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Managing Siting Activities for Nuclear Power Plants

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MANAGING SITING ACTIVITIES FOR NUCLEAR POWER PLANTS

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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.

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.

Since the early 2000s, many IAEA Member States have expressed interest in the potential benefits of introducing nuclear power into their power production strategies to diversify their energy mix. These Member States are collectively referred to as 'embarking countries'. Furthermore, new nuclear power plants or additional units are planned in over a dozen Member States that are expanding their existing nuclear power capacity after several decades of inactivity.

The IAEA has responded by enhancing the assistance it offers to cover the specific needs of these Member States. In 2007, the IAEA developed an approach to assist countries considering or planning their first nuclear power plants. The aim is to help Member States understand the commitments and obligations associated with developing a nuclear power programme. Countries that already have nuclear power can also assess their preparedness for expansion. This approach, which is set out in IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), Milestones in the Development of a National Infrastructure for Nuclear Power, is referred to as the 'Milestones approach' and is, in practice, a nuclear power programme management guide. The Milestones approach identifies 19 infrastructure issues that require early attention for a nuclear power programme to be implemented successfully. The completion of the specific steps required to address these issues serves as the basis for assessing gaps and designing and developing IAEA assistance projects for embarking Member States.

Among the 19 infrastructure issues, the issue of site and supporting facilities (i.e. the selection of appropriate sites) is one of the main challenges and has an impact on many other infrastructure issues. The purpose of the siting activities goes beyond choosing a suitable site and acquiring a licence. A large part of the work associated with this infrastructure issue is in regard to producing and maintaining a validated, referenced bank of data that can be used during the lifetime of the nuclear power plant. As a result, in 2012 the IAEA published IAEA Nuclear Energy Series No. NG-T-3.7, Managing Siting Activities for Nuclear Power Plants, which discusses managing siting activities for a nuclear power plant using recent siting experience from Member States.

This publication is a significant revision of IAEA Nuclear Energy Series NG-T-3.7. The revision includes recent developments in managing siting activities in the nuclear and energy industries and provides guidance on site selection methodology and evaluation. The publication complements the IAEA Safety Standards related to site selection and evaluation.

The IAEA wishes to acknowledge the assistance provided by the contributors and reviewers listed at the end of the publication. The IAEA officer responsible for this publication was J. Haddad of the Division of Nuclear Power.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Nuclear power today makes a significant contribution to electricity generation, providing 10% of the global electricity supply as reported in 2020 and accounting for more than a quarter of low carbon electricity worldwide [1]. The increased demand for assistance in developing and implementing well managed programmes for the introduction of nuclear power in embarking countries led the IAEA to develop the IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), Milestones in the Development of a National Infrastructure for Nuclear Power [2] (hereafter referred to as the IAEA Milestones approach). This publication describes in detail the infrastructure needed to support the development and implementation of the safe, reliable, economical and peaceful use of a nuclear power programme in embarking countries. It proposes a three phase approach for such development and lays out a sequential process to execute it, including the formulation of specific milestones. It also elaborates on the 19 infrastructure issues that need to be addressed by a Member State for each milestone. One of the identified infrastructure issues refers to the selection and evaluation of the site and the supporting facilities required for a nuclear power plant (NPP).

The project to select the site for an NPP needs to begin early, be well managed and deploy good communications with all stakeholders, including regulators. Done well, it will ensure the right choice of site(s) considering safety, environmental, technical, economic and social factors. If not properly planned and executed, it is likely to result in major delays or even failure to complete the intended programme.

In response to requests from Member States for practical guidance on managing and coordinating this issue, in 2012 the IAEA published IAEA Nuclear Energy Series No. NG-T-3.7, Managing Siting Activities for Nuclear Power Plants [3]. The publication was developed to provide guidance on the process of siting and site evaluation with an emphasis on management, technical, economic, social and environmental aspects.

Considering subsequent experience and lessons learned from that publication's application, as well as recent developments in the subject, the publication has now been revised to take into consideration the following:

— The publication in 2015 of the revised version IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), Milestones in the Development of a National Infrastructure for Nuclear Power [2], which provides the latest view of the basis for the IAEA's Milestones approach and reflects on the lessons learned from the Fukushima Daiichi accident.
— The experience gained by the IAEA in relation to its assistance to Member States and the feedback obtained from the Integrated Nuclear Infrastructure Review missions and other assistance services in the related topics.
— The publication of IAEA Safety Standards Series No. SSG-35, Site Survey and Site Selection for Nuclear Installations [4] in 2015, which provides recommendations on the safety aspects of the siting process for a nuclear installation, as well as the publication in 2019 of the revision of IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [5].
— The provision of the Site and External Events Design Review Service to assist Member States with site selection, site evaluation and design aspects, taking into consideration site specific external hazards. This service has provided significant data and lessons learned since the 1980s.
— The need to consider the specific lessons learned from recent extreme natural events that have affected nuclear installations.

Siting and site evaluation are processes conducted in four sequential project stages within the three phases identified in Ref. [1]. The operational stage occurs after Phase 3 and is only briefly discussed in

this publication. It ought to be noted that some activities that are started during the stages discussed in this publication continue throughout the operational stage, such as management activities and monitoring requirements. All these stages are explained in Section 4.

1.2. OBJECTIVE

The objective of this publication is to assist Member States to ensure that a suitable site and its supporting facilities for an NPP are identified, selected, evaluated and licensed through a well planned project. This publication was developed for countries starting the project of selecting a new site for an NPP, which may include (i) those with operating power reactor units at sites selected and evaluated some time ago or (ii) those introducing a nuclear power programme for the first time with sites that are new or with sites that were initially selected years ago. This guidance aims to:

— Identify key issues that affect decisions on the suitability and selection of adequate sites for new NPPs and related supporting facilities;
— Establish a well defined management process (as discussed in Section 3) for the planning, control, implementation, verification and coordination of the siting and site evaluation activities as conducted at the beginning of the nuclear power programme.

1.3. SCOPE

This publication addresses the management of both safety and non-safety aspects to be considered in the siting and site evaluation processes for an NPP and its supporting facilities. Thus, it includes important factors such as considerations on nuclear safety and nuclear security, technology and engineering aspects, economics and cost, land use planning and preparation, availability of water, non-radiological environmental impacts, emergency planning, socioeconomic impacts and involvement of stakeholders.

This Nuclear Energy Series is intended to be used by decision makers, senior managers and other technical specialists from the following:

— Governmental organizations including the Nuclear Energy Programme Implementing Organization (NEPIO)[1], regulatory authorities and the owner/operator;
— Organizations involved in siting and site evaluation, and contractors providing services to the nuclear industry.

This publication can be used by Member States expanding their existing nuclear power programmes, which face different issues from those introducing their first NPP. Those Member States have to develop a comprehensive programme to address changes in the regulatory framework and associated safety requirements; the availability of new data and information related to site aspects; the existence of new methods, procedures and analysis tools for site investigations and external hazard assessments; the need to evaluate the safety impact due to the operation of additional nuclear reactor units in the same site with due consideration of the events that produce ‘common cause failures’; growth of the surrounding population; additional constraints on water availability; and so on. It may seem the obvious solution to build additional power reactor units on existing NPP sites. However, it is still necessary to demonstrate

[1] As indicated in Ref. [2], it is assumed that the government of an embarking country will create a mechanism (which may involve both high level and working level committees) to coordinate the work of the organizations involved in the infrastructure development. In this publication, this mechanism is called the nuclear energy programme implementing organization (NEPIO). It ought to be noted that this designation is used here for illustrative purposes only, since the country may organize the activity in a different manner more appropriate to its own customs and needs.

that such an option is as appropriate as finding a new site for the additional units, as site related conditions and regulatory requirements and guidance may have changed in the intervening years. Thus, even in this situation, it is necessary to carry out most of the work described in this publication.

All safety aspects mentioned in this guideline are addressed from the purely managerial standpoint and only for compatibility with issues of a different nature (environmental, economics, etc.) covered at the siting phase. All safety aspects find proper coverage in the relevant safety series and associated technical publications [1–4, 16, 19, 24, 25, 30].

1.4. STRUCTURE

This publication was structured with the objective of addressing the needs of different audiences. Thus, high level managers are guided to read this section as well as Section 2 to get a general idea of the importance and implications of the siting and site evaluation processes that form part of the Milestones approach in the development of a nuclear power programme, although it is noted that valuable insights may be obtained by reading the other sections as well. Section 2 discusses siting and site evaluation in the framework of a nuclear power programme. Sections 3 and 4 provide comprehensive information on management considerations, as well as a discussion of the attributes, criteria and processes to be considered in the siting and site evaluation processes, and needs to be read by all managers involved in the development of the NPP programme. Sections 5, 6, 7 and 8 provide information on how to conduct the different stages of the siting and site evaluation processes and to resolve the specific issues of each stage, based on the general considerations provided in Sections 2, 3 and 4. More explicitly, users of any of Sections 5 to 8 ought to first read the earlier sections. A list of references and a glossary of terms are also provided. It is organized so as to provide the required fundamental information. As a siting and selection programme moves through the various phases, the publication can be used as a ready reference with the necessary information clearly demarcated.

2. SITING AND SITE EVALUATION ACTIVITIES IN THE FRAMEWORK OF A NUCLEAR POWER PROGRAMME

2.1. THE MILESTONES APPROACH

The IAEA's Milestones approach as set out IAEA Nuclear Energy Series No. NG-G-3.1 (Rev. 1), Milestones in the Development of a National Infrastructure for Nuclear Power [2] has been widely adopted by countries embarking on a new nuclear power programme. The Milestones approach describes a set of 19 infrastructure issues to be addressed during three distinct phases in the development of the infrastructure for a nuclear power programme, each punctuated by a milestone. One of the identified infrastructure issues refers to the selection and evaluation of the site and the supporting facilities required for an NPP. Siting and site evaluation are processes conducted in four sequential project stages within the three phases identified in Ref. [1].

Figure 1 illustrates how these stages are inserted into the three phases of the Milestones approach for implementing a nuclear power programme for the first time. At Milestone 1 (at the end of Phase 1), the survey stage ought to have been successfully implemented through a regional scale analysis applying simple screening criteria and, as a result, a limited set of suitable candidate sites ought to have been identified. In Phase 2 of the Milestones approach, the site will ideally be selected and fully evaluated,

concluding with the confirmation of its acceptability. In Phase 3, the pre-operational stage, a detailed site characterization will ideally be completed and verified during the design and construction of the NPP and incorporated into the documents for licensing.

As shown in Fig. 1, the site survey stage needs to begin early in Phase 1 to ensure that one or more suitable sites are available for developing the nuclear power programme. During Phase 1, the regions of interest for a potential NPP site are identified at country scale, as discussed in Section 4.2. According to the Milestones approach [2], one of the main objectives of Milestone 1 is the identification of a suitable candidate site (or sites) before the commitment of significant additional resources in subsequent phases of the nuclear power programme. Thus, an important outcome at Milestone 1 is that one or more suitable candidate sites have been identified and therefore the nuclear power programme can go forward.

Following Phase 1 and early in Phase 2, the site selection stage provides a screening and ranking analysis so that a preferred site, or sites, can be selected and the site evaluation stage can proceed. This will require the selection of the technologies that are to be considered, or at least the selection of a range of potential technologies, so that bounding values for any technology specific factors can be considered, as discussed in Section 4.1.4.4. Much of the site evaluation work then needs to be carried out during the rest of Phase 2, so that the site(s) can be evaluated and approved before issuing the formal bid invitation specification.

In Phase 1, the NEPIO may be the only 'nuclear power' organization in existence in the country. During this phase, it is important that the arrangements for managing the quality of the work are as effective as those that will be developed by the operating organization and the regulatory body during Phase 2. Thus, the NEPIO has to establish a method for effectively managing siting activities until an

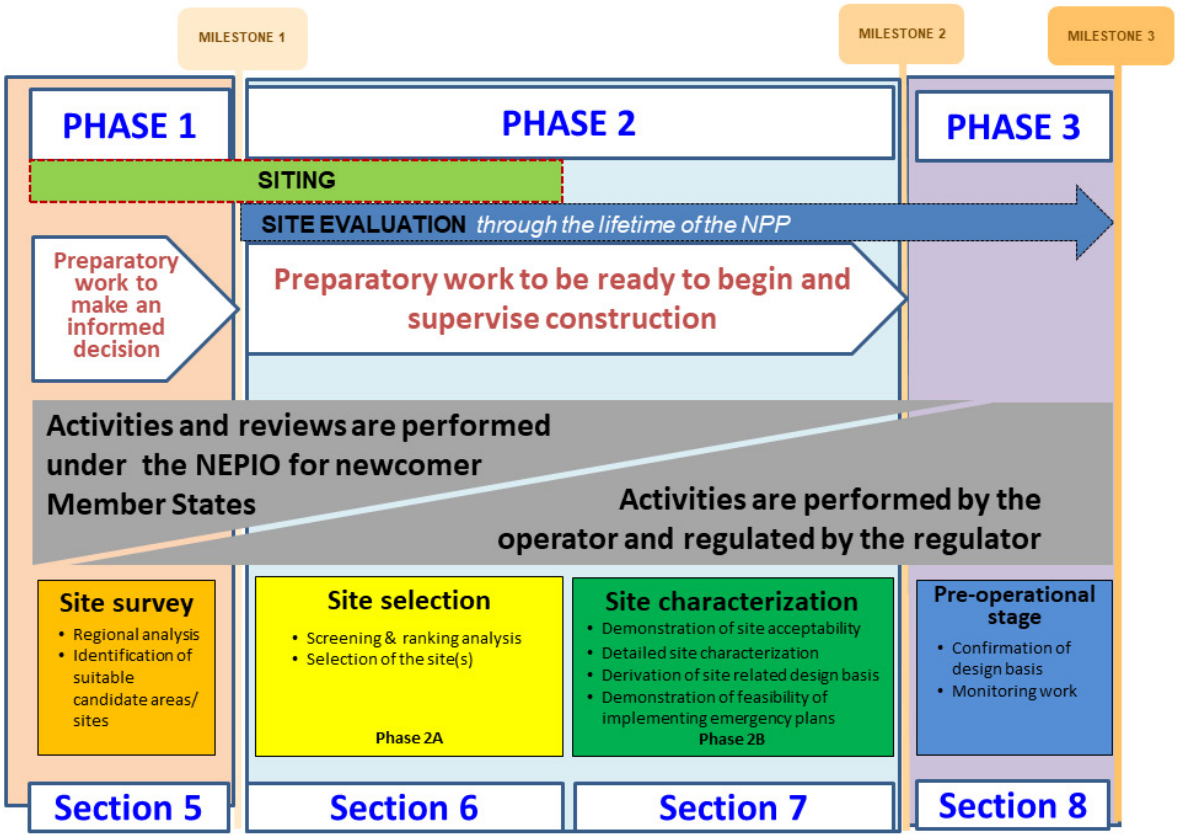

FIG. 1. Organization of the siting and site evaluation processes within the three phases of the Milestones approach and identification of relevant section within this document.

integrated management system is established, as discussed in Phase 2 of the Milestones approach, and an 'independent review committee' that can effectively carry out the roles of the regulatory body during these early siting activities is constituted. These are necessary in order to give the regulatory bodies, when constituted, the confidence that all the work to date has been properly managed and reviewed, and to avoid repetition of work and potential project delays. During Phase 2, a large amount of work related to siting and site evaluation activities is performed at a time when the organizations involved in such activities may still be evolving.

Phase 3 includes the formal confirmation of the site related design basis and the completion of all licensing and approval processes established by the nuclear regulatory body, including ongoing monitoring of the site before operation. Monitoring will continue throughout operations to confirm that the site continues to meet the design intent.

The relationship between infrastructure phases, siting activities and the organizations with responsibility for siting for embarking countries is illustrated in Fig. 1.

2.2. INTERFACES WITH INFRASTRUCTURE ISSUES

Siting and site evaluation activities will ideally not be considered as a standalone process, since they interface with several others of the 19 infrastructure issues identified in Ref. [2]. Below is a discussion of the issues with the most interaction with the site and supporting facilities infrastructure issue.

2.2.1. Management

The application of best practice principles for managing the project begins at the site survey stage and will continue throughout all subsequent stages of the siting and site evaluation processes. In effect, best practice principles are continually developed and improved through the stages of the processes, and as more information is collected and a better understanding of the site and the NPP project is gained.

In addition, siting and site evaluation activities will ideally be integrated within the overall project quality arrangements for the nuclear power programme. The IAEA publication Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2 [6], applies to all activities during the lifetime of an NPP, including siting and site evaluation. This includes quality management and quality assurance for siting and site evaluation processes. However, since the activities for siting and site evaluation are initiated long before the selection of the NPP technology and, consequently, long before the beginning of the NPP design and construction, this facet of the management system programme will ideally be established at an early time and designed to be consistent with its later application within the NPP programme, including a proper and realistic assessment of the schedule and cost estimate for conducting all stages of the siting and site evaluation processes.

More details on management considerations are given in Sections 3, 5, 6, 7 and 8, adjusting the management aspects according to the specific objectives of each of the siting and site evaluation stages.

2.2.2. Legal framework

As indicated by Ref. [2], the legal framework for nuclear power will ideally establish the responsibilities of all organizations necessary for implementing a successful nuclear power programme.

At the beginning of the site selection stage, it is advised to conduct a systematic review of the existing legal framework, both to understand the legal process affecting each of the potential areas or sites and to identify specific legal obstacles that could impair or delay decision making concerning selection of the site for an NPP. All levels of the governance system, i.e. at (i) national level, (ii) provincial or State level, (iii) county or departmental level and (iv) city/town level, may need modification to permit consideration of the location of a suitable site for an NPP. In addition, and when needed, the proper legal framework for such purposes need to be established.

2.2.3. Regulatory framework

A competent, effectively independent and well resourced nuclear regulatory body that has the strong support of the government is crucial to the long term success of a national nuclear power programme and the confidence of the public and international community. The regulatory framework will be developed during Phase 2 following plans and guidance formulated by the NEPIO at the end of Phase 1.

For countries embarking on an NPP programme for the first time, the regulatory requirements to be applied for the selection and evaluation of the site for an NPP may not yet be in place in Phase 2, when these activities are to be carried out. In this case, they have to establish credible proxy requirements to use until specific national requirements are enacted; for example, adopting the related IAEA Safety Standards complemented by the national regulations of other Member States. This will ideally be 'good enough' to get through the site evaluation process [7].

2.2.4. Electric grid system

As stated in IAEA Nuclear Energy Series No. NG-T-3.8, Electric Grid Reliability and Interface with Nuclear Power Plants [8], the safe and economic operation of an NPP requires compliance with both 'export power' and 'import power' requirements. Therefore, the siting and site evaluation processes will ideally properly include considerations in relation to the electric grid system. These aspects are discussed in greater detail in Section 4.1.4.2.

2.2.5. Human resource development

The siting and site evaluation project may require skills not existing in the Member State. The project may therefore provide a long term opportunity to locally develop a range of technical and scientific disciplines in universities, research institutes and engineering and industrial organizations, using and building upon the available local resources with the assistance of external sources with proper expertise. Sections 5 to 8 will identify appropriate disciplines and skills required during the siting and site evaluation stages.

2.2.6. Stakeholder involvement

Within the selection of an NPP site, stakeholder involvement is one of the most challenging tasks, as the acceptability of the site is associated with the acceptability of the NPP project and a wide range of issues are likely to be under scrutiny by the public and other stakeholders. Worldwide experience has shown that making the process for siting and site evaluation as transparent as possible allows the involvement of all stakeholders and helps the process to be better understood. Greater understanding of all the issues, including the need for power, the possible alternatives, the benefits and risks of nuclear power and the reasons for the selection of the preferred site, reduces resistance to the project.

From the very beginning of the siting process, good communication will ideally be deployed with all stakeholders. The critical element is that all stakeholders will ideally be involved substantively and frequently in the siting and site evaluation processes at the appropriate time. Further guidance on stakeholder involvement is included in Section 3, as well as in Sections 5 to 8.

2.2.7. Environmental protection

Environmental issues span all aspects of a nuclear power programme. The siting process includes consideration of the protection of the site's air, water, wildlife and cultural resources from the impact of the construction and operation of the NPP. They are among the factors influencing the site survey, since they fall within the category of exclusionary and discretionary attributes.

Consideration of environmental issues will ideally result in the selection of a site that is acceptable with regard to environmental and socioeconomic impacts. This will be assessed in greater detail once the specific design characteristics of the NPP have been defined, as discussed further in IAEA Nuclear Energy Series No. NG-T-3.11, Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes [9].

2.2.8. Emergency planning

Emergency planning for the protection of plant personnel, emergency workers and the public beyond the site boundary is a necessary element of overall plant safety and provides an additional level of defence in depth. Emergency preparedness and response plans will ideally consider both the NPP and the surrounding community. Demographic characteristics of the selected site or sites have to be studied as part of site evaluation and licensing. If, after thorough evaluation, it is shown that no appropriate measures can be developed to meet emergency planning requirements, the site has to be deemed unsuitable for the location of a nuclear installation of the type proposed. Emergency planning provisions, including protocols with local and national government as well as appropriate international arrangements, have to be established.

2.3. CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

Due attention will ideally be paid to the implications of climatic variability and change, particularly in relation to the possible consequences of meteorological and hydrological extreme events and rising water levels. These potential implications will ideally be considered for the planned operating lifetime of the plant, taking into account the uncertainties in the climate projections [10]. Many countries have incorporated general and/or specific requirements for considering the impact of climate change into the design, construction and operational stages of new projects.

Many countries have also committed to following the guiding principles of sustainable development in the selection, evaluation and development of a site for an NPP. In these cases, the project is guided by the ‘precautionary principle’, a concept that requires effective considerations to anticipate, prevent and correct the causes of any degradation, including environmental degradation. The lack of full scientific certainty will ideally not be used to postpone preventive measures.

2.4. USE OF PAST SITING STUDIES AND REASSESSMENT OF ORIGINALLY DETERMINED SITE CHARACTERISTICS

In some Member States, activities for the selection and/or evaluation of a site for an NPP were launched and performed many years ago, perhaps as long as several decades ago. For various reasons, some of those nuclear projects were cancelled, suspended or delayed, and no NPPs were built or operated at those sites.

Another case is when a Member State decides to build additional reactor units on an existing site with an NPP, either in operation, in permanent shutdown condition or undergoing decommissioning. In this case too, the site was originally selected and evaluated many years ago.

In both cases, the site has already been selected (i.e. no new siting process is to be carried out) and the characterization of the site has been performed based on data, information, methodologies and criteria available and valid at the time. Since that time there have been improvements in the state of international practice for data collection and analysis, and regulatory requirements and guidelines may have substantially changed. Therefore, it could be considered necessary to conduct a comprehensive assessment of past studies and to formulate and implement a work plan for completing and updating all related data and information, based on a gap analysis between existing data and the current state of the

practice. It is not to be assumed that nothing needs to be done in relation to the site, that all necessary site related data for the new project are already available and that the nuclear power project can proceed from this point. If such a wrong decision is made, critical issues that need to be addressed may arise later in the programme, generating delays and additional costs. The proper use of past studies requires that the following steps will ideally be performed:

— *Compilation of original site related data and information*. Collect and organize the original database, including information on the methodologies, criteria, models, analyses and calculations made at the time, into a geographic information system (GIS), if not already existing.
— *Evaluation of the available database/GIS.* This assessment will ideally aim to evaluate data reliability, understand the way in which uncertainties were treated in the available results and assess the continued validity with respect to present needs in terms of regulations, requirements and state-of-practice in this subject. The evaluation of previously compiled data will ideally include the ongoing viability of the field and laboratory methods and approaches used, the identification of the uncertainties or biases identified and quantified in the earlier approaches, the analysis of the completeness of the required data, the applicability of the data given the current site configuration and any changes in the relevant conditions of the site, site vicinity and region.
— *Performance of a gap analysis*. In all cases, the existing databases will require some degree of augmentation to develop the complete set of information needed in accordance with possibly new regulatory requirements and recognized international practice, particularly in relation to the requirement to conduct an adequate treatment of uncertainties in the assessment of external hazards. The areas in which augmentation is required are identified through a gap analysis.
— *Implementation of a work plan to fill the gaps*. The gap analysis will ideally lead to the formulation of a comprehensive work plan of activities, including field and laboratory work as well as studies and analyses to update and upgrade available site related data and information as it corresponds to current requirements and recognized engineering practice.

2.5. COUNTRIES EXPANDING THEIR NUCLEAR POWER PROGRAMMES

Countries expanding their nuclear power programmes face different considerations and issues from those introducing their first NPPs. In these countries, regulatory bodies are already established and the operating organization looking to operate the new NPP has been identified. Some of the main issues to be considered are the following:

— Updating the regulatory framework, as well as procedures and processes for site investigations;
— Evaluating the use of existing sites for additional NPP units;
— Re-evaluation of sites selected several years ago with new regulations.

2.6. NATIONAL RADIOACTIVE WASTE FACILITIES CLOSE TO NUCLEAR POWER SITES

While the scope of this publication is the siting of an NPP, some countries may decide to locate waste or spent fuel management facilities within the site on which the NPP is to be built. Although the criteria for siting waste processing, waste storage and spent fuel storage facilities are similar to those for an NPP, selection of a repository site will require other considerations, with special emphasis on the geological aspects of the site and long term management.

Considerations related to the siting of waste facilities are not developed in this publication but are defined in IAEA publications [11–15].

Waste predisposal facilities ought to be considered during the siting activities for a new NPP. The processes for the treatment of liquid waste, as well as storage capacity for liquids, are usually part of

NPP design. Such facilities could therefore be co-located with an NPP. Storage facilities at NPP sites are essential, at least for interim storage.

Safeguard issues related to waste storage and management have to be considered as well.

For a State embarking on nuclear power, the possibility of siting a low level waste disposal facility in the close neighbourhood of a new NPP will ideally also be considered. It will be cost effective if siting investigations for an NPP and for a near surface repository are combined. Locating a deep repository close to a new NPP might also be worth considering during the siting project, as this option helps manage siting issues for the NPP and the waste facilities simultaneously.

2.7. LESSONS FROM THE FUKUSHIMA DAIICHI ACCIDENT ASSOCIATED WITH SITING ASPECTS

The initiating events of the Fukushima Daiichi NPP accident in March 2011 in Japan were directly related to the characteristics of the site of the plant, as was demonstrated by the IAEA's Fukushima Daiichi Accident report [16]. This was the first accident at an NPP generated by an extreme external event, and the worst since the Chernobyl disaster in 1986. Reference [16] presents a detailed assessment of the causes and consequences of the accident. It was concluded that the accident was caused by the flooding originated by a huge tsunami that followed a substantial earthquake. Therefore, regarding the objectives of this publication, it is important to pay special attention to section 2.1 of Technical Volume 2 of Ref. [16], on the assessment of the plant in relation to external events. Below is a list of some of the lessons learned that are mentioned in that report and are directly related to siting and site evaluation considerations:

— Selecting adequate candidate sites in accordance with their topography, natural ground level conditions and flood levels resulting from the hydrological hazard assessment.
— Selecting an adequate final plant grade level at the selected site, preferably a level corresponding to the dry site concept. If this is not possible and a wet site is adopted, maintain flooding protection systems, components and structures during the lifetime of the installation.
— Assuming high conservatism in natural hazard assessments, considering that very low annual frequency of occurrence values ought to be adopted for design and that all involved uncertainties are duly considered.
— Applying updated methodologies according to the current state of the art and practice.
— Considering complex scenarios of extreme external events.
— Paying due attention to the consideration of all uncertainties in natural hazard assessments.
— Performing periodic safety reviews during the operational stage.
— Updating and revising applicable norms and standards.
— Implementing timely upgrading measures if, as a result of the reassessments, higher than design basis are obtained.
— Considering the case of multiple units at a site and multiple sites in the same region.
— Implementing monitoring and warning systems for detecting the occurrence and evaluating the intensity of natural hazards in order to proceed with the plant emergency response programme.

3. MANAGEMENT CONSIDERATIONS

As indicated in Ref. [4], the siting and evaluation[2] processes of a site suitable for an NPP are crucial stages in the development of a nuclear power programme. Unrealistic planning and faulty execution, lack of information and insufficient knowledge of how to identify and apply recognized good practices[3] during the site selection and evaluation processes could cause major delays later, either at the construction stage or at the operational stage of an NPP. The outcome of these processes may even affect the overall success of the nuclear power programme and could result in the site being evaluated as unacceptable when substantial resources have already been spent or committed, particularly in the analysis of safety related issues, which generally require significant resources for detailed evaluation. If the site related design parameters are changed during the operation stage, re-evaluation of — and possibly upgrades to — the NPP during its operation may consequently be necessary. These upgrades may require extended shutdown periods and cause considerable cost escalation.

Additionally, the process for selecting a site has changed substantially since the time when only economic, engineering and geopolitical considerations were the primary site attributes used for such purposes. Currently, a more comprehensive scenario of safety requirements, economic considerations, environmental impacts, social aspects, societal trend changes in the perception and acceptance of nuclear energy and the need to obtain stakeholder consensus through a broad based participatory process including local communities is to be considered, in addition to the economic, engineering and geopolitical considerations mentioned above.

An integral part of the process for selecting a site for an NPP needs to include a systematic consideration of those aspects that may cause a rejection of the selected site and, consequently, affect the whole nuclear power programme. However, a balance has to be found between the need to collect enough information to make a sound decision and the need to control costs early in the overall nuclear power programme (before the final site is selected and all approvals obtained).

It is widely recognized that when a Member State decides to begin or expand its nuclear power programme, the choice of sites is likely to be politically contentious. To support decision making with sound scientific evidence, a country embarking on a new nuclear power programme will ideally properly assess from the beginning whether a suitable site is available for such purposes, including making an environmental impact assessment (EIA).

3.1. KEY ISSUES

Management of siting and site evaluation processes requires the expertise of an experienced project team under a quality project management framework. Many of the issues will be common to other large industrial conventional projects and it is not within the scope of this publication to identify standard project management requirements. However, the activities that constitute the siting and evaluation processes also include several unusual features, as highlighted in this section. Member States ought to take these into account when appointing the project team. The project manager will ideally have broad experience in managing complex and similar programmes with diverse, sometimes conflicting data collection objectives. Specific aspects of these activities, which may vary in importance during the different stages of the siting and site evaluation processes, are listed below.

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[2] Site ‘evaluation’ is also called site ‘characterization’ in some Member States and full descriptions of all these concepts are given in subsequent sections of this publication.

[3] Such good practices are described in the IAEA Safety Standards Series.

3.1.1. Multidisciplinary project and management complexity

Siting and site evaluation are complex multidisciplinary and interdisciplinary projects that require a wide range of different types of interrelated competencies. Managing such projects can cause difficulties that would not usually be found in other types of conventional industrial projects because of the complexity of nuclear safety requirements. A number of subject matter experts from different resources or companies all need to bring together their approaches and data results into a cohesive whole, and this has to be managed effectively under a project management framework.

Decisions during the siting and evaluation processes involve complex considerations that require constant examination and management control and supervision, including technical, legal, socioeconomic and political issues.

3.1.2. Planning of interrelated activities

Planning is clearly a requirement of any project, but where there are many sites to be evaluated, considerable data to be obtained or collected (some of which will require a considerable elapsed time), many specialists to be engaged and legal and ownership issues to be addressed, the plan needs to recognize the interrelationships and timescales for these types of activities to be appropriately performed. They will probably dominate the programme, rather than issues associated with workload and resources. Incorporating a robust quality programme will also take significant planning.

3.1.3. High level scientific content

As with all aspects of a nuclear power programme, the level of scientific content of siting and site evaluation projects is very high, which requires senior scientists with their own specific knowledge and experience to work closely with other scientific and technical disciplines within the time constraints of the project. Usually, high level scientists are not permanent members of project teams, since they may be employed in universities, research institutes or as private companies or consultants. They ought to be hired on a consultancy basis for tasks with a clearly defined scope and their required contribution to the overall process will ideally be clearly understood and agreed.

3.1.4. Role of expertise and expert judgement

Siting and site evaluation activities require a significant amount of expert judgement, which has to be justified and documented appropriately for future reference. The safe operation and economic viability of the NPP are significantly influenced by such judgement, which is to be drawn from appropriate prior experience of site related studies and of design and operation aspects of NPPs. The participation of multiple experts requires the appropriate treatment of their assessments and judgements to arrive at a final integrated result of the assessments. The project team has to consider all interpretations of the informed technical community and ensure that all team experts have full access to the database developed for the project and have interactively participated in the project.

The siting and site evaluation processes are significantly strengthened by the performance of independent reviews of the results and conclusions. These ought to be performed by teams of experts who have technical experience at least as strong as the project team and who are independent of those performing the activities. The types of independent review activities will ideally be commensurate with the importance of the data in the decision making (e.g. the safety importance of the data). Many Member States have specific quality standards to guide project teams in the application of review activities for specific situations, but Member States lacking such programmes ought to be guided by external quality standards. Specific types of review activities include the following:

— Participatory independent peer review during work execution;

— Expert panels;
— Independent third party review by contract;
— Process audits by a third party accredited auditing company.

The independent peer review activities will ideally be conducted at all stages of the siting and site evaluation processes, starting with a low level review during the siting stage and progressing to a more detailed review during the site evaluation process. The findings and guidance from these reviews ought to be duly addressed.

3.1.5. Team building and communication

The project team will consist of many specialists and it will take special efforts from the project manager to ensure that all issues are treated equally and that good communications are maintained. Also, the organization involved will change: the role of the NEPIO in Phase 1 will eventually be combined with the operating organization, the regulatory body and the government sponsoring department.

3.1.6. Treatment of uncertainties

The identification and characterization of the external hazards that may affect the safety of the NPP will play a significant role in its design and it is one of the essential outcomes of the site evaluation process. The uncertainties involved need to be well characterized and properly considered in the derivation of the site related design basis.

3.1.7. Data acquisition and long term data management

Siting and site evaluation activities require a significant amount of existing data to be reviewed to determine whether they meet quality objectives. New data will also be acquired. High quality data will support the reduction of uncertainties, particularly in the case of external hazards. Data will ideally be acquired in sufficient quantity and quality to address open questions and support the assessment of the hazard or question to be resolved. Data are to be defined, assessed and interpreted by highly qualified teams. Data ought to be supplemented by expert judgement, but such expert judgement does not replace the need for valid data.

As the siting and site evaluation processes are conducted as a number of sequential stages, it is essential that data from each stage be appropriately collected and available to feed into the studies at subsequent stages. This imposes a significant requirement for proper and secured data management originating from the beginning, recognizing that the operating company may not initially even be in place. In the earliest stages, when several potential sites are being investigated by many different specialists, assembling and maintaining a database of information with appropriate justifications is a challenging task. Collection of the data required for the selection and evaluation of a site may occur with significant time lapses between the different stages of the siting and site evaluation processes, as discussed in Section 2.4.

The proper data management of a siting and site evaluation project requires both a robust document management system and the use of a GIS based on a hierarchical approach and covering all involved issues. The document management system is used for tracking documents, commenting on them, and managing the review process and the approval documentation. Within the GIS, a large volume of multisource data, including those describing geographical, topographical, geological, geophysical, geotechnical, hydrogeological, meteorological, hydrological, oceanographical (for coastal sites) and environmental characteristics are pre-processed, stored and analysed in a geospatial database. Additionally, data and information are collected that do not lend themselves to a GIS based system; these data have to also be appropriately stored and available for use. A GIS implemented from the beginning of the siting and evaluation project will be transferred later to the operating organization, which will maintain and update it

during the operational stage. Three categories of tools can be applied for data management, including data collection, processing, analysis and maintenance:

— Tools suggested or required by regulatory bodies (whether nuclear safety or environmental protection).
— Commercially developed tools by specialized (consulting) enterprises. The public domain also holds GIS tools that can be used in the siting process for data analysis, though specialized GIS tools are typically commercially available.
— Internally developed tools, especially for siting purposes. This can be done by specialists inside the siting team or in cooperation with academic and/or other research institutions.

3.1.8. High project cost and funding

The costs of siting activities are significant and the Member State needs to be clear how they are being funded. If activities start under a NEPIO, they are likely to be government funded. By the time site assessment occurs, it is likely that the operating organization is controlling the activities, but it will need to be clear whether they are providing the upfront funding and how the risks of project delays or cancellation are being accounted for.

3.1.9. Broad legal and regulatory impact, framework and licensing process

The legal issues related to siting are very broad and can range from protection of cultural heritage or environmental aspects to local codes and standards. The site related activities will ideally be addressed within the provisions of the national legislation and regulatory framework, which ought to clearly define the responsibilities of the nuclear regulator regarding the siting and site evaluation processes and the main requirements and criteria to be fulfilled. This includes the international commitments of the Member State (e.g. nuclear safety, nuclear security and environmental conventions).

Siting activities will ideally be addressed by the national nuclear legislation, in particular within the provisions on the authorization process for NPPs. In any case, the law ought to clearly define the regulatory responsibilities with regard to siting activities and the main requirements.

It is essential that arrangements are put in place to manage the regulatory interface and to maintain an awareness of all communications between project experts and regulatory experts. In addition to the nuclear regulator, there will probably be involvement of different regulatory authorities and institutions for the protection of the environment, wildlife, and cultural and historical heritage. More information on the regulatory aspects for siting can be found in Ref. [7].

As the siting process involves a significant number of safety related issues, this work is performed within the nuclear regulatory framework. This will ideally be consistent with the IAEA Safety Guides on siting, including Refs [4], [17–19], among others. Depending on the country's legal system, approvals may also be needed from other government organizations/regulators. It will be necessary to coordinate between the nuclear regulatory body and other local and regional organizations and governmental agencies that have related roles. It is suggested that arrangements for communication between organizations and with other stakeholders are clearly set down and agreed.

As siting activities may have started before the regulatory body has been formed, the independent review committee, part of the NEPIO, ought to fulfil the regulatory role during this time.

It is crucial to make available from the beginning of the site survey stage the general criteria that the regulatory authority will request in relation to the licensing process for the NPP. In this regard, guidance is provided in IAEA Safety Standards Series No. SSG-12, Licensing Process for Nuclear Installations [20]. Essential questions to be addressed are as follows:

— Is the siting process to be reviewed by the regulatory authority?
— Is the selected site to be reviewed as part of a specific licensing process by the regulatory authority?

— If so, when and how is the site related design basis required to be reviewed? Is this before they can be provided to the vendors?

This is a critical aspect of defining and developing the milestone schedule of the project, the sequence of activities, the review and revision process and the involvement of stakeholders.

3.1.10. Land purchase difficulties

The procurement of land (including purchase, lease, rent or granting use, as practised in some Member States) for an NPP is a complex task, since it involves multiple stakeholders, including government, private entities and the local population. It also requires a long strategic vision in relation to potential needs for future expansion, such as for additional electricity production units and other facilities (e.g. waste treatment). Land use requirements to satisfy the needs of the logistics of construction with all supporting facilities and utilities, as well as operational needs, have to be accurately estimated. The site itself has to be under the full control of the owner/operator, regardless of the type of legal format adopted for its procurement, since the management has to be able to directly initiate emergency response actions. Additional land use requirements, such as to accommodate the construction of suitable high voltage transmission lines or heavy haul roads, have to also be considered.

3.1.11. Education and training

The siting project may well bring requirements for skills not previously developed in the country. The project may therefore provide an opportunity to develop a range of technical disciplines in universities or industry. The project manager may also need to include provision for staff to shadow experts and learn new skills.

3.2. ASSOCIATED RISKS

In addition to the risks identified when implementing a nuclear power programme, specific risks associated with the siting and site evaluation processes will ideally be evaluated from the beginning as part of the project management plan, since they can significantly affect the costs and schedule of the overall project. The following is a list of examples of the specific risks associated with the site selection and evaluation processes (omitting most risks associated with use of data collected or decisions made):

— Difficulty in obtaining access, permits and authorizations to the areas required for executing field work (e.g. geological mapping, geomorphological studies, and geophysical and geotechnical investigations for both onshore and offshore regions). The access permits and authorizations may need to be obtained from the government (including perhaps the military), other countries if cross border data are necessary, public and/or private organizations and institutions, companies, and/or owners with potential conflicting interests in relation to the NPP project.
— No availability of applicable regulatory requirements for demonstrating site suitability and, therefore, no completion of the site evaluation process.
— Changes in the regulatory and legal requirements during the long period required for executing the siting and site evaluation processes.
— Legal challenge or judicial review against the decision makers in the Member State (e.g. the body responsible for environmental assessments and/or the nuclear regulator) in the case of poorly executed siting and site evaluation processes and inadequate independent review, resulting in legal conclusions that the decision makers did not exercise enough due diligence.
— Poor project management, including scheduling and resource management, poor data management, poor information management or poor team communications.

— Investing significant expense and time in detailed site characterization before all necessary approvals to construct the NPP have been obtained.
— Difficulties in assembling the required team of experts for the site selection team, including consideration of communication difficulties due to issues such as different languages, cultures and work styles.
— Difficulty in understanding all the components of the contracting scheme (either one general consultant/contractor or individual speciality consultants/contractors), determination of whether the selection process is competitive or non-competitive, evaluation of the bidders and selection of the consultants/contractors/subcontractors.
— Disclosure of a cultural or archaeological resource during the field investigations, causing significant delays in the work schedule or the need to move to a new location.
— Weather conditions during field investigations (e.g. strong winds and surges for coastal sites that would preclude crane operations; heavy rains, snow and snow melting preventing access to site).
— Delays that result in seasonal impacts on data collection, affecting schedule and cost.
— No proper consideration of the time and formalities (e.g. shipping and custom clearance) required for the transportation of samples for laboratory testing outside the country or importation of appropriate equipment for site characterization activities.
— Uncertainties regarding the results from geological, geophysical and geotechnical investigations and from the assessments of natural hazards, which may result in the need to conduct additional studies (e.g. discovery of previously unknown active geological faults or unexpected subsurface field conditions that may render inappropriate the planned exploration methods).
— Hazardous waste contamination encountered on the site and in its vicinity, with an impact that depends on the extent of the condition and the required remediation.
— Use of the intended land by third parties during the time between site selection and land acquisition.
— Protection issues related to the integrity of monitoring stations (e.g. seismological, geodetic, meteorological, oceanographic, hydrogeological wells) by vandalization, requiring repair and/or replacement in fixed installations and sensor equipment.

3.3. MANAGEMENT AND QUALITY CONSIDERATIONS

Data collected and/or assessed in the earliest stages will affect decisions throughout the entire life cycle of the NPP. Low quality data or data that are not properly handled may have significant cost and schedule impacts. Therefore, to minimize overall project risk, even in the earlier stages attention has to be paid to the project structure, the qualifications and experience of those executing the work, the quality of the data and the process for decision making. Together, this amounts to a first line management system. It is recognized that the management system will expand in complexity as the work progresses through the various stages and at some point will transition to the operating organization for a complete integrated management and quality system to guide the entire NPP project. In that regard, IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [6] applies to all activities during the lifetime of an NPP, including siting and site evaluation. Note that an integrated management system includes consideration of worker health and safety. This is particularly important during all aspects of field work, but is not considered further in this publication.

As a minimum, a comprehensive project plan ought to be prepared that includes a detailed description and plan of the different interrelated activities. An organizational hierarchical structure for carrying out the tasks, with a clear definition of the responsibilities, duties and objectives of each of the levels, will ideally be developed, including, to some extent, the institutional stakeholders (regulators, governmental institutions, etc.).

Data and documents (e.g. facts and statistics collected either for reference or analysis, documents such as specifications, drawings, calculations, analysis, judgements, reviews and reports) ought to be systematically stored in accordance with approved quality management practices and written processes for record keeping.

3.4. STAKEHOLDER INVOLVEMENT

The political, social and economic consequences arising from the use of nuclear energy have generated considerable public concern and debate. Mistakes and shortfalls in interaction with stakeholders can thwart excellent project management and can lead to an unfavourable public opinion that creates an image of the operating organization, the authorities and the project itself as something hostile.

In general, the issues of siting and site evaluation are similar to any major industrial project. There will be those keen to share in the economic benefit, those supportive of the project so long as it is 'somewhere else' and various groups that are against NPPs. What is clear is that stakeholder involvement is especially important in a siting project.

In fact, a stakeholder involvement programme is a necessary and desirable part of the siting process, in order to consult with and include interested and affected individuals in the selection and decision process. It is now impossible to implement nuclear projects without a considerable amount of active consent from stakeholders. Authorities and operating organizations also face extremely high scrutiny from stakeholders.

When done well, stakeholder participation improves the quality and legitimacy of a decision and builds the capacity of all involved to engage in the process. It can enhance trust and understanding among parties. Stakeholder participation will ideally be fully incorporated into the decision making processes and ought to be recognized by operating organizations, authorities and other stakeholders as a requisite of effective action, not merely a formal procedural requirement. Effective participation needs to be a dynamic two way process. Simply dictating to the public or informing the public of decisions cannot be considered stakeholder participation.

The critical element is that all stakeholders will ideally be involved early, substantively and frequently in the site selection process. Engagement of all stakeholders requires the following:

— A clarity of purpose;
— A commitment to use the process to inform project actions;
— Adequate funding and staff;
— Appropriate timing in relation to decisions;
— Full government support (providing legitimacy to the process).

Much has been written on the topic of stakeholder involvement, and the IAEA has published a publication entitled Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [21]. Those involved in the process directly ought to refer to the above mentioned publication, as well as the International Nuclear Safety Advisory Group (INSAG) publication entitled Stakeholder Involvement in Nuclear Issues (INSAG Series No. 20) [22]. Sections 5–8 highlight some of the key issues appropriate to the different stages of siting and site evaluation.

3.5. ORGANIZATION AND ROLES

Attention ought to be paid to the need for activities related to siting and site evaluation to be conducted by organizations and individuals who are well aware of and trained in applying quality standards and safety culture practice. In safety culture practice, safety issues receive the care, dedication and competence warranted by their significance, as documented in INSAG Series No. 4, Safety Culture [23]; IAEA Safety Reports Series No. 74, Culture in Pre-operational Phases of Nuclear Power Plant Projects [24] and related publications.

3.5.1. Organization

The siting team will ideally report to a senior director of the nuclear power programme and ought to be given appropriate time and resources (financial, human and logistic) to carry out the necessary

investigations. The siting team has overall responsibility for implementing siting activities for the period and purpose defined in its project terms of reference. This could be limited to the site selection activities, or it could also include site assessment and acquiring a site permit.

The exact organizational chart will depend on how the siting project fits in with the overall project, particularly whether the project is to implement a new nuclear programme or add an NPP on an existing site. In some cases, the group is a virtual team under matrix management. An example of a possible structure is shown in Fig. 2.

A siting team composed of 10 to 15 professionals is usually considered adequate, but additional consulting services are likely to be required from time to time. The number of professionals also depends on the safety specialists to be involved, and this aspect is further developed in the IAEA Safety Guides, including Refs [4], [17–19], among others. The siting team will include experts familiar with each principal discipline involved (Section 3.6), together with those able to collect and process local information. It will also include those with expertise in decision making through ranking and other similar techniques. Some experts will have knowledge in more than one discipline and may undertake the 'intelligent customer' role (see next section) when purchasing specialist services from consultants. For disciplines related to more important site characteristics, a full time team member may be selected.

It is important that all the required expertise is included from the beginning, as a complete understanding of the commitments and requirements can only be achieved by establishing a fully competent siting team. This team may evolve and belong to different organizations during the implementation of the siting activities.

3.5.2. The intelligent customer role

The siting team will need to procure expert services across a range of subject areas. Some of these will be external specialist contractors, such as experts in rock and soil structure characterization. However, to perform the role of an intelligent customer, it is important that the in house siting team has enough expertise to know what is required, what risks are associated with unknown or developing information and how the collected information is used for decision making.

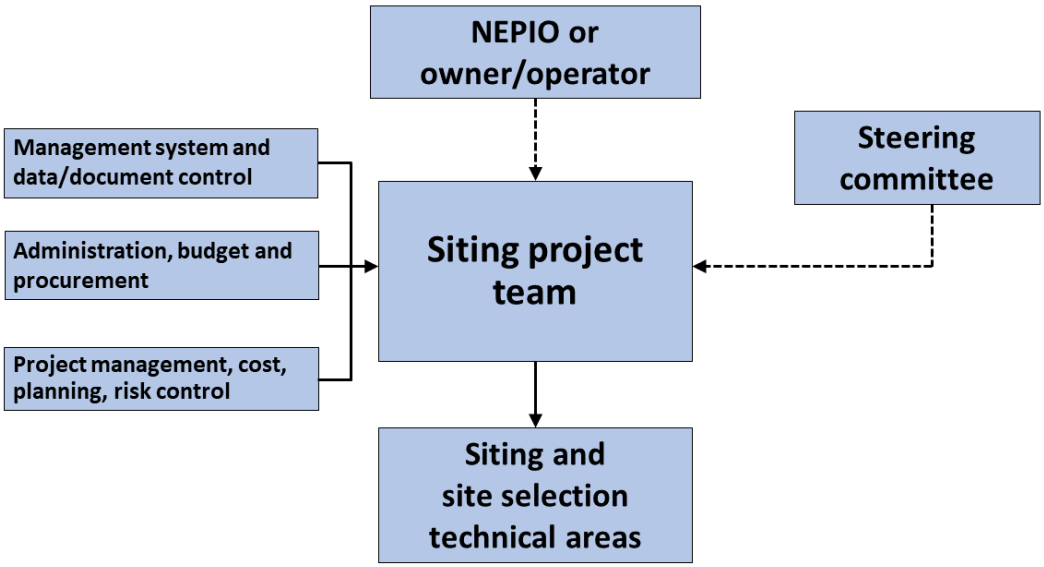

FIG. 2. Example of siting team/group organization.

3.5.3. Technical review group

The technical review group is an essential element of ensuring the quality of siting assessments and decisions. As noted earlier, siting decisions require input from many specialized areas, and it is important that the project manager has sound advice from those able to provide independent reviews of key documents and conclusions, to increase the ability of the project manager to make sound judgements and perform consistent interpretations of key technical and specialized issues. The members will ideally be independent of those carrying out the work, and ought to report directly to the project manager.

3.6. EXPERTISE REQUIRED AND RELATED ACTIVITIES

3.6.1. Types of expertise required and functions

The skills and expertise of the siting management team will be diverse and will reflect the safety culture and quality management of the organization, which includes processes for conducting independent reviews.

A strong siting team is composed of three key types of staff who work in concert:

— *Management*: With the ability to establish the processes, capacities and capabilities required to complete siting and site evaluation activities to the desired degree of quality. There ought to be communication and coordination with the technology selection team as well.
— *Specialists*: With backgrounds and expertise in one or more specific technical and scientific disciplines, including in developing a GIS database. The selection of the team specialists and the constitution of the team will reflect the particular needs of the stage under execution.
— *Generalists*: With broad skills and experience across multiple technical disciplines, including experience in multidisciplinary technical integration and team management. They will have the ability to work with others on the team on cross-cutting issues, including data collection and analysis, as well as the integration of a wide range of specialists' results into a cohesive site evaluation case. A generalist function requires significant experience in siting/site characterization activities.

3.6.1.1. Key functions of management team

The management team is ultimately accountable for the quality and timeliness of the siting and site evaluation activities in accordance with the project objectives. Their key function is to establish the vision, culture, capacity and capabilities to execute these activities, and this is generally accomplished through a project management framework in association with recognized quality assurance standards. The result is a set of credible quality-assured siting and site evaluation records that form the basis for site suitability. Management functions are delegated to the siting and site evaluation team through the management system, which will ideally include competencies that can ensure the following:

— Establishment of appropriate management system procedures to control the scope, depth and quality of assessments and engineering activities performed at the different stages of the process;
— Organization, planning, work control, personnel qualification and training, and activity verification and documentation, to ensure that the required quality of siting and site evaluation work is achieved;
— Maintenance of records of all work carried out in the process, including the results of the field work, laboratory tests, and geotechnical analyses and evaluations.

The management team has to have overall situational awareness of all activities in the NPP project and be able to direct siting project staff as needed. One or more of the senior management staff ought to have direct siting and site evaluation experience, as well as awareness of available operating

experience and regulatory requirements to inform decision making. Additionally, one or more of the senior management staff will ideally ideally have practical power plant experience in one or more of construction, commissioning, operations and maintenance, and application of regulatory requirements to be able to inform siting and site evaluation decision making.

The project manager has a critical role in the success of the overall programme. In addition to the relevant professional and technical competencies, the project manager ought to have:

— Known leadership qualities;
— Effective communication skills;
— A clear vision of the objectives of the mission;
— Good, effective team building and management skills;
— A clear understanding of the review process and what needs to be done;
— The ability to work under pressure.

The project manager has the responsibility to look for the best technical coordination among other tasks or projects completed or planned that are relevant to the siting and site evaluation programmes. The project manager is responsible for communicating with team members on a regular basis to ensure they are adequately prepared and informed, including providing relevant information obtained by other experts on the team; for maintaining the schedule and budget; and for communicating with senior management, particularly with respect to key findings that may have an impact on the current understanding of the siting and site evaluation processes.

3.6.1.2. Key functions of generalist staff

A generalist function may either be a managerial role or a specific staff function, such as project manager, but generally requires significant experience in team facilitation and siting/site characterization activities. A generalist may not have depth of experience in specific disciplines, but may have significant and broad experience across many disciplines that enables them to:

— Maintain a high quality site evaluation programme that meets Member State as well as regulatory requirements.
— Drive consistent specialist technical assessment using documented processes and tools.
— Maintain team awareness of:
    - The objectives of the site characterization activities and the need to balance specific areas of discipline in overall decision making;
    - The key project steps and how they will be conducted;
    - Quality assurance expectations to be applied to specific activities;
    - How specific specialist expertise will be integrated into the overall site suitability case;
    - Use of available operating experience from other projects.
— Integrate a wide range of specialists' results into a cohesive site evaluation case.
— Act both as a challenge function and facilitate the resolution of differences of technical opinions between competing specialist conclusions.

For a site characterization project, several generalists communicating with one another but reporting to the management team may be needed across multiple thematic areas, such as, but not limited to:

— Collection and analysis of site data;
— Stakeholder engagement, e.g. communication regarding the site evaluation programme and management of engagement activities with specialists;
— Collection and evaluation of data about the technologies being considered for the site;
— Conduct of manufacturing and construction, e.g. characterization of activities and effects;

— Conduct of operation and maintenance, e.g. characterization of activities and effects;
— Conduct of decommissioning, e.g. characterization of activities and effects, as well as prediction of costs for preliminary decommissioning plan (generally needed for construction).

3.6.1.3. Key functions of specialist staff

As in any team, individual members will have expertise in a specific discipline or in multiple disciplines, and the selection of the team members and the constitution of the team will reflect the particular needs of the stage under execution. For example, the team will ideally include expertise on thermodynamics to understand the needs of the cold source or heat sink, and on electric grid connections and capabilities to determine if the significant electric power capacity of an NPP can be accommodated by the existing grid, etc.

3.6.2. Disciplines required for the project

The siting team has to include disciplines that will be available according to the needs of the specific activities of each stage. In principle, the division between technical disciplines specific to site related aspects and other disciplines can be indicated as follows:

Technical disciplines

— Geography and topography;
— Geology and tectonics;
— Seismology;
— External hazards specialists;
— Volcanology;
— Geotechnics, earthworks and foundation engineering;
— Oceanography;
— Meteorology;
— Hydrology and hydrogeology;
— Human activities and external human-induced event assessment;
— Land and water use;
— Socioeconomics;
— Demography and population distribution;
— Analysis of feasibility of emergency planning;
— Environmental assessment, monitoring and EIA (radiological and non-radiological);
— Archaeology and historical monuments;
— Grid infrastructure.

Other supporting disciplines

— Nuclear technology;
— Nuclear safety and nuclear security;
— Human resources, training and capacity building;
— Stakeholder involvement;
— Community development/sociology;
— Physical layout planners;
— Procurement of goods and services for executing the project;
— Legal;
— Project management;
— Quality management;

— GIS specialists;
— Permitting and licensing in conventional and nuclear facilities;
— Sustainability.

3.6.3. Activities

Figure 3 shows a scheme of the grouping of disciplines or areas of studies, the assessments to be performed and the deliverables to be provided for the first three of the activities indicated above, leading to implementation of site preparation. This figure also demonstrates that development of the EIA is a separate process that proceeds in parallel and interfaces closely with the siting and site evaluation programmes, particularly with respect to data collection and evaluation.

The types of activities to be carried out during the siting and site evaluation processes may be divided into four main types, as indicated below:

— Type 1: Data collection (illustrated by row 1 of Fig. 3):
  - Gathering of studies and existing data;
  - Field work, field reconnaissance, field observations and field explorations;
  - Field testing, measurement and monitoring;
  - Laboratory testing;
  - Preparation of specific topical reports for each of the areas or disciplines.
— Type 2: Data analysis, assessments and reporting (illustrated by row 2 of Fig. 3):
  - Data processing;
  - Data interpretation and analysis;
  - Data management;
  - Preparation of reports for the specific assessments (specific hazard and feasibility assessment documents).
— Type 3: Preparation and issuance of final deliverables (illustrated by row 3 of Fig. 3):
  - Preparation, review and approval of the topical reports for each of the areas or disciplines and the site evaluation report (SER);
  - Preparation, review and approval of all documents related to licensing of the site;
  - Making operative the site data information system.
— Type 4: Design, procurement and construction for site preparation (not shown in Fig. 3):
  - Construction and installation of necessary infrastructures (roads, water main and drainage, power, sewage installation, communication lines, lighting, etc.);
  - Installation of housing and administrative facilities;
  - Construction and installation of the physical protection system;
  - Performance of ground levelling;
  - Making operative the monitoring systems and networks of the site.

All activities are ultimately focused on providing enough information for the project to be fully licensed. Guidance is provided in IAEA Safety Standards Series No. SSG-12, Licensing Process for Nuclear Installations [20]. Whether site approval is combined with construction approval or obtained first, if a site is not licensable due to an error in the siting process, including non-conformance with regulatory requirements, the cost to the project will have been enormous.

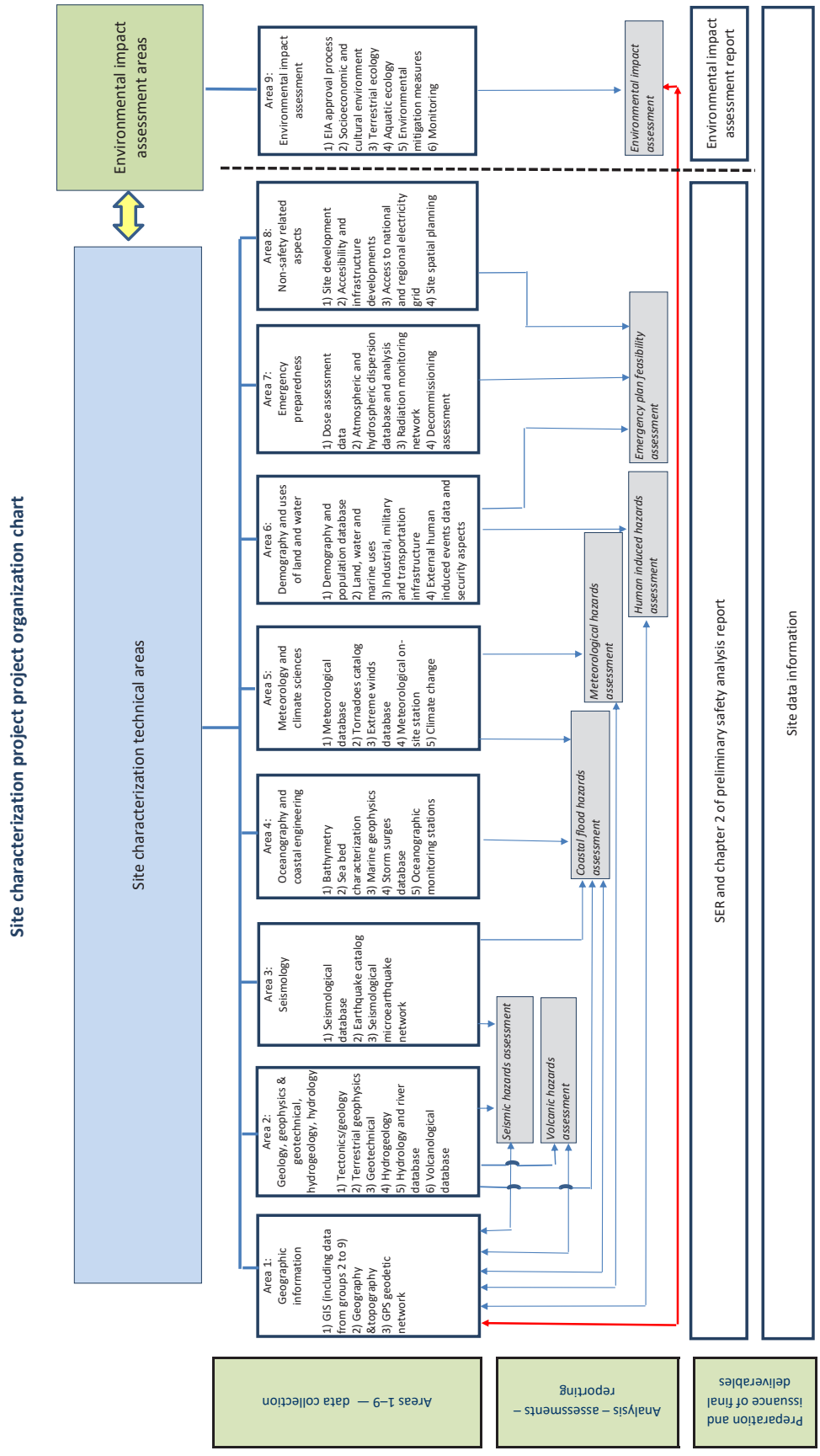

FIG. 3. Relationship between data collection, analysis, assessment and reporting, and final deliverables within the site evaluation stage.

4. SITING AND SITE EVALUATION ATTRIBUTES, CRITERIA AND PROCESSES

In this publication an NPP is considered to consist of one or more nuclear power reactor units located in a given site, whether fully separated from one another or sharing some common structures, systems and components. These units may exist under a single licence or multiple licences as established by the regulatory authority.

The significant differences of an NPP compared with a conventional power plant, with respect to site specific aspects, relate to the need to maintain some of the cooling function of the reactor core safely and reliably during an extended period after shutdown, and the strong emphasis on consideration of extreme hazardous events (i.e. events of very low annual frequency of occurrence and high intensity), through the assessment of all potential credible types of sources, whether from internal, natural or human-induced (external) causes.

The term 'site area' is defined as a geographical area that contains an authorized facility, activity or source, within which the management of the authorized facility or authorized activity or first responders may directly initiate emergency response actions. This is typically the area within the perimeter fence or other designated property marker. This publication refers to the site as housing an NPP constituted by one or several reactor units and all associated facilities. For the purposes of this publication, the term 'site' is considered to be the same as 'site area'.

In addition to a proper space to accommodate the layout for one or more power reactor units to be built in one or more phases, the siting and site evaluation processes ought to consider that an NPP requires other supporting facilities as follows:

— Availability of land for the proposed number of power reactor units, together with auxiliary facilities. This will ideally include the area that will be required temporarily during the construction of the plant units, with enough space for accommodation, canteens, training, first aid, etc., for the substantial temporary labour force. Additional land ought to be identified and earmarked for an eventual exclusion area, to prevent population settlement or industrialization during the consideration of the potential site.
— Availability of land for nuclear waste or spent fuel management facilities, as discussed in Section 2.6.
— Considerations related to the siting of nuclear waste facilities are not developed in this publication, but they are presented in Refs [11–15].

During the siting process, the areas or sites are evaluated through the use of a specific set of attributes, which are defined in quantitative terms by assigning quantitative criteria to each. Although a great number of attributes may potentially be used to describe a site or area, attributes used at this time are only those for which criteria can be developed to discriminate among the areas or sites. Those attributes for which there is no useful information, or that are generally similar across the entire area to be evaluated, are not used for the siting process as they will not help to show differences between sites. When a site is finally selected for detailed site evaluation, additional specific information on all relevant attributes will be collected.

The selection of a suitable site for an NPP involves considering a large number of attributes in order to reach an optimal decision. In general, decision making problems with multiple criteria for the screening, comparing and ranking of different options involve a set of alternatives that may be in conflict with each other; in other words, a site may be optimal for some criteria but not for others, forcing a decision among sites of which none are completely optimal.

If the criteria applied are too general, they will not narrow down the areas of interest sufficiently. Equally, if the criteria are too limiting, the process may eliminate suitable sites in the early stages of the siting process. For example, the adopted criteria may be based on a certain technology with a defined

seismic capability (i.e. the ability of the technology to withstand the calculated maximum earthquake effect, as discussed in Ref. [19]) and using sea water cooling; but it may then be found that there are no suitable sites complying with both of those conditions. In that case, it will be necessary to repeat the evaluation, changing the criteria to either allow the use of cooling towers or accept a greater seismic capability (recognizing the additional costs). As another example, it may be decided during the course of the process to separate higher level attributes into smaller increments and apply separate criteria to each of them, facilitating a more detailed analysis of those attributes that are particularly important for decision making.

In any case, the criteria have to not be out of conformance with the national site related regulations and IAEA safety requirements. Therefore, modifications to the exclusionary or discretionary attributes and criteria are either to select new attributes not formerly seen to be necessary for decision making, to change the definitions of the criteria to reduce the size of the error bands surrounding the initially selected criteria values (thus introducing additional but acceptable uncertainty) or to collect further site specific information to better define those attributes at the site being evaluated. Therefore, it is important to benchmark the selected attributes so that the criteria applied are neither too general nor too limiting, while recognizing that the results may still necessitate reviewing and modifying the defined criteria.

4.1. ATTRIBUTES AND CRITERIA

The selection and evaluation of a suitable site for an NPP requires the adoption and application of a clear set of screening attributes (exclusionary and discretionary, the latter being used for comparison and ranking), with their quantitative descriptive criteria covering the general aspects of a site as listed below. An ‘attribute’ is defined as the characteristic requiring investigation, and the ‘criteria’ are quantitative descriptions of the characteristics (for example, the characteristic of ‘distance to source of cooling water’ is an attribute of the site, and ‘*x* km’ is the quantitative criterion).

Attributes are generally grouped into two types, usually termed exclusionary and discretionary. Attributes related to safety are shown in the table included in Annex I of Ref. [4]. Attributes related to non-safety issues are discussed further here. Sections 3 and 4 provide further information on defining and applying attributes and criteria during the siting process.

4.1.1. Exclusionary attributes and criteria

Exclusionary attributes represent requirements that, if not satisfied by site conditions, would preclude the construction of the NPP at that location. They are used to discard regions/areas/sites that are unacceptable because there are no available, practicable engineering solutions, site protection measures or administrative measures, or because the solutions are excessively cost prohibitive. Exclusionary attributes and their accompanying quantitative criteria will ideally be established at the very beginning of the siting process to clearly set up the basis for eliminating areas on considerations of ‘go/no go’ situations. Exclusionary attributes and the corresponding criteria ought to be based on regulatory requirements, plant design requirements and/or local conditions. Since in Phases 1 and 2 of the Milestones approach the design of the plant and its safety features are not yet known, a typical approach is to propose a spectrum of NPP design scenarios that may be used to obtain generic and bounding values to support the development of key attributes and criteria. The exclusionary attributes and corresponding criteria apply mainly during the site survey stage and will ideally be defined, established and agreed among all parties involved at the beginning of Phase 1.

The exclusionary attributes and their criteria ought to be defined carefully to avoid design aspects, specific hazards or the likelihood of occurrence of a hazard becoming the sole basis upon which a site selection rejection decision is based, since too much reliance on one or a few attributes may lead to the discarding of a site with otherwise favourable qualities for safety as a whole. National regulations, if developed, or IAEA safety requirements usually establish the exclusion distance (also called the screening

distance value) or the probability level (also called the screening probability level) to be considered as the criteria for each of these attributes. Examples of exclusionary attributes are as follows:

— Inadequate or insufficient cooling water;
— Volcanic phenomena, as indicated in table 1 of Ref. [25];
— Geological and geotechnical hazards, as indicated in Ref. [26];
— Population density;
— Archaeological, historical heritage and cultural sites;
— Environmentally protected areas or species, national parks or areas defined by international conventions if applicable in the Member State;
— Non-feasibility of implementing emergency plans.

4.1.2. Discretionary attributes and criteria

Discretionary attributes are associated with issues, events, phenomena, hazards and design aspects for which engineering solutions are available. Implementation of the necessary solution is a matter of cost, construction and operational possibilities, and timing and schedule. They are not 'go/no go' attributes but are utilized to identify broad areas with more favourable than unfavourable conditions, frequently expressed in terms of overall cost to the project. For example, a higher water table increases construction costs and flooding risks, while ease of access to cooling water reduces operating costs.

Discretionary attributes and their associated quantitative criteria will ideally also be established at the beginning of the siting process, according to the specific policies, regulations, practices and legal framework in and by each Member State. These ought to be agreed among all parties involved with respect to identifying the most significant attributes to consider and the relative weight given to each of them. During the site selection stage (stage 2 of the siting process), the discretionary attributes and criteria will be used for comparison and ranking of the investigated regions or sites that have passed the exclusionary screening in the site survey stage.

The discretionary attributes and corresponding criteria are intended to fulfil three objectives: (i) to reduce the number of areas under consideration to a manageable number; (ii) conversely, to increase the number of candidate areas if their number is too small to cover the range of potential site locations or if there are no sites identified; and (iii) to rank and compare sites on the basis of the weight assigned to the attributes. In the first and second cases, the exclusionary criteria may first need to be revisited and revised, accordingly, in order to allow some regions or areas that were excluded in a first screening to be considered as potential candidate areas, with proper consideration of the unfavourable conditions that led to that first exclusion.

Discretionary criteria include safety and nuclear security attributes for which the site is beyond the exclusionary distance, but for which their proximity may yet have an impact on the cost or practical feasibility of developing the NPP project.

Attributes, whether exclusionary or discretionary, can be grouped into four types of factors, as described below.

4.1.3. Health, safety and nuclear security factors

The relevant health, safety and nuclear security factors are covered in a separate publication that is part of the IAEA Safety Standards Series No. SSG-35, Site Survey and Site Selection for Nuclear Installations [4]. To provide a complete and balanced view of all the factors that need to be considered, this publication provides a list of the health, safety and nuclear security factors below, but it does not develop them in detail.

4.1.3.1. Magnitude and frequency of natural external events

These include (though there may be others):

— Seismic hazards, e.g. active faults, surface faulting, vibratory ground motion due to earthquakes.
— Volcanic hazards.
— Geotechnical hazards. e.g. slope instability, soil liquefaction, landslides, rock fall, avalanche, permafrost, erosion processes, subsidence, uplift, collapse.
— Flooding:
  - Coastal flooding or low water intake level, e.g. wave action, storm surges, seiches, tsunamis;
  - River flooding, e.g. overtopping due to dam breaks, or low water levels due to drought or low river water levels.
— Blockage of intake channels (due to biofouling, ice, debris, ship collisions, oil spills or fires).
— Extreme meteorological events, e.g. hurricanes, tornadoes, tropical storms, straight-line winds, ice, snow, hail, lightning, drought, extreme precipitation, extreme temperatures, sand and dust storms, etc.
— Forest fires (whether of natural or human origin).
— Credible combinations of events.

4.1.3.2. Human induced external events

These include (though there may be others):

— Aircraft crashes, including impact, fire and vibration type loads;
— Explosions from transport accidents (including drifting smoke) involving e.g. trucks, trains, tankers, gas carriers;
— Explosions from fixed installations, e.g. other nuclear installations, military ranges and arsenals, oil and gas operations or storage facilities, gas pipelines, chemical plants, installations processing or using hazardous materials or waste, etc.;
— Toxic liquid/gaseous releases, radiological releases;
— Ship collisions or shipwrecks;
— Electromagnetic interference.

4.1.3.3. Characteristics related to radiological impact

These include:

— Transport and dispersion in air;
— Transport and dispersion in groundwater;
— Transport and dispersion in surface water;
— Population and emergency preparedness aspects;
— Distance from population centres;
— Requirements for exclusion area and low population area;

4.1.3.4. Emergency planning

Physical characteristics and site characteristics that may hinder emergency plans (particularly relating to local transport infrastructure and communications networks):

— Evacuation routes and access routes;
— Population density;
— Special population groups (hospitals, prisons, etc.), transient populations.

4.1.4. Engineering and cost factors

During the site survey and site selection stages, safety and non-safety aspects related to engineering and cost play a significant role in the analyses of the suitability and comparison of the candidate sites. This section provides guidance for the consideration and proper evaluation of engineering and cost aspects.

4.1.4.1. Cooling water (heat sink)

NPPs need a reliable heat sink for operation (as with any conventional power plant) and for safety reasons.[4] For a long period after a reactor trip or reactor shutdown, the nuclear fuel continues producing heat that needs to be removed. During the siting process, the costs associated with cooling water availability and transport, as well as related operational costs (e.g. pumping and treatment of cooling water), need to be evaluated for each candidate site, including right of way for the pipeline corridor if relevant for the design. A maximum reasonable cooling water transport distance and height will ideally therefore be set for use in the exclusionary and discretionary criteria. This maximum may be modified as other aspects are evaluated, reflecting the willingness of the project team to accept a greater cost for water transport to establish a site that is more favourable in other respects. More details on requirements and design aspects are given in Ref. [27].

4.1.4.2. Electrical grid and load centres

The safe and economic operation of an NPP requires (i) that the NPP be connected to an electrical grid that has adequate capacity for accepting the power generated by the plant, and (ii) that the existing electrical grid provides a reliable enough electrical supply to the plant for fulfilling its functions during startup, operation and both normal or emergency shutdown stages. Therefore, costs related to the need to upgrade the electrical grid or consider power loss with distance, etc., are relevant to siting decisions. These considerations ought to be analysed in a coordinated way between the NEPIO and the grid operator. The IAEA Nuclear Energy Series No. NG-T-3.8, Electric Grid Reliability and Interface with Nuclear Power Plants [8] contains further information and guidance.

It is most economical for NPPs to be located relatively close to their major load centres (e.g. large populations, energy intensive industries, industrial centres) in order to minimize the cost of transmission lines and power losses. This requirement needs to be balanced with safety related criteria on locating a safe distance from large population centres. Some Member States locate NPPs at some distance from population centres, with the strategic objective of creating new load centres to encourage economic and industrial development.

4.1.4.3. Suitability of transport infrastructure

Ease of transportation of large, heavy equipment, including construction equipment (notably cranes that can themselves lift very heavy and large loads), from its manufacturing location or port of entry to the site is an important aspect.[5] The travel distance, the loading capacity and structural integrity of roads,

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[4] The amount of heat generated by residual fission is called the decay heat and is much lower than that generated by normal operation at full power. With current designs, the thermal power of the reactor immediately after shutdown is around 6.5% of the thermal power before shutdown, although this reduces to around 1.5% after one hour, and 0.4% after one day.

[5] The steam generator was previously the heaviest and longest item of equipment in an NPP. However, with the latest trend of modularization in construction, which reduces construction time and costs, the size and weight of other equipment that needs to be transported to the site has increased for some designs. A number of contemporary NPP designs may contain hundreds of prefabricated modules per unit, some of which could weigh more than 1000 t. The new integrated modular designs have some equipment items that are even heavier than the heaviest components of reactor types of larger power capacity.

bridges, tunnels, curvatures, clearances and slopes on the route, the availability of rail networks, etc., have to be studied with respect to the size and weight of the equipment. Many of these issues can be avoided if site accessibility with marine or river-going vessels is assured. River, canal or sea routes and coasts have to be studied for key issues, such as limitations imposed by bridges, the capacities of existing harbours and the feasibility of constructing suitable new harbours.

The special nuclear security and safety needs relating to the transportation of nuclear fuel and radioactive waste during the operational period have to be considered during the siting and evaluation processes. A specific long term consideration is the future need to transport facility waste and spent fuel to a permanent facility, taking into account potential changes to transport routes over the life cycle of the facility. Suitability of transport infrastructure is also particularly important for the daily operation and maintenance of the facility and for emergency planning provisions, particularly if off-site response or evacuation is needed.

4.1.4.4. Technology of the NPP

Many NPP technologies are currently available, ranging from water cooled designs to evolutionary and advanced reactor designs. Each design will be affected differently by the site characteristics and regional conditions, and, in turn, the environmental impacts of the plant on the region will vary.

Other information that is useful in siting and site evaluation includes the expected total power capacity and, if available, the number of reactor units that will be considered for the NPP. This information is typically used for assessing the suitability of the heat sink for cooling purposes and the required site area, as well as for other purposes.

As noted earlier, in Phases 1 and 2 of the Milestones approach the design of the plant and its safety features are usually not yet known; therefore, this is typically addressed by proposing a spectrum of NPP design scenarios that may be used to obtain generic and bounding values. Thus, in many countries, a bounding envelope approach (plant parameter envelope) may be used to establish the suitability of a site for multiple technology types and the use of multiple versus single unit approaches. The bounding approach considers the maximum and minimum values (encompassing the entire range of emissions, operating values, etc.) for all the technologies being considered, although if widely different technologies are being considered, more than one bounding envelope may need to be established. Next, the worst case value of the bounding range, for any aspect being considered, is considered in the siting evaluation. After the final plant technology has been selected, the corresponding values of the parameters are compared to the bounding values used to confirm that the analysis encompassed the actual values for the adopted technology.

4.1.4.5. Site development aspects

The following issues related to the development of the site have to be considered during the site selection and evaluation processes:

— *Availability of industrial infrastructure*: The availability of industrial centres in the vicinity has many advantages, such as the availability of a supply chain including qualified workers with experience in quality standards for construction activities, the availability of facilities for minor repair work and the provision of non-specialist parts during construction and operation.
— *Availability of labour*: An important temporary workforce is required during the construction of an NPP, and available qualified local labour at reasonable rates is an advantage.
— *Availability of utility services and construction material*: The site will require a suitable supply of electricity for construction purposes, heating/cooling of the site facilities and appropriate telecommunications, among other uses. Additionally, huge quantities of aggregates and cement will be needed during construction. Local availability helps to reduce transportation costs. Adequate quantities of fresh water for construction have to also be available.

— *Availability of land for construction*: Availability of land for the proposed number of units, together with auxiliary facilities, has to be considered. However, a considerably larger area is required during the construction of the plant for temporary purposes. In the case of modular construction, an even larger area that may span several hectares can be required for the storage, prefabrication and preassembly of modules.
— *Site topography and land characteristics*: The presence of nearby mountains or steep terrain has a large impact on the costs associated with earth-moving activities. Steep slopes can also be unstable and cause damage to safety related facilities because of landslides. On the other hand, there can be site protection measures and safety benefits of this type of locale. The sites have to also be investigated for the presence of large scale topographic features that cannot be relocated or altered, such as stream channels, deep incised valleys, knobs, sinkholes, abandoned mines, etc. Hard rock sites with irregular topography and very soft soils require huge cut and fill operations and result in increased costs of preparatory work. There may also be land remediation or preparation costs.
— *Land cost*: The cost of land varies from one region to another. In some cases, it may be necessary to purchase additional land to construct a new town with suitable facilities to support the workforce. It may also be necessary to purchase land in other areas for grid enhancements, transportation arrangements, etc. Compensation (either financial or by provision of other land areas) may be required for land of special interest.
— *Climate*: Climate and related weather events can have a significant impact on site development, construction schedule, quality and costs. Climate may affect the length of the construction period, the quality of construction activities, the ability to transport materials to and from the site, worker health and safety on the site or even the timing of specific on-site activities; for example, this may apply in the case of construction in extremely cold or hot regions, areas with strong winds over long periods or exposure of the site to severe weather (e.g. hurricanes or typhoons). To address these specific climate conditions, the site characterization programme will provide the required data and information to those responsible for planning the project and the construction programme.

4.1.4.6. Multiunit sites

There are several advantages to locating multiple power reactor units at a single site. If constructed in series, this approach allows the costs of construction and associated infrastructure to be shared among the units and the design and construction teams to move directly from one unit to the next. Operations and maintenance staffing can often be shared. Where the proponent has planned ahead and characterized the site for a multiple unit facility, the cost of site characterization studies per unit is also reduced.

However, the planning of a multiunit site requires the proponent to consider the total multiple unit risk profile, regardless of the sequence and timing of construction and operation, to confirm site suitability for the life cycle of all the units. This requires consideration of potential site related common-cause events that could emerge either in the design of the installation or through the operating and maintenance programme.

All the other factors (e.g. cooling water supply) need to be assessed considering the total size and power capacity of the combined units of the NPP. Equally, the impact of the larger generating capacity being at the same point on the grid needs to be considered. There may be some specific stakeholder concerns associated with using a single site for multiple power reactor units.

4.1.4.7. Nuclear security

The location of the nuclear facility is identified during the siting stage. The siting of a nuclear facility has the potential to increase or decrease its vulnerability to external security threats, as well as to increase or decrease the potential consequences that could result from malicious acts. During site selection, nuclear security considerations will ideally be evaluated alongside safety and other considerations. The siting of a nuclear facility can require agreements with neighbouring States [28–30].

Nuclear security goals at this stage for the State, the competent authority and the operator include evaluating the following [28]:

— Any local or regional threats that could affect the facility;
— Security interfaces and interdependencies with existing nearby nuclear facilities;
— Topography that may enhance or increase the vulnerability of the security of the site;
— The potential impact of radiological releases to the environment or populated areas (e.g. population centres, critical infrastructure, airports and other transport assets, and international borders);
— The availability of sufficient response forces to respond in a timely manner to a nuclear security event;
— Free space for site reconfiguration, including expansion, if security needs to increase.

4.1.5. Socioeconomic factors

As the NPP requires a substantial workforce for construction and operation, it will inevitably have a significant socioeconomic impact on the region, both positive and negative. In addressing socioeconomic aspects, the scope and depth of consultation with stakeholders needs to consider and even preserve the historical significance of the region and its cultural attributes, which may involve different aspects of society with different socioeconomic values (for example, indigenous cultures). Addressing these values early and respectfully with stakeholders can build a positive long term relationship by finding suitable compromises in the project where possible.

4.1.5.1. Future land use planning and site ownership

The suitability of the planned development of the area following construction of an NPP needs to be considered. The placement of an NPP can affect land use planning in the region around the facility for a century or more. In particular, for the safety and nuclear security of the facility, the operating licence requires the owner/operator to consider and adapt to changing long term impacts on on-site and off-site emergency planning. The owner/operator of the facility will, as part of site characterization, need to seek long term commitments from the regional authorities that land uses in the region will not affect the long term safe operation of the installation, which could result in extensive and costly adaptations to the installation.

Examples of such obstacles include the encroachment of permanent population centres and special facilities (e.g. hospitals, prisons, schools) into the emergency planning zones adjacent to the installation, which would impede emergency or evacuation plans, and the development of industrial facilities and infrastructures that could present unanticipated external hazards on the installation not accounted for in the safety case.

The owner/operator will need to provide reassurances, in turn, to the public and decision makers through legal controls such as land ownership, which imposes direct controls over land use, or softer controls such as stakeholder involvement in land use planning decision making. Some areas may be designated as of scenic value or cultural heritage and will need to be protected. Historic buildings and fortifications are an important cultural asset and are often associated with tourism.

4.1.5.2. Regional economy

The factors to be considered here are related to the project's impact on the economy of the region, including both positive and negative impacts. Positive impacts include economic development opportunities and improvements to local infrastructure and community services such as fire and police services, utilities, health care, education, recreation and transportation.

The NPP will also have a positive economic effect through both the direct and the indirect (service sector) labour market, providing employment for various skilled and unskilled workforce groups. In

addition to increased income revenues there will also be indirect effects such as increased knowledge, competitiveness and quality of the local resources and industry.

Any regional development plan will be affected by the project. The new land use, projected economic growth, role of the provided energy (electricity or heat) and secondary economic benefits ought to be reflected. There are advantages for those areas that have development plans in place. Selecting a site in such an area would allow the economic impact of the NPP to be maximized more quickly. The ease of planning applications and compensation costs, and local taxes for using sites, will also depend on development opportunities.

There may also be negative economic impacts of the NPP. The economy of the region may be predominantly based on non-industrial services (e.g. tourism, aquaculture, agriculture), in which case the nuclear facility may (but not necessarily) result in degrading the visual and aesthetic character of the area around the site, changing the aquatic conditions or industrializing the area. The financial (or political) loss of interruptions to the existing economic activities may be substantial and will need to be considered. The site may be in the vicinity of special cultural zones. These include areas of archaeological interest, historical or cultural value, etc., which may involve tourism or scientific activities. The protection of such areas is highly regarded in society and any impact on those sites is not likely to be acceptable.

4.1.5.3. Local society

NPPs require a significant workforce, both temporary and permanent, throughout their life cycle, from site preparation to construction to the final decommissioning several decades later. The different skills required by the activities of each of these stages will almost certainly need to be largely imported from other areas/regions, as local industry may either not have the necessary resources or be in competition for those resources if they are limited. The economic benefits and possible industrial development near the NPP may attract additional workers. The social fabric of the area, if it is relatively isolated, may be strained or altered by the sudden influx of a significant number of people. There will be impacts on local infrastructure and community services.

Availability of professional staff and capital through taxes paid by the NPP may also change patterns of behaviour. In addition, the existence of local colleges, trade schools and other training facilities near the site needs to be evaluated. The ability of the social infrastructure around the site to withstand the impact of the NPP will vary. Another important factor will be environmental justice; if socially and financially less capable groups are not positively affected or are disproportionately negatively affected, the project may be rejected.

4.1.6. Environmental factors

4.1.6.1. Strategic environmental assessment

A strategic environmental assessment is an increasingly common document prepared to assist in preparing policies, plans and programmes. Its main objective is to assemble known environmental information to be used to avoid or mitigate any expected significant negative environmental impacts arising from these policies, plans and programmes and, importantly, to enhance their positive environmental outcomes, including social and economic impacts that are environmentally relevant. Further information about the strategic environmental assessment is provided in IAEA Nuclear Energy Series No. NG-T-3.17, Strategic Environmental Assessment for Nuclear Power Programmes: Guidelines [31].

4.1.6.2. Radiological and non-radiological environmental impacts

The process of developing an EIA is described in IAEA Nuclear Energy Series No. NG-T-3.11, Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes [9]. Environmental considerations are a critical aspect of successful siting and site evaluation

processes, both in terms of minimizing environmental impact and in obtaining public acceptance. These considerations will strongly influence the siting and site evaluation processes, and typically involve the protection of air, water, wildlife and cultural resources. Consideration of the environmental factors needs to recognize that environmental considerations differ in magnitude and scope between construction and operation. It is also necessary to establish a reference baseline of environmental characteristics for all the issues in order to be able to carry out an EIA.

Obtaining the necessary environmental permits may differ considerably for various sites in terms of complexity and duration. Therefore, finding a site with fewer environmental concerns is likely to shorten the permitting process and reduce the construction and operation costs. While all issues related to radioactive releases are dealt with in the related safety requirements and reviewed by both the nuclear regulator and the environmental regulatory agency, potential non-radiological environmental impacts are handled separately and generally the environmental agency takes the regulatory lead.

In the first stages of the siting process, as part of the activities dedicated to environmental protection in new nuclear power programmes, a comprehensive programme will ideally be undertaken to collect all available information regarding the environment of the potential sites. This includes discussions with the environmental agencies, desktop studies and site reconnaissance. A scoping report [9] is prepared to serve as the basis for planning the necessary environmental investigations and analyses. By highlighting the key environmental issues of the nuclear power project at this early stage, the analysis of initial environmental information may indicate areas of concern and data gaps that need to be filled prior to completion of Phase 1 (decision to proceed with the project) of the Milestones approach.

When the final candidate sites have been identified, the collected environmental information ought to represent a thorough compilation of all existing available data, which will continue to be used later on in the process, as described further in Ref. [9]. Data gaps will be filled later in the site evaluation process, including field studies to support the EIA (a separate document). As many of the field studies require a year or longer to complete (to encompass all seasons), it is important to make planning the EIA programme a priority. The process of developing an EIA is described in Ref. [9].

Types of environmental concerns that can play a significant role in the siting and site evaluation process are summarized as follows:

— Aquatic ecology and marine environment;
— Terrestrial ecology;
— Fresh water, including surface water and groundwater;
— Air quality;
— Noise;
— Landscape (including viewscape) and aesthetics.

4.2. PROCESSES

Two different concepts will ideally be clearly recognized from the beginning: (i) the concept of ‘siting’ and (ii) the concept of ‘site evaluation’. Each concept involves different processes, which are conducted sequentially.

Siting is the process of selecting a suitable site for a nuclear installation[6], as it is defined by the IAEA Safety Glossary [32]. The selection of a suitable site is an integral part of the implementation of

[6] The term ‘nuclear installation’ includes NPPs; research reactors (including subcritical and critical assemblies) and any adjoining radioisotope production facilities; spent fuel storage facilities; facilities for the enrichment of uranium; nuclear fuel fabrication facilities; conversion facilities; facilities for the reprocessing of spent fuel; facilities for the predisposal management of radioactive waste arising from nuclear fuel cycle facilities; and nuclear fuel cycle related research and development facilities.

the principle of defence in depth for preventing accidents, as stated in Principle 8 of the IAEA Safety Fundamentals in Ref. [33].

The site evaluation process follows the siting process activities. This process includes detailed investigations, studies and assessments, with consideration of all safety factors that could result in the release and dispersion of radioactive material that could affect the facility workers, the general population and the environment (see Ref. [18]). Issues relevant to safety (e.g. feasibility of access and evacuation in case of emergency situations, location of people and resources) are to be considered. In addition, environmental, socioeconomic and other factors not directly bearing on safety of the facility have to be considered during site evaluation. Note that the siting and site evaluation processes progress through several sequential stages. This is meant to imply the increasing use of technical and economic resources from the beginning to the end, going initially from studies at the country and/or regional scale in Phase 1 to smaller areas and individual sites in Phase 2. When the final site(s) is(are) selected, a complete characterization is required and, therefore, detailed and costly investigations, studies and assessments have to be conducted.

The siting and site evaluation processes include five different stages, which are developed from the beginning of the nuclear power programme during the whole life cycle of the NPPs, as follows:

Siting process

(1) Site survey stage;
(2) Site selection stage.

Site evaluation process

(3) Site characterization stage;
(4) Pre-operational stage;
(5) Operational stage, in relation to re-evaluation of site characteristics.

Stages (1) to (4) are illustrated in Fig. 4 with respect to Phases 1 to 3 of the milestone schedule and the subsequent sections of this publication. The detailed outcomes in comparison with those for the stages of the siting process and the site evaluation process are also shown in Fig. 4. Stage (5) is not discussed in detail in this publication. These stages have the following specific objectives, all of which are discussed in greater detail in later sections.

4.2.1. Site survey stage

In the site survey stage, large regions of interest[7] are investigated to find potential suitable areas within which could be located suitable site(s). The suitability of the areas is identified through the application of established exclusionary attributes and the corresponding quantitative criteria, as discussed further in Section 4.1. This first screening leads to the rejection of unsuitable areas and the identification of one or more candidate areas. At this stage, if large areas that are essentially similar in characteristics can be identified, then flexibility is maintained to select sites later based on other characteristics, or perhaps the strategic interests of the Member State. If potential areas are quite constrained, then perhaps only specific sites of minimally adequate area for the project can be identified at this stage.

[7] At country scale, regions of interest ought to be defined prior to starting the site selection process. The region of interest is the geographical area in which the Member State is willing to site the power plant, considering reasonable limitations of topography, water availability, population constraints, strategic considerations, etc. The regions of interest are geographic regions defined according to the specific geographical and political subdivisions and the policy (e.g. technical, socioeconomics, security) characteristics of the Member State, including also consideration of the service area of the power generation utility that will operate the NPP.

Stages of siting	**Site survey** **Phase 1** • Regional analysis • Identification of suitable candidate areas/sites	**Site selection** **Phase 2A** • Screening and ranking analysis • Selection of the site(s)	**Site characterization** **Phase 2B** • Demonstration of site acceptability • Detailed site characterization • Derivation of site related design bases	**Pre-operational** **Phase 3** • Confirmation of design bases • Monitoring work
Input and output	• Potential regions • Potential sites • Candidate sites	• Input: Candidate sites • Preferred candidate sites	• Input: Preferred candidate sites • Site characterization • Derivation of site design basis	• Confirmation • Licensing and ongoing justification • Candidate sites
Methods and tools	**Regional analysis** The high-level review of the Regions of Interest to identify some potential siting areas. This is largely based on excluding areas that do not meet critical exclusionary criteria.	**Screening analysis** The application of further (discretionary) criteria or simple assessment to identify those sites most likely to provide a suitable site, with the objective of reducing the number of potential sites to be analysed in detail. **Ranking analysis** The quantitative evaluation of the candidate sites by discretionary criteria, weighted by their importance, resulting in a preferred order reflecting those sites that best meet all the identified criteria.	**Detailed site investigations** Tools in this stage are standard site investigation methods, for example: • Geology, geophysics and geotechnical; • Seismology; • Oceanography and coastal engineering; • Meteorology and climate sciences; • Demography and uses of land/water; • Emergency preparedness; • Non-safety related aspects. Data collected in a Geographic Information System (GIS) and reported in a Site Evaluation Report (SER) and EIA. **Environmental impact assessment (EIA)** **Derivation of site design basis** Data needed to proceed with the design of the facility are provided in the bid documents.	**Confirmation and ongoing justification** Tools at this last initial stage are mainly long-term monitoring that to be continued during the operational stage, for example: • Seismology; • Meteorology; • Sea river, water table levels; • Evaluation of demography and uses of land/water.
Review and validation	Data on potential siting areas reviewed, potential sites validated, and final candidate sites selected by management committee.	Data for preferred candidate sites reviewed, and selected site(s) agreed/endorsed by the management committee.	Proper reviews are performed on the EIA and derivation of design basis documents.	Preliminary and final safety analysis reports completed. As appropriate, reviews are performed on final safety analysis reports and document updates prepared.

FIG. 4. Outcome of the siting and site evaluation processes for an NPP.

Typically, for this initial screening, the exclusionary attributes (discussed in Section 4.1.1) are given broad acceptable criteria values to account for the lack of detailed specific data about the characteristics of the regions of interest being evaluated. It may be that sufficient acceptable areas can be identified using these broad criteria values. Using this method, it is understood that acceptable areas may be rejected because of the lack of specific data about the area. However, if the use of broad exclusionary criteria leads to the result that no (or too few) suitable areas are identified, it may be necessary to use more precisely defined criteria values for the exclusionary attributes while still in compliance with all safety requirements (an example being to reduce previously established screening distance values between the specific attribute and the NPP location). After this more detailed consideration of the exclusionary criteria, if suitable areas cannot be identified, the situation is critical and the programme cannot go forward (see paragraph 3.12.1 of Ref. [2]). Although unlikely, this possibility is presented here to emphasize the importance of the site aspects in the implementation of such a programme.

It is noted, however, that social acceptability may be identified as an exclusionary criterion and if acceptance of the location for the plant cannot reasonably be obtainable, the site may need to be excluded regardless of safety attributes. After suitable areas have been identified, sites of an appropriate size (areal extent) are identified within the suitable areas in order to proceed with the site selection stage. The areal extent of the candidate sites being considered is dependent on many factors, including the number of NPPs to be constructed in the present (and possibly future units), ancillary facilities or amount of unusable land embedded in the site (such as steep slopes, wetlands, etc.). Note that the larger the site and the more complex it is, the more difficult it will be to conduct site characterization, with impacts on the schedule and cost if the footprint of the reactor units to be housed there is not known. It is advisable to identify sites with different characteristics (e.g. utilizing different water bodies as a source of water, proximity to different population centres). This provides a better forum for evaluating options for site selection.

4.2.2. Site selection stage

The second stage of the siting process is site selection, in which the suitable candidate sites identified previously are assessed by screening and comparing them on the basis of discretionary attributes with their associated objective criteria values (Section 4.1.2). Ranking of the sites, performed based on favourable characteristics established on the basis of safety, non-safety and nuclear security considerations, results in the identification of the preferred candidate site(s). Data associated specifically with the review and ranking process ought to be collected and carefully evaluated. Once the candidate sites are ranked and the ‘preferred’ candidate site(s) are nominated, the authority in charge of making the final decision on these matters formalizes the selection of the site(s) for the NPPs in accordance with the established formal procedures and all legal aspects. The selection of more than one site is advisable to provide more than one option in case of the rejection of one of the selected preferred sites, such as due to further information collected during detailed site characterization or for strategic reasons.

The site evaluation process follows the siting process, overlapping the site selection stage. For the purpose of this publication, the detailed site evaluation begins once the site(s) is(are) finally selected and extends during the operational lifetime of the NPPs until the final decommissioning stage. Thus, site evaluation is applied specifically to a given selected site(s). As a summary, site evaluation is the process that includes the following sequential stages.

4.2.3. Site characterization stage

This stage includes the detailed assessment of the finally selected site(s), which aims to do the following:

— Demonstrate site suitability;
— Perform detailed characterization, including environmental assessment;
— Derive the site specific design parameters for the NPPs;
— Demonstrate the feasibility of implementing emergency plans.

4.2.4. Pre-operational stage

Confirmation and completion of the assessments that are begun earlier (i.e. during the design, construction and commissioning stages) are completed and ongoing monitoring continues. All the site related activities involving confirmatory and monitoring work are taken up in the pre-operational stage, conducted in Phase 3 of the Milestones approach. In the pre-operational stage, studies and investigations that began in previous stages are continued after the start of construction and before the start of operation of the NPPs, to complete and refine the assessment of the site characteristics determined in the previous stages. The site related data obtained during this stage allow a final assessment of the models used and conclusions reached in the original design. The pre-operational stage corresponds to the construction and commissioning phases of the NPP project and is described in this publication in Section 8.

4.2.5. Operational stage

In this stage, within the framework of periodic safety reviews, re-evaluation of site characteristics will ideally be performed in addition to ongoing monitoring. Following the approval of the final safety analysis report (SAR) for the NPPs, the site evaluation in the operational stage starts. In the operational stage, appropriate safety related site evaluation activities are carried out over the operating lifetime of the NPPs, mainly by means of monitoring, including environmental monitoring and periodic safety review. This includes all confirmatory, monitoring and re-evaluation work conducted throughout the operational stage, and especially during periodic safety reviews of the installation. The operational stage is not emphasized in this publication.

As output of the detailed characterization of the selected site(s), a final report, usually called the SER, is prepared, which summarizes all site investigations, analysis and results obtained. The SER constitutes the basis for the 'site description' chapter of the SAR for the NPP. Also, the results from this characterization stage provide a significant amount of the data and information required for assessing the environmental non-radiological impact, which is provided in the EIA report. Figure 5 illustrates in a general way the tasks performed and the decisions made in the process described above.

Figure 5 does not include the activities conducted in relation to the EIAs, although they will be required by the specific and applicable environmental regulatory requirements.

5. PHASE 1 — SITE SURVEY STAGE

5.1. OBJECTIVES

The site survey is the first stage of the siting process and involves the study of large regions at country scale with the objective of finding suitable potential candidate sites [4]. Unsuitable regions or areas within the regions are rejected through a screening analysis, applying mainly exclusionary criteria. This stage uses high level available data associated with the application of well established criteria. It is usual to call this study a 'desk study', as it includes existing documentation and field reconnaissance visits. No new data are collected in this stage.

5.2. LEGAL FRAMEWORK

During Phase 1, the NEPIO will evaluate the current situation and determine the need to put in place legislation to establish an independent nuclear regulatory body with adequate human and financial resources and a system of authorization, inspection and enforcement. The report ought to also identify

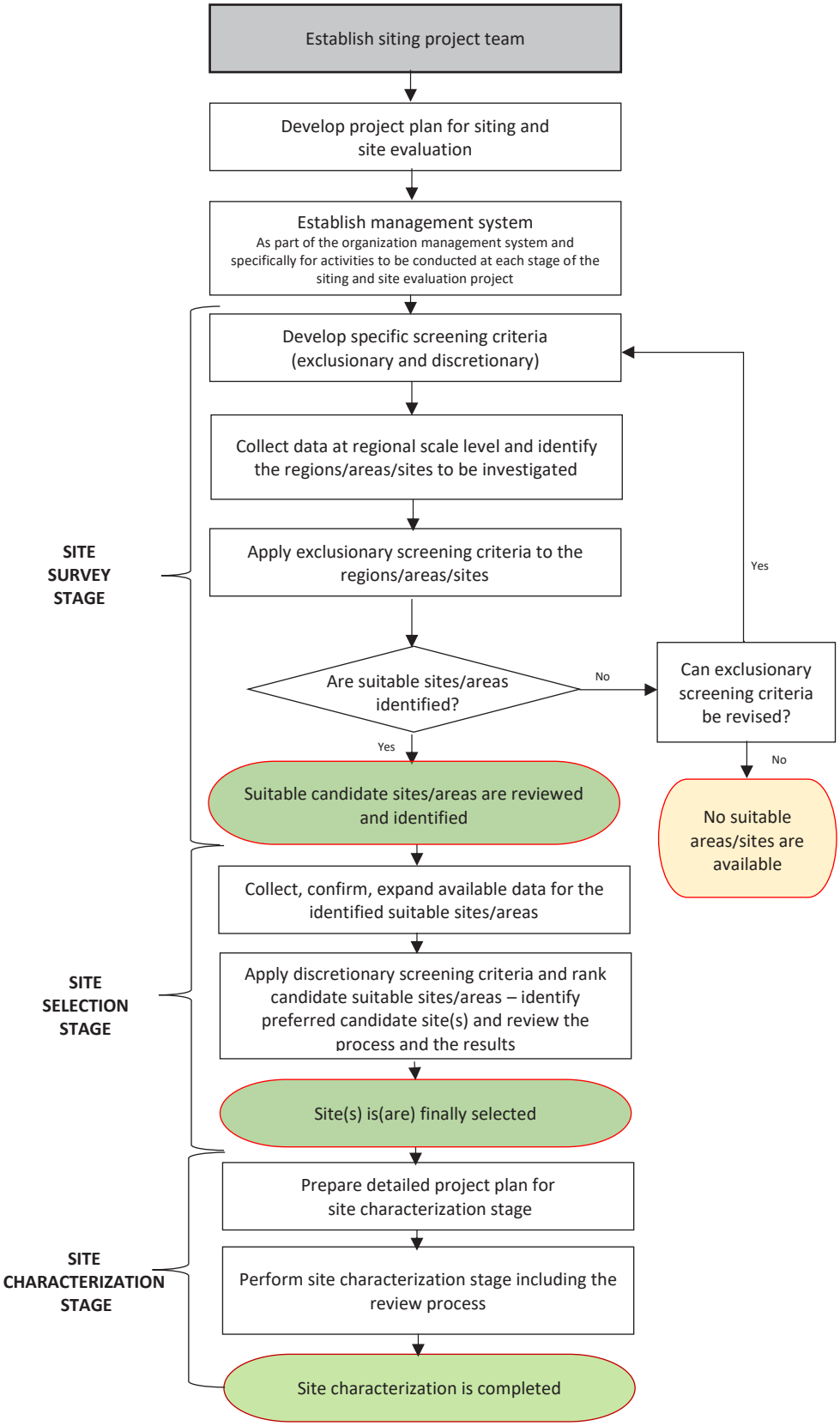

FIG. 5. General flow chart of tasks and decisions during the siting process and site characterization stage (excluding EIA studies). More detail on the site characterization stage can be found in Fig. 8.

all additional legislation that may affect the nuclear programme, including legislation that would need to be enacted or amended, such as any pertaining to site selection and evaluation. For embarking countries, specific detailed criteria for defining site suitability (either exclusionary or discretionary criteria) are not usually yet available at the beginning of the site survey stage. Nonetheless, it is important to prepare, discuss and obtain management and/or regulator agreement on the exclusionary and discretionary criteria that will be used to make decisions regarding site selection prior to beginning the site survey.

5.3. REGULATORY FRAMEWORK

As indicated in Section 4.1, it is essential that adequate related criteria, particularly exclusionary attributes and criteria that can exclude a site or a region entirely, be set up at beginning of the site survey stage by the NEPIO. These exclusionary attributes (mainly related to external hazards, operational issues, environmental aspects and/or legal and societal aspects) will ideally be established early to avoid spending time and resources on activities and tasks in a given region or area that could ultimately be excluded. Such 'acceptance' or 'exclusionary' attributes and criteria have to be prepared by the NEPIO organization or responsible siting team, presented to the regulatory body (if it exists) for discussion and subsequently acceptance so as to be applied in the siting process as preliminary siting criteria. The siting team ought to be prepared to provide information showing the legal and technical basis supporting the proposed criteria, as well as the processes used to establish confidence in those criteria.

5.4. MAIN TECHNICAL INPUTS

In addition to inputs related to the specific NPP type, other technical inputs may be known specifically or may be drawn from consideration of a range of potential technologies. The main technical inputs will be of two types:

— The readily available data and information to be collected from international, national and regional sources, including government sources, national institutes, airports, universities, private concerns, published references, etc. Examples include:
  - Geographical and topographical maps, and satellite and remote sensing imagery;
  - Bathymetric data from rivers, estuaries and the sea;
  - Geological, geophysical and tectonic maps;
  - Seismology data;
  - Meteorological data;
  - Hydrographic data from rivers, lakes and the sea;
  - Demography and population data;
  - Use of land and water, restricted areas and cultural heritage;
  - Information about local and regional environmental aspects;
  - Additional information obtained from the scientific literature published in international and national journals, which may provide useful data on specific matters appropriate to the site survey stage.
— A project description and a detailed list of facilities required to support it, which includes:
  - A brief but complete description of overall project characteristics (such as organizational and technical descriptions, planning, etc.);
  - Facilities needed during the construction stage;
  - Facilities needed for the operation of the power plant as an industrial facility;
  - Facilities required for the project due to its specific nuclear characteristics, such as fresh and spent fuel storage, radioactive waste storage, possibly spent fuel (if declared as waste) and radioactive waste disposal, etc.

5.5. PROCESS OF THE SITE SURVEY STAGE

The site survey is the first stage of the selection process of a suitable site for an NPP and is the only stage to be performed during Phase 1 of the Milestones approach. Its results will affect the final conclusions for Milestone 1.

The execution of the site survey stage will allow the NEPIO to properly answer the question of whether one or more suitable candidate sites are potentially available in the selected regions or areas of interest and, consequently, whether the programme can proceed further. It is assumed that for an embarking country, this initial stage of the siting process will be executed by the NEPIO through the constitution of a siting team and that adequate funding and implementation mechanisms are in place for proceeding promptly and efficiently in its execution.

The process to be conducted is constituted by a sequential implementation of several steps, illustrated in Fig. 6 and described in the following sections.

5.5.1. Establishment of the siting team by the NEPIO

Detailed guidance regarding the constitution and organizational aspects of the siting team to be put in place for executing the site survey stage is the first step (Section 3.5).

5.5.2. Development of the site selection, evaluation project plan and terms of reference

The development of the detailed project plan for the whole of the siting and site evaluation process will ideally be carried out at the beginning of the site survey stage by the siting team as one of its first tasks, including a milestone schedule in line with the nuclear power programme and an estimate of the required budget and resources. If any of the work is to be contracted to third parties, detailed terms of reference ought to be developed to guide that work and ensure that the work is performed according to the quality requirements of the project (Section 3.3).

5.5.3. Establishment of the management system

In Phase 1 of the Milestones approach, the management requirements for the whole NPP project are addressed by the NEPIO. The expertise needed for addressing all relevant issues will ideally be identified and the gaps filled with consultants, if necessary, to obtain the required resources and skills. As part of this development, the management requirements for the site selection and site evaluation project are treated as a priority, and preparation of the corresponding management system begins with an emphasis on the development of the system for data management (GIS) and information (document) management (Section 3.1.7).

5.5.4. Development of specific attributes and criteria

Development of specific exclusionary and discretionary attributes and criteria, if not established already in the Member State, ought to be executed at the beginning of the site survey stage by the NEPIO, recognizing that the regulatory body is usually not in place and a later review and approval process will be required. In most cases, for embarking countries, these criteria will be developed specifically for the NPP project (Section 4.1).

5.5.5. Identification of the regions and areas to be investigated and collection of associated information

This step involves the identification of the regions and areas to be investigated at country scale. The regions and areas of the country to be considered in the survey stage will ideally be well defined and delimited from the beginning of the site survey stage by the NEPIO and be explicitly indicated in

the project plan. Policy, political and strategic considerations play a key role in defining such areas, and no detailed guidance can be provided in this publication since area selection is strongly influenced by the specific cases of the Member States. Also included in this step is the collection of the available data and information and the organization of the corresponding database, covering the geographic area of the investigated regions, areas or sites, including areas subject to environmental impact, as well as extending to the regions that may generate external hazards to the NPP. International organizations or other Member States may have useful data on local seismology, geology, oceanography, etc.

5.5.6. Analysis of collected data and application of exclusionary criteria

Analysis of all data collected, application of the exclusionary criteria and identification of suitable and non-suitable areas or regions are the main activities of this step (Section 4.1.1).

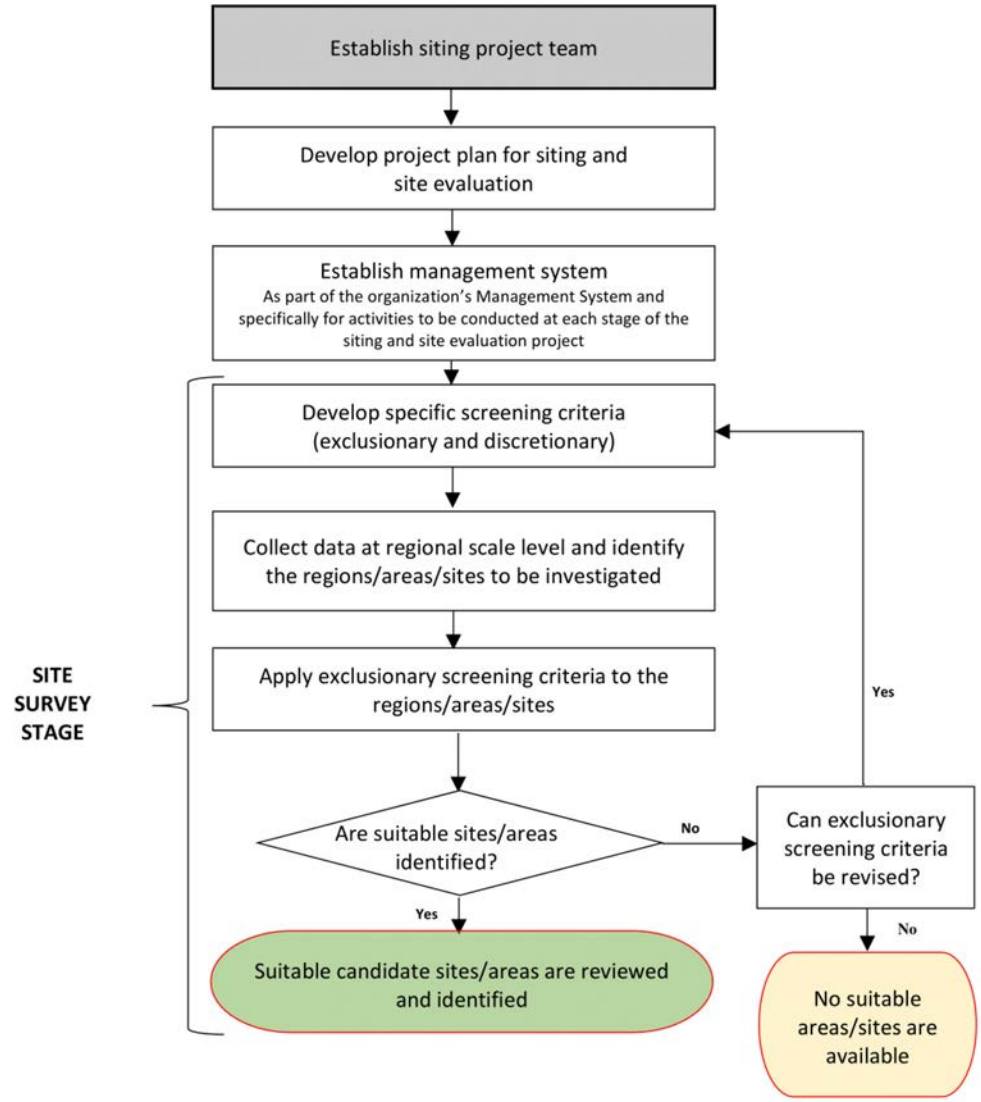

FIG. 6. Scheme of site survey stage as part of the siting process performed in Phase 1 (extract from Fig. 5).

5.5.7. Review of screening procedure

A review of the previously established screening criteria (Section 4.1.1) may proceed if the results of the performed analysis led to non-available suitable sites in the identified regions. A thorough discussion and analysis of the exclusionary criteria can proceed among all NPP project participants and, if so agreed, the exclusionary criteria may be revised and a new analysis be conducted. The process starts again at the stage of development of specific attributes and criteria.

5.5.8. Identification of candidate sites/areas and reporting

The final step is the preparation, review, revision and issuance of the deliverables of this stage.

5.6. ATTRIBUTES AND CRITERIA

At the site survey stage, exclusionary and discretionary criteria will ideally be established for attributes that can be easily applied using the available data and information without the need to conduct detailed on-site investigations. The exclusionary criteria prevail over the discretionary criteria at this stage, and the attributes are selected accordingly. Section 4.1 of this publication provides definitions and detailed guidelines on exclusionary criteria used for screening regions or areas. The most important considerations for the selection of the exclusionary attributes are summarized as follows:

— Attributes that, if not satisfied by site conditions, would preclude the construction of an NPP at that location;
— Attributes that can generate issues, events, phenomena or hazards for which, generally, there are no available practicable engineering solutions, site protection or administrative measures; or they are excessively demanding in relation to the feasibility of engineering, construction and operational solutions to mitigate the issue, such as through design or site protection measures.

Because no area may comply with all conditions and requirements, the site survey requires balancing the cost of mitigating the different unfavourable attributes of each available potential site.

Section 4.1 presents an example of a comprehensive list that can be adopted for starting the first analysis. In accordance with the specific conditions of the Member State, the list can be expanded or reduced, and some of the attributes may be discarded and other new attributes added. Attributes important to safety have to be retained as exclusionary attributes, however. The environmental scoping report prepared prior to or during this stage can be referred to in order to obtain the environmental attributes of concern.

The outcome of this task is a comprehensive list of attributes to be addressed from the beginning of the siting process. This is presented to all parties involved in the NPP project, discussed and agreed. The list will be the basis for planning the collection of data and information; the institutions, organizations and private companies to be contacted; and the activities to be carried out.

The next step is the development of the specific performance quantitative criteria to be applied to each of the exclusionary and discretionary attributes. This task is the basis for the rejection of potential areas. Thorough discussions with stakeholders ought to be conducted and final consensus on the list of criteria to be achieved.

The exclusionary and discretionary criteria will ideally be properly selected in accordance with the specific regulations applicable in the Member State, the type and design basic characteristics of the NPP technology or technologies under consideration, and the prevailing socioeconomic and political conditions. Section 4.1 presents detailed guidance on the definition of the exclusionary and discretionary criteria.

5.7. ACTIVITIES

The activities in this stage are mainly desktop studies and field reconnaissance visits as follows, and in principle, it is not expected that field activities, laboratory testing tasks and sophisticated calculations and analysis will be conducted in this stage.

— *Desktop activities*: Desktop activities aim to search, collect, compile, evaluate and organize all already available data and information in national and international institutions, libraries and archives, including information available from previous NPP siting studies or from conventional infrastructure projects. These data are analysed, organized in a project GIS and connected with all national institutions with jurisdiction in the attributes to be investigated. The preliminary results of the desktop activities in this stage will be the identification of potential areas and sites through the application of the defined criteria and the exclusion of unsuitable potential areas or sites.
— *Field reconnaissance activities*: Field reconnaissance visits ought to be conducted in the areas identified for selecting potential candidate sites. These visits will ideally be focused on those attributes that require careful examination in view of the available data and information, and on the need to clarify or confirm specific issues. Additionally, the field reconnaissance ought to identify issues that are apparent but for which no information is currently available.
— *Reporting*: A final report will ideally be delivered at the end of the site survey stage.

5.8. MANAGEMENT

At this initial stage, the NEPIO and a siting management team ought to be in place, with the experience to operate using sound management system principles, including the quality expectations of the activities to be performed in this stage. One of the critical aspects from the beginning of this stage is keeping track of the collected data.

5.8.1. Siting team

The siting team appointed for the site survey stage has the overall responsibility for implementing activities for the period and purpose defined in the project terms of reference. The siting team will ideally report to a senior manager of the nuclear power programme and ought to be given appropriate time and resources (financial, human and logistic) to carry out the necessary activities.

A siting team composed of five to ten professionals is usually considered adequate at the site survey stage, but additional specialized consulting services from internal or external sources are likely to be required for dealing with specific topics. One or more environmental experts usually form a part of the siting team through all stages of the process, in recognition of the need for ongoing consideration of environmental issues. The key requirement is to ensure that all the required disciplines will be covered by the siting team internally or through use of external expertise.

5.8.2. Project plan and schedule

The site survey project plan, herein called project plan, can be a formal document prepared by the NEPIO (or the entity responsible for the site survey) used to guide both project execution and project control. The primary uses of the project plan are to document planning assumptions and decisions, facilitate communication among project stakeholders and record approved scope, cost and schedule baselines.

The project plan is a statement of the scope, objectives and participants of the project, and is updated during each stage of the project. It provides a preliminary delineation of roles and responsibilities, outlines the objectives of the work, identifies the main stakeholders and defines the authority of the project

manager. It acts as a kind of contract between the NEPIO and the siting team manager to facilitate clear communications and coordination.

Since the project plan establishes the guidance for what will be a complex project, it is important that it be developed by experts who understand the complexities involved and have a global view of the entire process; that it is thorough and detailed; and that it allows for modifications as the project progresses and additional information is collected. Sufficient time and resources have to be allocated to preparing this primary document. During this stage, it may be difficult to mobilize the many and varied required competencies, considering the broad range of issues to be studied and the vast areas to cover, which may extend over multiple geographical regions.

Difficulties may arise during activities due to discussions on the attributes and criteria to be applied. The review process, which could, at the end, include assessments from international agencies, regulatory contacts and a final political decision, may take a significant time. As a whole, if it is considered that three to six months may be needed for the technical studies, one year may be a good provision for the whole process.

5.8.3. Integrated quality management

At the site survey stage the system will ideally provide a single framework for the site survey activities and ought to provide confidence that consideration of health, environmental, quality and economic aspects is fully integrated with consideration of nuclear safety aspects, to avoid the possibility of their potential negative impact on safety. If the parameters and analyses do not lend themselves to direct verification by inspections, tests or other techniques that can be precisely defined and controlled, the assessments are then reviewed and verified by qualified individuals or groups that are independent of those who did the work. The activities to be conducted during the site survey stage will ideally be integrated within the overall project quality arrangements that will be formalized in Phase 2, recognizing that they may be initiated long before the NPP project is established.

5.8.4. Document and data management

Various supporting documents will be created to support the site survey activities (e.g. calculations, reports, drawings, maps, specifications, meeting minutes, decisions). In addition, to ensure that these data are properly referenced and maintained for a long period, special consideration ought to be given as to the best method of data organization to facilitate their later use. A robust document management system is also necessary to properly manage the numerous reports that will be developed, reviewed, revised and approved over the course of the project.

5.8.5. Review procedure

At the site survey stage, the participation of recognized experts as independent reviewers ensures sound judgements and consistent interpretations of key technical and specialized issues, and a review mechanism will ideally be part of the project plan.

5.9. STAKEHOLDER INVOLVEMENT

The site survey stage is devoted to conducting a general survey of potential sites and identifying relevant suitable candidate sites. This, therefore, requires that important consultations with key stakeholders be part of the process. Initial guidance on stakeholder involvement is given in Section 3.4.

It ought to be kept in mind that siting activities that are seen by the public can be considered as a kind of ‘turning point’ in the communication of the intention to build an NPP to the public in general, and

to stakeholders in particular. A project that was kept under strict confidentiality restrictions will start to move into the spotlight.

Some Member States have a fully open process for communicating with all stakeholders from very early in the nuclear power programme, such as before the decision has been taken to develop and implement it. These types of stakeholder communications are not generally related to site specific issues. For a fully open communication process in relation to site specific issues, it is advisable that the site be already procured. Many Member States, however, do not have a programme for open site specific communications until potential sites have been selected or procured. These States focus their communications on governmental, agency and local representatives, sometimes referred to as 'statutory stakeholders'.

Statutory stakeholders are considered to be organizations and bodies that are, by law, required to be involved in the planning, development or operational activity (usually government entities), as discussed in Section 3.4. It ought to be noted that communicating with stakeholders does not mean sharing all information. This phase of activities requires a proper handling of confidential information, thus avoiding the misuse of information that may result in an increase in the land cost, activation of site opponents, etc., when a site has not been identified. A proper process of handling information that is confidential and exempt from disclosure will ideally be fully established.

In keeping with good industry practice, the proponent is expected to consult with stakeholders early in the siting process and before any substantive decisions are made. Initially this will be the responsibility of the NEPIO or, in its absence, the government department sponsoring the work or the proposed operating organization of the NPP. Different stakeholders will likely require different approaches, and considerable expertise is necessary in handling the overall stakeholder process.

This early stage of siting primarily involves providing information on the benefits and potential impacts of the NPP project and the overall objectives of the process, as well as obtaining available information and data from stakeholders. Communications may be more focused on general discussions on the benefits and impacts of nuclear power and not on specific aspects of individual sites. It will include items such as:

— Identifying the key stakeholders and other interested parties that are important for the siting and site evaluation processes. This requires involving statutory stakeholders and interested parties that will be important for the site development activities.
— Developing a stakeholder involvement strategy. Ensure that the required resources and competences are made available to handle communication with interested parties during siting and site evaluation activities.
— Linking site survey activities with the stakeholder involvement plan. Provide information about the benefits and risks of nuclear power, including the non-zero potential for severe accidents. The latter is a key aspect to be addressed from the beginning.
— Developing a public participation plan from the early stage of the programme to be fully implemented when it is appropriate for public involvement.
— Providing media releases and background reports, regularly and at key decision points.
— Networking (e.g. small meetings and briefings) with government and local officials, educational institutions, industry groups, media and other opinion makers, when appropriate.

It is also important to seek to establish local and regional networks of expertise. These networks may be composed of technical experts in health, regional planning, land use and other fields. Such networks may contribute to the effectiveness of the siting process by identifying and further refining important criteria to be applied in subsequent steps. In addition, these networks may become future communication resources as the project reaches the site specific stage. Other activities may include:

— Identifying other interested and affected parties that will need/want to be contacted immediately upon announcement of candidate sites;

— Building communication channels with local and regional elected officials so that formal relationships are established before the announcement of candidate sites.

It is particularly important that the process of ranking candidate sites is transparent and linked with a well developed stakeholder involvement plan.

The relevant publications to be consulted during this activity are IAEA Nuclear Energy Series No. NG-T-1.4, Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [21] and INSAG Series No. 20, Stakeholder Involvement in Nuclear Issues [22].

5.10. ENVIRONMENTAL CONSIDERATIONS

During the site survey stage, a comprehensive programme ought to be undertaken to collect all available information regarding the environmental characteristics of the potential areas. The purpose of this activity is to identify all known environmental issues that will be considered as an exclusionary attribute (e.g. protected areas), as well as to identify concerns that may affect cost or schedule and therefore will ideally be considered as part of the discretionary attributes (e.g. sensitive habitat in the receiving water body, nesting seasons).

5.11. COLLECTION OF DATA AND APPLICATION OF EXCLUSIONARY CRITERIA

Data are collected, documented (Section 3.1.7) in a proper quality system and reviewed, and then validated exclusionary criteria are applied in order to come to a list of potential sites. At this stage neither ranking nor selection is performed. Note that technical, economic and safety attributes will have been considered at this stage to reach a possible list of up to ten candidate areas or sites. This step may need some iteration, as some criteria of the exclusionary attributes may have to be reconsidered in order not to reject favourable sites on minor quantitative differences of the criteria (Section 4.1).

5.12. OUTCOME AND DELIVERABLES

The outcome of the Phase 1 site survey stage is the identification of suitable candidate areas within a given region of interest that comply with the adopted exclusionary criteria. Those areas are considered acceptable for locating an NPP, and further investigations and studies can be performed in the subsequent stages of selection and evaluation. Any sites identified within these candidate areas are considered to pass the exclusionary screen and can be chosen as the location of the NPP project.

The main deliverable of Phase 1 is a site survey report, which may include a site survey summary report and a number of topical reports according to the similarity of the treated scientific, technical, economic and political topics or disciplines, including maps, drawings, figures and tables. Another important deliverable of this first stage is the initial development of the GIS, which will contain all the data and documents collected and elaborated during this stage.

6. PHASE 2A — SITE SELECTION STAGE

6.1. OBJECTIVES

Site selection is the second stage of the siting process. This stage has the objective of selecting the preferred candidate site, or sites, for the NPP. In this stage, potential sites will be identified in the candidate areas established at the previous site survey stage, and they will be assessed, compared and ranked through the application of the established discretionary attributes and criteria.

Thus, the outcome of this stage is the decision on the selected site(s) for housing the nuclear power reactor units of the nuclear energy programme. Good international practice suggests that the outcome of the site selection stage be more than one preferred site, to allow for an alternative plan in case of a change in the prevailing conditions at the selected site (e.g. public acceptance/rejection, political and geostrategic context change, socioeconomic changes and findings from the on-site detailed site characterization). If a second site option has been decided and the project schedule is a primary consideration for the overall programme, the site evaluation can be performed in parallel. If budget is a primary consideration, detailed characterization of the two sites can be performed sequentially.

This site selection stage is denoted Phase 2A because it is the first part of Phase 2 of the milestones framework, which will be followed by full site characterization in Phase 2B (Section 7).

6.2. INPUT FACTORS

In general, the input factors for the site selection stage are the following:

— Information and data collected at the previous site survey stage and organized in the project GIS;
— Topical reports and the site survey report from the previous stage, including the list of candidate areas/sites and related documentation;
— Information collected previously but not used at the site survey stage;
— Updated version(s) of high level policy documents;
— Updated version(s) of applicable regulatory and legal requirements, if available.

6.3. PROCESS OF THE SITE SELECTION STAGE

Usually the site selection stage directly follows the previous site survey stage. Funding and resources are usually committed for both stages so that they are conducted as a continuum.

There may be a ‘grey’ area at the end of the selection process, from the moment at which the decision is made regarding the selected site(s) to the moment at which the site is finally procured and secured. The duration of the procurement of the land for the site will depend on a number of factors, from negotiation of the land price with the owner to completion of the legal process for procurement and from formal registration until the owner/operator is in possession of the land.

In general, the process to be followed is constituted of the sequential implementation of a number of steps. A basic scheme of the process followed in this stage is represented in Fig. 7 and described below, with details provided in the following sections.

The process consists of the following steps:

— Updating of the project plan, incorporating the lessons learned from the previous survey stage and introducing the necessary modifications in accordance with the experience gained from that early process.

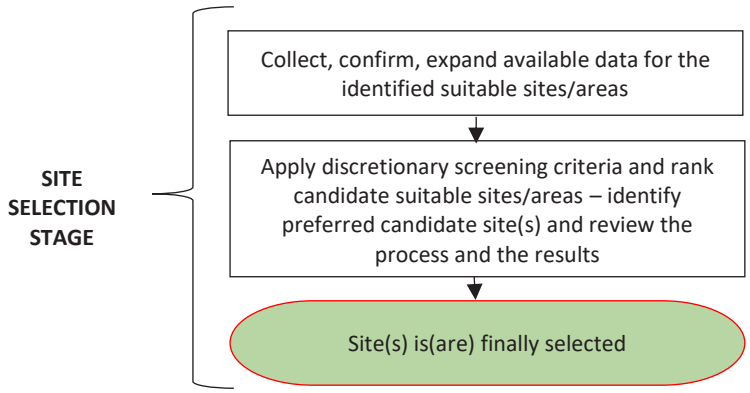

FIG. 7. Scheme of site selection stage as part of the siting process performed in Phase 2A (extracted from Fig. 5).

— Review and analysis of all available data, information and reports elaborated from the previous survey stage. Particular attention ought to be paid to those candidate areas that were considered suitable at the site survey stage, but not enough information was available for a thorough assessment of some attributes to be used for applying the discretionary criteria.
— Planning for the execution of additional investigations and studies aimed to expand the available data, as may have been identified in a gap analysis.
— Collection of additional data as identified, defined and planned.
— Application of the discretionary criteria, comparison and ranking of candidate sites with due justification, and records of the reasoning and judgements to be made. Identification of the preferred site(s) as the final output of the step.
— Independent review of the process implemented, tasks performed and results obtained.
— Preparation, review, revision and issuance of the site selection report.
— Preferred site(s) presented for final decision.
— Decision on the selected site(s).
— Obtaining control of the land with respect to future uses for the site(s) most likely to be finally selected for the NPP.

6.4. ATTRIBUTES AND CRITERIA FOR THE SITE SELECTION STAGE

During the site selection stage, in principle, the same list of attributes prepared for the previous site survey stage is to be used (see Sections 4.1 and 5.6). However, as part of the updating of the project plan, some additional attributes may be incorporated or cancelled with respect to that initial list. For example, the cadastral regime and data for each of the candidate sites and the legal aspects related to land procurement may be considered as discretionary attributes during the site selection stage.

In the site selection stage, the discretionary criteria discussed in Section 4.2 are used for site ranking. The candidate sites are ranked with respect to how well they fit the discretionary site criteria from a site development and business perspective. It is necessary to balance the presence of unfavourable characteristics with the costs necessary to mitigate them, as no site will be completely favourable in all respects relative to others. All sites still under consideration have passed the exclusionary criteria filter and therefore are suitable for development of the project.

6.5. RANKING PROCESS

There are a number of options for ranking sites, some of which are commercially available methodologies for ranking any type of selection of choices. For example, one approach is to use the

differential cost that would be required to make each site equal and seek to minimize this parameter. The assumption is made that a site with certain deficiencies, e.g. higher seismic input, will be equally safe as one with lesser seismic input as long as they are both designed to the required level of return frequency (the demand coming from the site characteristics). The negative aspect of the site with higher seismic input is quantified by the cost differential in the design and construction of the NPP for the higher seismic level. It is not necessary to know the design details of any particular plant because eventually the differentials are relative.

Another approach translates quantifiable site characteristics into a common suitability scale expressing preferences for one site over another. This approach can be summarized as follows:

— First, each of the attributes is considered individually and is ascribed a description, which is quantitative wherever possible. The descriptions (referred to as 'criteria') will ideally allow an independent observer to assess every site with respect to that attribute. For example, the distance from the site centre point to the occurrence of the attribute (such as distance to sufficient water, transportation resource, presence of environmentally sensitive species or transmission lines) can be identified. In some cases, a quantitative description cannot be applied but a discrete qualitative description can be developed (such as anticipated degree of local public support, amount of site preparation necessary or amount of necessary local infrastructure development). These descriptions (criteria) ought to be aimed at allowing each site to be clearly described with respect to each attribute using the available information. The descriptions are usually given an ordinal value somewhere between one and five, for example, or one and ten, with the higher number being the best case and the lower number being the worst case. Note that in some cases, distance may be better if shorter (such as distance to transmission lines) or longer (such as distance to sensitive species).
— The next step, which is performed separately, is to compare the attributes to each other and weigh the importance of each to the site decision making process. This is a subjective process and has to be performed by a group of experts knowledgeable in the entire process of the NPP project development and in the importance of the attributes being considered. Again, there are a number of comparison methods in the literature and commercially available to rank the importance of each attribute. For example, the importance of the attribute may be considered in relation to the significance of an error in describing the site, the cost to mitigate or the strategic implications for site decision making. Some attributes may be ranked of equal importance. The weights are usually normalized to a value of one (or one hundred) for ease in handling the further calculations.
— Each site is then evaluated against the criteria for each attribute and assigned the appropriate ordinal value. A grid such as a spreadsheet is often used for this purpose. A spreadsheet will allow the criteria descriptions and weighting as well as the data specific to each site to be shown, so that the assignment of the ordinal value can be clearly understood.
— Finally, a simple mathematical operation is performed (using the spreadsheet) to multiply the ordinal value of the score of the criteria for each attribute for each site and the attribute weight. The scores are summed for each site, resulting in a total weighted score for each site. The highest scoring sites are the best suited for the development of an NPP, with cautionary consideration of the following:
    - The uncertainty associated with the information used to describe the sites, which is the basis for the criteria descriptions and ordinal value assigned to each;
    - The weighting of the attributes.

The results may show that too many sites are closely ranked and further discrimination between sites is necessary. In that case, it is necessary to consider again the descriptions of the criteria (perhaps they do not properly allow differences between sites to be shown) or the weighting of the attributes. For a particularly important attribute on which the final site selection decision is based, very rarely it may be necessary to collect further information to support the decision making process. The objective is to show that a few sites are clearly better than the others. Any of the top ranked sites can then be selected as the preferred site(s), depending on strategic considerations.

6.6. ACTIVITIES

The activities to be carried out during the site selection stage are basically of the same type as the ones executed during the previous site survey stage, i.e. (a) desktop activities, (b) field reconnaissance activities and (c) reporting. However, the analysis of the available data and information on the attributes of the candidate sites may lead to the need to perform specific additional studies, investigations and even some field work (in rare cases) in some of the candidate sites in order to have a balanced knowledge of those critically important attributes for all sites under consideration and comparison. In this regard, it is to be kept in mind that the site selection process will ideally make use of an increasingly detailed availability of data and assessments. These needs ought to be properly identified, and sufficient time and adequate funding ought to be allocated long enough in advance for its timely execution during the stage. That may require that the planning and execution of those additional activities (mainly of the field work type) be initiated during the site survey stage, so that the results and analysis will be available at the site selection stage. As a summary, during the site selection stage the following activities are to be conducted:

— *Desktop activities*: Desktop activities to analyse and incorporate the new data obtained in this stage into the existing organizational structure of the data and information, including input to the GIS, and to perform the ranking and comparison of suitable candidate sites;
— *Field activities*: Specific field reconnaissance and/or field activities, aiming to provide additional data and information to the desktop activities mentioned above, if necessary, and remove uncertainties that may lead to the discarding of sites with otherwise favourable characteristics;
— *Management activities*: Presentation of the comparison and ranking of the candidate sites and suggestion of the preferred site to the NEPIO (or owner/operator) authorities, and decision by the NEPIO (or owner/operator) on the finally selected site(s);
— *Reporting*: As indicated in Section 6.10.

It is not easy to estimate the time required between selecting the preferred site(s) and procuring the land for further work, but it has to be considered in the overall timing of the project. Necessary activities during this time include procurement of the land for the site and securing the site (fences, controlled entrances, access roads, boundary protection measures, etc.).

6.7. MANAGEMENT

In Phase 2 of the Milestones approach, the integrated management system will ideally be implemented. It will have to evolve with time into a robust management system, especially when the site evaluation process is to be conducted. The complexity of the overall programme suggests that personnel with expertise in nuclear power programme development ought to be an essential part of the management structure, as this type of capability requires years of experience to develop. At this stage, a main objective is to keep track of the collected data.

6.7.1. Siting team

The siting team appointed for the site selection stage has the overall responsibility for implementing the project plan and all activities required for this stage in order to achieve the established objectives. The siting team will generally be the same team that conducted the site survey stage for continuity between both stages. Additional expertise, consultants and contractors may be called to participate in this stage.

6.7.2. Project plan and schedule

The project plan previously developed at the site survey stage is the formal approved document used to guide both project execution and project control, and ought to be reviewed before beginning this stage. The project schedule is the basis for the conduct of the work and will ideally be carefully developed and kept updated. The revised version of the project plan ought to be endorsed by the management. The project plan ought to also be presented to the regulatory authority for information.

6.7.3. Integrated quality management

The activities of this stage will ideally be integrated within the overall project quality arrangements and ought to demonstrate continuity with the previous provisions made during the site survey stage. In many cases, the parameters and analyses may not lend themselves to direct verification by inspections, tests or other techniques that can be precisely defined and controlled. In these cases, assessments are reviewed and verified by independent experts or groups. This will ideally also apply to all activities and items associated with nuclear safety issues. In recognition of the risk associated with receiving a later objection on the selected site(s), the ranking process and results ought to be independently reviewed. The comments of the reviewers will ideally be documented and addressed.

6.7.4. Document and data management

Data management requirements for the site selection stage are the same as those defined for the site survey stage.

6.7.5. Review procedure

Decisions to be made during the site selection stage require inputs from many specialized areas, and it is important that the project team and the decision makers have sound advice from those able to provide independent review of key documents and conclusions. These experienced professionals may be obtained from other countries that have successfully conducted the site selection process. The independent peer review ought to be held at the end of the site selection stage. Such a review will decrease the likelihood of the selected site(s) being rejected at a later stage.

The site selection will ideally be based on the final draft report ranking the candidate sites. This report will be presented to the board of managers of the overall programme in order to allow the project to proceed as described in Ref. [1].

6.8. STAKEHOLDER INVOLVEMENT

As discussed in Section 3.4, the involvement of local and national stakeholders is as essential in the site selection stage as in the previous site survey stage. In the site selection stage, the suitable candidate sites or areas will be evaluated in greater detail. This will require the involvement of additional technical, and possibly financial, stakeholders, as well as neighbouring countries if appropriate, in addition to the statutory stakeholders. Associations (such as non-governmental organizations (NGOs)) and the public, whether standalone populations living in the neighbourhood of the future plant or local institutions (communities, counties, districts), as well as all those stakeholders that are not usually linked to the siting/project team by any agreement, could be introduced at this stage to the project. It is appropriate to have an active stakeholder communications programme explaining the process of site selection and the criteria, particularly when and where the different types of stakeholders (including the public) will be involved and how their input will be considered. The involvement of well trusted organizations

(i.e. regulatory authorities for safety and the environment, specific NGOs, etc.) could have an added value impact on the stakeholder involvement and communication project.

It is likely that stakeholder support for an NPP site may vary among the sites being considered, thus explaining and providing clarifications during the site selection stage, especially during screening, comparison and ranking activities, is highly advisable.

In this phase, open and transparent engagement with key stakeholders, including decision makers, the public, the media and neighbouring countries, is to be encouraged and is critical to the long term success of the NPP project. To build and maintain trust and confidence in the nuclear power programme, these communications will ideally address all the issues of nuclear power, nationally and locally, including the benefits and risks of such projects, as well as the commitments and obligations of all parties involved in the nuclear power programme.

Communication with the stakeholders in the selection process of the site for the NPP requires proper and careful handling of the information, the criteria used and the assessment performed in order to keep a careful and delicate balance between the wishes and expectations of the stakeholders and the needs of the nuclear power project. The siting team ought to conduct the analysis and assessments with a deep knowledge of those wishes and expectations, reflecting them properly in the comparison and ranking criteria of the suitable candidate sites.

During the site selection stage, the activities that involve the participation of the stakeholders, and that may change during the implementation of the stage, may include:

— Identifying the key stakeholders and involving other interested parties that are important for the site selection.
— Implementing and adjusting the stakeholder engagement plan as an integral part of the management of the siting project.
— Organizing and supporting a public information office composed of project staff members and advisory and technical review group members, who would be trained to share information and engage appropriately with the public.
— Educating communication staff through training and scientific visits from and/or to similar nuclear facilities for selected parties.
— Conducting community interviews to identify interested and affected parties and to identify membership for a potential community advisory group (e.g. composed of elected and appointed officials, and leaders of community, environmental and neighbourhood groups). This could provide useful inputs to the process that would be viewed as not necessarily being influenced by the applicant's views.
— Strengthening communication channels with surrounding communities and local and regional elected officials, aimed at both aligning the project with their interest(s) (i.e., socioeconomic development) as well as mitigating the impact of candidate sites on their communities. However, one of the key issues while communicating with interested parties is to ensure that this sharing of information will not increase the land procurement cost.

Once the sites have been ranked and the preferred sites identified, more focused activities could include:

— Improving the public participation plan developed in the site survey stage, according to the need for the site(s);
— Establishing information centres within each community that hosts a preferred site;
— Conducting meetings, workshops and open houses at the information centres.

Mutual trust between partners strengthens the sense of community and encourages open and honest communication focused on engagement with the public to fully understand and address their

concerns. The full involvement of regulatory institutions during this phase could add value to the smooth implementation of the process.

Further guidance on stakeholder involvement related to the site survey is given in Section 3.4. Additional information may be found in IAEA Nuclear Energy Series No. NG-T-1.4, Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [21] and INSAG Series No 20, Stakeholder Involvement in Nuclear Issues [22].

6.9. ENVIRONMENTAL CONSIDERATIONS

During the site selection stage, environmental data collected earlier continue to be evaluated. As the candidate sites are further assessed, environmental information about them is assessed in greater detail. Only in very rare instances will ideally it be necessary to perform environmental field studies at this stage.

6.10. OUTCOME AND DELIVERABLES

The outcome of the Phase 2A site selection stage is the comparison and ranking of the suitable candidate site(s) and the presentation of the preferred candidate site(s) by the siting team. The main deliverable of Phase 2A is a site selection report, which may include a site selection summary report and a number of topical reports according to the similarity of the treated scientific, technical, economic and political topics or disciplines. The minutes of the meetings in which decisions were made by the parties involved, as well as the application of the discretionary screening criteria, are part of this report. The site selection summary report, or the full site selection report, ought to include a detailed description of the application of the screening criteria for all investigated sites or areas, including a detailed justification and demonstration of the reasons that led to the ranking assigned to each attribute for each of the candidate sites. All data collected, including maps, drawings, figures and tables, are included, as well as a detailed description of further investigations and studies to be performed in the next stage of evaluation of the selected site(s).

Another important deliverable of this first stage is the implementation of the GIS, which will contain all the data and documents collected and elaborated during the entire programme.

Organizational and management aspects in place during this stage will ideally also be reported for future consideration of the appropriate quality level of investigations, data and decisions.

IAEA Nuclear Energy Series No. NG-T-3.2 (Rev. 1)[8], Evaluation of the Status of National Nuclear Infrastructure Development [34], provides guidance on the summary of the conditions to be presented and demonstrated at this stage.

7. PHASE 2B — SITE CHARACTERIZATION STAGE

7.1. OBJECTIVES

The site characterization stage is the first stage of the site evaluation process and it starts once the site(s)[9] for an NPP is(are) selected as a result of the previously performed siting process. The objectives

[8] Note that although the publication NG-T-3.2 refers to the full achievement of site selection and site characterization, only the output of Phase 2A is considered in these comments.

[9] Herein it is assumed that in some cases, several (usually two) sites are selected for detailed site characterization.

of the site characterization stage, denoted herein as Phase 2B of the phases defined in the Milestones approach, are the following:

— Demonstrate, or confirm, the acceptability of the selected site(s) in relation to the established criteria for safety, nuclear security and non-safety related aspects, including environmental aspects;
— Perform a full characterization of the selected site(s) to a full areal extent/radius sufficient to characterize potential impacts on the site (which depends on the aspect being investigated);
— Derive the site related design parameters for the design of the NPP;
— Confirm the feasibility of implementing emergency plans in case of a nuclear accident;
— Perform a preliminary EIA to comply with environmental requirements as established by the competent authorities of the Member State.

A sound, comprehensive and reliable characterization of the selected site(s) will provide adequate data and information to be used for the design of the installation, as well as a high level of confidence that those characteristics will not affect its safe operation.

The output of this stage constitutes the key basis for preparing the tender documents for the bid process to select the vendor for the NPP project. Having a fully characterized selected site for which all parameters required for design, construction and pricing are well defined prior to the call for bidding will increase the accuracy of the bids and reduce any risks associated with unknowns about the site.

7.2. INPUT FACTORS

The input factors for the implementation of the site characterization stage are the following:

— Information and data collected in previous site survey and site selection stages as they were organized and populated, as much as possible, in the project GIS.
— Topical reports and site survey and site selection reports, as well as all related documentation from previous stages.
— Updated version(s), as needed, of policy documents of the nuclear power programme and the NPP project in accordance with the progress of fulfilment of all requirements of the Milestones approach, including information regarding the technology or technologies under consideration.
— Applicable regulatory and legal requirements. If specific regulatory requirements in relation to site characterization aspects are not available yet, the NEPIO or owner/operator may choose to adopt regulations and/or criteria applicable in another Member State or, perhaps, from the country of origin of the technology, if already known.
— Applicable environmental requirements as established by the competent environmental protection authorities.
— Adequate planning, funding and resources allocated and committed by the nuclear project management, including a realistic estimate of the required duration of the site characterization stage and its correlation with the NPP project's milestone schedule.
— Although at the time of starting the site characterization stage the vendor of the NPP may have not yet been decided and the type of NPP that will be deployed may not be known, it is suggested to make the list of possible reactor type designs under analysis available to the site characterization team. In this regard, and as an input factor, it is suggested to establish a plant parameter envelope (PPE) with a potential range of values of those parameters of the NPP that may affect the selected site.[10]

[10] Documents such as the utility requirements document or the European utility requirements document present a clear and complete statement of utility requirements for the next generation of NPPs, which could be used as generic design basis considerations for developing a PPE.

Accordingly, some general layout arrangements of the planned reactor units may be considered to perform the necessary ground investigation and assess the size of the necessary area within the whole of the procured site area. Usually the plant layout is not yet available and, therefore, the exact location of the units within the site is also not known.

7.3. PROCESS OF THE SITE CHARACTERIZATION STAGE

For embarking countries, the owner/operator organization may already have been constituted at the start of the site characterization stage, or the NEPIO may still be in charge of performing the activities of the programme. During site characterization, the amount of specialized data collected will necessitate separate types of software for managing and analysing the separate data sets. This will add to the overall costs of site characterization; therefore, this is just one example of why only the site(s) most likely to be selected for the project will ideally move into detailed site characterization.

In general, the process is constituted by a sequential implementation of a number of steps, as follows. A basic scheme of the process to be followed in this stage is represented in Fig. 8. This figure does not include the parallel process for developing the EIA:

— The first step is updating the project plan to be appropriate for the site characterization stage, incorporating the lessons learned from the previous stages and introducing the necessary modifications in accordance with the experience gained during the siting process. The updated project plan will ideally include:
  - Review and analysis of all available data, information and reports elaborated from previous survey and selection stages, focusing on the information and data collected in relation to the selected site(s).
  - Establishment of the requirements and criteria to fulfil the objectives of the stage.
  - Planning and scheduling of the stage, considering the possibility of performing the stage in a number of discrete activities in order to comply sequentially with the established objectives and to avoid performing tasks for obtaining results that will not be used if the site acceptability is not confirmed. For example, the following discrete activities can be proposed with the indicated objectives:
    (i) demonstration of acceptability of the selected site(s), as confirmation of the assessments conducted at the siting process stages;
    (ii) assessments to derive the site related design basis (including the beyond design basis case (i.e., in which accident conditions are more severe than those of a design basis accident) and demonstrate the feasibility of implementing emergency response actions;
    (iii) preparation, issuance, review, revision and approval of reporting documents.
  - Definition of the detailed contractual scheme to be used for the site characterization stage in accordance with the contracting policy defined in the high level policy document.
  - Estimation of the required funds, ensuring their availability in the global budget of the NPP project, including an indication of the cash flow needs.
— Updating the structure and composition of the existing siting team from the earlier siting process, to result in finalizing the organization of the site characterization team.
— Contracting services and supplies in accordance with the defined procurement policy and the detailed contractual scheme.
— Execution of the activities of the site characterization project considering the different defined phases of the stage, including site preparation activities (as may be conducted for any major construction project).
— Performing the independent review of the process as implemented, including the review of the tasks performed and results obtained.

— Communicating progress and results obtained with the regulatory body and stakeholders, according to their respective roles and responsibilities.
— Preparation, review, revision and issuance of the deliverables.

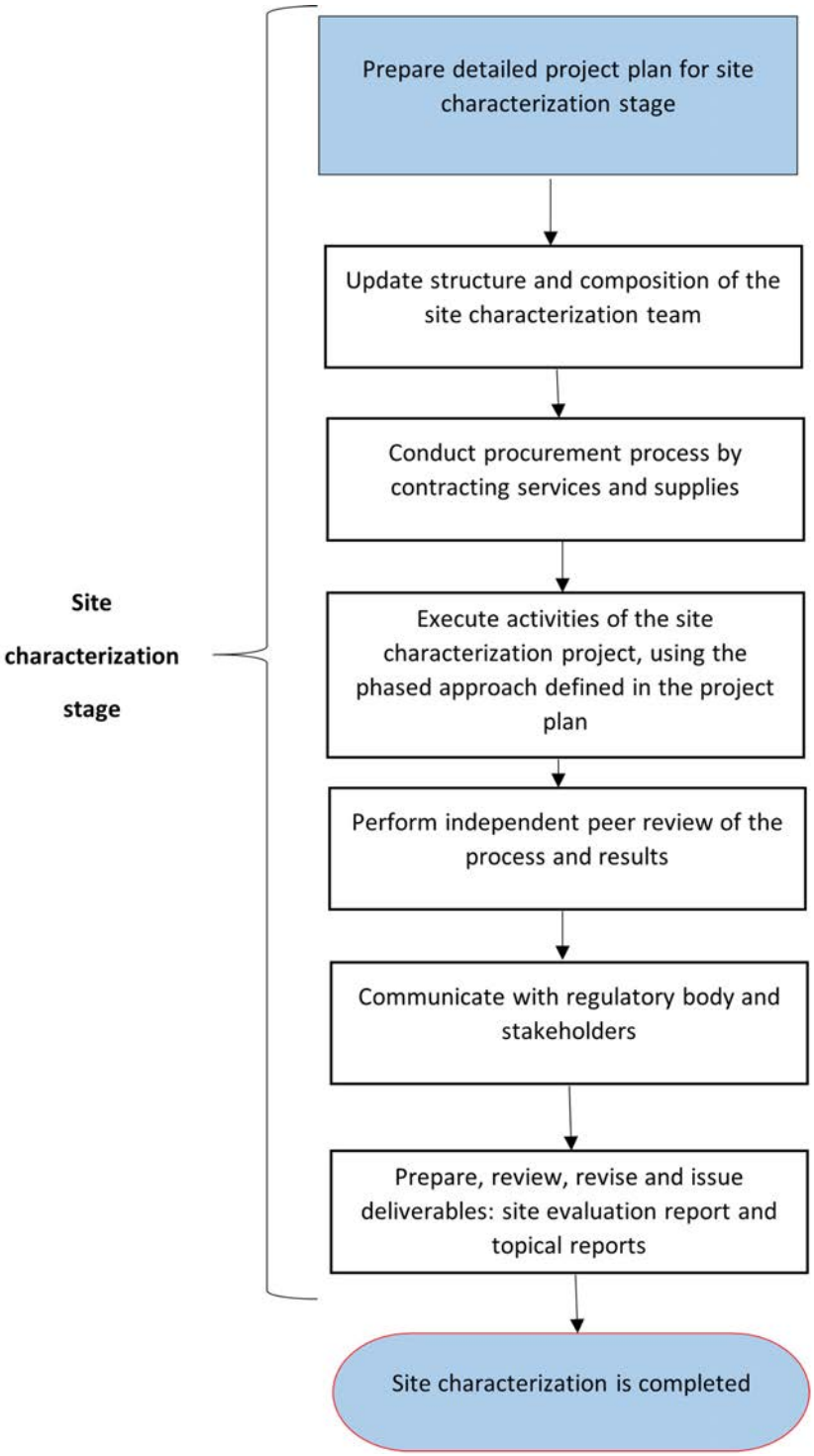

FIG. 8. Scheme of the process to be followed for the site characterization stage.

During the site characterization stage, elements of the EIA will also be performed. Some of the data sets will be shared between these two activities. The EIA process is discussed in IAEA Nuclear Energy Series No. NG-T-3.11, Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes [9].

7.4. ATTRIBUTES AND CRITERIA

In the site characterization stage, the main attributes to be addressed correspond to the site safety evaluation aspects in accordance with the defined objectives indicated in Section 7.1, nuclear security aspects and those non-safety aspects for which detailed site specific data are required for the design and construction of the NPP. The complete list of attributes mentioned in Section 4.1 ought to be reviewed for completeness and validity in accordance with the specific characteristics of the site(s) under consideration. Some of the attributes important in previous stages no longer need to be further evaluated in this stage.

The criteria, methods and approaches to be used for addressing the attributes of this stage will be established in the regulatory requirements. They will ideally be defined in the terms of reference for contracting the supply of services and goods from contractors/subcontractors.

The IAEA Safety Standards for site evaluation provide a detailed description of the recommended criteria, methods and approaches to be used. Generally, the physical (e.g. site, site vicinity, near region and region) and temporal (e.g. prehistoric and historical) scales defined in the IAEA Safety Standards are applied for each of the external hazards under consideration and as corresponds to each case.[11]

7.5. ACTIVITIES

The activities to be carried out during the site characterization stage are substantially different from those activities carried out during the previous stages of the siting process. These activities have to be systematically conducted and documented to a high level of quality. Site characterization information at the onset of the NPP project underpins significant decisions concerning both the facility design basis as well as other safety and control measures. The background and support documentation behind the site related design basis determined at the site characterization stage will be needed over the lifetime of the NPP to help understand and justify the determination of the original site related design parameters, as well as to inform later activities, such as periodic safety evaluations and decommissioning. More specifically, the activities to be carried out during the site characterization stage involve the following activities.

7.5.1. Planning

The planning process includes a detailed identification of all relevant topics, areas, scientific disciplines, potential contractors/subcontractors, participating experts and research and scientific institutes. The required planning of each activity, as well as the interrelationships requiring integrated planning ought to be addressed. All of this ought to be scheduled to fit the NPP milestone schedule. A detailed project plan with a corresponding programme and estimate of resources is the result of this activity.

In planning the site characterization stage, a phased approach for carrying out the numerous activities in the different fields of study (seismology, geology, environmental, hydrology, etc.) allows sequential progress in the fulfilment of the objectives of the stage. For example, a first phase could be defined to conduct all necessary specific studies to finalize the demonstration of site acceptability (suitability). The

[11] It should be also mentioned that a typical decision to be made corresponds to whether to apply a deterministic or a probabilistic approach to assessing the external hazards affecting the NPP site. The definition of what and why one or another of those approaches will ideally be used ought to be well formulated in the project plan, adequately documented and indicated in the terms of reference of the contracts for conducting the external hazard assessments.

subsequent phases would include more expensive or demanding activities that can be carried out once the site acceptability has been demonstrated. Thus, if negative results are obtained, decisions already made on the selected site may be changed or adjusted with a lesser expenditure of resources.

Management activities include the procurement of the goods and services required for carrying out the project plan. The time required for selection of contractors, subcontractors and individual experts will ideally be appropriately allocated. The preparation of the terms of reference required for each of the contractual arrangements ought to be prepared and approved by the management of the site characterization project, and the contracting process needs to be implemented. The IAEA publication GSR-2 [6] identifies the necessity of establishing arrangements with vendors, contractors and suppliers for specifying, monitoring and managing the supply to the owner/operator of items, products and services that may influence safety.

7.5.2. Monitoring networks and stations

Several monitoring networks and stations will ideally be installed from the beginning of the site characterization stage in accordance with the requirements of the nuclear, environmental and other appropriate agencies. A typical list is as follows:

— Radiological monitoring network;
— Geodetic site station, linked to the national geodetic network;
— On-site meteorological station (height sufficient for dispersion studies);
— Local microearthquake network;
— Oceanographic/river hydrograph station(s);
— Environmental monitoring network;
— Hydrogeological network.

The planning of the monitoring networks and stations ought to be performed with a proper estimate of the resources required for the different phases of the implementation, including:

— Equipment specification and procurement, considering the need for spare parts for long periods;
— Equipment delivery, customs clearance, installation, calibration and activation;
— Construction of support and housing facilities for the network equipment;
— Considerations to avoid damage, destruction or theft;
— Storage of processed data.

Many of these monitoring networks and stations require the availability of power and communications networks at the site(s) and nearby region. Also, many of these networks and monitoring stations may be managed by specialized institutions with whom specific contractual, technical and reporting arrangements will ideally be put in place. Most, or perhaps all, of the monitoring networks will need to be in operation during the lifetime of the NPP.

7.5.3. Field work and laboratory investigations

A substantial number of field work and laboratory investigations are to be conducted during the site characterization stage, in accordance with the work plans defined in the project plan and intended to fulfil the objectives indicated in Section 7.1. Among them, the following activities are the main contributors to the cost of the site characterization stage:

— Terrestrial topography survey, mainly conducted, for example, through a LiDAR campaign.
— Bathymetry survey for coastal sites, to be coordinated with the terrestrial surveys.
— Geological mapping and geomorphology, including reconnaissance visits if so required.

— Geophysical surveys according to the specific site characteristics and the need to collect detailed information for assessing natural hazards, e.g. magnetic survey, gravimetry survey or high resolution seismic reflection/refraction profiles. At coastal or near coastal sites, the need to perform offshore geophysical surveys will ideally be defined and coordinated with terrestrial surveys, and care will ideally be taken that terrestrial and offshore campaigns are of different character.
— Geotechnical studies at the site vicinity and site area, to determine the soil parameters and profiles. The detailed specification of the borehole drillings to be executed (number, depth, either continuous or punctual sampling techniques, parameters to be determined, etc.) ought to be part of the project plan, and attention will ideally be paid to the qualifications of the potential contractors/subcontractors and their experience in conducting such investigations in similar geological environments. The geotechnical work to be performed at this stage ought to be distinguished from the detailed geotechnical investigations to be performed later, at the design and construction stage, by the vendor.
— Geotechnical and geochronological (age dating) studies at laboratories. Attention ought to be paid to the capabilities of local laboratories for performing the required studies. Foreign laboratories will ideally also be identified in relation to the required qualifications and availability, recognizing the tight milestone schedule and the high demand for these very specialized services.
— Hydrogeological and hydrological studies (generally continuous monitoring), including data on permeability and porosity, groundwater measurements at the site to monitor the groundwater levels and pressures in the appropriate aquifers during both seasonal and yearly fluctuations and during storm events.
— Meteorological studies, including extreme values for air temperature, wind speed, precipitation (liquid equivalent), and snowpack; rare phenomena including lightning, tropical cyclones, typhoons and hurricanes, tornadoes, and waterspouts; and other phenomena that have the potential to give rise to adverse effects on the safety of a NPP including dust storms and sandstorms, hail, freezing precipitation and frost related phenomena.
— Environmental studies including in the immediate vicinity and to a distance to account for possible effects, including flora and fauna in water and on land; with particular attention paid to rare, threatened and endangered species as well as those of economic value.
— Socioeconomic and demography studies and surveys designed to provide information on current populations and growth projected over the lifetime of the facility including sensitive populations.
— Preliminary industrial, communication and transportation facilities studies.

7.5.4. Analysis and assessments

The analysis and assessments to be performed during the site characterization stage will ideally cover all attributes required, as defined in the project plan. The analysis and interpretation of all data collected from the field work, from laboratory investigations and from the publicly available technical and scientific literature forms the basis of the assessment.

It is to be remembered that there is a need to consider the evolution of parameters with time. This may be of prime importance for safety, as well as for the continuing uninterrupted operations of the NPP. Parameters may change with time as a result of such issues as droughts resulting in lack of cooling water, climate change and sea level changes, increasing importance and frequency of tornadoes or population increase and growth in industrial activities.

7.5.5. Reporting

Numerous reports will be delivered at the end of the site characterization stage, as indicated in Sections 4.2.3 and 6.10. Interim progress reports may also be generated during the execution of the tasks, and numerous documents will be produced by many parties during this stage (e.g. main contractor, subcontractors, specialized institutions, laboratory reports, consultancy firms, individual experts, governmental and NGO organizations, stakeholders). All of these will ideally be read, analysed,

processed, distributed, accepted or approved, revised and ultimately archived by the site characterization team. Moreover, the entire report development and preparation process requires significant efforts to ensure that due record is kept of all decisions, changes, deviations and corrections.

7.6. MANAGEMENT

The activities involved in the site characterization stage require that their implementation be conducted within a robust integrated management system. Significant contracting controls will be required because of the amount of work to be performed and funding to be managed. Thus, a full project management approach is advised, including technical management, scheduling, contracting, cost control and risk analysis. Periodic reviews of the progression of work will ideally be performed with complete reporting to the higher management of the NPP project.

At the site characterization stage, the key issues that ought to be considered in the management of the activities are identified and highlighted as follows.

7.6.1. Multidisciplinary, interdisciplinary project, management complexity

This type of project requires the expertise of many different disciplines, some of which may not be initially aligned as to data collection and analysis requirements. Ultimately, the project team has to reach consensus on the interpretation of the data and the suitability of the site for the NPP. Therefore, a well organized site characterization team ought to be in place, working within a clear organization chart under the supervision of the project manager and in close cooperation with the NPP project proponent. Team members will ideally have well defined responsibilities. This team will monitor a large number of subcontracted activities with the objective of obtaining high level properly analysed data and consensus conclusions.

7.6.2. High level of scientific and technical content

The level of scientific and technical content of the studies and investigations to be performed in this stage is high and requires qualified specialized experts in each of the necessary fields. Nuclear quality assurance requirements are among the most stringent known and the data sampling program has to be designed so as to enable collection of suitable, high quality data with known uncertainty in the collection and analysis of the dataset.

7.6.3. Interrelation between site characterization and the EIA activities

During the site characterization stage, a preliminary EIA ought to be performed through a complex interdisciplinary process that requires the collection and evaluation of data to be used and applied to both the characterization of the site and the EIA. Ecological data (field environmental studies) are collected and analysed by specialized experts who may need to be licensed or prequalified by the country's environmental agency. Most of these data are also used by the public communications managers, the NPP vendor and others. Collection, analysis and maintenance of the data is typically integrated with other types of data collection and is under the responsibility of the site characterization team.

As noted above, the data are used to complete many objectives, but the underlying databases will ideally be consistent. Therefore, the site characterization and environmental groups have to be closely integrated throughout the entire project, including the planning, team composition and transfer of data. At the end, the results ought to reflect this integrated role.

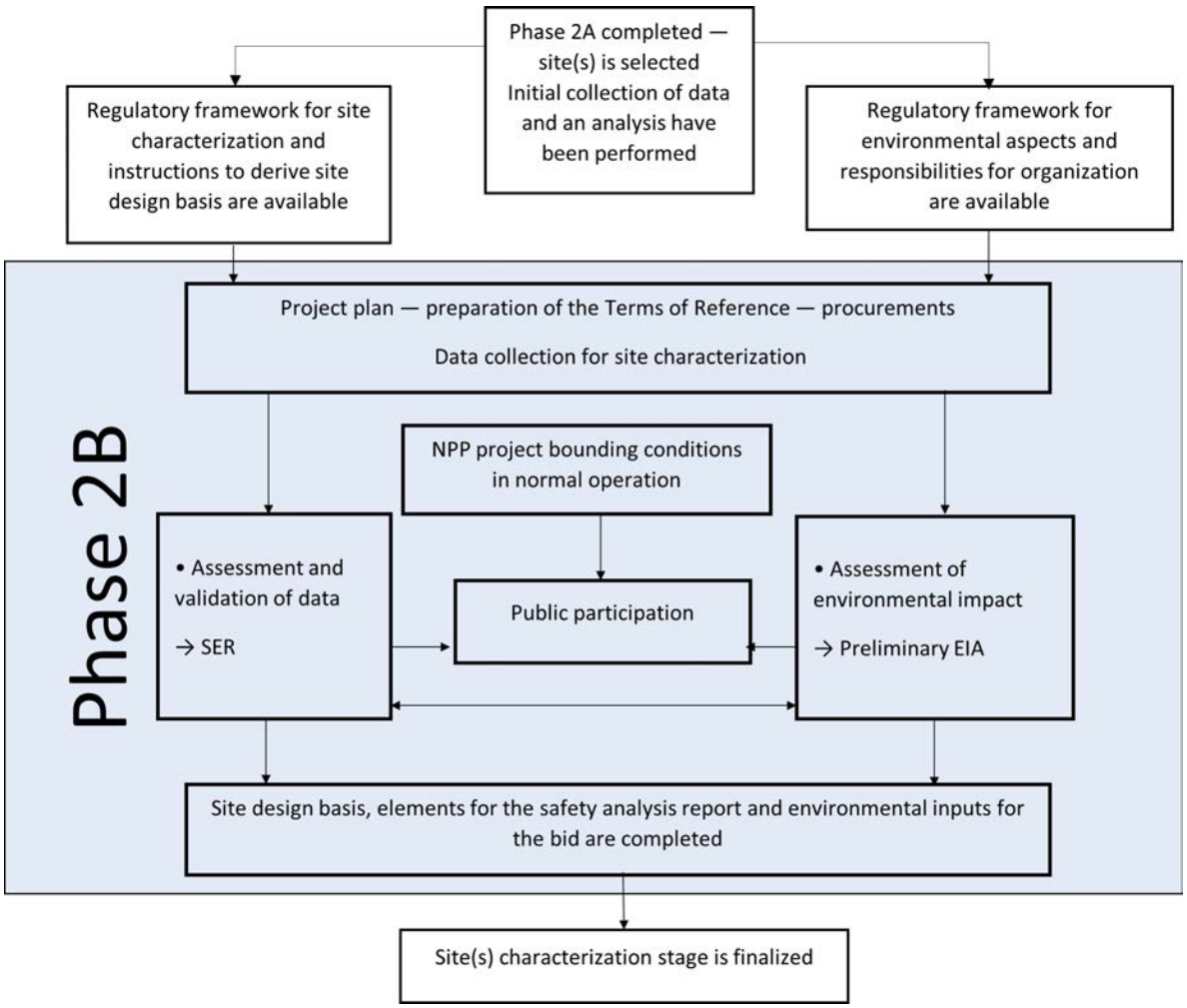

FIG. 9. Interrelation between site characterization and EIA activities in Phase 2B.

As a summary, the main activities to be achieved during Milestone Phase 2 in relation to the site are:

— Preparation of terms of reference governing data collection as required for site characterization and EIA;
— Execution of both assessments to fulfil the objectives defined in Section 7.1;
— Preparation of the related final deliverables for both the SER and the preliminary EIA;
— Consultation with the public (local communities).

Figure 9 illustrates the links between the four activities. Care ought to be taken to optimize efforts and coordinated activities in order to avoid duplication and inconsistencies among the different documents as they are prepared.

7.6.3.1. Project cost, planning and funding

The costs of the activities to be carried out during the site characterization stage are significant. Interaction with the regulatory body is also relevant for the success of the process and delays may have an impact on the whole NPP project schedule. The budget estimate will ideally consider contingencies resulting from the uncertainty of site conditions affecting data collection and corresponding assessments,

as well as unexpected additional investigations and other delays. The funding may need to extend on a multiannual basis (one to a few years) and will ideally be agreed from the beginning of the stage.

7.6.3.2. Procurement of services

A large part of the activities will be subcontracted within the overall responsibility of the site characterization team (or at this stage, under the responsibility of the overall project team). The definition of the work packages for conducting the activities and allocation of the work to either a general contractor or specialized contractors, whether experts or institutions, ought to be discussed and defined from the beginning in the site characterization project plan. The preparation of the detailed technical, economic and planning specifications of the outsourced activities of this stage will therefore fall under the responsibility of this team. Objectives, schedule, resources and risks will ideally be reviewed by the team and adequately incorporated into the tender documents. An important issue will be to specify the quality assurance requirements for providing the services and an auditing function by both a technical team and perhaps the regulatory body. The procurement activities fall under Requirement 11 of the IAEA publication IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety, General Safety Requirements [6] in the section on management of the supply chain. Detailed guidance is given in the IAEA Nuclear Energy Series NP-T-3.21 [35].

7.6.4. Site characterization team

The team in charge of this stage will be named the site characterization team, and it will have the overall responsibility for implementing (either directly or through subcontracting) the activities for this critical stage to achieve the objectives mentioned in Section 7.1 above. By this time, the site characterization team ought to be integrated into the owner/operator organization. The site characterization team will ideally report to a senior director of the nuclear power programme of the owner/operator organization and ought to be given appropriate time and resources (financial, accounting, human, project control and logistic) to carry out the necessary activities.

The site characterization team may be composed of perhaps around 20 professionals. This team will have the responsibility to contract, manage and monitor a significant number of internal and outsourced activities in different scientific and technical fields. The team may be part of a larger institution, which will provide support such as administration, human resources management, procurement and accounting. In some cases, the group is a virtual team under matrix management, though at the site characterization stage it is suggested to constitute an integrated dedicated team working in close collaboration with other fields of the NPP project. It is important that the roles and responsibilities of each team member are defined and approved by the NPP project manager.

7.6.5. Project plan and schedule

The site characterization project plan will ideally include a detailed list of activities to be performed, schedule, budget and risk management aspects. It will be approved by the entity in charge of the NPP project, either the NEPIO or the owner/operator. Noting the potential high impact on the future of the project (in terms of cost, delays and even safety), the project plan ought to clearly guide both project execution and project control.

As part of the general planning of the site characterization project, a detailed schedule of all activities to be performed by the different groups will ideally be prepared by the site characterization team. A key aspect to be addressed for such a purpose is the total expected duration of the site characterization stage, considering a balance between the needs of the overall NPP milestone schedule and a realistic estimate

of the duration of this stage to comply with the defined objectives. In this regard, the following examples may help to understand these issues:

— The on-site monitoring of meteorological, hydrogeological and environmental parameters requires at least one full year of records to cover all seasons, in order to record seasonal variations. Additionally, time is required for procuring the monitoring installations and their equipment, including construction (e.g. meteorological mast, wells), installation, calibration and testing prior to being placed into full operation. Additional time of approximately 20–24 months is required for the tasks of procuring, commissioning and processing the data (including quality assurance activities) and presenting results. Some regulatory agencies want more than one year of base data, which will ideally be understood and considered in the project schedule.
— A complex seismic study in a seismically active zone may take in the order of three years to complete.
— The procurement of services and goods involves sequential tasks to prepare the technical specifications, define the bidders list, execute the bidding process, evaluate the submitted bids and assign the contracts. The uncertainties associated with these activities ought to be carefully treated to avoid delays that will seriously affect the successful completion of the procurement process.
— Many activities are of sequential type, one being the input to the next. Although parallel tasks can be performed in some cases, the critical path is defined by the tasks that will ideally be performed sequentially.[12]
— A critical aspect is the execution of laboratory testing, particularly geochronological age dating analysis at specialized laboratories.
— Permissions and authorizations for conducting field work, e.g. geophysical and geotechnical field work, may be an unpredictable factor with a large amount of uncertainty in its estimate. Attention ought to be paid to the need for obtaining permissions from environmental and governmental agencies. This will ideally be under the responsibility of the NEPIO or owner/operator.
— Reporting is a critical phase, since all topical reports and the final SER are extensively reviewed, revised and approved by many parties, e.g. the report originators and independent reviewers, the site characterization team, the management of the owner/operator organization and the regulatory body.

There are numerous issues that pose significant risks to the budget and schedule of the project. Considerable effort needs to be devoted to understanding and identifying the potential risks and minimizing or eliminating them through proper project planning, etc. (see Section 3.2). The conduct of the work and the overall schedule are also dependent on the number of resources, as well as the team's skills and experience in completing similar work.

Considering all those factors, the duration of the execution of the site characterization stage will ideally be realistically estimated as more than 20 months. Typically, the duration may range from 24 to 30 months for a full site characterization project, until approval of both (i) the final SER and (ii) the preliminary EIA report by the nuclear regulatory authority and the environmental regulatory authority, respectively, noting that the nuclear regulatory authority may review both the site evaluation and the preliminary EIA reports. Other federal and local authorities may also be involved in reviewing these reports, and if the reviews are sequential in nature (i.e. the review of one authority is completed before another authority begins), additional time has to be allotted. That estimated duration does not consider the time required for procurement of the goods and services, as well as all permissions for site access and activities; nor does it include time for review by the regulatory authorities and the typical requests for additional information, which may involve additional field work and analyses. It should also be said that it is highly dependent on the adopted contractual scheme and the managerial and specific adopted review approaches.

[12] One example is the collection of the LiDAR data and the geological mapping of the site vicinity and near region areas, to be followed by the geophysical and geotechnical field work. LiDAR is a surveying method that measures the distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor.

7.6.6. Integrated quality management

The activities of the site characterization stage will ideally be integrated within the overall project quality arrangements. The activities that are entailed in the integrated quality management within the integrated management system will be standards for the collection, processing and analysis of the data, validation and verification procedures, and so on.

7.6.7. Document and data management

Most of the data collected during this stage could be later incorporated into the chapter on the site description of the SAR; as such, the quality and traceability of the data are of prime importance. Development of the SAR is discussed in Safety Guide No. GS-G 4.1, Format and Content of the SAR for Nuclear Power Plants [36]. Data and document control measures, as discussed in Section 3, will ideally be fully implemented by this point.

7.6.8. Review procedure

The data and results of the site characterization stage ought to go through an independent peer review process, both to comply with nuclear safety requirements and to take into account the potential impact of the results of this stage on the direct costs and planning of the NPP project. For some topics, such as the assessment of natural external hazards (e.g. earthquakes, tsunamis, volcanic hazards), a standardized review process may be regulated, or international or national best practices could be endorsed and applied by the site characterization team.

7.7. REGULATORY FRAMEWORK

7.7.1. Regulations and guidance for site evaluation

In general, the detailed full characterization of the selected site(s) for the NPP will ideally be initiated with clearly established regulatory requirements in correspondence with the objectives to be achieved in this stage. These regulatory requirements are one of the input factors to be available at the beginning of the site characterization, and they ought to include both of the following:

— *Demonstration of site suitability*: The established acceptability (or exclusionary) criteria, including the list of exclusionary attributes and the compliance criteria in terms of distance, age or any other adequate parameter as necessary, ought to be confirmed by the regulatory body.
— *Site related design basis for the design of the NPP*: To satisfy this objective, the regulatory requirements for the derivation of the site related design basis will ideally be made available to the NEPIO or owner/operator and to the site characterization team.

However, in Phase 2, for embarking countries, these regulatory requirements may have not yet been established when they would be required. It should be again emphasized that there are significant risks to the budget and the NPP project schedule in performing the site characterization stage if the specific requirements of either regulatory or non-regulatory character are lacking, thus leading to a delay in providing the input of the site parameters required for design of the NPP. If they are not defined yet, the results of the stage will be limited to the assessment of the external hazards, with no definition of the site specific design parameters as required for the Member State. A way to deal with this issue is for the site characterization team to propose to the management of the NEPIO or owner/operator organization a set of specific criteria that may be adopted based on similar regulations in another Member State or in the

countries of origin of the potential vendors. The proposal will ideally be presented to the regulatory body and it is suggested to get an agreement on this critical issue.

7.7.2. Site licensing process

The results of the site characterization stage play a significant role in the licensing process of the NPP programme. Essentially, there are two approaches for the site licensing process, as follows:

— Approval of the site by the regulatory body through issuance of the 'site licence' before authorization for construction is obtained. In this approach, the SER and topical reports are essential elements for the issuance of the site licence. Based on such documents and following a (usually lengthy) process of review, revision and approval, the regulatory body will approve the site for NPP construction.
— Approval by the regulatory body of the NPP construction with approval of the site in the same process (i.e. a combined approach with a combined licence) as issuing the construction licence/permit. In this approach, the SER and topical reports are also essential elements for the issuance of the licence, but they are summarized in the chapter on site characteristics (typically Chapter 2) of the SAR. Based on such documents and following the process of review, revision and approval, the regulatory body will approve the site for initiating the NPP construction.

For both approaches, the site characterization stage will provide the required input in the form of topical reports, the SER and specific parameters of the site related characteristics. The timing and the participation process by the regulatory body are different for each of them, and this is to be properly considered in the planning, execution and delivery of the deliverables of this stage.

7.8. STAKEHOLDER INVOLVEMENT

As the site characterization stage is being conducted at the specific selected site(s), the stakeholder involvement process will ideally become even more interactive, and activities and programmes are to be accordingly tailored to the characteristics and features of this stage. Some enhancements to earlier plans may occur as the finally selected site(s) are publicized. Networks ought to be refined and more formalized mechanisms for soliciting stakeholder input will ideally be devised and implemented. Activities ought to include the initiatives resulting from Phase 2A related to the site selection stage, as well as additional efforts, such as:

— Formally designating a site specific advisory or working group on the activities related to the site characterization; within this group, designating a spokesperson to communicate with the media and public.
— Tailoring the stakeholder involvement plan under implementation to the site characterization activities.
— Ensuring that site characterization activities are included within the stakeholder involvement coordination plan.
— Starting a site specific newsletter, hotline, web site and other communication devices.
— Fully including the regulatory body in the stakeholder involvement and communication mechanisms in the implementation of site characterization activities.
— Including neighbouring countries, technical institutions and organizations in the stakeholder involvement and communication mechanisms in the implementation of site evaluation activities. This is of utmost importance if the country is within a subregional integration organization.
— If the power plant is already selected, involving NPP manufacturers, competent institutions and/or owner/operators and regulatory bodies of countries that are using the same plant in the project.

Regulatory bodies, government bodies and stakeholders will always request additional information, and it is important that all such communications are logged and that information provided is always consistent. Neighbouring countries might also request key information, and it is important that all such communications are consistent with the full scale development of the project. Key mechanisms for such communications will ideally be established using optimal established mechanisms (commissions, regulatory institutions, ministries, including the ministry of foreign affairs, etc.).

It is also important that general education related to the nuclear programme be introduced into the education system, even at the primary school level, especially in the nearby regions of the selected site(s). Accurate, factual information on nuclear issues ought to be made available and easily accessible to all teachers. Among the basic facts to be discussed openly are information on the potentially harmful consequences of the normal operation of various nuclear facilities and of abnormal events and accidents that either have occurred or are reasonably credible possibilities. The estimated consequences of such an accident and the means for limiting consequences and probabilities need to be discussed in simple terms. The relevant publications to be consulted during this activity are IAEA Nuclear Energy Series No. NG-T-1.4, Stakeholder Involvement Throughout the Life Cycle of Nuclear Facilities [21] and INSAG Series No. 20, Stakeholder Involvement in Nuclear Issues [22].

7.9. ENVIRONMENTAL CONSIDERATIONS

The detailed preliminary EIA for the NPP project is completed during Phase 2 of the milestone schedule using data and assessments obtained during this stage. The preliminary EIA is used to estimate the magnitude and characteristics of the impacts to human health and the environment from the project, using data from the PPE where plant specific information is not yet available. Later, when plant specific data are available, they can be compared with the PPE data, and if the PPE data are bounding (the plant specific data fall within the boundaries of the PPE data), then the EIA need not be revised, although some regulators may require a plant specific update in the final EIA.

The assessment is performed by identifying the gap between the baseline condition without the project and the projected environmental quality condition due to project implementation, within a defined period of time and using the required methods for estimating the impacts. The methods will ideally identify the impact flow mechanisms among the various environmental components, directly or indirectly, during the construction, operation and decommissioning phases.

7.10. OUTCOME AND DELIVERABLES

The outcome of the site characterization stage is the full and detailed determination of all site related characteristics of the selected site(s) with the intention of fulfilling the objectives indicated in Section 7.1.

The deliverables of this stage are an impressive amount of data and assessments that ought to be organized in numerous documents, as follows:

— A SER, including maps, drawings, photographs and videos.
— Topical reports as supporting documents for each of the topics or fields addressed during the stage, including maps, drawings, photographs and videos.
— Preliminary EIA, including maps, drawings, photographs and videos.
— A robust document management system to handle the chain of report generation, reviews, revisions, etc. Web based reporting tools may be considered to handle the large amounts of data, documents, documentation and reports generated in the project.
— An updated site related database organized and populated, as much as possible, in the NPP's project GIS, including also the minutes of decision meetings, the documentation and records related to the integrated management system or quality assurance system under which the investigations and

studies were performed, all the data and documents collected and elaborated during the stage, all documentation related to the review process followed during the assessments, and the records and resolution of non-conformities, etc.

The final reports will ideally be verified as mentioned in IAEA Nuclear Energy Series No. NG-T-3.2 (Rev.1), Evaluation of the Status of National Nuclear Infrastructure Development [34].

8. PHASE 3 — PRE-OPERATIONAL STAGE

8.1. OBJECTIVES

The pre-operational stage has the objectives of (i) confirming the assessments and monitoring the parameters of site characteristics that were performed and determined during the previous stages of the siting and site evaluation processes, and (ii) updating the site related design parameters on the basis of the detailed information of the plant specific design provided by the selected vendor in Phase 3 of the Milestones approach. It will also include support to the site preparation and implementation of the site's physical infrastructure by the owner/operator.

This pre-operational stage is part of the site evaluation process, and it is developed during the Phase 3 of the Milestones approach, either as part of the activities to implement the first NPP in an embarking country or as part of the contracting, design, construction and commissioning of a new NPP in those Member States with existing NPPs in operation. In Phase 3 of the Milestones approach, the owner/operator of the NPP project will ideally be fully in place.

During the pre-operational stage, limited studies and investigations that were performed in previous stages are continued after reaching Milestone 3 and during the design and construction of the NPP, with the following aims:

— Monitor site specific parameters as defined by the established long term monitoring programmes in the different topics and areas, e.g. meteorology, seismology, hydrology, hydrogeology, environmental parameters and conditions;
— Process specific site data obtained from the monitoring programmes and from the detailed site investigations performed by the vendor to confirm or adapt the models used in the assessments of the site related design basis of the NPP and of the EIA;
— Support design and construction needs in relation to the detailed site area investigations (e.g. geotechnical, geophysical, hydrogeological studies) performed by the vendor in Phase 3;
— Support the needs of the owner/operator in relation to site related aspects required for the licensing process, and update and adapt to the detailed information of the plant specific design provided by the selected vendor.

8.2. INPUT FACTORS

The input factors of the pre-operational stage are mainly constituted by the deliverables of the previous site characterization stage, i.e. the following:

— Actual plant layout;
— SER, including maps, drawings, photographs and videos;
— Topical reports for each of the topics or fields addressed during the site characterization stage, including maps, drawings, photographs and videos;

— Preliminary EIA, including maps, drawings, photographs and videos;
— An updated and comprehensive site related database organized and populated, as much as possible, in the NPP's project GIS.

These deliverables will have been used for the bidding process of the NPP and for obtaining licensing approval as established by the regulatory body in the Member State.

8.3. ACTIVITIES

8.3.1. Implementation of site and environmental monitoring

During the pre-operational stage, the main activities include the implementation of the monitoring programmes defined by the site characterization studies that are usually included in the SER as a specific chapter or section, and the EIAs as required the preliminary EIA report.

A non-exhaustive list of the monitoring programmes includes the following networks and parameters:

— Radiological monitoring network;
— On-site meteorological station;
— Local micro-earthquake network in the site's near region area;
— Hydrographic stations for river sites;
— Oceanographic stations for coastal sites;
— Geodetic monitoring network;
— Hydrogeological monitoring network, for monitoring groundwater and aquifers at the site's near region area;
— Geotechnical parameters at the site area during construction of the NPP.

This activity will include the maintenance, calibration and repair of all instrumentation and equipment and the need to keep in force contractual arrangements with equipment and services suppliers. Similarly, if sampling is required for laboratory analysis, this ought to be properly registered and documented. Processing and interpretation of the data obtained has to be performed by qualified experts.

The site team will execute, coordinate and/or supervise, as appropriate, all these activities.

8.3.2. Support to construction and design basis activities

The construction of the NPP project will last many years, covering all engineering and technical disciplines, and leading to a licence to commission and operate the power plant at the end of Phase 3 of the Milestones approach.

The site team will assess the results and data obtained from the ongoing monitoring activities to determine how they fit within the site related design basis evaluated in the previous site characterization stage. The objective of this work is to confirm the already defined site related design basis with the data obtained from the monitoring programmes in operation during the long period of construction and commissioning.

It should be emphasized that during the early phase of the construction of the NPP project, a significant expense is incurred to conduct important geotechnical activities performed at the precise location of the structures and buildings that are important to safety. A huge amount of geotechnical work is performed by the vendor or main contractor in that specific area of the site. On a minor scale, geophysical and local geology work is also included in this phase. All data obtained from such work will ideally be duly processed and interpreted to confirm the site related design basis. If non-conformities or deviations are obtained, specific new studies may be required.

8.3.3. Support to licensing process activities

The site team will support the owner/operator organization groups responsible for preparing, developing and issuing the documents required for the licensing process of the NPP, particularly the SAR and the final EIA reports, which are the main documents for which site related data, information and assessments are obtained during Phase 3.

8.3.4. Preparation of the final EIA report

During the pre-operational stage, the preliminary EIA report prepared during the previous Phase 2B site characterization stage is reviewed and finalized, incorporating the following:

— Adjustments based on new environmental regulations or requirements that have been developed, with which the EIA report has to comply.
— Any additional data obtained from ongoing monitoring programmes, which have to be analysed particularly with respect to effects on existing preliminary conclusions.
— Final data from the vendor organization to confirm that the bounding PPE numbers used in the preliminary EIA are not exceeded by the final data of the selected vendor. If so, the preliminary EIA has to be revised to incorporate the new data. Some regulators require that the final EIA be revised to incorporate the vendor's data even if they are within the bounding numbers used for the preliminary EIA.
— If a non-radiological EIA and a radiological EIA have been separately developed, as may be the case to permit non-radiological construction activities to commence in advance of the nuclear reactor specific activities, then the regulator may require that the two EIA reports be integrated to result in one comprehensive EIA.

While some limited environmental monitoring may be ongoing throughout the life of the NPP project until decommissioning is completed, the EIA report itself is typically not updated after this stage.

8.3.5. Maintenance of the GIS site related and environmental databases

The site related team will be responsible for maintaining the NPP's project GIS, to be further populated with all data obtained and documents delivered as result of all construction and monitoring activities carried out during Phase 3.

8.3.6. Production of the radioactive baseline

Additionally, before any radioactive materials are brought to the site, a study of the site's radiological baseline ought to be conducted, which will enable the owner/operator organization to trace the radioactive impact of the plant during operations, if any.

8.4. MANAGEMENT

At the pre-operational stage, the licensee (i.e. the owner/operator) will ideally be fully in place and ready for operation, including the integrated management system defined in accordance with its roles, responsibilities and functions. The management system and quality assurance of the site related aspects are completely integrated into the operator's system.

8.4.1. Site team at pre-operational stage

The site team will be reorganized as part of the organizational structure of the owner/operator to execute the activities required during this stage. As such, the key issue of the activities is to keep close consistency with the main deliverables of previous stages that were reviewed by the nuclear and environmental regulatory authorities. It is suggested that a minimum number of persons from the site characterization stage be still available to retain knowledge of the historical background of the actions, decisions and results from previous stages.

8.4.2. Document and data management

All documents and data produced during the previous stages, as well as during implementation of this stage, will ideally be stored securely and incorporated into the same unique GIS system of the operator organization in order to be accessible during the whole life of the NPP. Databases that ought to be updated with time (such as through periodic monitoring) ought to be identified.

8.4.3. Review procedure

On the same principles as for earlier stages, review procedures will ideally be implemented as needed, for instance when updating the section on the site characteristics in the SAR for the operations stage.

8.5. STAKEHOLDER INVOLVEMENT

As explained in previous sections, involvement of local and national stakeholders is still essential in this final phase. Considering that one of the characteristics of the pre-operational stage is the full transfer of competencies and data from the site characterization team to the group or unit dealing with site related aspects in the owner/operator organization, the communication activities will now be fully transferred to the communication group or unit of the owner/operator organization.

In this phase and under the overall project communication team, open and transparent communication with all stakeholders, including decision makers, the public, the media and neighbouring countries, is to be encouraged. These communications ought to continue addressing all the issues of nuclear power's benefits, nationally and locally, as well as the risks, commitments and obligations of all parties involved in the nuclear power programme to build and maintain trust and confidence in the nuclear power programme. The group or unit dealing with site related aspects in the owner/operator organization will provide support on site aspects in relation to the communication needs, as required.

8.6. ENVIRONMENTAL CONSIDERATIONS

The environmental programme at this stage is focused on implementing the ongoing monitoring programmes, finalizing the EIA as required due to acquisition of new data (such as from monitoring programmes or from the vendor design details) or changed regulatory requirements, and complying with other pertinent licensing requirements.

8.7. OUTCOME AND DELIVERABLES

The outcome of this stage is that the owner/operator has confirmed the site characteristics, considering the information produced during the construction phase, and it has developed a comprehensive monitoring plan to be implemented during the operation of the NPP.

The main deliverables of the pre-operational stage are as follows:

— A set of specific topical reports containing the answers to questions raised by the regulatory body during the review and assessment of the SAR prepared by the vendor;
— A set of periodic reports, including the results and data collected from the monitoring networks and stations and the assessments resulting from the interpretation of such records and data, incorporated into the operator's GIS system;
— Observations that may be made during site works;
— An update of the site related aspects of the SAR for the operational stage;
— An update of the preliminary EIA to produce the final EIA;
— Contribution to the bidding process and support to the selected vendors and contractors;
— Transfer of the site data to the NPP project team in the owner/operator organization.

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GLOSSARY

candidate sites. A list of sites that appear suitable based on the site survey stage.

intelligent customer. One able to manage non-technical professionals from a position of knowledge.

NEPIO (nuclear energy programme implementing organization). For countries introducing nuclear power, the NEPIO is the organization leading the effort to achieve a nuclear power programme. It is responsible for (i) compiling all the information necessary for the government to make an informed decision on whether or not to proceed with the development of a nuclear programme, and (ii) coordinating and overseeing the development of the necessary infrastructure (including the development of a competent regulatory body and operating organization) to bring the country to the point of issuing a bid for the first NPP project.

nuclear energy/power programme. The nuclear energy/power programme includes all the activities and projects aimed at developing nuclear power activities, entailing sustained attention to many interrelated activities over a long duration and involving a commitment of at least 100 years throughout the installation planning, preparation, construction, operation, decommissioning and waste disposal management stages. A nuclear energy/power programme will require the establishment of a sustainable national infrastructure that provides governmental, legal, regulatory, managerial, technological, human and industrial support for the nuclear power programme throughout its life cycle.

nuclear energy/power project. The nuclear energy/power project includes all activities that aim to build the physical nuclear power installation. This could be for the production of electricity, for seawater desalination or for any other peaceful purpose.

potential sites. Sites within the area of interest that have not been ruled out by the regional analysis.

preferred candidate sites. Those sites that are most suitable based on the ranking analysis and from which the State can choose the sites to implement its nuclear power programme.

ranking analysis. The evaluation of the candidate sites against a wide range of criteria, weighted by their importance, which results in a preferred order reflecting those sites that best meet all the identified criteria.

screening analysis. The purpose of this stage is to reduce the number of sites eligible to proceed in the ranking analysis stage to a few (less than 10) that can then be analysed in detail. This involves either further exclusionary criteria or very simple assessment to identify those sites that are most likely to be suitable.

selected sites. The site(s) chosen for the nuclear power programme as a result of the process of site selection.

siting team. The group of people responsible for developing a siting project.

ABBREVIATIONS

EIA	environmental impact assessment
GIS	geographic information system
INSAG	International Nuclear Safety Advisory Group
NEPIO	nuclear energy programme implementing organization
NPP	nuclear power plant
PPE	plant parameter envelope
SAR	safety analysis report
SER	site evaluation report

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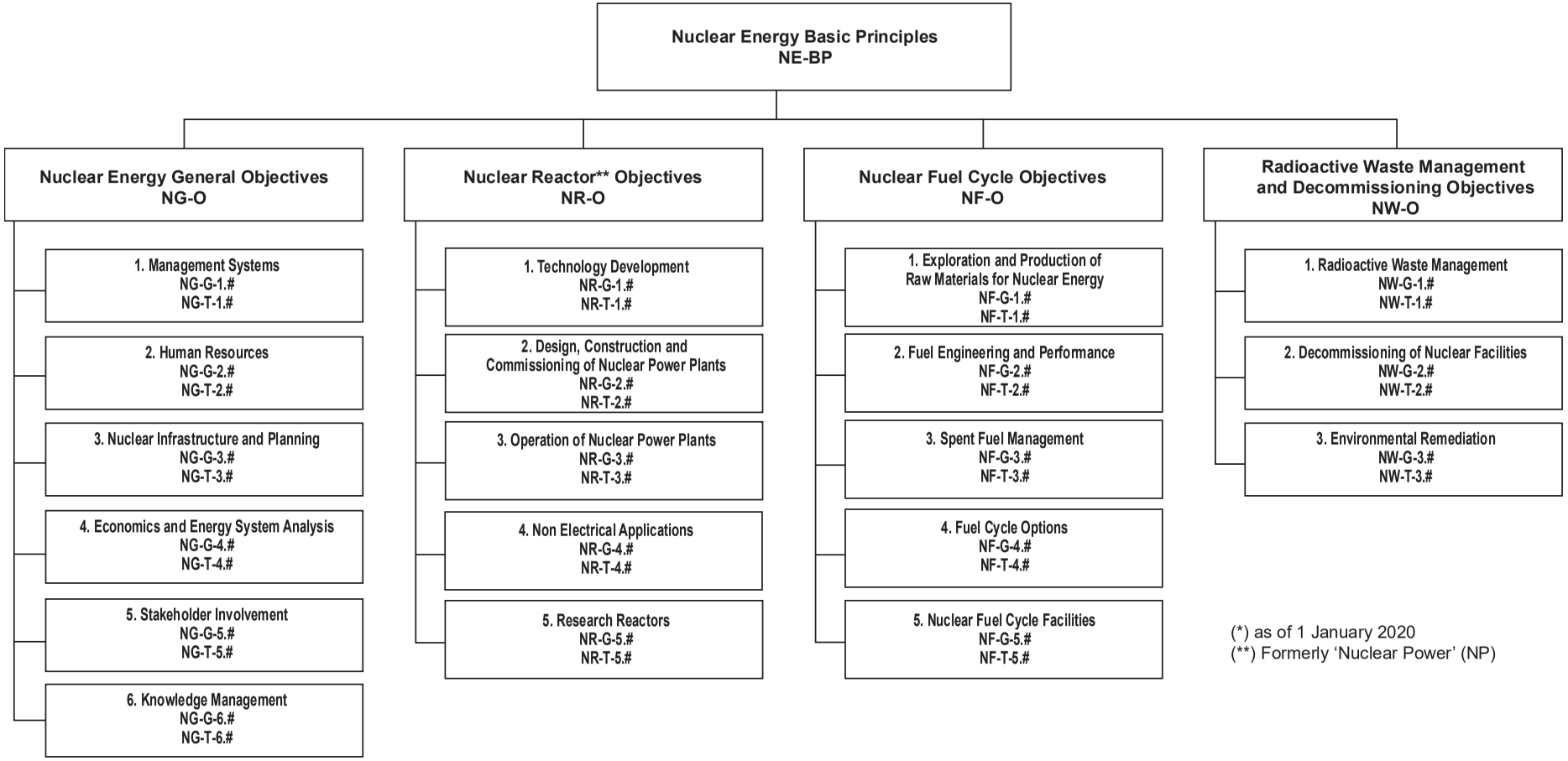

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