on-site storage. The business case should discuss the inherent safety of on-site dry storage systems. Independence of energy supply should also feature prominently in the business case, as should the ability of nuclear generation to offset growing emissions of greenhouse gases. Fundamentally, the owner and vendor should make the case that the project is both safe and beneficial from many perspectives; that case should include reference to the outstanding safety record of the global commercial nuclear power industry.

The cost of decommissioning a nuclear power plant can typically run at US $500 million per unit, with the actual cost depending on the plant’s size. For a nuclear power plant, the government will likely have placed requirements on the owner to fund a reserve to cover the decommissioning cost at the end of plant life. In a regulated market, the owner may pass this expense to its customers via a surcharge on the electricity supply rates. In a deregulated market, the owner may not be able to pass this cost on to customers, so decommissioning expenses will need to be added to other project expenses in business case cost analyses.

6.1.2. Financing

The facility owner/user will be responsible to investing stakeholders for determining what will likely be a mix of financing options to fund the project. Options to finance construction may include:

- Public (government) funding;
- National development funds;
- Stock sales;
- Bonds;
- Vendor financing;
- Private financing.

Each of these has advantages and disadvantages, and their availability will depend on the proposed project as well as its host country. The owner, to be successful, will need to work with financial consultants to identify and propose a viable funding package to support construction to stakeholders (including, potentially, public service commissions). It will be prudent for the owner to consider the potential for cost overruns and identify how the funding picture will respond to them. In other words, who will pay for overruns — the owner, the vendor or the owner’s shareholders? The prudent owner and its consultants will have considered many factors in developing the funding package.

During operation, revenues will come from the sale of heat and power to the respective end users, usually through long term supply contracts. These revenues will support safe operation of the plant, provide funds to cover debt payments, accumulate decommissioning funds and include a return on investment for shareholders. Revenues from cogeneration by-products are also a possibility (depending on the project), but they are also subject to uncertainty.

The owner/user will likely also incur pre-construction costs, for example licensing costs, permitting costs, costs to develop the business case, etc. Many of these costs may not be directly reimbursed by project funding vehicles, and they will be considered to be ‘a cost of doing business’. A lesson learned in nuclear projects over the past several decades is that the owner should have substantial financial resources, and ideally experience in nuclear construction, to successfully handle the financial challenges of construction. Nuclear power (and nuclear cogeneration) projects are not as well suited to a small owner entity with large ambitions but very limited resources.

Managing the Financial Risk Associated with the Financing of New Nuclear Power Plant Projects (IAEA Nuclear Energy Series No. NG-T-4.6) [22] contains details on the relevant aspects.

6.1.3. Project management

Section 5 of this publication detailed just some of the many requirements that the owner and vendor will need to address for the project to be managed successfully. The owner/user has a responsibility to all shareholders to ensure that the project meets all these requirements and is well managed throughout planning, construction and operation.

Meeting this responsibility will be challenging. Example considerations include the following:

(a) There will likely be intense competition among firms interested in participating in the project, including EPC vendors. The owner will need to find the best fit among them.
(b) The owner and vendor will need to harmonize the activities of companies on the nuclear and non-nuclear side who may have little familiarity with each other’s business environment and constraints. Workforce training will be key in activities such as determining and harmonizing end user requirements and reactor capabilities, as well as addressing technical feasibility, industrial operability and economic competitiveness.
(c) The owner will need to decide, in consultation with vendors, end users and the government, the scale and structure of the project (e.g. cost structure and targets, perhaps inclusion of or reliance on a demonstration project, etc.).
(d) The owner may consider engaging an energy services company to design, install, finance, own, manage, operate and maintain a CHP plant on the user’s site, providing the company with metered electricity and heat. In that structure, the energy services company will be responsible for fuel purchase, the operation and maintenance of on-site energy plants (e.g. boilers and reactors), the operation and maintenance of site energy distribution systems, the purchase of imported electricity when required, and the export and sale of surplus electrical power. If the energy source is from nuclear power, this company will be the nuclear operator in this structure. Many other structures or variations are possible, and the owner will be responsible for finding the right structure for the project and its business environment.
(e) A major responsibility will be hiring and developing the relatively large plant staff to operate and maintain the facility. Because nuclear power requires specialized and exacting work and a complex and specialized scientific and engineering culture, a large contingent of skilled, technically specialized service professionals is required. Most current nuclear plants require on average approximately 800–900 staff members per two-unit site, a number that might decrease for the simpler and smaller nuclear plants currently proposed, based on small modular reactor technologies. However, staffing — whether on-site or remote, or a combination thereof — will always be higher than for alternative energy sources, so the owner and vendor will need to maintain constant focus on having adequate numbers and skills and the required nuclear culture in their respective staffs.

6.2. TECHNICAL ASPECTS

6.2.1. Siting

In addition to the various regulatory requirements related to siting, the owner will be responsible to all parties for considering aspects of siting that are perhaps not directly related to regulatory requirements. A prime example is considering the views of the public. It is much easier to site a facility where there is broad support for it than to site it in the face of widespread opposition. Open and honest communication with the public and local government stakeholders will help the owner to assess the level of both support and opposition. If there is opposition, the owner will need to assess its depth and breadth, and whether it can be overcome. However, a general lesson learned from the history of nuclear power is that it arouses strong opposition among a fraction of the public, and the extent of this opposition varies significantly by locality. The prudent owner will find a site that will not incur major public and local government opposition.

A compelling case can often be made that the best location for a new nuclear cogeneration facility is the site of an existing nuclear power plant — either by backfitting cogeneration capability onto one or more existing nuclear power plants or by collocating a new nuclear cogeneration facility (including a new nuclear power plant) with an existing nuclear power plant or plants. Either way, issues such as suitability from an emergency preparedness standpoint, population density and other siting issues may already be resolved.

However, some considerations that might make a site compelling as a location for a nuclear power plant (distance from population centres) may not be compelling for a cogeneration facility. The owner and vendor might be in the position of making the case that, using a specified new and extremely safe reactor technology, a site that is perhaps less suitable for a large nuclear power facility (e.g. close to population centres) may be suitable for a next generation reactor, powering, for example, a district heating project.

6.2.2. Selection of reactor technology

The chosen reactor technology will need to meet the applicable regulatory requirements, which vary by country, as discussed in Section 5.5. However, other factors should also be considered in selecting a design technology, such as:

— It has to be safe and licensable;
— It has to be of proven reliability;
— It should be economically attractive;
— It should pose relatively low technical and financial risks;
— It should be constructable in time to meet end user timelines for needing the project’s electrical and cogeneration products;
— It should be flexible enough in operation to support end user objectives and needs;
— It should have maintainability built into the design;
— It should have a reactor whose size fits the project’s needs. The size will depend on the needs of end users, the financial resources available to the owner and special considerations (e.g. ability to transport large components to the site by rail, road, or water);
— It might be the case that factory built or modular technologies are attractive, depending on country, site, end user needs, etc.

Because vendors of next generation nuclear power plants are each linked to, and advocating, one of a wide variety of technologies expected to be marketed, a decision on technology is closely linked to the choice of vendor. Hence, the suitability, capability, financial strength and integrity (among other essential characteristics) of the vendor will inevitably inform and be a major factor in the decision on technology.

Choosing to retrofit an existing nuclear plant to provide a cogeneration capability means that the decision to do the backfit involves a yes/no evaluation as to whether the existing technology is a good fit for the proposed cogeneration expansion. The owner’s decision making process may involve choosing between a backfit project and a new build project (which might be collocated with an existing nuclear power plant).

6.2.3. Coupling

The responsibilities placed on the owner and vendor for coupling involve ensuring that the coupling design will be suitable and reliable. The coupling between a nuclear plant and an industrial site should be determined by the need to transport the cogeneration products (steam, heat, electricity, hydrogen) in a safe, reliable and economical way. The nuclear safety and leakage requirements discussed in Section 2.2.3 will need to be borne in mind. Fundamentally, the coupling is relied upon as a major Part of the equipment that keeps the nuclear and non-nuclear sides separate. It helps ensure that unacceptable leakage of radioactive materials or radioactivity does not occur, and it keeps the cogeneration facility from adversely affecting the safety of the nuclear power plant. It is therefore key to making the case that the nuclear power plant will operate safely and that the public can rely on the cogeneration product as being uncontaminated with radioactive materials.

The owner and vendor will also need to bear in mind the maintainability and reliability considerations that are always applicable to industrial applications and particularly to nuclear facilities. For example, any SSC associated with coupling should be designed and constructed using materials and processes that will hold up in the presence of the challenging environments they may be subjected to, and they should be easily inspected and maintained as needed.

6.3. SAFETY CONSIDERATIONS

6.3.1. Design

Any licensable nuclear power plant design can be deemed safe by the regulator if the applicant makes a sufficient site specific safety case. However, there are still safety features that can enhance safety, enhance the viability of the project and improve public perception of the project. Some considerations include:

- Ultrasafe designs may be permitted to make the case that off-site emergency planning measures can be reduced or eliminated, depending on the regulatory framework. The success of any such outcome also depends on convincing the public that the reduced emergency planning measures are appropriate and safe. If the case is made and accepted, such reactor designs may be suitable for areas with higher population densities than are typically accepted by the regulator or the public for ‘conventional’ nuclear power plants.
- Reactors with simple, demonstrable safety concepts (e.g. inherent safety features, reliance on passive safety systems) are both easier to license and probably less costly to construct and operate.

6.3.2. Construction

Nuclear safety during construction of a nuclear power plant means that the plant is being constructed consistently with the design approved by the regulator. In this way, stakeholders (most importantly the owner and the regulator) can have confidence that the as-built plant will conform to the design and licensing bases as documented in the safety analysis report and other documents, and that it will be safe to operate. The owner, the vendor and all of the vendor’s subcontractors share responsibility for ensuring that the plant is constructed consistently with the design and licensing bases. The owner should ensure that its staff understand the exacting requirements and how to implement them. It is very important that a nuclear safety culture be established and maintained.

The owner should select a vendor who understands nuclear safety and safety culture, and then carefully oversee the quality of the vendor’s work. The vendor in turn should select appropriately qualified subcontractors and suppliers, and then carefully oversee their work and verify its quality to nuclear standards. Failure to do this could result in failure of the entire project. There are documented cases where nuclear power plants were fully constructed but never operated because of lack of attention to quality assurance. A lesser but still very adverse outcome is extensive rework of SSCs found not to be compliant. All construction participants have a responsibility to stakeholders to ensure that this does not occur.

Heavy construction also entails personnel safety hazards. The owner, vendor and subcontractors performing work on site all have the responsibility to ensure careful attention to industrial safety to protect their workforces against death or injury. Specific hazards need to be controlled or eliminated before work begins. Safety culture has to be present at all levels, ensuring zero tolerance for unsafe practices or failure to follow procedures.

6.3.3. Operation and maintenance

Responsibilities during operation and maintenance again focus in Part on nuclear safety, both while the cogeneration facility is operating and while it is not. This is because once a nuclear power plant is operated, the presence of irradiated nuclear fuel means there is decay heat, which has to be removed even when the plant is not operating. Procedures for safe operation have to be strictly followed by well trained operators, maintenance staff, engineers, radiation protection staff and administrative personnel (e.g. those who maintain safety related records). The consequences and penalties for failing to conduct these activities safely can be severe. A nuclear safety culture that will not tolerate poor or unsafe performance has to be established and maintained every day of the plant’s lifetime. Failure to follow such principles and practices can result in unnecessary, extended and expensive shutdowns to correct pervasive safety culture deficiencies. It can also result in challenging and potentially unsafe plant transients.

In addition to making the safety case to regulators and other stakeholders in the host country, to the extent that the site is near national boundaries, the laws and safety requirements of adjoining countries may also need to be considered. For example, an emergency planning zone may extend into a neighbouring country, requiring that country to be involved in emergency planning in a similar way to the governments and other stakeholders in the host country.

Owners and vendors also have the responsibility to ensure that industrial safety is maintained. Hazards will vary with the chosen technology. They will in any event include potential exposure to ionizing radiation, although the magnitude of radiation levels present will vary with plant design. Hazardous chemicals, as well as high pressure and high temperature fluids, will be present, again depending on the design.

6.3.4. Decommissioning

The safety impacts of decommissioning are likely to be limited. Once nuclear plant operation at power, and thus nuclear fission, ceases, decay heat declines steadily over time. It will be in the interest of all stakeholders to remove spent fuel to either an off-site disposal facility (if available) or to an on-site or off-site dry cask storage facility. All fuel should have cooled enough to support dry storage within a few years of final plant shutdown. Once all spent fuel is in dry storage, decommissioning of the rest of the facility can commence. Another alternative is to begin decommissioning with spent fuel still in the spent fuel pool. However, such an approach requires careful attention to avoid any potential impact on spent fuel pool cooling during the decommissioning of the rest of the plant.

Some advanced reactor designs may have features that can reduce the tasks associated with spent fuel management (e.g. some small modular reactor concepts are designed to operate for up to 30 years without refuelling) and this can also affect the actions taken for decommissioning (e.g. if wet storage is not needed). The extent to which the decommissioning process will need to be described in licensing documentation, and the time frame in which it will need to be addressed, will vary according to each country’s regulatory framework. In any event, the owner has the responsibility to all stakeholders to demonstrate, as Part of the business case and communication plan, that a viable and safe decommissioning process can and will occur. It is important to understand that the public has been presented with the point of view that spent fuel disposal is both a safety issue and an intractable problem via news media over a span of decades. The owner will need to demonstrate the facts to stakeholders — that spent fuel disposal is technically viable but requires political will, and that spent fuel storage is quite safe.

6.4. ENVIRONMENTAL PROTECTION

6.4.1. Environmental impact study

The owner/user and its vendor partner will be responsible for developing the design, and its interface with the site and its environs during construction and operation, to support development of the environment impact assessment (EIA). To do this, the user should finalize the capacity and size of the nuclear cogeneration project. The scope of work and mode of execution of the cogeneration project, such as infrastructure, design, detailed engineering, procurement, of systems and subsystems, erection, testing and commissioning should all be decided. The scope of work required for site related activities such as site levelling, construction of civil structures, electrical works, seawater intake, reject disposal and utilities should be firmed up by the user.

The environmental impact study in support of the EIA will typically consist of the following elements, or similar:

(a) Generating baseline information regarding the status of the environment by carrying out baseline surveys of environmental parameters such as air, water, noise and soil.
(b) Identifying project related activities that might or would have a potential impact on the environment or the public and providing the mitigation measures for the impacts.
(c) Preparing appropriate scale maps of the project and its environs, including ecologically sensitive areas.
(d) Conducting marine ecological studies to determine water quality and the impact of brine disposal (if applicable), as well as impingement and entrainment of marine organisms in cooling systems.
(e) Conducting bathymetry surveys, studying current tides, taking wave measurements, and performing other surveys and studies to identify the profile of the sea- or lakebed in order to design the intake channel and outfall diffuser (as applicable).
(f) Conducting land use and land cover pattern studies for the proposed project site and study area to identify the impact of the proposed project on the land.
(g) Predicting pollution load/stress levels in air, water, land and other environmental matrices due to plant impacts.
(h) Examining the availability and adequacy of the envisaged measures for control or mitigation of pollution and other environmental impacts.
(i) Analysing the consequences of potential accidents, documenting the steps adopted to avert accidents and the plans to mitigate environmental and human health consequences of severe accidents.
(j) Identifying potential hazards from, and interactions with, nearby existing industries.
(k) Specifying the environmental monitoring required in the operational Phase of the plant to evaluate the effectiveness of the various environmental control measures adopted.
(l) Assessing the benefits arising from the project (e.g. avoided emissions).
(m) Describing the administrative mechanisms to be implemented to oversee:
    — The implementation of control/ mitigative measures (in the environmental management plan) before commissioning of the plant;

— The operation and maintenance of such systems;
— Compliance with monitoring programmes;
— The provision of required funding.

6.4.2. Assessment of alternatives

To meet applicable environmental protection requirements, the owner and vendor will likely need to demonstrate that the facility's environmental impacts are not only small, but smaller than alternative approaches for attaining a beneficial end (e.g. generating electricity, producing hydrogen, district heating).

Either the owner/user, the vendor, or their respective contractors and consultants will need to be thoroughly familiar with environmental law in the country in which the plant will be sited to ensure development of a high quality, acceptable EIA. Such laws are often quite complex. To the extent that the site is near national boundaries, the laws of adjoining countries may also need to be considered.

6.5. REGULATORY RESPONSIBILITIES

6.5.1. Regulatory practice

To be successful in completing and operating the cogeneration facility, the owner and vendor will need to establish a reputation with the nuclear regulator as a trustworthy applicant/licensee, and vendor agent of the licensee, who adhere to the equivalent attributes to those specified for the regulator in Section 5.5 of this publication. Specifically, the applicant and licensee have to consistently:

(a) Demonstrate 'safety first' focus at all times (nuclear safety, security, industrial safety), and construct and operate the facility in a manner that protects the health and safety of the public;
(b) Submit licensing documents that are truthful, accurate and complete, and that clearly demonstrate compliance with applicable requirements;
(c) Demonstrate competence in all aspects of plant construction and operation as applicable to each Phase and require the same of the vendor and its subcontractors;
(d) Focus on compliance with safety and security requirements;
(e) Be timely in interactions and document submittals to allow the regulator to plan its work;
(f) Be open with the regulator and the public;
(g) Demonstrate full understanding of nuclear quality assurance and quality control, and fully implement them throughout the life of the facility — and require the same of the vendor and its subcontractors (lack of which may be the most common cause for failed nuclear projects);
(h) Implement a rigorous self-oversight programme that identifies and thoroughly evaluates errors and other issues, prioritizes them appropriately for correction, and makes the corrections in a timely manner consistent with the priority and relevance to safety;
(i) Demonstrate close communication with the vendor and ensure that information provided to the regulator is consistent between the two companies;
(j) Ensure that sufficient funding and human resources are available and provided to support safe facility operation.

6.5.2. Regulatory interaction

The successful applicant and licensee will recognize the need to be proactive with regard to regulatory interactions. Frequent communication and meetings are necessary to present the safety case, discuss construction progress and discuss corrective actions for performance problems, among other reasons. The owner/applicant/licensee can only reasonably expect the regulator to complete its reviews in a manner consistent with project timelines and deadlines if the applicant plays its part. This means the applicant communicating effectively with the regulator and submitting licensing documents and products that meet the applicable requirements while minimizing the need for the regulator to request additional information.

6.6. CONTRACTUAL RESPONSIBILITIES

Alternative Contracting and Ownership Approaches for New Nuclear Power Plants (IAEA-TECDOC-1750) [1] examines the alternative contracting and ownership approaches for the development, construction, commissioning, operation and decommissioning of new nuclear power plants, while identifying the issues faced by IAEA Member States considering the applicability of such approaches to their respective national programmes.

6.6.1. Procurement

The owner and vendor are responsible for completing the project on schedule and within budgeted costs. This is very challenging for a complex project such as a nuclear cogeneration facility. Procurement will be a major challenge and will need to be managed carefully. The vendor will obviously have a major role in ensuring that procurement contracts for goods and services are executed in a timely manner and with sufficient specification of applicable codes and standards, quality control, etc. Performance guarantees for procured goods and services will need to be specified in contracts.

Several contracting delivery models (project delivery methods) are available to pursue and construct the facility. The owner/user should evaluate the different models and make a considered decision. The conventional delivery models are as follows:

(a) Engineering, procurement and construction (EPC);
(b) Engineering, procurement and construction management (EPCM);
(c) Design–build (DB);
(d) Design–build–operate (DBO) and design–build–operate–maintain (DBOM);
(e) Design–build–own–operate–transfer (DBOOT);
(f) Build–own–operate–transfer (BOOT);
(g) Design–build–own–operate (DBOO);
(h) Build–own–operate (BOO).

The nuclear industry is currently using the EPC, EPCM and BOO models.

The contract delivery model that has been used to construct numerous nuclear projects worldwide is EPC. The typical contract delivery model that has been used to construct several desalination projects worldwide is DBOM or EPCM, along with an operation and maintenance contract — typically for seven years.

The scope of work of the vendors during the site development, construction, installation, testing and commissioning should be clearly defined. Scope with respect to electric power supply, utilities such as water and air, etc., should also be clearly defined in a timely manner to support construction, commissioning and operation.

Industrial process owners (end users) will need to rely on established nuclear technologies to make informed investment decisions, or alternatively to have a contract vehicle in place that shares the risk of new technology in a way that is acceptable to them and their shareholders, as applicable. If the reactor technology is not fully proven (e.g. through dependable operation of a full scale example of the technology), end users may be willing to carry Part of the technology risk, depending on contract terms and protections for their investment. Some of the technology risk should reasonably reside with the vendor, who presumably wants to incentivize potential ‘first customers’ for a given new technology. The financial investment for a nuclear cogeneration facility will be quite large, so the user, vendor and end user(s) will need to carefully negotiate a contract that spreads risks and rewards in ways that are acceptable to each party.

6.6.2. National and local industrial and labour involvement

The nuclear cogeneration facility will obviously require a major industrial effort. Even for nations with prior experience in nuclear power, it is likely that the degree of involvement of local labour and industry will vary significantly between the nuclear side and the balance of plant/cogeneration side. Nuclear construction requires highly specialized and experienced companies, as well as highly trained individual labourers and other employees. Companies providing services on the balance of plant or cogeneration side need to be qualified in heavy industrial construction and project management, but the user is more likely to find adequate skill sets in the local area for that work than for nuclear work. Even where skill or capability gaps exist, they are probably more easily and quickly addressed for non-nuclear capabilities than nuclear capabilities. Thus, the user and/or vendor(s) may well find it necessary or advantageous to bring in expertise from outside the local area or even outside the host nation for much of the nuclear work, while using more local resources for the cogeneration work. It will likely not be feasible to import labour resources for every aspect of work on the nuclear side, so an important aspect of project planning is to determine the right mix of resources for all parts of the project. Decisions on that subject will be highly dependent on the workforce situation (the availability of qualified companies, as well as educated and skilled workers) at the local and national level.

The user and vendor are responsible for management of all facets of the project construction effort. As discussed in earlier sections, to be successful the project will need a carefully orchestrated plan for bringing materials and labour together, on- and off-site, to construct and operate a high quality and safe cogeneration facility. Manufacturing will need to meet exacting standards, and a highly trained and qualified workforce will be required. A significant fraction of manufacturing and staffing during construction will likely be supplied by the vendor. That will, of course, meet the vendor's assumed goal of maximizing its participation in the project, and it recognizes that the vendor presumably has a skilled workforce familiar with its design and components. This will particularly be the case for work on the nuclear side of the project.

However, it is in the user's interest (and may be a host country requirement) that some significant fraction of the industrial effort be sourced either with the host country or even locally. The user will be operating the facility for many years, and it is optimal that it meets national and local goals for industrial participation.

The successful user will work closely with national and local governments, private industrial concerns, and national and local labour organizations (unions, if applicable) to determine present capabilities and those that can reasonably be developed. As previously noted, it may be more practical to use national resources heavily on the cogeneration side of the project, while importing specialized resources for some of the work on the nuclear side. Additional training and oversight will be needed to ensure that companies and labour not previously involved in nuclear work provide products that meet the exacting standards required for construction of a nuclear power plant. Interest on the Part of the government, local organizations and labour organizations to involve national and local providers will not be allowed to have an adverse impact on nuclear safety and quality.

The user and vendor will need to work with the host country to support that country in:

- Putting in place policies for industrial capacity to participate in the project;
- Building capacity to learn the chosen nuclear and cogeneration technologies to the extent necessary;
- Identifying capabilities of the national industries to permit viable support for the project;
- Establishing partnerships to extend local involvement.

6.6.3. Technology transfer

Some vendors have signed contracts with users in host countries that involve technology transfer in order to induce the user and/or country to purchase and construct at least one facility using the vendor's design. Under such contracts, in return for a contract to construct a vendor's design in a given country, the user and/or host country receive otherwise patented design information from the vendor that would allow the user and/or host country to construct the same or similar design at another facility (or additional units at the same facility) without purchasing the additional reactor from the vendor. Transferred information could be tangible, such as design and construction specifics, chemical formulas, etc. It could also be intangible, such as know-how and trade secrets. Such arrangements are more likely to be sought by host nations with a significant industrial capability that could make effective commercial use of the transferred information. It is much less likely in an 'embarking' country with little or no prior involvement in nuclear power, and which may have limited industrial capability.

Vendors may approach users about such a possibility or the user may approach the vendor. In any event, the parties to the contract will need to decide if technology transfer as Part of the contract terms makes sense to them. From the vendor's perspective, is interest in selling a limited number of facilities worth the fact that the vendor will lose proprietary control over its design? The vendor may wish to limit the transfer, for example such that the host country is only allowed to build the transferred design in its own borders and may not market the design to other countries.

6.7. COMMUNICATION ASPECTS

6.7.1. Communicating with the public

The regulatory process will typically require the regulator to inform the public of applications under its review. Requirements related to public communication may be placed on the user as well. However, for project success the user should take it upon itself to communicate effectively with the public, likely going well beyond regulatory requirements for such communication. An informed public will be able to understand the project's benefits and safety measures, and the public will be less likely to oppose the project based on misconceptions. Further, the public may identify concerns that the user will need to address. Fundamentally, forthright communication with the public is essential to project success.

A nuclear cogeneration project brings specific public communication challenges. Any nuclear project requires extensive, innovative, proactive and careful outreach to minimize or address likely public concerns about nuclear technology. Effective communication will include identifying and implementing methods to reach likely interested individual stakeholders and groups. Some concerned stakeholders will be located near the planned facility, while others may be distant, perhaps not even in the host nation. Regardless, project success requires effective communication with these interested and potentially concerned stakeholders.

Other members of the public may be concerned about the cogeneration project. Such concerns may be economic (e.g. the high upfront cost of this type of project) or related to the safety of the cogeneration energy distribution system or the fact that the cogeneration heat source is a nuclear power plant. These individuals and groups may be distinct from those concerned about nuclear safety, or they may overlap.

The user should methodically identify stakeholders with whom it should communicate, considering all persons and groups whose interest or concern is reasonably foreseeable. Local governments that may or may not have a regulatory role for the project will, in any event, be key stakeholders and will be able to help identify effective ways to communicate with their public constituents. Communication should begin as early as possible with the goals of informing the public, stimulating interest in the project and its benefits, and addressing concerns.

Careful thought should be given to how to reach different groups of the public. Just holding an announced public meeting may not be effective, because people are busy in their lives and may not attend such meetings in significant numbers unless they are very concerned about the project. Alternatives such as attending meetings of civic organizations, or providing information at public events such as festivals, should be considered. The most effective ways to communicate will vary depending on the local area culture and lifestyles.

An important principle in communicating with stakeholders is to tailor the communication to the audience. For example, data on risk and probability for a nuclear accident scenario are highly informative to an insurance company, but less so to the public. The public needs to hear information that shows that the project and facility will be constructed and operated safely. The information needs to avoid technical jargon, but it also needs to respect the intelligence of the public. The user needs to be sensitive to preconceptions and mistrust issues that may be present in discussions related to nuclear power. The goal should be to inform the audience in a truthful and complete manner, and in ways and using terms that will be meaningful to them and respect the intelligence of all participants.

6.7.2. Media

The importance of the rolling news cycle is also key in planning communication activities with the so called mainstream media (newspapers, television networks, etc.). It is crucial to have credible and skilled communicators available to interact at short notice and to follow up as needed. It is often important to distinguish between the national media and the local media, who may have different requirements and expectations.

In one example, the Nuclear Regulatory Commission in the USA has sought to improve its interactions with the media, and a 2003 task force report suggested that the Commission should “make more effective use of interviews, meetings with editorial boards, letters to the editor, appearances on news programs, human interest pieces and frequent proactive use of press conferences.” [80]

Members of the user and vendor staff who may or will interact with the media should be specifically trained on how to do so successfully. The training should include, but not be limited to, focus on the constraints under which reporters and media organizations operate, as well as what drives their actions.

Social media rather than the mainstream media is the means by which many or most of the public receive information that they consider to be reliable. It may in fact be not at all reliable, because it is often completely disengaged from facts. The user needs to recognize this, and to apply resources and methods to participate effectively and in a timely manner in social media discussions. The user can often be the first to post on items affecting its operation, but it will also need to respond quickly to misinformation posted by others.

7. ADDITIONAL INFORMATION FOR USER AND VENDOR

This section provides additional pointers and perspectives on subjects already discussed in earlier sections. While the discussion often focuses on one cogeneration application (e.g. district heating) as an example, many of the principles and ideas discussed also apply to other cogeneration facilities. The user and vendor should consider the concepts discussed as having potentially broad application to any cogeneration project they are considering.

7.1. MARKET MAPPING

Mapping the markets is obligatory for the user and context dependent for the vendor. Usually, the user and vendor will act independently, but some limited interaction between the two may occur.

As an example, the aim for both the user and the vendor (if the vendor will perform such activity) of a district heating project with nuclear cogeneration is to identify the potential of the heating business for district heating for an urban agglomeration or for industrial processes. The specific local conditions (e.g. type of housing, energy efficiency of buildings, level of agglomeration, climatic conditions, specific requirements of end users, distances), as well as the existence of local heating resources, together with their economic performance, create a diversity of situations that are challenging to analyse with the limited resources available to a vendor or user. Nuclear heating project market mapping should aid understanding of the business's viability to support a decision on whether to proceed with the project proposed.

Mapping for a district heating project should be an effort at local, regional, and national levels since the proposed nuclear district heating facility will presumably be beneficial for the construction of future district heating systems aiming to reduce emissions and improve efficiency. Aggregating this effort at the international level can also provide a solid basis for technology providers and vendors to better identify specific needs for the research–development–innovation process. Access to relevant international databases dedicated to heating needs is critical to prepare the supply chain in line with market requirements.

The integration of modern tools, such as geographic information system (GIS) technology, can ensure high performance mapping and easier ability to understand market potential in order to successfully develop the business and achieve end user satisfaction. Qualitative analyses are also needed to support the business plan.

The recent movement towards the use of renewable energy for heating, the use of residual industrial heat, geothermal energy, heat pumps and heat production by incineration of a fraction of municipal waste are examples of market changes creating new opportunities. A concept that is being used increasingly often is multiple local heat resources connected to the same distribution network in order to make better use of local resources to minimize climate impacts. However, an outcome that is beneficial for end users is still required. This new concept is very different from the classical one offered by fossil fuel.

The technology developer may also consider orienting its product towards the heating and cooling market since cooling requirements may be assumed to increase because of climate change and increased expectations concerning quality of life, particularly in the developing world. Users and vendors may contribute together to the development of a district heating and cooling system that is responsive to local market conditions.

In the context of the climate policies of future markets, some countries may impose emission taxes on fossil fuels, which would presumably increase the cost of such products. Such a situation would favour the development of alternatives based on heat recovery, renewable energies and nuclear.

For the case of new nuclear cogeneration units, market mapping will need to consider possible siting options in an attempt to harmonize nuclear siting requirements with the markets for the heat produced. In the retrofitting case where the heat source location is known, the distance to the customers (or more exactly the length of the thermal grid) will be an important input to market mapping. Currently, the cost of transport of heat through large diameter pipes may be low even for long distances (100–150 km). Preinsulated pipes may be buried underground to further reduce heat losses.

7.2. UNDERSTANDING END USER NEEDS

It is very important to create mutual understanding of needs, requirements and options with end users to formulate the best approach to meeting customer needs. This is crucial for the user since it is responsible for owning and operating the nuclear cogeneration business, but it is also important for the vendor since it may affect customers' views of its products and services, and the likelihood of success in selling such products and services in the future.

From the user's point of view, the main elements characterizing satisfaction with the operation of the facility include:

- — Meeting technical performance parameters such as the rated amount of heat transferred to the end users;
- — Sufficient flexibility to adapt to changes in end user demand and also to weather conditions;
- — Demonstrable and consistent safe operation of the cogeneration facility;
- — Reliability of the entire system;
- — Favourable economic performance, especially meeting production cost targets.

End user satisfaction will likely be based on factors such as:

- — Price of delivered product;
- — Reliability — product provided as contracted and as demanded;
- — No significant adverse impacts of the nuclear side on the cogeneration side;
- — Ability of the facility to respond flexibly to changes in end user needs;
- — No significant unexpected and unbudgeted expenses;
- — No long term shutdowns caused by user performance problems;
- — Honest and forthright user.

The final consumers of a DHS are likely to be very sensitive to price. Consequently, it is suggested that the user be very careful in terms of their estimation of the delivered heat price and also fully transparent with end users on the basis and structure of the costs.

In practice, the price is influenced by the heat production cost, interface and backup costs, distribution cost and associated profits. Current market conditions should be analysed carefully, and special attention should be paid to possible evolutions in those conditions. The possible sources of cost increases should be identified, and possible countermeasures discussed. Lack of transparency in price formation will likely lead to poor final user satisfaction. Therefore, the suggested approach is to produce and provide a transparent and realistic estimation of the facility costs and potential perturbations to those costs.

For district heating, the influence of the variation of heat demand and the requirements for adaptability to it should be investigated in terms of technical feasibility/performance and economics.

Achieving mutual understanding between the user and the vendor, together with a real grasp of the actual consumer needs, is quite a complex process. Different perceptions and biases may produce misconceptions. A relevant example is hot water supply. Perhaps the end user is dissatisfied with the price of hot water, considering it to be high, while the supplier has to deal with challenges such as large heat losses, low consumption in warmer seasons and daily peaks and troughs in demand. Success depends in Part on mutual understanding of challenges that impact on each participant in the process.

7.3. FEASIBILITY

Preparation of a Feasibility Study for New Nuclear Power Projects (IAEA Nuclear Energy Series No. NG-T-3.3) [35] offers the relevant information to assist interested Member States in developing a feasibility study for nuclear power projects.

Investigation of opportunities and barriers should be approached at the beginning of the feasibility study. Nuclear cogeneration is an opportunity for the decarbonization of the heating sector. Vendors may use new developments in technology and material sciences to enable heat to be sold over relatively long distances (~100–150 km). On the other hand, the development of small modular reactor systems has opened up the possibility of siting a nuclear cogeneration facility closer to the heat load agglomerations or industrial platforms typical of more heavily populated areas.

The energy market framework (energy trading, approvals of tariffs, long term contract rules) is of critical importance for economic feasibility. Since the reactor's life of ~60 years is much longer than the life cycle of typical industrial or district heating installations (15–20 years), the use of nuclear heating is dependent on a mechanism based on long term rather than short term contracts.

For this reason, there is an inherent tension between the natural tendency of the long term recovery of a nuclear investment and the likely shorter duration of a heating business. In this sense, it is preferable for the nuclear investment to be controlled by the state as a guarantee of conducting business over a long period of operation. A much shorter payback time (perhaps as little as five years) could apply to the retrofitting case (converting an existing NPP to the cogeneration mode to provide district heating).

Investment in the thermal energy distribution network may not be prudent for the nuclear investor, because it would create additional risks. A separate investor may be required. From the point of view of this investor, three cases may be discussed:

(a) A densely populated area with a sufficiently developed thermal energy distribution network; the nuclear heating source is easy to implement;
(b) An existing distribution network, but a nuclear power plant an extended distance away involves a larger investment;
(c) No existing distribution network, large investment.

Another important point is related to the use of local resources, for example those of biomass and municipal waste, geothermal heat, residual heat from industrial installations, renewable, etc. The availability of these resources varies from one country to another, and from one urban agglomeration to another. Integrating these resources into the business plan and finding an integrated solution is more likely to be successful than trying to force market penetration at the expense of these alternative sources. In this sense, the model of a district heating network with several heat injection points is much more practicable and useful for end users, with the business model being focused on economic efficiency and energy efficiency. This situation creates uncertainty about the flow of income and expenses, but it can be accommodated by a plant that predominantly sells electricity and provides a small fraction of energy for heating. The essentially opposite concept of a reactor exclusively dedicated to thermal energy supply is less well explored, so a rigorous feasibility study and business case would be particularly crucial for such an application.

In the retrofitting case, the feasibility investigation for the investment in NPP to be transformed into a cogeneration facility is not as complex as in the case of new NPPs, since the local context is quite well defined and the nuclear Part is already in operation. However, in the case of a new nuclear cogeneration plant, the feasibility study should be carried out at the initial stage (conceptual design) in order to allow optimization of the cogeneration project and create the greatest possible benefit to end users.

The feasibility study should include site location, the needs and opportunities for the investment, and a conceptual design for the system, including some details concerning the connection of the cogeneration plant to the heating grid. Additionally, basic elements concerning the operation and maintenance of the plant and the heat transport/distribution/storage capability will be introduced to provide a more complete and credible picture of the costs and benefits of the proposed investment.

The economic analysis will take into account, among other considerations:

— Generation of electricity and heat and their sale;
— Security of supply;
— Sufficient storage capabilities;
— Environmental benefits, emissions and associated taxes;
— Benefits for end users;
— Economic impact of flexibility in operation.

TABLE 3. OPPORTUNITIES AND BARRIERS TO BE CONSIDERED

Opportunities	Barriers
Recent development of technologies; SMRs avoid long distance transport of heat	Large investment costs for the transport and distribution infrastructure
Societal awareness of climate warming and the need to decarbonize the heating sector	Negative experience of district heating for some customers (comfort, price, lack of transparency)
Great interest in hydrogen and huge potential for decarbonization of the process	Public acceptance of nuclear energy
High temperature nuclear system, dedicated to industrial needs	Shorter lifetime of the DHS or process heating business compared with nuclear plant life

The analysis should address advantages and disadvantages (opportunities of utilizing nuclear cogeneration for a given application versus barriers to doing so), addressing points such as those presented in Table 3.

In the development of cogeneration technology there is a need for deeper investigation of:

— Possibly selecting an unconventional working fluid with properties such as high specific heat capacity to transfer the heat efficiently from the NPP to distant end users;
— Finding an approach to use site specific parameters to evaluate the variability of the operating regimes to find the optimal blend of electricity and heat in plant output.

Research work is also needed to continue to enhance software simulation tools to support critical decision making.

7.4. STAKEHOLDER INVOLVEMENT/PARTICIPATION

A significant number of stakeholders will need or want to be involved in the implementation of a nuclear programme. In the case of nuclear cogeneration the number is even larger, taking into consideration the potential diversity of end users, such as large building owners, dwelling owners, industry and other participants in the selected heat market; owners of the grid for heat distribution; owner(s) of backup system(s); and government authorities with oversight of the selected cogeneration products.

It is suggested that the milestones approach is implemented for the success of a nuclear programme, and similarly for a nuclear cogeneration project. In this context, a strong strategy for involving stakeholders in the decision making process is advised to support sustainable decisions and share responsibilities. The user should produce stakeholder engagement plans. In doing so, the user should take special care to convey correct understanding of the cogeneration concept to stakeholders at a technical level that meets the needs of each stakeholder. The range of stakeholders may include, among others:

(a) Final consumers and representatives of final consumers (municipalities, consumer or municipality associations);
(b) Government entities (such as ministries, agencies for development or regulation);
(c) Investors (financial organizations, shareholders);
(d) Industry (utilities, supply chain, vendors, technology owners);
(e) Research organizations and technical services organizations;
(f) Academia;
(g) Non-governmental organizations.

The user may be a utility, a municipality, or another government entity. Different roles will be played by different stakeholders, but all are of the utmost importance for the success of the cogeneration project. Due to the high capital cost, nearly 90% of the NPPs currently under construction are run by state owned companies with governmental responsibility for costs and risks. For nuclear newcomer countries (embarking states), some preconditions such as stable political conditions and support are necessary, as are activities to prepare adequate infrastructure such as institutions, the regulatory framework and competence building. All of these are the responsibility of national authorities and governments, but the user has a major interest in their success.

Special attention should be paid to the public, which should be treated as a partner. The general key interests of the public are connected with the project location, benefits and risks. However, the information provided to the public should also include relevant elements of the cogeneration project, such as the general objectives, planning, costs, main participants and even some technical details presented in plain language. The communication channels should include meetings with the local community, meetings with all stakeholders, the Internet, events, an information office, hosted visits to the facility, etc. Different tools, such as websites, social media, forums, public hearings, public debates, presentations, brochures, flyers, etc., may be used. The involvement of professional communicators will be crucial, as many technical staff members likely to be employed by users will not be skilled in interacting successfully with the public.

Because of the wide diversity and large number of stakeholders, the user will need to perform or commission an analysis of the role of the various stakeholders likely to participate significantly in the decision making process. However, the user will need to avoid the tendency to exclude some stakeholders from the process. Rather, communication resources should be applied consistently with the potential effect of the project on each stakeholder, and the potential impact of each stakeholder on the success of the project. The analysis to support this effort is usually based on two criteria:

(a) The influence of the stakeholder (decision power);
(b) The known or projected interest of the stakeholder in the facility and potential issues related to it.

Among many messages that should be addressed to the public and other principal stakeholders to inform them about the nuclear cogeneration project involvement are:

— The efficiency of cogeneration in recovering otherwise wasted heat;
— The positive impact of nuclear cogeneration on protection of the environment by decarbonizing the heating sector;
— The positive economic impact of a long term source of secure and affordable energy.

In some situations, identified as having potential for the heating business, the distribution infrastructure may be missing or may require costly upgrades. In many countries these costs may be covered by public funds. From this point of view, the role of stakeholders may be crucial to convince local, regional or national authorities to use funds allocated to decarbonization for investment in modern heating grids. The impacts of applying funds in this area potentially include significant reduction in energy losses during heat transport, along with using carbon free energy sources.

Investors are increasingly interested in harmonization of short term interests (the economic viability and profit potential of the business) with long term value (environmental, social) to society, especially if stakeholder dialogue focuses on that. The user and vendor should pay close attention to stakeholder dialogue to build a sustainable cogeneration business.

The preparatory Phase leading to the decision to build a nuclear cogeneration facility is very important and sharing responsibility and participation in the decision making process is a key factor for the sustainability of the project. However, stakeholder participation also remains important in subsequent stages, for example in the authorization process. Some activities are obligatory, as stated in the current legal frameworks of many Member States, such as consultation with stakeholders (particularly the public) in the environmental impact assessment process.

7.5. VENDOR SELECTION

For successful technology delivery, vendor selection is a key step. A prescreening to include acceptable technologies is necessary. A set of candidate vendors may result. Vendor selection criteria may include:

— Experience (e.g. number of similar projects already successfully implemented);
— Reputation;
— Financial stability and capability;
— Managerial ability;
— Quality of the products and work;
— Technical performance of technology and products;
— Economic and sustainability aspects.

A widely applied selection method to reduce the number of vendors or suppliers is the multicriteria decision making method (MCDM). Alternatives are mathematical programming and artificial intelligence techniques. In practice, the MCDM has multiple variants, all of them including both qualitative and quantitative criteria.

The decision making process is based on the evaluation of a set of performance indicators facilitating the identification of the best solutions, followed by sorting and classification of candidate vendors. The suggested steps for such a process are:

(a) Establish criteria for identifying candidate vendors;
(b) Identify candidate vendors;
(c) Select the candidate evaluation method;
(d) Consider uncertainties;
(e) Construct a decision tree and assign weights to criteria;
(f) Rank candidates;
(g) Perform a sensitivity analysis to inform the decision;
(h) Make the final decision or recommendation.

7.6. NEGOTIATION OF THE BUSINESS MODEL

In existing energy markets, cogeneration sometimes consists of a combined facility selling deregulated (competitive) electricity and regulated (national, regional or local) heating. End users are strongly interested in product reliability and quality, and they wish to pay as low a price as achievable. Interest may be focused on a regulated price model, possibly supported by incentives. In other situations, interest may be directed towards a price model that favours energy efficiency. Tensions result from the fact that end user consumers are required to be served on a price model favouring energy efficiency. Some price setting models, especially in deregulated markets, will also likely reduce the ability to directly transfer fixed costs to end users. An example of good practice is that, in the unregulated heating price market of Finland, the district heating industry has initiated a dialogue with large consumers, called ‘price dialogue’, with the intention of creating transparency in price formation.

In the heat supply market, nuclear may follow the old model of heating based on fossil fuels, consisting of a network with a single heat source and a backup. However, the requirements of end users may be met more easily in an electricity like network in which several producers feed electricity into the same network, allowing end users to have choices in terms of price and performance parameters. A more distributed generation of heat, for example by using multiple local resources (such as biomass, wasted heat, heat pumps, renewable, etc.), will also produce competition and thus multiple benefits for end users.

The user’s business model should consider both the customers’ and the heat providers’ perspectives. The customers in district heating may be dominated by professional or commercial interests such as large building owners, or by individually owned dwellings. The main resources of the infrastructure are the heating network and the energy production units. The interest of the heat providing utilities is in dependable production of heat, not electricity production from the cogeneration facility. In many cases the nuclear unit and the distribution network are independent entities. The nuclear unit user/owner should manage the optimization of electricity and heat production in order to satisfy the contractual requirements and expectations of all end users.

7.7. AUTHORIZATION FOR CONSTRUCTION AND OPERATION

As nuclear technology is involved in the nuclear cogeneration business, an intergovernmental agreement between the user’s and vendor’s countries (if different) will need to be negotiated and signed. The nuclear cogeneration facility will follow the steps of the authorization process for an NPP stipulated in the legislation and regulations of each Member State. Siting, environmental impact assessment and licensing are the main steps.

The size of the plant is an essential consideration when siting a new nuclear plant in the cogeneration mode. If a large plant is planned, this normally implies a site that is distant from urban agglomerations and industrial platforms (although there are exceptions where NPPs are sited next to industrial facilities), with an important influence on the investment cost of the connection to the consumer and also the cost of heat transport. Such reactors also, by virtue of their size and design, may not be well matched to end user needs or be very flexible in operation. For these reasons, large reactors may not be appropriate for use in the cogeneration mode for heat. By using an SMR, the distance to end users may be reduced based on the implementation of a reduced emergency planning zone, if regulatory policy permits this. Some SMR designs are also likely to be much more flexible in operation than large NPPs.

Close cooperation between the user and the vendor is crucial to obtain the various authorizations and licences. The user will likely use consultancy services for the required studies, analysis and documentation. Knowledge of the chosen technology is a key factor, and the vendor may be the owner of that technology. Otherwise, a close relationship with a separate technology owner will be needed. The safety of the interface between the nuclear unit and the heat distribution grid will play a central role in authorizations. Normal operation and accident conditions (including the impact of postulated external hazards) should be evaluated in detail, as will of course be required by the nuclear regulator. For process heat, the user will need to demonstrate the functionality of the process and its safety conditions in the case of a failure of one or more industrial units.

The licensing process is centred on the provision of a safety and risk analysis report to be submitted to the regulatory authorities for review and comment, and ultimately approval. In the case of a cogeneration plant the coupling between the nuclear and industrial sites will be included in the safety assessment.

From the point of view of the environmental authorization, an EIA study will need to be conducted, taking into consideration not only possible failures in the system, but also positive impacts such as the reduction of greenhouse gas emissions and waste heat. Cooperation with the vendor (or owner of the technology) is of great importance in developing and providing relevant performance demonstration results for the proposed technology.

Regulatory frameworks vary among countries, so the user and vendor will need to ensure that they understand and comply with the host country’s complete regulatory framework.

7.8. PROCUREMENT

Especially in the case of small countries with small energy systems, joint procurement is advised. A collaboration agreement is needed, stipulating the cooperation of two or more users for the procurement process.

7.9. CONTRACTING

In the DHS related business, both the nuclear plant and the distribution network are capital intensive, and consequently long payback times are necessary. In this context, a long term contractual heat supply commitment is suggested, at least among the nuclear plant owner, distribution companies and large end users. It should be noted that the expected lifetime of the nuclear plant is at least twice that of the distribution infrastructure.

Another challenge is the ability of final consumers to switch to other heating alternatives. Therefore, a multisource concept is suggested in order to offer more certainty to the user that it will retain a market for its product even if some users switch to other suppliers. In such open networks, flexible contracts may be of great advantage.

For open networks, the nuclear heating option requires adaptation to become competitive. High price elasticity in the contract is suggested, in contrast to the traditional approach. On the other hand, open networks will stimulate the producers, including nuclear, to stay competitive and identify new applications for heat utilization. Special attention should be dedicated to the diversity of preferences and needs of the final consumers. These elements should be adequately reflected in the contracts.

The metering system should be discussed between users and end users and accepted based on knowledge of principles and performance. There is a clear tendency to stimulate the energy efficiency of buildings and implement disruptive technologies such as the ‘Internet of things’ and artificial intelligence. Such developments are likely to significantly influence heat consumption patterns over the long nuclear plant lifetime. The user will need to proactively revise the means of offering the product, such that disruptive technology assists rather than hinders the ability of the user to obtain a return on its investments.

7.10. DESIGN

The design task will be performed by the vendor and its subcontractors and consultants. For a cogeneration plant the design will include (in addition to the nuclear power plant design):

— The heat extraction method;
— The interface (obligatory due to safety and backup needs);
— The heat transmission system (distance, diameter, insulation, installation type — buried or not);
— Operation modes, including multisource aspects, if applicable.

The formulation of the design specifications for the cogeneration facility is the responsibility of the user. Therefore, the user will need to have sufficient expertise to address the applicable technical parameters. The user should also have a working knowledge of design parameters downstream, applicable to delivery of the heating product to end users. Special attention should be paid to the diversity of the end users and the variability of conditions. The end users expect reliability, good prices and enough flexibility to adapt the heating to their demands. The process heat industry requires adequate temperature level and heat flux as well as flexibility of supply to accommodate production planning. The vendor should build a deep understanding, not only of the technical specifications defined by the user, but also of the requirements specified by end users.

From the cogeneration point of view, the design will only affect the secondary loop of the nuclear power plant. Depending on the reactor type and especially on the manner in which heat is extracted, this interaction may be simple or complex, for example in the case of the need to introduce a new loop as an additional barrier to prevent the transfer of radioactivity into the heating grid.

Depending on the nature of the electric grid and the terms of heat supply through cogeneration, the design will need to support load following specifications and requirements, either on the electrical production side or on the cogeneration side, or both.

7.11. PROJECT IMPLEMENTATION

It is advised that the user and vendor build a common team dedicated to project implementation. This approach allows mutual support during the process. Special attention should be paid to technical support; development of local infrastructure; common analysis of risks; and building a common strategy to avoid risks where possible, and/or to mitigate their consequences. Such collaboration may form the basis for replication of the arrangement between the user and the vendor if the development of a fleet (additional similar or identical units to follow) is considered.

7.12. OPERATION

At least two different operating organizations will be involved in delivering the heat energy to the end users — one for the nuclear plant and one for the cogeneration product (e.g. the heating grid). The role of the vendor during facility operation is to offer information, technical support (e.g. maintenance and engineering services) and consultancy, as the user requests.

Even though the responsibility for facility operation is the user’s, the user and vendor should cooperate with regard to the following key aspects: operational safety, operational performance, and environment and health protection. Operational performance is closely related to flexibility. In both DHS and process heat there will be significant variability in the heat demand. In the case of industrial application of cogeneration products, the variation may even be larger than would be the case for DHS. The nuclear unit should be able to adapt heat and electricity production in response to changing requirements. The vendor should demonstrate the flexibility of the nuclear unit in such circumstances, and consequently it will need to assess reactor and facility performance against a large set of transient loads imposed by the DHS or industrial processes. The user will need to discuss the potential for any important changes in the structure of the load with the vendor, for example by modifying the industrial platform. Some energy storage capability might be useful to help adapt the nuclear unit operation to the short periods with low demand for both electricity and heat. From the point of view of the protection of the health and of environment, the vendor and its proposed design have to follow the same standards as for any NPP.

7.13. DECOMMISSIONING

Decommissioning is the responsibility of the owner of the facility and will to a large extent follow the general practice typical of NPP decommissioning. Decommissioning of Facilities (IAEA Safety Standards Series No. GSR Part 6) [81] indicates the top level responsibilities of the facility owner (user), as follows (reference omitted):

“— Selecting a decommissioning strategy as the basis for preparing and maintaining the decommissioning plans (i.e. the initial decommissioning plan and the final decommissioning plan) throughout the lifetime of the facility.

— Preparing and submitting an initial decommissioning plan and its updates for review by the regulatory body.
— Establishing and implementing an integrated management system. If the licensee changes during the lifetime of the facility, procedures shall be put in place to ensure the transfer of responsibilities for decommissioning to the new licensee.
— Fostering a safety culture in order to encourage a questioning and learning attitude towards safety, and to discourage complacency.
— Estimating the cost of decommissioning actions and providing financial assurances and resources to cover the costs associated with safe decommissioning, including the management of the resulting radioactive waste.
— Notifying the regulatory body (or the government, if so required) prior to the permanent shutdown of the facility.
— Submitting a final decommissioning plan and supporting documents for review and approval by the regulatory body, in accordance with national regulations, in order to obtain an authorization to conduct decommissioning.
— Managing the decommissioning project and conducting decommissioning actions or ensuring oversight of the actions conducted by contractors.
— Managing the remaining operational waste from the facility and all waste from decommissioning.
— Ensuring that the facility is maintained in a safe configuration during the period of transition following permanent shutdown and until the approval of the final decommissioning plan.
— Performing safety assessments and environmental impact assessments in support of decommissioning actions.
— Preparing and implementing appropriate safety procedures, including emergency plans.
— Ensuring that properly trained, qualified and competent staff are available for the decommissioning project.
— Performing radiological surveys in support of decommissioning.
— Verifying that end state criteria have been met by performing a final survey.
— Keeping and retaining records and submitting reports as required by the regulatory body.”

The owner will need to deal with the additional task of decommissioning the cogeneration side of the facility. However, as this should not involve significant radiological considerations, decommissioning of that side of the facility should be similar to decommissioning of similar non-nuclear energy transmission facilities. One additional consideration is that the owner will need to put measures in place to prevent decommissioning activities on the non-nuclear side from inadvertently involving SSCs on the nuclear side. Further, the likely presence of spent nuclear fuel on-site during decommissioning will require careful protection and isolation of facilities supporting the safety of the spent nuclear fuel from other decommissioning activities. Care will need to be taken to not cause any impacts on spent fuel cooling or storage systems. The owner can expect to provide a detailed decommissioning plan to the regulator for approval; the plan will need to demonstrate that the decommissioning will be accomplished safely from a nuclear perspective. Industrial safety and environmental protection aspects of decommissioning will also need to be addressed, perhaps with a different regulator.

8. EXAMPLES OF NUCLEAR COGENERATION PROJECTS

This chapter presents four relevant summary level examples of existing or planned nuclear cogeneration facilities. In each case some instructive points are presented for consideration by entities considering a role as the user (U) or vendor (V) of a similar project. The tables for each example summarize some notable aspects of vendor and user requirements and responsibilities within the meaning of those terms in this publication. Additional details of these projects are found in the references.

8.1. OPERATIONAL NPP WITH RETROFIT DISTRICT HEATING: BEZNAU NPP, SWITZERLAND

The Beznau NPP, comprising two Westinghouse PWRs (365 MWe each), has been generating power since 1969 and 1971, respectively, and is owned by the Swiss energy utility Axpo. A retrofit for district heating was completed in 1983/84, employing turbine steam extraction at 127°C from the two PWR units, and has been serving a maximum of 15 000 out of 20 000 customers connected to the district heating network. It has a proven 100% availability record for meeting district heating demand. The peak district heat load for water with a temperature of 120°C sent out of the NPP gate is 80 MWt, leading to a loss of electricity generation of 7.5 MWe. The project is well covered in Refs [82, 83]. Table 4 highlights notable requirements, responsibilities and lessons learned by user and vendor involved in the project.

TABLE 4. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY THE USER AND VENDOR IN RESPECT OF BEZNAU NPP DISTRICT HEATING PROJECT

Assessment criteria	Requirements, responsibilities and lessons learned
Economics	User/vendor requirements: — Cost competitive product in context of the oil crisis in the 1970s–1980s (high cost of competitive fuels) (U[a]) — Flexibility and availability of nuclear plant for district heating on demand (U) User/vendor responsibilities: — Value added in addressing high heating costs in the area while making the nuclear plant economically competitive even with low electricity demand (U/V[b]) Remarks/lessons learned: — The user (owner/operator) of the NPP provided 100% availability of carbon free and affordable nuclear heat on demand for more than 30 years of continuous operation (U) — The user of NPP made 60% profit from sale of heat (U) — The off-taker, the district heat transmission company, only recovered half of the cost paid to purchase the heat from the NPP due to heat losses in a long transmission line (30 km range and 290 km of pipeline) — The economics of widely distributed small end users significantly remote from NPPs is potentially challenging, depending on the cost of alternatives (U/V)

TABLE 4. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY THE USER AND VENDOR IN RESPECT OF BEZNAU NPP DISTRICT HEATING PROJECT (cont.)

Assessment criteria	Requirements, responsibilities and lessons learned
Technical	User/vendor requirements: — Coupling with safety features: new cogeneration concept at that time (U/V) User/vendor responsibilities: — Design for extraction of steam and multiple intermediate heat transmission loops between extracted turbine steam and the end user heating systems to optimize thermal efficiency (V) — Ensure reliability through redundancy: one of two reactors, 2×100% heating capacity, and standby oil boilers (V) Remarks/lessons learned: — One reactor provides 100% heating demand while the other reactor is shut down for maintenance (U/V) — In addition, oil boilers are installed on the reactor site as backup in case both reactors are off-line and to help handle peak loads, and these have been used (U/V) — Double stage cogenerated heat extraction reduces loss of electrical output (U/V)
Safety	User/vendor requirements: — No off-site release of unacceptable amounts of radioactivity (U) User/vendor responsibilities: — Multiple isolation loops between reactor and heat end users for defence in depth (V) — Pressure in district heating system kept well above pressure in turbine crossover piping to reduce possibility of release of radioactive materials to heating system (V) — Two sets of safety valves to further protect against release of radioactive materials to cogeneration process fluid (V) Remarks/lessons learned: — Emergency shutoff valves tested monthly to validate reliability (U)
Environmental	User/vendor responsibilities: — Design objective to minimize environmental impacts and emissions (U/V) Remarks/lessons learned: — As an alternative to fossil fuel, the project is very environmentally friendly — Reduces waste heat from the NPP that otherwise would go to the river
Communication	User/vendor requirements: — Crucial to communicate to stakeholders the value added and benefits of the project, including its availability, reliability and sustainability (U) User/vendor responsibilities: — Case made to stakeholders that the cogeneration system is simple and largely maintenance free (V) — Emphasize advantage of long term price stability (unaffected by volatile fossil fuel prices) (U) — Decision to build project contingent on clear public support and acceptance Remarks/lessons learned: — High public acceptance due to long record of reliability and public vote to participate (U)
Regulatory	User/vendor requirements: — Comply with all nuclear regulatory requirements (U) Remarks/lessons learned: — Benefited from extended NPP[c] operating period (14 years) prior to cogeneration with well established regulator, greatly reducing capital requirements and financial risks (U)
Contractual	Remarks/lessons learned: — Challenging financial condition remedied by renegotiation of financial terms during operating period (U)

TABLE 4. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY THE USER AND VENDOR IN RESPECT OF BEZNAU NPP DISTRICT HEATING PROJECT (cont.)

Assessment criteria	Requirements, responsibilities and lessons learned

[a] U: user.
[b] V: vendor.
[c] NPP: nuclear power plant.

8.2. OPERATIONAL NPP WITH DESALINATION: OHI NPP, JAPAN

Ohi NPP, owned by Kansai Electric Power Co., included four units:

— Units 1 and 2 comprise two Westinghouse PWRs (1175 MWe each) that started operation in 1979 and are now in decommissioning. While operating, they provided desalinated seawater through MSF at a rate of 2600 m^3/d.
— Units 3 and 4 comprise two Mitsubishi Heavy Industries PWRs (1180 MWe each) that started operation in 1991 and 1993, respectively. They are providing desalinated seawater through RO at a rate of 2600 m^3/d.

The desalinated seawater product of these cogeneration facilities has been used for nuclear plant steam makeup and in-house potable water consumption (not sent off-site).

The project is covered in Refs [2, 84]. Figure 7 shows an image of the Ohi NPP and the MSF seawater desalination facility for Units 1 and 2. Table 5 highlights notable requirements, responsibilities and lessons learned by the user and vendor involved in the seawater desalination project.

8.3. FUTURE NEW BUILD INDUSTRIAL STEAM PRODUCTION: HTGR NPP WITH STEAM COGENERATION, POLAND

In the Euratom project GEMINI+ (2017–2021), a study on cogeneration for industrial steam production using a conceptual design of a modular HTGR (180 MWt/unit) was conducted. The design reactor outlet coolant temperature is 750°C, and the nuclear steam supply per unit is 165 MWt (230 t/h) at 540°C and 13.8 MPa. The deployment market targets chemical industries in Poland. The project is covered in Ref. [85], for example, and the concept is presented in Fig. 8.

Table 6 highlights notable requirements, responsibilities and lessons learned by potential users and vendors involved in the project.

8.4. FUTURE NEW BUILD HYDROGEN PRODUCTION: GTHTR300C, JAPAN

Stakeholders in Japan (including the Japan Atomic Energy Agency, Mitsubishi Heavy Industries, Toshiba, IHI Corporation) performed a study on hydrogen production using a GTHTR300C HTGR modular reactor sized at 600 MWt/unit. The reactor outlet temperature is 850–950°C and the power generation is through a direct cycle helium gas turbine. Heat cogeneration is provided by IHX with a heat supply temperature of up to 900°C, and thermal or hybrid processes are considered for hydrogen production. The prelicensing basic design has been completed, and operation is targeted for the 2030s. The deployment market considers power utilities, as well as high temperature heat industries such as hydrogen

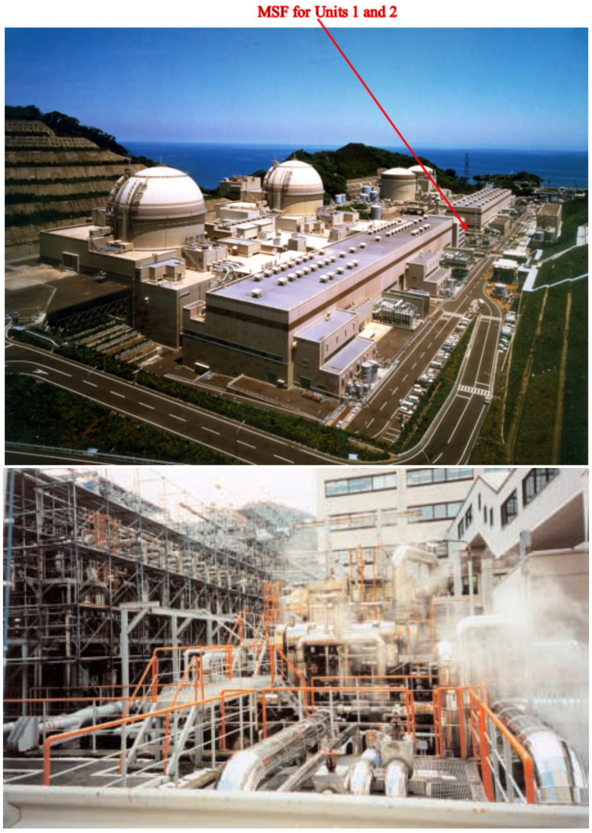

FIG. 7. Ohi NPP (top) (courtesy of Kansai Electric Power Co.) and MSF seawater desalination facility for Units 1 and 2 of Ohi NPP (bottom).

and steel production. The design therefore includes both electrical production and hydrogen production. Figure 9 presents the layout comprising the nuclear power plant and the hydrogen cogeneration plant, and Fig. 10 shows a schematic representation of the cogeneration process.

Figure 9 shows the originally proposed concept of the cogeneration system for GTHTR300C, which is a representative concept for the next generation HTGR systems proposed to date. In the concept, the hydrogen plant has a hydrogen production rate of more than half a million normal cubic metres per day ($0.6 \cdot 10^6$ Nm^3/day). The electricity needed for hydrogen production is met in-house from the efficient gas turbine power cogeneration of up to 200 MWe.

The project is well covered in Refs [86–94].

Table 7 presents notable requirements, responsibilities and lessons learned by the potential users and vendors for the potential hydrogen cogeneration project using the GTHTR300C reactor design.

TABLE 5. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY USER AND VENDOR FOR SEAWATER DESALINATION AT OHI NPP

Assessment criteria	Requirements, responsibilities and lessons learned
Economics	User/vendor requirements: — Need for desalination due to lack of alternative sources for plant makeup and potable water (U[a]/V[b]) — Nuclear steam cost competitive to other energy/production options (U) User/vendor responsibilities: — The user chose unaffiliated desalination specialist plant vendors to construct turnkey MSF[c] and RO[d] plants (U/V) — The user and affiliated (subsidiary) service vendors shared operation and maintenance shifts for desalination plants (U/V) Remarks/lessons learned: — Desalination plants for Units 1 and 2 had worked well enough to support the decision to construct the RO facility for Units 3 and 4 (U) — Cost and water quality of desalination were not a factor to decide the types of desalination plant types and vendors (U)
Technical	User/vendor requirements: — Operated at 50–100% of full capacity as needed to supplement insufficient or expensive fresh water on site (U) — Limited on-site space for desalination plants (U) User/vendor responsibilities: — MSF for Units 1 and 2 located next to reactor building to reduce piping runs and heat losses, and to utilize available space (U/V) — Chose RO for Units 3 and 4 because it did not require steam for the process and allowed siting further (800 m) away from reactors (U/V) Remarks/lessons learned: — Coupling for Ohi-3 and -4 RO identical to RO coupling for a fossil powered cogeneration facility, with the exception that the nuclear desalination plant covers the plastic casings of RO membranes with carbon steel for enhanced strength and integrity (U/V)
Safety	User/vendor requirements: — Detectable radiation levels not permitted in product water since partially used for in-plant potable water (U/V) User/vendor responsibilities: — Need to demonstrate safety of product to plant staff (U/V) Remarks/lessons learned: — Successful operation with no evidence of any anomalies to date and no detectable leakage of radioactive substances into the product water (U/V) — The user decided to decommission the Unit 1 and 2 reactors approaching their 40 year life, rather than seek a 20 year life extension, citing the high cost of making safety upgrades to meet the stricter post-Fukushima (2011.3) regulatory standards. Decision unrelated to cogeneration facility (U) — Units 3 and 4 are currently operating (U)
Environmental	User/vendor requirements: — Discharge brine protected from, and monitored for, radioactive contamination (U/V)
Communication	User/vendor responsibilities: — Important to communicate with plant staff and other stakeholders such as local communities and governments on safety (U)

TABLE 5. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY USER AND VENDOR FOR SEAWATER DESALINATION AT OHI NPP (cont.)

Assessment criteria	Requirements, responsibilities and lessons learned
Regulatory	User/vendor requirements: — Need to make safety case to regulator not familiar with nuclear cogeneration (U) User/vendor responsibilities: — Need to understand the roles of all levels of government in the regulatory process (U) Remarks/lessons learned: — For this case, continued operation of the desalination plant is inextricably linked to that of the nuclear plant (U)

[a] U: user.
[b] V: vendor.
[c] MSF: multistage flash.
[d] RO: reverse osmosis.

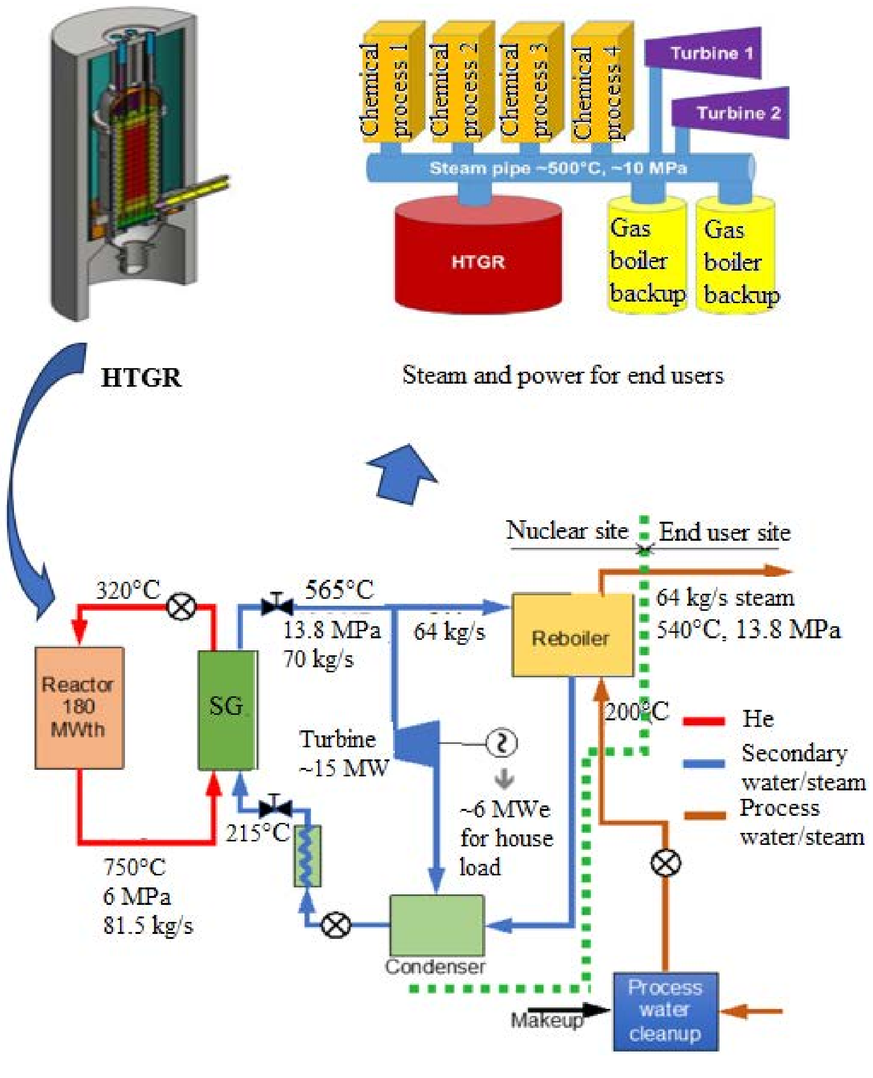

FIG. 8. *Industrial steam production using an HTGR.*

TABLE 6. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY POTENTIAL USERS AND VENDORS FOR INDUSTRIAL STEAM COGENERATION USING A CONCEPTUAL HTGR NPP

Assessment criteria	Requirements, responsibilities and lessons learned
Economics	User/vendor requirements: — Produce steam corresponding to industry needs (V[a]) — Provide potential for advanced cogeneration (other cogeneration products) in future phases (V) User/vendor responsibilities: — Multinational partnership to develop the concept (Japan, Korea, Rep., the USA) to take advantage of the resources, experience and skills of multiple participants (V) — HTGR[b] is a proven technical concept but needs to be shown to be economically competitive (V) — Poland's largest electric utility possibly interested in participating, providing potential boost to project viability (U[c]) — Targeted first application is industrial sites with steam networks (V) — Selection of reactor technology (HTGR) supports high reactor temperature for future hydrogen production (U/V) — Unit size is limited to ~200 MWt to match the majority of the steam use network in Poland (V) — Modular/series construction of multiple units to achieve standardization and simplification, and reduce upfront costs (V) Remarks/lessons learned: — EPC[d] (vendor company or consortium of companies) would be majority owned by user (owner/operator), minority owned by end users (chemical plants) and investors (U/V) — Need for an industrial demonstration plant to verify licensing and economic feasibility of first of a kind HTGR nuclear cogeneration, and before that for an experimental reactor (tens of megawatts in size) to prepare for construction capability and supplier chain (U/V) — The development cost including FOAK[e] construction would be spread over/borne by follow on units (perhaps 10) of reactor construction (U/V)
Technical	User/vendor requirements: — Minimize investment cost by limiting R&D to support project viability and competitiveness (U/V) — Cogeneration project needs to support industrial sites with steam networks (U) — Nuclear reactor would replace conventional boilers on the steam networks for chemical plants and power (U) User/vendor responsibilities: — Potential design with intermediate steam loop with reboiler to support safety and efficiency goals and objectives (V) — No electrical output from nuclear plant for target application but flexible for different electrical–steam mix in future applications (U/V) — System design should be flexible to respond to changes in demand (V) — Road transportable reactor vessel to reduce costs and increase siting flexibility (V) — Demonstration plant will be commercial scale to reduce cost and time to useful product (V) Remarks/lessons learned: — Need backup heat source (multiple reactors or fossil backup) to achieve end user goal of ~100% availability (V)

TABLE 6. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY POTENTIAL USERS AND VENDORS FOR INDUSTRIAL STEAM COGENERATION USING A CONCEPTUAL HTGR NPP (cont.)

Assessment criteria	Requirements, responsibilities and lessons learned
Safety	User/vendor requirements: — Have to demonstrate that potential accidents in the industrial site will not have adverse impacts on the nuclear plant (U/V) — Design has to demonstrate that no radioactive material contamination of the non-nuclear industrial facilities will be credible (U/V) — Design objective that potential off-site releases would be so small that there would be no need for an emergency planning zone beyond the nuclear plant site boundary (dependent on regulatory framework) (U/V) User/vendor responsibilities: — Design will need to incorporate distance and other safety measures between reactor and end users to minimize hazards to reactor facility (V) — Design may use a reboiler as an additional barrier between nuclear and end users (V) — Separate test reactor in planning to support development of infrastructure in Poland (U/V) Remarks/lessons learned: — As discussed above, demonstration of safety, along with economics, is planned using a full scale FOAK plant of the modular design as the first experience in Europe (U/V)
Environmental	User/vendor requirements: — Have to demonstrate minimal environmental impacts per national requirements (V) User/vendor responsibilities: — HTGR has inherent advantages over water reactors, with lower potential for radioactivity levels and potential releases (V)
Communication	User/vendor responsibilities: — Vendor consortium needs to convince stakeholders in Poland — which has no nuclear power history — of the wisdom of investing in a new approach (V) — Encourage dialogue between the Polish Government and foreign nuclear regulators to help build regulatory capabilities and infrastructure (V)
Regulatory	User/vendor requirements: — Comply with as yet undeveloped regulatory requirements (U/V) User/vendor responsibilities: — Make a cogent safety case for the inherent safety advantages of HTGR (e.g. large heat capacity, passive decay heat removal) (V) — Verify that the regulatory framework is in place (a strong regulatory framework is essential for project viability) (U/V)
Contractual	User/vendor requirements: — Obtain a nuclear based offer to provide industrial process heat as soon as possible to move the project forward (V) User/vendor responsibilities: — EPC: consider a single company or consortium to commercialize the concept (V) — EPC will propose to design and construct experimental reactor as well (V)

[a] V: vendor.
[b] HTGR: high temperature gas cooled reactor.
[c] U: user.
[d] EPC: engineering, procurement and construction.
[e] FOAK: first of a kind.

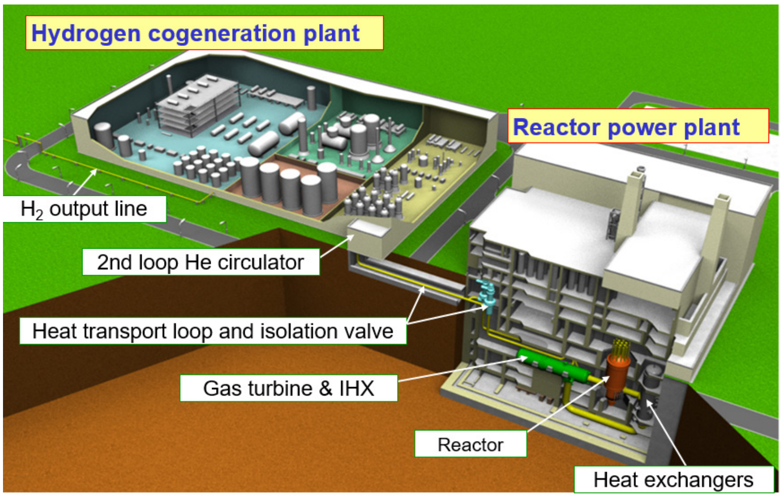

FIG. 9. Layout comprising the nuclear power plant and the hydrogen cogeneration plant.

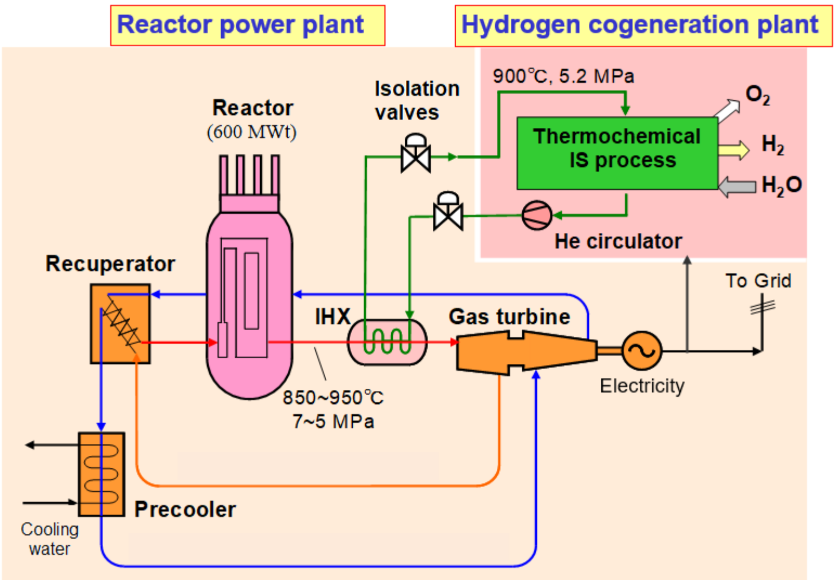

FIG. 10. Schematic representation of the cogeneration process.

TABLE 7. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY POTENTIAL USERS AND VENDORS FOR HYDROGEN COGENERATION USING GTHTR300C

Assessment criteria	Requirements, responsibilities and lessons learned
Economics	User/vendor requirements: — The project would use large scale production to take advantage of economies of scale (U[a]) — The project has to show, and is designed to show, competitive hydrogen cost (U) User/vendor responsibilities: — Thermochemical water splitting is the chosen concept for large scale production and high thermal efficiency (V[b]) — Substantial R&D is needed, and has been performed, to support this design (V) Remarks/lessons learned: — The design includes a conventional (non-nuclear class) hydrogen plant with separation from the NPP[c] to reduce cost (V)
Technical	User/vendor requirements: — A variable cogeneration ratio of power to hydrogen allows a spectrum of electrical vs hydrogen production load balances to take advantage of market demands and economics at any given time (V) — Due to the high degree of internal recycling in thermochemical processes, feed water quality has to be very high to minimize accumulation of impurities (V) — Potential need to accommodate load following (U/V) User/vendor responsibilities: — The user and vendor will need to meet the consumer's expectations for availability and convenience (U/V) — The developed concept ultimately needs to be demonstrated on a large scale (U/V) Remarks/lessons learned: — Feasibility of H_2 production has been demonstrated for steam methane reforming, the I–S[d] thermochemical cycle and high temperature electrolysis with the nuclear heat source (HTGR[e]) simulated by hot helium gas (U/V) — The I–S process with nuclear heat source achieves hydrogen production by splitting water thermochemically without CO_2 emission (V)
Safety	User/vendor requirements: — NPP safety functions (confinement, decay heat removal, reactivity control) should not be impaired by potential explosion/fire hazards from the H_2 operations (by keeping the NPP site physically separate from the H_2 production site) (U/V) — The NPP control room has to be protected against ingress of toxics such as from the I–S process (U/V) — The design has to minimize tritium migration from the NPP to the hydrogen production process (V) User/vendor responsibilities: — An integrated safety and risk assessment of combined system should be performed (U/V) — The proper separation distance in case of hydrogen explosion should be determined (U/V) — Emergency planning consistent with postulated hazards should be implemented for both the nuclear and the industrial (hydrogen production) facilities (U) Remarks/lessons learned: — The concept incorporates the inherent safety advantages of the HTGR (e.g. large heat capacity and passive decay heat removal) (U/V)
Environmental	User/vendor requirements: — Wastewater treatment in the I–S process will need to be addressed (V) — Toxic gas release to environment has to be prevented in the design (U/V) User/vendor responsibilities: — Nuclear assisted use of fossil fuels may be considered solely as a transition technology (V) — The design will need to include thermochemical cycles to deal with toxic interim products and wastes (V)

TABLE 7. NOTABLE REQUIREMENTS, RESPONSIBILITIES AND LESSONS LEARNED BY POTENTIAL USERS AND VENDORS FOR HYDROGEN COGENERATION USING GTHTR300C (cont.)

Assessment criteria	Requirements, responsibilities and lessons learned
Communication	User/vendor responsibilities: — Extensive testing and a demonstration facility could strengthen confidence in the concept and a future plant (U/V) — Social acceptance can be encouraged by emphasizing the benefits of nuclear cogeneration products (such as district heating/cooling from using nuclear power conversion cycle waste heat) to the public at little or no cost (U/V) Remarks/lessons learned: — A facility that combines NPPs and explosive gas (H_2) will cause concern among some stakeholders — a clear safety case therefore needs to be presented in plain language (U/V)
Regulatory	User/vendor requirements: — Tritium concentration in products has to be maintained below regulatory limits (U/V) User/vendor responsibilities: — The licensing process will be FOAK[f] and different from LWR[g] oriented cogeneration systems, so project owners will need to be sure that a rigorous and predictable regulatory framework is in place prior to any decision to proceed (U/V) — Safety demonstration will be needed for the coupling of the cogeneration plant to the HTGR to ensure reactor safety and product safety (low levels of tritium in hydrogen) (V/U)
Contractual	User/vendor requirements: — Such a project will involve a FOAK complex contract, so contracting terms will need to be developed carefully and be consistent with risk mitigation principles (U/V) User/vendor responsibilities: — Due diligence will need to be conducted regarding the long term cost and revenue structure (U/V)

[a] U: user.
[b] V: vendor.
[c] NPP: nuclear power plant.
[d] I–S: iodine–sulfur.
[e] HTGR: high temperature gas cooled reactor.
[f] FOAK: first of a kind.
[g] LWR: light water reactor.

9. CONCLUSIONS

9.1. MAIN CONCLUSIONS

The worldwide need for energy will continue to expand as the global population continues to increase and developing countries push to develop their economies and improve the lives of their citizens. Moreover, the security of energy supply, involving stable access to energy sources on a timely, sustainable and affordable basis, is of key importance and even of greater focus than it used to be, as countries are targeting achievement of their commitments in terms of climate goals and reducing their dependence on fossil fuels. Cogeneration projects carry important advantages in meeting these needs for cleaner and more reliable energy. Such facilities can meet multiple energy needs and yield increased efficiency by taking advantage of what otherwise might be wasted energy.

At the same time, there is an increasing imperative to reduce global emissions of greenhouse gases. Many voices in the scientific community, and many governments and non-governmental organizations, have stated in strong terms that action is needed in the near term. Yet energy consumption will in all likelihood continue to grow. This creates substantial tension between competing priorities. Among energy technologies that do not emit greenhouse gases, so called renewables are probably less suitable for cogeneration because of their intermittency and (in the case of wind energy or solar photovoltaics) inability to directly produce high temperature heat products. Nuclear energy largely stands alone as a cogeneration energy source that can provide energy on demand and does not generate greenhouse gases.

Given its advantages, a utility or other entity interested in cogeneration (the user as designated in this publication) would be remiss in not considering nuclear. Like all energy sources, nuclear energy has environmental impacts, and like all energy sources its use entails attention to risks specific to the technology. In addition, nuclear technology is complex; it requires simultaneous focus on the ‘big picture’ and exacting attention to detail. Further, it requires a larger initial capital investment than other energy source options, with assurance of major savings in fuel costs once the facility is in operation. The selection of the energy source will require careful consideration and balancing of many site specific and country specific factors, including the financial wherewithal of the project’s investors, the level of nuclear expertise available and the views of stakeholders — including national and local governments and the public. It also requires a long term commitment once the decision to proceed is made.

Once a decision is made to proceed with a nuclear cogeneration project, the project will bring together nuclear power plant and cogeneration infrastructure. The nuclear and non-nuclear sides of the facility will need to be managed simultaneously, safely and harmoniously, with interactions between the two addressed carefully through design and operation. Neither side will necessarily have much, if any, experience with the other, so the user and vendor will need to develop the communication, leadership, and nuclear culture upfront as the project proceeds. The success of project implementation will be affected if these capabilities are only developed slowly over time based solely on lessons learned from the project’s own failures. As with any large scope, long term construction project, cost overruns should be minimized, but also to some extent expected (with compensatory and/or corrective actions planned accordingly).

This publication is intended to assist users and vendors considering a nuclear cogeneration project in identifying subjects for evaluation to both support a decision on whether to proceed and assist in managing such a project to a successful conclusion when undertaken.

This is not a standalone guidance document. It provides summary level guidance intended to work harmoniously with the multiple references it cites, which typically provide a greater level of detail on specific subjects. As its title indicates, it provides guidance to the owner/user of the potential cogeneration facility. It also provides guidance to the vendor the user will engage to provide much of the facility design and to play a major role in oversight of its construction.

The exact role allocated to the vendor will depend on many factors. The user may retain the project management role, or it may designate that role to the vendor. Regardless, both entities have an important stake in the successful deployment of the project, and both need to establish good cooperation and communication for the project to be implemented.

To provide high confidence of ultimate success, the user will need to establish the appropriate expertise and safety culture in its own organization to oversee the work of the vendor. Prior reputation based on success at other sites or in other countries is not a reason to assume that the current project will be successful and relax oversight. As with all complex and demanding technologies (others include large civil construction projects and space exploration), project leadership and management, from project inception to final remediation after decommissioning hopefully decades later, are the keys to success.

The user and vendor will also find useful general information regarding nuclear cogeneration in Opportunities for Cogeneration with Nuclear Energy (IAEA Nuclear Energy Series No. NP-T-4.1) [13].

9.2. SUGGESTIONS

This publication contains many suggestions, and references many more. The prospective user and vendor should review them for applicability. Some salient overarching suggestions include the following:

(a) Whether the user or the vendor initiate discussions with the other regarding the potential for a nuclear cogeneration project, both need to ensure that a full and complete evaluation of the project, including alternatives, costs and risks, is commissioned before any decision to proceed.
(b) The user should give preference to vendors with an understanding of the relevant licensing/engineering processes, and with demonstrated competence in nuclear construction projects.
(c) Both the user and the vendor will need to recognize that a nuclear cogeneration project is fundamentally different from a baseload nuclear power plant. The plant siting, design and operation will, in addition to being safe, need to accommodate the specific product delivery needs of end users. The needs of electricity customers, as well as the needs of cogeneration heat customers, will need to be met.
(d) The financial structure of the project is very important. Considering the financial risks and uncertainties involved, the financial structure will need to allocate risks and rewards appropriately. The vendor should be strongly incentivized to control overruns and adhere to schedules. The user should ensure that financial resources are or will be sufficient to complete the project, even in the case of significant cost overruns. A project that is 80% complete and then terminated is of no more practical use than a project that is 0% complete.
(e) Both the user and the vendor should be very familiar with the nuclear infrastructure in the host country before proceeding. While the user of course is not the regulator, it is very important that a strong, competent and independent nuclear regulator be in place.
(f) A nuclear cogeneration project will require strict attention to quality and nuclear safety throughout construction and operation. Failure to maintain such attention has been shown to result in long delays in project completion due to stop-work or rework. Inattention during operation can result in long shutdowns to address the root causes of shortcomings that have led to events or incidents. Such shutdowns are unacceptable to end users and should be viewed as such by the user and vendor.
(g) The licensing process has to be clearly understood. The user and vendor have to demonstrate their competence, integrity and reliability to the regulator. They should recognize their burden to address regulatory information needs promptly and fully, and to proactively engage with the regulator throughout the facility and project lifetime. Although the user is responsible for satisfying regulatory requirements, it can be very difficult to do so without adequate vendor support.
(h) A nuclear project of any sort will require strong communication with stakeholders. A communication plan that identifies and prioritizes the involvement of stakeholders, as well as the best techniques and approach to involve each one, is essential.
(i) The user should carefully consider where outside expertise is needed. The project will involve many fields of knowledge, and many or most of these will not reside with the user as the project is

considered. The user should not overestimate its capabilities or underestimate the need to augment that capability either by hiring outside firms or bringing that expertise onto its own staff.

(j) Because the nuclear plant lifetime (40–60 years) may well exceed that of the connected industrial cogeneration plant (10–60 years), in terms of facility and/or possibly product for end users, the user will need to construct its supply contracts in a way that provides assurance for vendor replacement of equipment and to investors that they will be able to see a fair return on their investment. Preference should be given to vendors with an understanding of the relevant licensing/engineering processes.

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ABBREVIATIONS

BOO	build–own–operate
BOOT	build–own–operate–transfer
BWR	boiling water reactor
CHP	combined heat and power
DB	design–build
DBO	design–build–operate
DBOM	design–build–operate–maintain
DBOO	design–build–own–operate
DBOOT	design–build–own–operate–transfer
DHS	district heating system
EIA	environmental impact assessment
EPC	engineering, procurement and construction
EPCM	engineering, procurement, construction and management
FOAK	first of a kind
GIS	geographic information system
GTHTR300C	Japanese Gas Turbine High Temperature Reactor 300 Cogeneration
HES	hybrid energy system
HPC	high pressure cylinder
HTR	high temperature reactor
HTGR	high temperature gas cooled reactor
HTSE	high temperature steam electrolysis
HTTR	high temperature test reactor
IHX	intermediate heat exchanger
IPC	intermediate pressure cylinder
ISO	International Organization for Standardization
LPC	low pressure cylinder
LWR	light water reactor
MCDM	multicriteria decision making
MED	multiple effect distillation
MHI	Mitsubishi Heavy Industries Ltd, Japan
MSF	multistage flash
MSR	moisture separator and reheater
NPP	nuclear power plant
O&M	operation and maintenance
PWR	pressurized water reactor
R&D	research and development
RO	reverse osmosis
SAR	safety analysis report
SDO	standards development organization
SG	steam generator
SMR	small modular reactor
SSCs	structures, systems and/or components

CONTRIBUTORS TO DRAFTING AND REVIEW

Aydogan, F.	University of Idaho, USA
Constantin, A.	International Atomic Energy Agency
Khamis, I.	International Atomic Energy Agency
Kovachev, M.	International Atomic Energy Agency
Paillere, H.	International Atomic Energy Agency
Skliarenko, V.	International Atomic Energy Agency
Tewari, P.	Indian Desalination Association, India
Yan, X.	Japan Atomic Energy Agency, Japan

Technical Meetings

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Key

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