IAEA TECDOC SERIES

IAEA-TECDOC-1915

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Considerations for Environmental Impact Assessment for Small Modular Reactors

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International Atomic Energy Agency

CONSIDERATIONS FOR ENVIRONMENTAL IMPACT ASSESSMENT FOR SMALL MODULAR REACTORS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA-TECDOC-1915

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2020

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Printed by the IAEA in Austria
June 2020

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Considerations for environmental impact assessment for small modular reactors / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2020. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1915 | Includes bibliographical references.
Identifiers: IAEAL 20-01319 | ISBN 978–92–0–108420–0 (paperback : alk. paper) | ISBN 978–92–0–108520–7 (pdf)
Subjects: LCSH: Nuclear reactors. | Environmental impact analysis. | Nuclear power plants — Environmental aspects.

FOREWORD

There is renewed interest in Member States in the development and deployment of small modular reactors having an equivalent electric power of up to 300 MW(e). The considerable development work on designs for these small nuclear power reactors aims to provide increased benefits in the areas of safety and security, non-proliferation, waste management, and resource utilization and economy, as well as to offer flexibility in design, siting and fuel options. In addition, research and development are being carried out on innovative concepts for small modular reactors for electricity generation and non-electric applications, such as process heat production, desalination and hydrogen generation.

To facilitate the development of environmental practices, the IAEA issued IAEA Nuclear Energy Series No. NG-T-3.11, Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes, covering mainly large reactors commercially deployable in the near term.

Specific technical characteristics of small modular reactors introduce new deployment possibilities. Under many regulatory regimes, the environmental impact assessment report is a prerequisite for licensing and an important tool to confirm that the potential site is suitable for the future construction and operation of a reactor of this type. This publication discusses the approaches to address specific issues relating to the environmental impact assessment for reactors of this kind. It is expected to be of interest to technology holders, licensing authorities and Member States.

The IAEA wishes to acknowledge the assistance provided by those who contributed to the drafting and review of this publication, in particular A. McAllister (Canada) and M.D. Notich (United States of America), who jointly chaired the technical and consultancy meetings held from 2012 to 2014.

The IAEA officers responsible for this publication were M. Hussain, G. Martinez-Guridi, F. Reitsma and M.H. Subki of the Division of Nuclear Power, and M.O. Phaneuf of the IAEA Environment Laboratories.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Facilitating the safe, secure, and environmentally responsible use of reactors of small and medium size in meeting the energy demand of the Member States is one of the multiple roles that the International Atomic Energy Agency (IAEA) has within its work related to small modular reactors (SMRs). SMRs have the potential to play an important role in global sustainable energy development and can offer advantages to Member States interested in expanding their existing nuclear capacity, as well as Member States embarking on new nuclear power programmes, particularly to those with small electric grids and limited investment capabilities. However, there are challenges to be addressed, among which are licensing of new technologies and public acceptance issues. At present, new concepts of SMRs are under development with various unique features, for example related to generated power, footprint of the SMR site, modular design, non-electric applications, siting locations, construction, refuelling, source term, and waste management.

In this publication, SMRs are defined as advanced nuclear power plants (NPPs) that produce electric power up to 300 MW(e); an SMR has individual modules, and each module typically has a nuclear reactor contributing to the total power. A module may be built in factories and shipped to nuclear sites for installation as demand arises.

Under many regulatory regimes, the environmental impact assessment (EIA) report is a prerequisite for licensing and an important tool to confirm that the potential site is suitable for the future construction and operation of an SMR. Due to the increasing interest in the development and deployment of SMRs, addressing specific issues related to the EIA for SMRs may be of interest for technology holders, licensing authorities and Member States.

An EIA report is a comprehensive description of the current state of the environment, the proposed nuclear project, and the environmental impacts of construction, operation, decommissioning, and abandonment; it also includes environmental management and monitoring programs. The EIA is carried out at an early stage of the licensing process; as such, available information (including engineering design) may not be detailed yet. However, this lack of detail may be compensated by other approaches including a conservative assessment. Another important aspect of the EIA process is public participation, which ensures that various stakeholders' views about the project's impacts are considered.

This publication is the main outcome of four consultancy meetings (11–13 April 2012, 9–11 October 2012, 2–4 September 2014, and 11–14 February 2019) and one technical meeting (28–31 October 2013). All meetings took place in Vienna, Austria.

1.2. OBJECTIVE

The objective of this publication is to provide a source of current information on considerations about EIAs related to SMRs. Within this overall objective, the publication discusses aspects of SMRs that may alter the factors affecting the environmental impacts of this type of plant as compared to those factors from current large NPPs. For practicality, the term 'large reactor (LR)' is used to mean 'large NPP' in this publication.

The publication is intended for use by Member States interested in deploying SMRs and related Environmental Impact Assessments, and other statutory and non-statutory stakeholders, such as governmental agencies, utilities, and current and future owner/operators.

1.3. SCOPE

This publication is intended to cover topics broad in nature, recognizing that certain Member States may evaluate some topics in a different manner or outside of an EIA process or both.

For the purposes of this publication, the EIA of an SMR would consider only the SMR facility itself, and not offsite manufacturing and refueling locations. These locations would be subject to applicable Member State regulations and licenses, as needed. In addition, associated infrastructure, such as transmission infrastructure, access roads and infrastructure, and accommodation for the construction workers, may be addressed to a greater or lesser degree in an EIA for a nuclear facility, depending on Member State EIA regulations and processes; however, for the purposes of this publication only transportation is included.

On the other hand, many of the SMR designs in various Member States are still at a conceptual level. In other words, an SMR is conceptually defined, but it still has to be approved by appropriate national authorities, built and operated. Accordingly, the benefits claimed by SMR manufacturers, such as fabrication of modules offsite and assembling of the modules at the site where the SMR will operate, still have to materialize. The experiences during regulatory approval, construction and operation of SMRs may also result in changes to the SMR designs.

Hence, the technology of SMRs is evolving and at different stages of development in various Member States. This publication offers a summary of environmental impacts that may arise from SMR technology, based on the current designs and state of development of this type of NPP. Therefore, the considerations herein may have to be revised as this technology changes and matures.

It is advisable that this publication is read together with the following publications by the IAEA: "Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes (IAEA Nuclear Energy Series No. NG-T-3.11)" [1] and "Prospective Radiological Environmental Impact Assessment for Facilities and Activities (IAEA Safety Standards Series No. GSG-10)" [2]. These publications provide Member States with guidance and information for performing non-radiological and prospective radiological impact assessment and assist in developing an effective environmental impact assessment process, respectively. If any EIA aspect is not included in this publication, it implies this aspect is already covered by these two references, and no differences are expected for SMRs.

1.4. STRUCTURE

This publication includes one introductory section, and six sections for the considerations in the environmental impact assessment process for SMRs. Section 1 explains the background and identifies the objectives, the scope and the structure of the publication. Section 2 describes the generic approach to the implementation of an EIA process that could be used to support SMR licensing, including examples of established EIA processes in some Member States. Section 3 discusses the main characteristics of an SMR that may affect the contents of an EIA. Section 4 elaborates the implications of characteristics that are specific to SMRs on the potential environmental impacts. Section 5 addresses potential accidents that may result in environmental impacts. Section 6 gives an overview of the alternatives of the EIA process, and Section 7 provides a summary and conclusions of this publication. Finally, a bibliography, by the end of the publication, offers several references that are relevant to the subject of this publication, but that are not explicitly mentioned in the publication.

2. GENERIC DESCRIPTION OF ENVIRONMENTAL IMPACT ASSESSMENT PROCESS

2.1. PURPOSE

The purpose of this section is to provide a generic description of the EIA for nuclear facilities and its relationship to the licensing process to clarify the role of the EIA in the overall regulatory framework. It is important for Member States interested in SMRs to have a regulatory framework that incorporates, as appropriate, the EIA process in a manner that is clear to all stakeholders.

2.2. EIA PROCESS

After preparatory activities within the framework of a nuclear power programme, such as reviewing the adequacy of the Member State's existing background for environmental protection, the first step in a new NPP project is the site selection process. This includes identification of several potential sites, which are evaluated against several criteria such as design suitability, socio-economic and preliminary environmental markers (e.g. biophysical, geological, climate and seismic characteristics), as well as gathering public opinion.

In some Member States, the EIA may be carried out for a few sites. However, since an EIA is an expensive undertaking, in some cases it is conducted after a site has been selected. In general, once the preferred site has been selected, the EIA process is aimed to inform the authorities within a process of making decisions, identifying, describing and assessing prospectively the effects and the risk of effects of a proposed activity or facility on aspects of environmental and socio-economic significance and summarising the opinion of stakeholders. An EIA process for a proposed nuclear facility requires in general the involvement of the facility's developer, relevant governmental agencies, the nuclear regulatory body and several other stakeholders, including, in some Member States, the public.

A typical EIA process can be found in the IAEA publication NG-T-3.11, "Managing Environmental Impact Assessment for Construction and Operation in New Nuclear Power Programmes" [1]. Reference [1] describes this process, and Figure 1 is a composite of two figures from this reference. In this figure, IEI means Initial Environmental Information and ESR means Environmental Scoping Report.

In addition, the IAEA published guidelines for strategic environmental assessment (SEA) for nuclear power programmes [3]. This publication states:

"Subject to national legislative frameworks, an SEA would normally be conducted when developing a nuclear power programme, building on any preceding SEAs for national energy strategies, policies and any associated plans. Such an SEA for a nuclear power programme would then provide the framework for subsequent EIAs. When considering a systematic approach to the development of nuclear energy, higher level SEAs for energy strategies, policies and plans focus on issues such as overall energy needs, the energy mix and, within this, the role of nuclear energy. Subsequent EIAs then focus on implementation details at the project level, when, for example, nuclear power plants or spent fuel storage facilities are to be constructed. In this context, the objectives and main focus of an SEA for a nuclear power programme depend on what is covered in those earlier SEAs, and may also be informed by related EIAs."

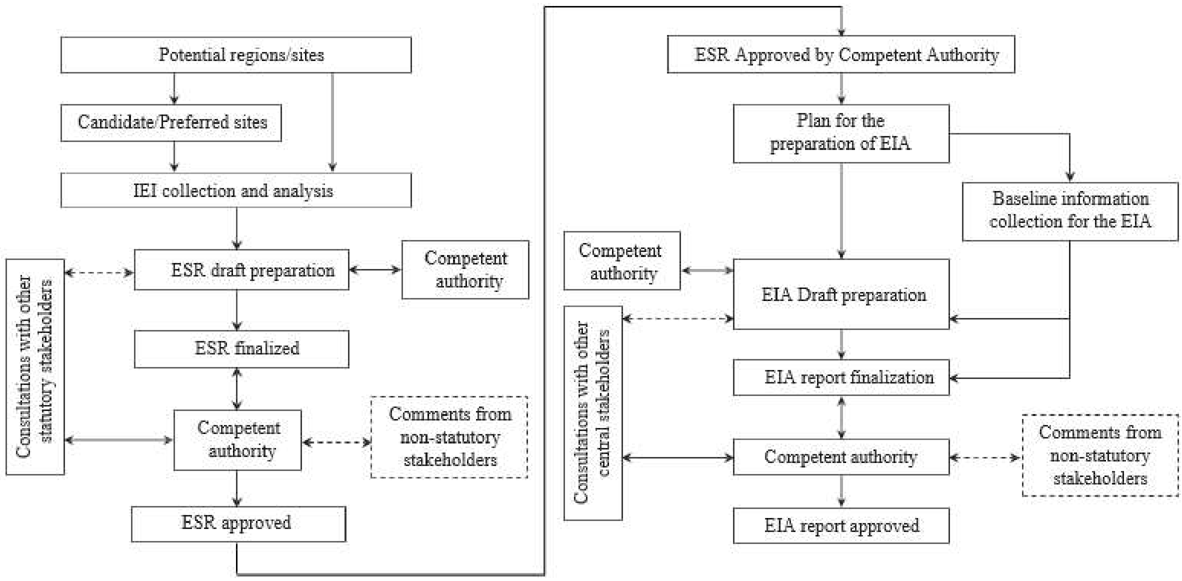

FIG. 1. The EIA process provided by IAEA (adapted from Ref. [1]).

Field work and studies on location are done to determine background conditions. Information of environmental background is obtained for a regional study area that is determined by environmental factors. For example, data related to the aquatic environment will depend on the watershed in the region. Background information is obtained up to several years prior to entering into the regulatory environmental assessment process.

Key elements of an EIA process are scoping and different stakeholders' participation, including the public. Scoping includes the development of the terms of reference and methodology to be used to evaluate data and environmental impacts; and presents the impacts to be assessed and documented in the EIA report. An effective public participation program by the proponent or the regulator or both is essential in ensuring that information is disseminated to the public and the public can provide input. For example, in many Member States with established nuclear power programmes, the public has the opportunity to comment on the EIA report.

Depending on the Member State's process in place, the statutory and non-statutory stakeholders may be given the opportunity throughout the EIA process to comment on various steps of the EIA, including the scope of the EIA and the report from the authority. It is advisable for the project proponent and the authority to encourage public and stakeholder participation in the process as this will foster understanding and acceptability of the project from the early stages onward.

Given that the deployment of SMRs may occur in areas with historically little to no exposure to activities related to nuclear power, public information and participation will be an important component to be effectively integrated in conducting the EIA.

Under many regulatory regimes, the favourable reception by the stakeholders and the approval by the competent authority of the report describing the result of an EIA process is a prerequisite for licensing. Some of the information in the EIA report is used in the licensing process, assuring the regulator that the project impact will be in compliance with the prescribed thresholds and providing the decision makers with adequate information to make an informed decision.

2.2.1. EIA process in Member States with an established nuclear programme

The EIA process is expected to be similar for assessing potential environmental impacts for LRs and for SMRs. Generally, each Member State has specific terms, definitions, systems and methods for conducting an EIA. For example, in the United States of America (USA), the EIA report is termed as Environmental Impact Statement (EIS) and the process is conducted by the Nuclear Regulatory Commission (USNRC) as set forth in the Code of Federal Regulations, Title 10, Part 51 [4]. In Canada, Impact Assessment (IA) is the term for EIA and the Canadian Nuclear Safety Commission (CNSC) is responsible for conducting the process for nuclear projects in accordance with the "Impact Assessment Act (2019)" [5]. In Japan, the EIA process is conducted by the project proponent and submitted to the appropriate authorities for review. There are other numerous different procedures that are implemented by each Member State.

2.3. GENERIC DESCRIPTION OF EIA CONTENT

The purpose of this subsection is to provide a generic description of the contents of an EIA report, and to provide some suggestions when developing such a report.

An EIA is a holistic analysis, encompassing potential radiological, ecological, human health, socio-economic, and other impacts related to the NPP at a proposed site. Such an integrated EIA approach should facilitate the consideration of requirements related to these impacts at the same time and in a balanced, objective manner, as appropriate. The scope of the assessment covers the entire life cycle of a proposed NPP project, from construction to decommissioning. It considers the effect of the proposed project on the environment during normal operations, with separate sections to assess the effects of potential accidents and malfunctions, and the effects of the environment on the project. While an EIA for a proposed NPP is as detailed as possible regarding the construction and operation phases, it typically is only conceptual for the decommissioning phase, describing the generally expected effects of this phase. This is because decommissioning may occur several decades into the future and selection of final decommissioning strategy is not yet complete.

The following non-exhaustive list includes a collection of topics which can be found in most EIA reports for NPPs in different Member States:

(1) Introduction and overview of the project
(2) Project justification and alternatives to the project considered
(3) EIA procedure
(4) Public and stakeholder engagement
(5) Description of the project (project components and activities)
(6) Assessment of alternatives to project components
(7) Nuclear safety
(8) Description of the existing environment (i.e. baseline conditions)
(9) Description of potential adverse impacts during construction, normal operation and decommissioning on:
    - Atmospheric environment (including air quality)
    - Soil quality
    - Aquatic environment (including water quality, quantity and flow)
    - Geology and hydrogeology
    - Aquatic wildlife and habitat (freshwater and marine)
    - Terrestrial wildlife and habitat
    - Human health
    - Landscape and cultural environment

— Transport / traffic
— Socio-economic factors

(10) Mitigation of potential adverse impacts described in (9)
(11) Significance of residual impacts (following application of mitigation measures)
(12) Cumulative impacts
(13) Potential impacts of accidents and malfunctions
(14) Transboundary impacts
(15) Environmental monitoring program
(16) Conclusions

When discussing any NPP, be it small, medium or large, from the point of view of an internationally accepted practice, it is advisable that the EIA content for SMRs will encompass all the areas listed above. However, modifications of this list are up to each Member State depending on specific guidance or requirements (such as regulatory requirements) it may have, and of course, can be influenced by the specific location, technology or life cycle(s) of the project being assessed.

Several points from the list above will be affected by deployment of SMRs as compared to that of large NPPs. They are discussed in more detail in Section 4.

2.4. ASSESSMENT METHODOLOGIES FOR EIA

Generally speaking, the methodology by means of which radiological environmental impacts (e.g., human health impacts and impacts to wildlife) are determined is the same for large NPPs and SMRs, and it is further discussed in the Prospective Radiological Environmental Impact Assessment for Facilities and Activities [2]. For non-radiological environmental impacts, numerous government and private publications are available.

It is often the case that Member States, through their respective regulators, prescribe a certain EIA methodology, leaving the choice of specific models to the EIA developer, as long as the developer can prove their suitability.

2.5. APPROACHES TO EIA

Environmental impact assessments can be performed using different approaches, that is, using either a prescriptive or an approach that is based on risk, or a combination of both.

The prescriptive approach relies on established benchmarks, published in national and international regulations, guidance publications and papers (e.g. water or air quality guidelines or limits, noise limits, etc.). Potential impacts are identified and quantified through calculations or models or both for each contaminant and each receptor. These numbers are then compared to guidelines, limits or other numerical thresholds accepted in the country's legislation, regulation and other recognized documentation to determine the acceptability of the potential impact; values below and above the benchmarks indicate acceptable and unacceptable impacts, respectively. The advantage of the prescriptive approach is that it provides predictable targets for both the regulator and the vendor/operator. The main disadvantages are that it may not consider all possible scenarios and may lead to requirements that are excessively conservative in some areas.

The approach to an EIA that is based on risk uses some established benchmarks but relies on the concept of risk assessment. For each combination of contaminant and receptor, this approach compares measured, modelled or calculated exposure or dose values (environmental values, EV) to benchmark values (reference values, RV) to obtain a risk quotient, RQ.

$$RQ = \frac{EV}{RV}$$

A risk quotient below a criterion indicates no potential adverse effect, and a quotient above this criterion indicates a potential adverse effect. This must then be further analysed to determine the acceptability of this risk. Appropriate mitigation measures may then be considered to try to reduce those potential adverse impacts deemed to have unacceptable risk.

An approach that is based on risk may involve a blend of science, policy and community inputs particularly where there are significant risks to highly valued and protected environmental assets. Community and stakeholder input to the process will be important in these circumstances to ensure the EIA is acceptable to all relevant parties [6].

3. CHARACTERISTICS OF SMRS

The characteristics of SMRs may have specific environmental implications that would be reflected in the development of an EIA report. This section will identify and discuss key specific features that are important when assessing environmental impacts of an SMR.

3.1. SMR TECHNOLOGY ESSENTIALS

Similar to LRs, the current SMR designs are based on the usual materials used for cooling the reactor (e.g. water, gas, liquid metal, and molten salt), and the reactor may predominantly rely on a thermal or fast neutron spectrum in the nuclear fission process. These designs include reactors cooled by water, reactors of high temperature cooled by gas, reactors cooled by liquid metal with spectrum of fast neutrons, and molten salt reactors. For further information refer to an IAEA publication briefly describing advances in SMR technology [7] and the different types of SMRs. This booklet is a supplement to the IAEA's Advanced Reactor Information System (ARIS) [8].

SMRs have specific characteristics that may make them different to LRs in the context of developing an EIA. These characteristics include generated power, footprint of the SMR site, modular design, non-electric applications, siting locations, underground construction, refuelling, source term, and waste management. They are briefly presented in the following subsections, and their potential environmental impact is discussed in Sections 4 and 5. In these discussions, a comparison is frequently made between a single SMR, which may contain several modules, and one LR. While it is not currently common, if a project proposes to deploy several SMRs, then the combined impact of the SMRs will likely be larger than for a single SMR, and the EIA should account for such impact. Similarly, if several SMRs are built over time at a site, then the EIA should be revised accordingly.

3.2. SPECIFIC CHARACTERISTICS OF SMRS THAT MAY AFFECT AN EIA

3.2.1. Generated power

SMRs have lower electrical and thermal power outputs than LRs. For those SMR designs that discharge warm cooling water from the condenser to the ultimate heat sink (UHS), such discharge is expected to be less than that from LRs, thus resulting in a decreased impact on the environment.

3.2.2. Footprint of the SMR site

Primarily due to its small power and compact facility design, an SMR and its associated infrastructure may have a site footprint that is significantly less than that of LRs. As such, SMRs may allow nuclear power to fit in an environmental envelope which is prohibitive for siting LRs, and the relatively small footprint of an SMR has a bearing on the magnitude of many environmental impacts that are expected from this type of NPP.

Land use requirements for SMRs are dependent on the design configuration and site location and characteristics. Compared to LRs, SMRs are being designed to have smaller security zones, exclusion zones and emergency planning zones.

Some SMR designs offer the possibility of manufacturing modules or major components in offsite locations. These new designs built at a factory aim to reduce lengthy construction times. Extensive factory fabrication of structures, systems and components with onsite assembly are intended to simplify construction work, shorten the build time, and could result in smaller construction footprint than for LRs due to the reduced construction infrastructure and equipment requirements. All these factors bring about different biophysical and socioeconomic impacts compared to those for LRs during construction.

In addition, SMRs that are marine based (immersed or barge-mounted) would require less infrastructure on site than a land-based (large or small) NPPs and the reactor is also more likely to be built offsite and moved into position once complete. Only auxiliary and support structures would need to be constructed on land. In exchange, there may be a footprint that is based in the sea that would include different impacts due to construction of underwater structures.

3.2.3. Modular design

Some SMRs are planned to be deployed as NPPs with multiple modules. Due to this possibility, various deployment strategies can be used. Multiple SMR modules could be deployed at a site, either installed at once or incrementally over an extended period. This is relevant to many aspects of the EIA such as alternatives of implementation of an SMR, and assessment of environmental impacts, including accidents (e.g., an accident involving several modules). As mentioned in subsection 3.2.2, Footprint of the SMR site, modules or major components may be manufactured in offsite locations.

3.2.4. Non-electric applications

SMRs lend themselves to more uses than just electricity generation. Heat generated from the SMR can be directed to other industrial applications occurring simultaneously on site. This cogeneration depends upon the SMR types and their coolant temperatures. Potential applications include sea water desalination, district heating and coal gasification [9], as well as process heat production, and hydrogen generation. SMRs that are not cooled by water, such as "High temperature gas cooled reactors (HTGRs)," are more suitable than LRs that are cooled by water when it comes to providing process heat at a high temperature. This capability for cogeneration is relevant in examining alternatives to the project, assessment of accidents (e.g., implications of an event at the co-located facility in the EIA), and other EIA areas.

3.2.5. Siting locations

SMR units can potentially be situated in many more locations than LRs due to their smaller footprint and less dependence on water cooling (especially for those SMR designs that do not require water for cooling the condenser, i.e. cooled by air). They can either be based on land or at sea and may be situated near population centres (if a small exclusion zone is considered acceptable) or close to communities in isolated areas depending on their objective. In contrast LRs are typically based on land, close to large water resources and located away from population centres.

Some Member States have remote regions that can only accommodate SMRs for supplying the demand of heat and electricity since once these SMRs are in place they would be able to function without substantial regional infrastructure and limited accessibility. However, sites in isolated locations may have significant impacts related to infrastructure due to road or railway construction. In addition, for accident scenarios, an EIA would need to factor in emergency preparedness and response times for offsite supporting agencies taking into consideration, as applicable, condition of roads, air transport facilities and weather conditions that could significantly delay offsite response. These considerations influence the types of mitigation approaches that are needed on the site to compensate for offsite uncertainties. In other Member States, it may be desirable to locate SMRs close to populated areas.

A few Member States are pioneering in the development and application of transportable SMRs that are fuelled at a factory and based at sea, including three main types: SMRs that are mounted on a barge, floating mounted on a rig, and based on the subsea. SMRs that are based at sea may need specific approaches for assessment of their environmental impacts. For example, impacts that are based on land (e.g., groundwater, terrestrial ecosystems) may be limited, and more focus may be placed on the impacts to aquatic ecosystems and accidents specific to this marine environment.

3.2.6. Underground construction

Some SMRs are designed to be built partially or completely underground for enhanced safety and security. Impacts to groundwater during the entire lifecycle, and the interaction of ground constituents with buried structures may warrant further investigation in the EIA.

3.2.7. Refuelling

SMRs offer in general two advantages for refuelling the reactors. One is a long refuelling interval and the other is the possibility of replacing the entire reactor vessel containing spent fuel, as described below.

Most SMRs have an average refuelling interval of about 24 months, which is similar to that of advanced designs of LRs. On the other hand, a few SMRs that may be deployed in remote regions or at offshore platforms are likely to have restricted access which may cause difficulties in refuelling the reactors. To address this challenge, the SMRs would need to have a long refuelling interval. Two examples of such SMR designs are a floating NPP that is mounted on a barge with a refuelling interval of 36 months, and a fast reactor that is cooled by sodium and designed to have a core lifetime of up to 30 years without on-site refuelling. This results in substantially decreasing storage of spent fuel on site, and frequency and amount of new fuel delivered into the site. These two factors may reduce the risk of an accidental release of radioactivity to the environment.

In addition, some SMRs are designed to be refuelled by replacing the entire reactor vessel containing the spent fuel, which is different to LRs that replace individual fuel assemblies. This SMR approach may decrease the possibility of refuelling accidents, and hence it also may reduce the risk of an accidental release of radioactivity to the environment.

The required lifetime of the core and refuelling may also be determined by the specific application. An example may be the limited lifetime (typically 20 years) of a mine in a remote location serviced by the SMR.

3.2.8. Source term

The amount of nuclear fuel in an SMR is usually substantially smaller than that in an LR. Therefore, the source term after a severe accident from an SMR (i.e., the amount of radioactive material released from the NPP) correspondingly is typically smaller than that from a LR and can, as a first approximation, be scaled by the thermal power ratio.

SMR designs typically have nuclear fuel of similar enrichment to that in a LR. Accordingly, the types of isotopes in the source term are expected to be similar between SMR and large reactors. A few SMRs have higher enrichments of the fuel to support operation over more than 2 years; in those cases, the source term is expected to be different in terms of both quantity and radionuclide composition for these SMRs. Some SMRs have a larger relative amount of fuel due to a lower fuel and power density (e.g. pebble beds vs. traditional fuel rods). Some SMR designs feature a fuel form that prevent significant fission product releases, further contributing to substantially reduced source term releases.

3.2.9. Waste management

Given the smaller and more simplified design of SMRs compared to LRs, the amount of liquid, solid, and gaseous waste produced by the former is expected to be less than that generated by the latter. However, at the time of writing of this publication, there is insufficient information to make a more definitive assessment about waste management for SMRs and the potential impact of waste generated by this type of NPP on the environment.

4. CONSEQUENCES OF SMR CHARACTERISTICS ON THE ENVIRONMENTAL IMPACTS OF SMRS

The design and technology characteristics of SMRs may have specific environmental implications that would be reflected in the development of an EIA report. This section presents the consequences of SMR technical characteristics on the environmental impacts of this type of NPP.

As mentioned in Section 1, the benefits claimed by SMR manufacturers, such as fabrication of modules offsite and assembling of the modules at the site where the SMR will operate, still have to materialize. Accordingly, there are uncertainties regarding input parameters such as the list of stressors and possible pathways in the environment.

Environmental issues that may be covered in an EIA, as applicable depending on the design type of an NPP, may be classified into the following ten environmental impact categories: atmospheric environment, soil quality, aquatic environment, geology and hydrogeology, aquatic wildlife and habitat, terrestrial wildlife and habitat, human health, landscape and cultural environment, transport and traffic, and socio-economic factors. These impact categories are among those that an environmental or nuclear regulator would typically expect to be included in the EIA prior to licensing (see also Ref. [2]).

Subsections 4.1.1 to 4.1.10 discuss the ten environmental impact categories. Related to these categories, three cross-cutting considerations require attention for both the EIA of an NPP and the EIA of an SMR: waste management and spent fuel, transboundary impacts, and accidents. Subsections 4.2, 4.3, and Section 5 address these three considerations, respectively.

4.1. OVERVIEW OF POTENTIAL ENVIRONMENTAL IMPACTS

The nature of environmental impacts originating from SMRs or LRs may not differ greatly, but it is expected that there may be differences in magnitude. This difference in magnitude will not be addressed in every impact category discussed here, unless deemed significant.

4.1.1. Atmospheric environment

Sources of impacts to the atmospheric environment during an SMR facility life cycle will include generation of combustion gases from machinery operations, dust and particulates, and controlled releases of radiological and non-radiological contaminants.

4.1.1.1. Construction

During the construction phase, the impacts for SMRs that are based on land and at sea are mainly from combustion gases generated by the machine equipment deployed at the site, as well as the dust generated by the excavation and blasting from site preparation activities. The impact magnitude would be a function of these factors and their duration. The magnitude of air quality effects may be lesser for some types of SMRs. SMRs that are based at sea would involve construction of fewer structures compared to SMRs that are based on land, as the reactors for the former designs would likely be constructed offsite and then placed on or under water.

The modularity of SMRs may also come into play, as some SMR designs include construction of reactor modules offsite with placement at the project site afterwards, which would eliminate some of the construction activity on site.

The phased approach of modularity for SMRs, namely adding reactor modules constructed offsite after the initial site is completed, is also a consideration. These modules would be added during the operation phase of the project, and therefore airborne releases due to installation of additional modules will have to be taken into consideration during this phase.

However, these additional airborne releases of conventional contaminants may not significantly increase total releases to air as only a relatively small amount of construction activity on site may be required to install additional modules.

4.1.1.2. Operation

During this phase, there is no significant difference between SMRs and large NPPs other than magnitude of impacts, both initially and in a phased modular approach.

4.1.1.3. Decommissioning

During this phase, there is no significant difference between SMRs and large NPPs other than magnitude of impacts.

4.1.2. Soil quality

Permeation into the soil of various pollutants that are deposited on the ground surface or leaked out of equipment and structures for SMRs that are based on land and at sea, can spread through groundwater or surface water features and alter the quality of soil in the site vicinity. Impacts to soil quality due to contamination during the life cycle of these SMR facilities will differ depending on the design of the facility and the site characteristics. The factors mediating these impacts include soil excavation and controlled release of radiological and non-radiological contaminants through ground and surface water.

4.1.2.1. Construction

For SMR designs with underground structures, given the amount of soil that would be excavated, consideration may have to be given to the management of that soil and dewatering impacts (e.g. water ingress, settlement and contaminant movement). Similarly, for SMR designs requiring dredging of areas located near a shore, the excavated material has to be managed. These activities would also occur for the construction of a LR and thus it is a question of magnitude, as SMRs generally have a smaller footprint at the deployment site. Compared with SMRs that are based on land, SMRs that are based at sea would have a significantly reduced impact on soils as there would be less construction activity on land at the site (even smaller land footprint), but may impact ocean and river beds more significantly (marine footprint).

As is the case for air and water quality, the modularity of some SMR designs may result in lesser impacts to soil quality during the construction phase, but may need to be taken into consideration in to operations phase.

4.1.2.2. Operation

In terms of impacts to soil quality, SMRs that are based on land and especially those based at sea may have a lower magnitude of impacts to soil quality compared to LRs, due to the amount of environmental releases, which is expected to be roughly proportional to the generated power and size of the footprint. The magnitude of impacts for SMRs that are based at sea would be expected to be lower than for SMRs that are based on land and LRs, as a portion of the structures would be in a marine environment with limited interaction with soil. Conversely, impacts to surface water quality from SMRs that are based at sea may be increased.

4.1.2.3. Decommissioning

There are no key issues due to characteristics of an SMR that is based either on land or at sea that would differentiate it from a LR during this project phase. The specifics of decommissioning activities of SMRs that are based on land and at sea could have a direct effect on the nature and magnitude of the impacts to soil quality. For SMRs that are based on land, decommissioning of underground designs may lead to increased magnitude and profile of effects to soil quality depending on the method of decommissioning (e.g. complete removal vs. decommissioning in situ). For SMRs that are based at sea, decommissioning of underwater works would tend to have a lesser magnitude of effects to soil quality. Decommissioning of structures that are on the water may occur offsite (e.g. structures that are mounted on a barge could be floated away) thus reducing the impact at the site.

4.1.3. Aquatic environment

Impacts to surface, ground and marine water quality during the life cycle of SMR facilities that are based on land and at sea will differ depending on the design of the facility and the site characteristics. Impacts could occur due to construction in the water, site runoff, dewatering activities, and controlled releases of radiological and non-radiological contaminants.

4.1.3.1. Construction

The size of the construction site, amount of deployed machinery, nature of the construction, duration of construction, need for dewatering, and works in the water, may all be factors that determine the magnitude of impact on water quality during construction of an SMR due to runoff, washing away hydrocarbons, dewatering, waste water, turbidity, etc.

Dewatering during construction may be augmented for SMRs that are designed for underground reactor placement, which may introduce soil pollutants into surface water bodies and increase turbidity. Those SMR designs that are either completely or partially below ground could impact multiple groundwater layers, each layer having its own characteristics and chemistry. Construction and dewatering activities could also alter the flow, quantity and quality of groundwater as well as sensitive groundwater features such as recharge/intake and discharge areas. All these potential impacts may be of lesser magnitude for above ground and marine SMRs as there would be less intrusion into the ground.

For SMRs that are based at sea, construction of works in the water may increase the suspended solids in the water, raising turbidity, and may result in release of hydrocarbons from submerged machinery into the surrounding water.

As is the case for air quality, the modularity of some SMR designs may result in lesser impacts to water quality during the construction phase, but may need to be taken into consideration in to operation phase.

4.1.3.2. Operation

Discharges from the cooling systems that are based on land and at sea, and other waste streams from various treatment systems for SMRs, have the potential to degrade the surrounding water quality. The magnitude of that impact depends on factors such as generated power, radiological and chemical releases and various constituents in the discharge.

Those SMR designs that include underground structures or installations may result in increased impacts to groundwater during their entire lifecycle compared to other SMRs or LRs. The interaction of groundwater with buried structures would need to be carefully considered, including groundwater flow, contamination due to contact with or leaks from the structures, and alteration of the interaction between groundwater and surface water.

For SMRs based at sea, leaks from the structures that are in and on the water (including reactors) may result in decreased marine water quality.

4.1.3.3. Decommissioning

The specifics of decommissioning activities of SMRs could have a direct effect on the nature and magnitude of the impacts to water quality, particularly in the case of SMRs that are based at sea. For example, underwater mooring structures may not be dismantled, to avoid further unnecessary disturbance of the site or to the sea floor and to avoid an increase of suspended solids in the water.

4.1.4. Geology and hydrogeology

Impacts to the geology and hydrogeology under and surrounding SMR facilities will differ depending on the design of the facility and the site characteristics. Impacts would occur mainly due to physical activities during construction and continued physical presence of the facility during operations.

There are no key issues due to characteristics of an SMR that is based either on land or at sea that would differentiate it from a LR during the construction, operation or decommissioning project phase.

4.1.5. Aquatic wildlife and habitat

Impacts to aquatic wildlife and habitat in freshwater or marine ecosystems may occur due to impacts to water quality, physical disturbance caused by structures that are in the water, noise, vibration, light, as well as the operation of cooling systems and related thermal discharges. For SMRs that are based on land, the difference with respect to impacts due to LRs may mainly be one of magnitude.

4.1.5.1. Construction

For SMRs that are based on land, the potential impacts to aquatic wildlife and habitat would be similar to those for construction activities of LRs, with variability of magnitude. Potential impacts would be mediated through destruction or physical alteration of habitat, as well as noise and vibration for a finite time.

For SMRs that are based at sea, potential impacts to aquatic wildlife and habitat would be expected to be greater than those from SMRs or LRs that are based on land due to increased construction in the water, thereby disturbing a greater portion of aquatic habitat either directly or indirectly through noise, vibration and light.

4.1.5.2. Operation

In terms of potential aquatic wildlife and habitat impacts, SMRs that are based on land and LRs would be expected to have similar profiles mainly based on limited physical alteration of habitat (e.g. noise, light, release of cooling waters), with a magnitude proportional to the generated power. For SMRs that are based at sea, additional considerations are needed. The turbines for underwater or floating SMRs could be in the aquatic environment. Therefore, the resultant noise and vibration from the operation of the turbines may result in impacts to aquatic fauna. In addition, increased marine structures for an underwater SMR may significantly alter the habitat of aquatic fauna and flora, either negatively or positively. Two examples include alteration /

relocation / loss of spawning grounds in the mid to long term, or establishment of fauna and flora populations at the site or directly on the structures. Should these populations establish themselves on site for the duration of operations, they will need to be considered in the decommissioning phase.

4.1.5.3. Decommissioning

Decommissioning impacts for SMRs that are based either on land or at sea would be similar to those for construction. The exception would be for underwater SMRs, which would need to take any positive alteration of aquatic fauna populations and habitat during the operations phase into account in decommissioning plans.

4.1.6. Terrestrial wildlife and habitat

Terrestrial wildlife and habitat impacts may occur due to impacts to air, soil and water quality, and physical disturbance caused by construction of structures that are based on land resulting in loss or alteration of habitat either directly or indirectly through noise, vibration and light. For SMRs that are based on land, the difference with impacts due to LRs may mainly be one of magnitude. However, SMRs that are based at sea would be expected to have a lesser magnitude and different profile of impacts compared to SMRs that are based on land and LRs, as fewer structures would be in the terrestrial environment and operations would occur in both aquatic and terrestrial environments.

4.1.6.1. Construction

For SMRs that are based on land with underground designs, there may be impacts due to dewatering and drainage. This may affect the groundwater table and flows, with a possible impact on surrounding vegetation, and indirect impact on wildlife sustained by that vegetation or relying on this habitat. Loss of habitat may also occur due to construction activities such as excavation, blasting, and waste storage and maintenance. Construction of facilities or structures for SMRs that are located above ground would be expected to result in similar potential impacts to those from LRs (including but not limited to habitat loss, and alteration of habitat due to noise, vibration and dust). For SMR designs with deep underground structures, excavation works may result in increased noise depending on the geological conditions encountered (e.g., need for blasting).

For SMRs that are based at sea, the impact on terrestrial wildlife and habitat would be reduced due to lesser construction activities and a smaller footprint on land than for SMRs that are based on land and LRs.

4.1.6.2. Operation

There are no key issues due to characteristics of an SMR that is based on land that would differentiate it from a LR during this project phase, other than variability of magnitude. For SMRs that are based at sea, there may be reduced impacts to terrestrial habitat, particularly in terms of noise and vibration due to turbines or cooling systems or both, as those elements of SMRs would tend to be located in or on water bodies.

4.1.6.3. Decommissioning

There are no key terrestrial wildlife and habitat issues due to characteristics of SMRs that are based either on land or at sea that would significantly differentiate SMRs from LRs during this project phase other than variations in magnitude.

4.1.7. Human health

Impacts to human health from potential radiological and non-radiological contaminants during all phases of the SMR life cycle are considered within an EIA, usually in the form of a Human Health Risk Assessment (HHRA).

Reference [2] provides comprehensive guidance on radiological impact assessment with respect to human health considerations for projects related to nuclear power.

Physical risks to workers may be different for SMRs that are based at sea compared to LRs, which are generally based on land, as the workers would be functioning in and around waterbodies and thus safety from drowning or possible increased injuries from slipping on wet surfaces should be considered.

The assessment of an SMR's potential impacts on human health from controlled radiological and non-radiological contaminants released by the project through all potential exposure pathways needs to reflect the potential for different fuel types, coolants and other chemicals that may differ from that of LRs and that can vary widely for different SMR designs. Advanced details on releases of contaminants and pathways are not available at early stages of design for the various SMRs, but will be expected to be estimated and modelled for use in the EIA and HHRA.

Humans may also feel effects from a project through landscape and culture and socio-economic effects. See also sections 4.1.8 and 4.1.10.

4.1.8. Landscape and culture

In addition to potential effects to health, humans may feel effects from a project based on other considerations such as alterations of the landscape, land use for recreation, hunting, fishing and gathering, and cultural and spiritual links to the environment surrounding a facility.

For SMRs, visual impacts could be proportionally lower than for LRs due to possible smaller size requirements of the SMRs. If the design includes underground placement of the reactors, SMRs may have even lower visual impacts than reactors located above surface. Similarly, SMR designs based at sea may also have lower visual impacts than those of NPPs based on land. These visual impacts in turn may have an effect on land use for recreational and subsistence use, such as hunting and fishing.

This highlights the necessity for good interaction with local stakeholders. Effective interaction will allow stakeholders to be adequately informed of the project and be able to participate in the EIA process such as to inform the development of the report on potential impacts and proposed mitigations measures.

4.1.9. Transport and traffic

Transport to and from a site is usually out of scope of an EIA, although some jurisdictions do include it in a limited manner. In areas with established infrastructure, there may be little to differentiate the transportation related impacts of a SMR and a LR. However, in the case of SMRs in remote locations, new road or rail infrastructure may be required, which could have local and regional impacts. To what extent these new roads, if at all, are to be scoped into the EIA for an SMR is left to the discretion of each jurisdiction.

4.1.9.1. Construction

In some SMR designs, prefabrication of modules may take place at a site other than that of deployment. Therefore, appropriate infrastructure may need to be developed to facilitate the transport of the large modules from one site to the other. Existing transportation infrastructure (roads, rail, and waterways) may not have been designed to handle the transportation of large or heavy loads. Local infrastructure may also be limited or absent in remote areas where SMRs may be deployed. SMRs based on land and located in isolated areas may have significant impacts related to infrastructure due to road or railway construction. Any construction or improvement of transportation infrastructure and corridors may improve accessibility in remote areas, which could result in improved movement of people, goods and services in those regions. Many SMR designs have specific targets in size (diameter of vessels) and weight of components and modules to facilitate easier transportation on existing roads and railway infrastructure.

4.1.9.2. Operation

The possible extended operating cycles for some SMR designs and possibly lower staff requirements for operation for SMRs compared to LRs (e.g., due to the size and design of SMRs and possibly due to the role of offsite maintenance facilities) may reduce the magnitude of the impact on road traffic loads compared to LRs.

Conversely, for SMRs based at sea, accessibility to offshore structures may increase traffic on water bodies.

4.1.9.3. Decommissioning

Decommissioning activities would generally use the same transport infrastructure as construction and operation, and therefore no additional impacts are expected.

4.1.10. Socio-economic factors

Throughout the whole life cycle of an SMR, socio-economic impacts will be defined by factors such as employment, revenues, living standards for the local and regional population, and visual impacts. These impacts may differ from those of LRs due to differences in an SMR's potential siting locations, size and footprint.

4.1.10.1. Construction

For SMRs that are based on land and at sea, due to prefabrication of many components, a relatively smaller workforce may be needed and for a shorter period than for a LR. However, if SMRs are constructed and operated in isolated areas, socio-economic impacts may be more noticeable than for SMRs and LRs built in populated areas. In isolated areas, infrastructure, such as seaports, roads, storage and medical facilities, have to be constructed and maintained. Additionally, the influx of money to construction workers will be felt more in an isolated area than in a populated area as living standards rise. The ingress of construction and operation workers may also bring about the need for more social services. Both these changes in the social and economic profile of the local and regional area may have an impact on the health and well-being of the population.

4.1.10.2. Operation

SMR facilities that are based on land and at sea may need smaller staffing for operation, administration and security than that for LRs. In addition, designs with offsite maintenance/refuelling of modules may require less staff at the reactor operation site than for

LRs. While the offsite location would have staff for these projects, offsite activities are out of scope of an EIA for an SMR at a given location.

4.1.10.3. Decommissioning

There are no key socio-economic issues due to characteristics of an SMR based on land or at sea that would differentiate it from a LR during this project phase, other than magnitude.

4.2. WASTE MANAGEMENT AND SPENT FUEL

Management of non-radiological and radiological waste, as well as spent fuel should be considered at all appropriate phases of the SMR life cycle.

4.2.1. Non-radiological waste

Non-radiological waste will be produced and require management. There are no key issues due to SMR characteristics that differentiate it from a LR during this project phase, other than potential amount of non-radiological waste to be managed.

4.2.2. Radiological waste

Once the SMR is commissioned, the quantity and composition of spent fuel and low and medium radioactive waste would be related to design aspects, such as the core size (e.g. fuel quantity), reactor technology, fuel enrichment level, and burnup rate for the SMR. Storage of spent fuel may occur on site or at a separate repository depending on each Member State's handling of such waste, as is the case for LRs. It is notable that some SMR designs envisage module replacement or offsite refuelling or both, which would preclude storage on site.

4.3. TRANSBOUNDARY IMPACTS

As is the case for LRs, locations for SMRs may include sites in proximity to international boundaries with two or more countries. Transportation routes and modes between offsite facilities and the SMR site may also cross international boundaries, particularly for factory-fuelled transportable marine-based SMRs. It is important to identify all potential transboundary impacts, as appropriate, for communication and information sharing between different national jurisdictions; see, for example, Ref. [10]. For example, effluents and other planned and unplanned releases during all phases of the SMR life cycle may have impacts across international boundaries. The means by which elements related to transportation are examined in a transboundary context can be informed by the IAEA report "Legal and Institutional Issues of Transportable Nuclear Power Plants: A Preliminary Study" [11].

The Report by the IAEA Director General on the Fukushima Daiichi Accident [12] mentioned that:

"In case of an accidental release of radioactive substances to the environment, the prompt quantification and characterization of the amount and composition of the release is needed. For significant releases, a comprehensive and coordinated programme of long-term environmental monitoring is necessary to determine the nature and extent of the radiological impact on the environment at the local, regional and global levels."

This report on the Fukushima Daiichi accident discusses transboundary implications in general, but does not differentiate between LRs and SMRs, or whether the SMRs are based on land or on sea.

4.4. STAKEHOLDER INVOLVEMENT

Reference [1] discusses stakeholder involvement in the environmental impact assessment process. This discussion is applicable to LRs and SMRs, and such involvement is expected to be similar for both types of NPPs. In general, there is no procedural difference for either type. The groups of stakeholders involved may differ (e.g. based on land vs based at sea), but the groups are always site specific, anyway.

5. ENVIRONMENTAL IMPACTS OF ACCIDENTS FROM SMRS

5.1. SCOPE

This section addresses potential radiological and non-radiological accidents (collectively referred to as 'accidents' in this publication) during the life cycle of SMRs (construction, operation and decommissioning) that result in a release of stressors to the environment.

5.2. SPECIFIC ASPECTS OF SMRs THAT INFLUENCE ACCIDENT ASSESSMENTS IN AN EIA

The methodology by which environmental impacts (e.g., human health impacts and impacts to biota) are determined from a radiological accident is the same for LRs and SMRs, and is further discussed in the Radiological Environmental Impact Assessment [2]. The methodology by which these impacts are estimated from a non-radiological accident also is considered the same for LRs and SMRs. SMRs based at sea will have unique impacts due to their direct proximity to water features.

On the other hand, risk is defined as the product of probability and consequence. The probability and environmental consequences of accidents are anticipated to be different for SMRs than those for LRs due to various SMR design and safety features. The main features of SMRs that impact the overall environmental risk are discussed below.

- Alternative coolants with better heat transfer capabilities – For example, molten lead can function as an effective heat sink up to far higher temperatures than traditional light or heavy water. This is a way for precluding significant core melt.

- Inherent core reactivity characteristics – Some SMRs are designed to self-manage thermal power output (including shutdown) during an accident. This feature may be used as a defensive measure to reduce or eliminate fuel melt in some cases.

- Melt resistant fuel – Some designs, such as an HTGR have fuel designs whose melting point is significantly higher than the temperatures that might be produced during accidents.

- Containment submerged in water – Some SMR designs cooled by water have a compact steel containment submerged in water which reduces the possibility of radioactive material release to the atmosphere during accidents.

- Integral reactor designs – Some SMR designs cooled by water integrate all main steam supply system components (e.g. steam generators), and sometimes the control rod drive mechanism, inside the reactor pressure vessel. This type of design does not have large bore piping, and thus the loss of coolant accident (LOCA) involving a large break, which is typically postulated for LRs, is eliminated.

- Refueling – For transportable nuclear reactor modules, the probability of fuel handling accidents at the site is expected to be reduced compared to that at LRs because the entire reactor vessel or module is replaced, so no individual fuel assemblies are handled.

- Cogeneration and co-location with other facilities – Should an accident occur at an SMR, a collocated industrial facility could be affected and stressors to the environment may be released from both the SMR and the other facility. There also exists the possibility of an accident occurring at the other facility that in turn affects the associated SMR, with a similar effect of releasing stressors from either one or both facilities.

- Unique Siting – Various siting alternatives for SMRs, such as underground and based at sea, may have different accident scenarios and environmental consequences as compared to LRs. For example, the release of hydrocarbons from components on a floating SMR into the surrounding aquatic environment. In addition, accidents at offshore SMRs that are situated far from the shore or from populated areas may have a lower impact on human health than that from LRs, which are based on land.

5.3. SOURCE TERM FOR ACCIDENT CONSIDERATIONS

The assessment of the environmental impacts of accidents are conducted, in part, with the use of estimated source terms and includes calculations of the radiological consequences on the public and environment. For SMRs that use different technologies and fuel types than those used by traditional reactors cooled by light water, this may change the magnitude and nature of the source term. As discussed in Subsection 3.2.8, SMRs have a smaller source term than LRs due to a smaller inventory of nuclear fuel in the core and lower power output. Therefore, it is expected that the consequences of accidents with radiological releases (e.g. radiological dose to humans and biota) would be of lesser magnitude for SMRs than for LRs. On the other hand, SMRs with multiple modules would need to consider events concerning several modules, including accident scenarios involving all modules at the site, in the estimation of the source term.

Included in the analysis of accidents is the use of input data and validated computer codes used to estimate the source term. In some cases, computer codes used for current operating NPPs may be applicable; however, technology differences may influence the applicability of codes in certain areas, so these differences need to be understood and documented. In other cases where SMR designs are more novel, codes may differ from the already validated codes. As a result, they may require additional evidence to demonstrate their credibility in an EIA.

5.4. OTHER SOURCES OF RADIOACTIVE RELEASES

Similar to a LR, other sources of accidental radioactive releases such as fuel handling, dry or wet storage of spent fuel and waste storage would typically be considered in the analysis of consequences of accidents for SMRs. However, a few SMRs are designed such that fuel handling occurs at offsite facilities. These facilities are usually out of scope of the EIA because an EIA would be limited to the installation/operation site. Depending on the Member State regulations, the transportation of fresh or spent fuel on and off site may similarly be out of scope of the EIA.

5.5. IMPLICATIONS OF ACCIDENTS ON EMERGENCY PLANNING

A nuclear power plant's emergency plans include both onsite and offsite preparations for responses to events with potential for consequences to workers, the public and the environment. The adequacy of the safety and control measures associated with prevention and mitigation of events and their potential consequences are typically evaluated under the licensing process for the proposed facility, and significant data to support the evaluation is collected as part of the EIA process. This includes characterisation of bounding plant events (possibly using scenarios involving the ‘worst case’ within an EIA) and prediction of the potential impacts on the public and environment considering commitments to establish adequate safety and control measures.

Decision making that is informed by risk and associated with a graded approach to consider specific facility characteristics such as power levels and inventories of radiological and non-radiological contaminants may be used; see, for example, Ref. [13]. However, operational experience for an SMR design may be unavailable or limited, leading to uncertainties in data. In these cases, more conservative predictions may be pragmatic to address the potential for discovery of significant safety issues later in the licensing and EIA process.

6. ALTERNATIVES

There are two types of alternatives that are considered as part of an EIA, namely, alternatives to the project and project component alternatives. Alternatives to the project provide decision makers and the public with information that allows for an informed decision as to whether the proposed project corresponds best to the identified objective (e.g. generation of 300 MW(e) of power), and whether other technologies would meet this objective. These alternatives are usually explained but not analysed in detail. In the case of a proposed SMR project, other energy sources such as photovoltaic cells powered by the sun, wind turbines, and hydroelectric generation, may provide similar power outputs (in MW(e)) as certain SMR designs and configurations. The onus is on the project proponent to show that construction and operation of an SMR is the preferred alternative over other energy technologies to meet the ultimate goal of the project. In the Member State where the project is being proposed, there may exist an SEA for this topic. The SEA is a programmatic-level analysis, and addresses issues such as sustainable development, land use plans, best practicable environmental options, cumulative effects, etc. The SEA could then help guide the selection of alternatives to consider and provide some justification for the selection of the preferred option.

The second type of alternatives are a suite of components within the project which may have various possible technological options. Similar to LRs, one important instance of component alternatives (i.e., the second type of alternatives) to consider in SMR EIAs is a system that is cooled by water or by air for the UHS. Systems cooled by water for NPPs based on land would include construction and operation of water intake and discharge facilities, cooling towers, and the associated piping for these facilities. In the case of SMRs, the flow of water to the cooling system would depend on the number and size of the reactors (that is, modules) on-site and could change over time as more modules are installed, or others decommissioned or removed. Impacts to the aquatic environment would similarly change depending on the number of modules and on water use. For SMRs based at sea, impacts from systems cooled by water would depend on the design of the facilities based at sea, and if any support facilities based on land are needed. For systems cooled by air, the considerations for SMRs would be similar to those for LRs, that is, they would have terrestrial impacts but no aquatic impacts. Other examples for an SMR project are power conversion options to include non-electric applications, and non-radiological waste management options. These component options are assessed against economical, technical and environmental criteria and the best alternative is selected to move forward in the project.

7. SUMMARY AND CONCLUSIONS

The objective of this publication is to provide a source of current information on considerations for EIAs related to SMRs. Within this overall objective, the publication discusses aspects of SMRs that may alter the factors affecting the environmental impacts of this type of plant as compared to those factors from current LRs.

The publication describes the generic approach to the implementation of an EIA process that could be used to support SMR licensing. Environmental impact assessments can be performed using either a prescriptive approach or an approach that is based on risk, or a combination of both.

The suite of impacts that would be considered in the EIA of an SMR project is expected to be similar to that of a LR as are the associated assessment methodologies (e.g., modelling). Environmental issues that may be covered in an EIA, as applicable depending on the design type of an NPP, may be classified into the following ten environmental impact categories: Atmospheric environment, soil quality, aquatic environment, geology and hydrogeology, aquatic wildlife and habitat, terrestrial wildlife, human health, landscape and cultural environment, transport and traffic, and socio-economic factors. These impact categories are among those that an environmental or nuclear regulator would typically expect to be included in the EIA prior to licensing. Potential transboundary impacts also have to be considered for SMRs.

On the other hand, SMRs have unique features that affect their potential impacts on the environment, and hence may have a bearing on the EIA. Nine characteristics differentiate SMRs from LRs, and include: generated power, footprint of the SMR site, modular design, non-electric applications, siting locations, construction, refuelling, source term, and waste management. For example, the magnitude and nature of the impacts may differ from those related to LRs due to SMR design features such as smaller footprint than that of a LR, modularity and unique deployment locations.

From an accident perspective, the probability and consequences of radiological and non-radiological accidents of SMRs are anticipated to be different to those of LRs due to various design features of SMRs. Due to the relative uniqueness of some SMR design features, enough evidence will need to be provided in the EIA to support the analysis of the accident scenarios and the resultant potential impacts to the environment. Given the modular nature of SMR designs, events involving multiple modules should be considered, as appropriate.

There are two types of alternatives that are considered as part of an EIA, namely, alternatives to the project and project component alternatives. The first kind of alternatives provide decision makers and the public with information that allows for an informed decision as to whether the proposed project corresponds best to the identified objective (e.g. electric power generation of up to 300 MW(e)), and whether other technologies would meet this objective. The second type of alternatives are a suite of components within the project which may have various possible technological options.

Depending on the Member States' process in place, the public and other stakeholders may be given the opportunity throughout the EIA process to comment on various steps of the EIA, including the scope of the EIA and the report from the authority. It is advisable for the project proponent and the regulatory authority to encourage public and stakeholder participation in the process as this will foster understanding and acceptability of the project from the early stages onward.

In conclusion, this publication represents an initial overview of aspects related to SMRs that may warrant consideration in an EIA. Given the evolving nature of SMR designs, Member State preparations for SMR deployment, and ongoing SMR projects, it is recommended that this publication be updated on a periodic basis, particularly to gather insights from EIAs produced as new SMRs go through regulatory approval processes in various Member States.

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ABBREVIATIONS

ARIS	(IAEA) advanced reactor information system
CNSC	Canadian Nuclear Safety Commission
EIA	environmental impact assessment
EIS	environmental impact statement
ESR	environmental scoping report
HHRA	human health risk assessment
HTGR	high temperature gas cooled reactor
IA	impact assessment
IAEA	International Atomic Energy Agency
IEI	initial environmental information
LOCA	loss of coolant accident
LR	large reactor (this term is used to mean large NPP in this publication)
NPP	nuclear power plant
SEA	strategic environmental assessment
SMR	small modular reactor (this term is used to mean small modular NPP in this publication)
UHS	ultimate heat sink
USA	United States of America
USNRC	(USA) Nuclear Regulatory Commission

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Consultants Meetings

Vienna, Austria: 11–13 April 2012, 9–11 October 2012, 2–4 September 2014,
and 11–14 February 2019

Technical Meeting

Vienna, Austria: 28–31 October 2013

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International Atomic Energy Agency
Vienna
ISBN 978–92–0–108420–0
ISSN 1011–4289