# Feasibility Study for Deployment of Future SMR in IAEA Member Country

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## Abstract

The paper focuses on a feasibility study conducted in the Slovak Republic (Slovakia) where an evaluation of the suitability of various sites for hosting a small modular reactor (SMR) nuclear power plant (NPP) was conducted. The study assesses mature SMR technologies and provide insights into the next steps for deploying an SMR in Slovakia. The approach of the study is based on the guidelines established by the International Atomic Energy Agency (IAEA) in NG-T-3.3, NR-T-1.10, SSR-1, SSG-35, and SSG-79 and considers the priorities and needs identified by Slovak stakeholders. The feasibility study is divided into two phases. Phase 1 involves a "red flags" study of the proposed sites to ensure their suitability for a new NPP. The outcome of Phase 1 confirms the suitability of multiple sites for hosting at least 1 market available SMR technology for further assessment. Phase 2 of the study characterizes the complex process of deploying an SMR in Slovakia. This phase includes a more detailed examination of the potential sites and an evaluation of various reactor technologies that best meets the needs of Slovakia. Various topics such as cogeneration, environmental, natural, and manmade hazards, waste management, and water usage are also addressed in Phase 2. The feasibility study is a collaborative effort between Slovak stakeholders and subject matter experts from Sargent & Lundy LLC. The study provides objective and defensible evaluations based on IAEA guidelines and reflect the priorities and values of Slovak stakeholders.

## INTRODUCTION

The Slovak Republic (Slovakia) is interested in incorporating a small modular reactor (SMR) nuclear power plant (NPP) into its portfolio of clean energy generation capabilities. Likewise, the U.S. government initiated a multiagency capacity building initiate called the Foundational Infrastructure for Responsible Use of Small Modular Reactor Technology (FIRST) Program to help partner countries safely and responsibly build small modular reactor (SMR) programs. The FIRST program helps partner countries like Slovakia take advantage of next generation nuclear innovations and technologies in their sustainable energy plans, meet their clean, reliable energy goals, while protecting the global climate and deepen relationships through government and industry.[1]

In support of these goals, U.S. Department of State (DOS), Bureau of International Security and Non-proliferation, Office of Cooperative Threat Reduction’s (ISN/CTR) Global Threat Reduction Programs, FIRST program paired Slovak stakeholders with Sargent & Lundy LLC (S&L) to carry out a feasibility study to evaluate replacing retiring coal-fired plants with secure and safe SMR technology. In this project, S&L works closely with Slovak stakeholders to evaluate potential sites including coal-powered thermal power plant (TPP) sites and evaluate potential western SMR technologies for deployment.[1]

It should be noted that as of the writing of this paper the feasibility study is ongoing with Phase 1 completion expected in the summer 2024 and Phase 2 completion in spring 2025.

## Slovak Republic Project Goals

The European Union (EU) binding target for climate neutrality means that by 2050, European countries are committed to achieving net zero greenhouse emissions as a whole. Mainly this will be achieved by cutting emissions, investing in green technologies and protecting the natural environment. Within the EU, nuclear power has been recognized as an integral part of the decarbonization need in replacing fossil fuels with clean technologies, for energy.

Slovakia, as a country with a long-term and well-established nuclear industry, sees its future optimal energy mix in balanced combination of nuclear and renewables backed up with a suitable portion of flexible sources. Since the Slovak energy sector is changing in terms of expected rise in electricity demand, increasing portion of intermittent renewables sources and reducing dependence on unreliable fuel supplies, together with the emission reduction commitment, only nuclear energy can deliver a stable and carbon-free source of energy for the base load. Moreover, Slovakia has a relatively small grid with current average load at level of 2.9 GW (2.0 GW base load up to 3.5 GW in the peaks) that implies that small or medium sources would be of most benefit when considering that no additional back-up energy sources would be needed. SMRs are the only market-available source of carbon-free energy that meets all these requirements.

Since SMRs have been identified as the single and optimal solution to cover future electricity demand increase while being net-zero greenhouse emitter, Slovakia via its stakeholders has commenced the first steps in putting SMR technology on the map of Slovak energy mix by conducting work~~s~~ on the feasibility study for the deployment of an SMR. The main driver of the study is the possibility to localize the SMR type of nuclear power plant in higher number of feasible sites with main advantage of possible transformation of the former coal sites or possible sitting near to heavy industry for providing electricity or process heat for the own consumption and the own decarbonization targets. The Slovak roadmap for first SMR deployed in the country targets the mid to late 2030s when an increased electricity demand is anticipated and the SMR technology is expected to be already deployed in the first western countries. Slovakia does not intend to host any First-Of-A-Kind type of SMR but is willing to be an early adopter within European countries. That’s due to the fact that Slovakia does have an immediate need to decarbonize the industry. Currently it has one of the cleanest energy mixes in Europe due to 5 nuclear units in operation and a high number of hydroelectric power plants that have approximately a 75% share of generated electricity in the country [10].

## Project Approach

The project started with S&L and Slovak stakeholders including the Slovak Economy Ministry, Slovenské elektrárne, the Nuclear Regulatory Authority, the Slovak University of Technology, US Steel Košice, the Slovak Power Transmission System, and VUJE meeting over the course of October 2023 through January 2024 to collaborate and refine the goals of the project ultimately aligning on the details of the project’s approach, scope, and roles and responsibilities. In January 2024, project leaders from S&L visited Slovakia to finalize the project approach.[2] It was decided that the feasibility study contents will conform with IAEA Nuclear Energy Series Guide No. NG-T-3.3, Preparation of a Feasibility Study for New Nuclear Power Projects, and the various project stakeholders will collaboratively address each of the guide’s topics. Given Slovakia’s strong existing civil nuclear power program, most of the effort in the feasibility study would be directed towards two main objectives: evaluation of pre-selected sites for the potential of future deployment of an SMR and SMR technology market surveys and evaluations.

Given these two objectives, the approach to work for the feasibility study was split into two phases. Phase 1 performs a red flag investigation of the proposed sites and SMR technology survey where Phase 2 will expand to complete a full site survey and technology assessment. The red flag investigation is performed in order to identify attributes of concern, or “red flags” that may require additional study or any “fatal flaws” where a location should be avoided all together. The evaluation process chosen in the project is objective, defensible, and based upon applicable IAEA guides. IAEA Nuclear Energy Series Guide No. NR-T-1.10, Nuclear Reactor Technology Assessment for Near Term Deployment, governs the process used to evaluate the SMR technologies surveyed. While IAEA Specific Safety Guide, SSG-35, Site Survey and Site Selection for Nuclear Installations, governs the process used to evaluate the pre-selected sites in Slovakia. The assessments facilitated through S&L and its subject matter experts (SME) reflect the priorities and values of Slovak stakeholders.

Prior to the start of this feasibility study, Slovak stakeholders identified five (5) potential sites for deployment of an SMR. These sites included two (2) retiring coal power plants, Nováky Brown Coal Power Plant and Vojany Black Coal Power Plant, two (2) existing nuclear power sites, Atómová elektráreň Mochovce and Jaslovské Bohunice Nuclear Power Plant and one (1) co-located steel production site, U. S. Steel Košice. In Phase 1 of the feasibility study, a red flags study examined these five (5) Slovak proposed sites to screen them based on project stakeholders developed exclusionary and discretionary criteria to ensure they are suitable for deployment of a new NPP.

In conjunction with the red flag study, a technology survey was performed in this phase including development of a consolidated plant parameter envelope (PPE). The PPE is a tool which allows for the identification of potential sites when a specific plant design or technology has not yet been selected. The PPE provides a means to screen sits ensuring they will be suitable for the deployment of any of the potential reactor technologies. The expected outcome of the red flags study including the PPE screening is to confirm that more than one site is suitable for further characterization and assessment. If only one or none of the suggested sites is found to be suitable, the project may decide to include alternative sites identified by either Slovak stakeholders and/or performance of a region of interest study by S&L SMEs.

After completion of Phase 1, the project will have a set of screened sites and technologies for further evaluation. In Phase 2 the project will continue to characterize the sites and technologies being considered for deployment of an SMR in Slovakia. To achieve this, areas that were previously evaluated for minimum viability will be assessed for suitability to prioritize sites and technologies for further consideration. The siting study will examine each of the potential sites in greater detail to provide a ranking reflective of their suitability for deployment of an SMR. Additionally, the reactor technology assessment will evaluate which reactor technologies most fully meet the needs of Slovakia.

## Project Phase 1: Red Flags Investigation

As noted above, Phase 1’s goal is to screen the pre-selected sites and identify SMR technologies which meet Slovak stakeholder requirements through the red flags investigation and the technology survey.

The red flags investigation started with Sargent & Lundy experts visiting each of the five (5) priority sites in January 2024 to gain an understanding of existing site layout, terrain, proximity to, quality and quantity of available water, establish communication and interview site owners and operators to understand unique site attributes, identify co-generation needs or opportunities, and beyond. These visits allowed Sargent & Lundy experts to identify obvious natural or man-made hazards and prepare a list of detailed site information needed to support the red flag investigation for these sites.

After returning from the site visits, S&L SMEs met to draft exclusionary and discretionary screening criteria to facilitate the “go” and ‘no-go” thresholds for the red flags investigation. Exclusionary criteria are used to discard sites that are unacceptable on the basis of attributes relating to issues, events, phenomena or hazards for which there are no generally practicable engineering solutions.[7] Discretionary criteria are associated with those attributes relating to issues, events, phenomena, hazards, or other considerations, for which protective engineering solutions are available.[7] These criteria, listed in Table I–1 of Annex I, are used to facilitate the selection process through iterative screening to eliminate less favourable sites when there are a large number of possible candidate sites. These criteria were established based on EPRI [9], IAEA [7] guidelines and S&L SME experience. These draft criteria were reviewed with Slovak stakeholders and confirmed. The aligned criteria are noted in Table 1 below.

TABLE 1. RED FLAG INVESTIGATION SITE SCREENING CRITERIA

|  |  |  |
| --- | --- | --- |
| Type of Criteria | Criteria Name | Criterion Description |
| Exclusionary | Seismic Hazard | ≤ 0.5 g maximal peak ground acceleration |
| Exclusionary | Liquefaction potential | No active or capable faults within X km radius of site centre point. |
| Exclusionary | Other geological hazards (Karst, Sinkholes, Subsidence, Mines, Volcanos) | Desirable sites do not have slopes greater than X degrees from horizontal within 1km of the site or greater than X degrees within 2km of the site. |
| No saturated granular deposits, SPT N-value less than X blows/30cm, on site |
| >X km radius from karst, sinkholes, or subsidence. >X km radius from mined areas or areas subject to future exploitation. >X km radius from active or dormant volcanic activity |
| Exclusionary | Flood events and protection | The entire site must be above major flood level, or it must be technically feasible to protect the entire site from such flood (taking into consideration X-years flood in case of near rivers). |
| Exclusionary | Precipitations events (heavy rain, snow, freezing) | Meteorological parameters (Probable Maximum Precipitation, X-year maximum rainfall, X year snowpack weight, X year Ice thickness) of site are less than those defined in PPE |
| Discretionary | Nearby Hazardous Land Uses | No hazardous land use sources are located within the SSG-79 Generic Screening Distance Value (>X km from airport, >X km from airway, >X km from facilities storing or handling flammable, corrosive or explosive material, >X km from sources of hazardous clouds, vapours, or gases, >X km from sources of fire such as forests, peat, storage areas for low volatility flammable materials, >X km from military installations storing munitions, >X km from military installations or air space usage such as bombing and firing ranges, >X km from railways or highways supporting transportation of hazardous materials). (5) |
| One hazardous land use source is located within the SSG-79 Generic Screening Distance Value, or other State value, for the specific source. [5] |
| More than one hazardous land use source is located within the SSG-79 Generic Screening Distance Value, or other State value, for the specific source. [5] |
| Exclusionary | Proximity to population centres - Population | "X,000 population and >X km buffer |
| X,000 population and >X km buffer |
| X,000 population and > X km buffer " |
| Discretionary | Population Density | Fewer than X persons per square kilometre (pskm) within X km radius of site center |
| Between X pskm and < X pskm |
| Between X pskm and < X pskm |
| Between X pskm and < X pskm |
| X pskm or more |
| Discretionary | Feasibility of implementation of emergency plan | No special population groups, no egress limitations, terrain characteristics are favourable to evacuation |
| Exclusionary | Availability and access to Cooling water | Water source does not meet minimum value for any of the considered technologies. |
| Discretionary | Topography | Less than X% slope across site major axis |
| Exclusionary | Site Size | Site does not meet minimum value for any of the considered technologies |
| Exclusionary | Non-radiological environmental impacts | No natural reserves, monuments, tourist spots, bio-sensitive areas within X km of site centre point. PPE thermal pollution complies with Slovak Law. |
| Discretionary | Non-radiological environmental impacts | Located as far as possible from natural reserves, monuments, tourist spots, bio-sensitive areas. |

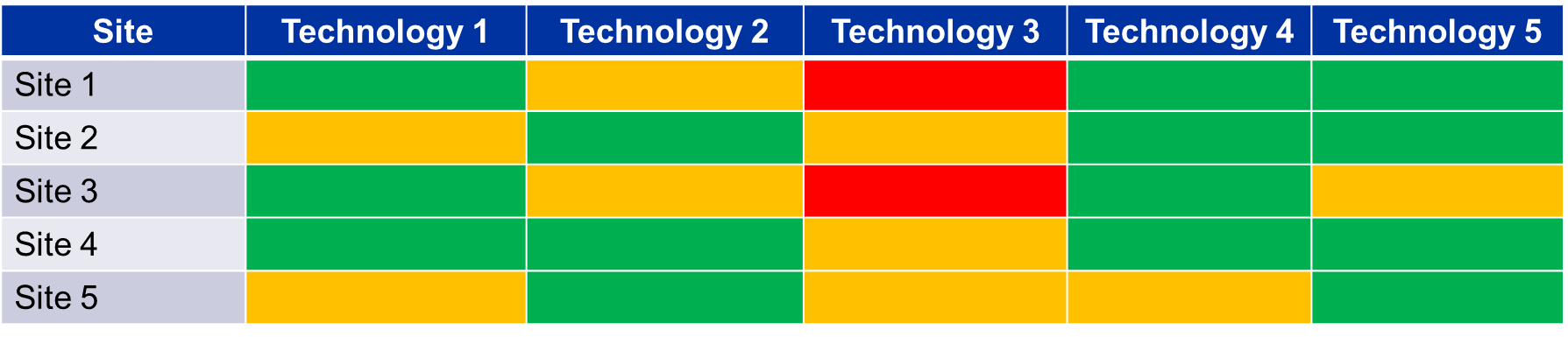
After establishing the exclusionary and discretionary criteria, S&L provided a list of information needed from Slovak stakeholders to facilitate the red flag investigation analysis. Slovak stakeholders utilized public, private information and data sets to respond to the request. It should be noted that this effort is not trivial and requires consistent collaboration as each region and site may have vastly different data sets available. The utilization of SMEs which have vast experience in nuclear siting activities is essential to ensure projects can progress given different qualities of available data sets. SMEs with the experience to review data wade through what is and isn’t available to draw conclusions is essential.

In addition to the site red flags investigation, Phase 1 includes an SMR technology survey. To successfully understand what technologies the Slovak Republic are interested in deploying, S&L facilitated development of a set of screening criteria with project stakeholders. The following criteria were decided to be the basis of screening technologies into the study:

* The technology is currently licensed in a country, is under review for a license in a country, or will be licensed for siting, construction, or operation in a country by 2028.
* The technology has load-following capabilities and is suitable to perform in grids with high percentages of variable renewable energy sources.
* The technology is capable of cogeneration of hydrogen, process steam, or district heat.
* A standard configuration of the technology can generate a minimum of 100 MW(e) electricity.
* The technology provider is interested in participating in this study.

The project utilized IAEA, Nuclear Energy Agency (NEA), and other organizations’ active lists of emerging advanced reactor technologies as its initial starting point for screening technologies. The IAEA Advanced Reactor Information System (ARIS) is a web-accessible database that provides IAEA Member States with balanced and comprehensive information about advanced nuclear plant designs and concepts. ARIS includes reactors of all sizes and all reactor types, from evolutionary nuclear plant designs for near term deployment, to innovative reactor concepts still under development.[3] The NEA Small Modular Reactor Dashboard provides a comprehensive assessment of the progress made by SMR designers and companies worldwide. Looking beyond technical feasibility, the NEA SMR Dashboard assesses progress towards first-of-a-kind commercial deployment across six dimensions: licensing, siting, financing, supply chain, engagement and fuel. The NEA SMR Dashboard reveals substantial progress towards SMR deployment and commercialisation in NEA and non-NEA member countries, with a subset of designs in more advanced stages of commercialisation and deployment.[4] Based on this screening a total of nine (9) SMR technologies were selected to be included in this study (Note: the technologies will be named in the final paper).

A request for information (RFI) was submitted to list of down-selected technology vendors in order to develop a PPE. The PPE attributes for each technology were based on the exclusionary and discretionary criteria developed above. Technologies were then screened for capability to meet the constraints of the sites. Technologies which could not operate within the constraints of any site are considered for exclusion from future evaluation. This technology to site matching was presented to Slovak stakeholders via the approach as outlines below in Fig. 1 where each colour corresponds to the level of relative risk as defined in Fig. 2



*FIG. 1. Technology to Site Matching*



*FIG. 2. Risk Legend*

## Project Phase 2: Feasibility Assessment

Phase 2 of the project will focus on addressing the various topics defined in NG-T-3.3, Preparation of a Feasibility Study for New Nuclear Power Projects with the primary focus being on site and technology selection.

The primary objective of this phase is to evaluate the candidate sites through a ranking and comparison process in accordance with IAEA SSG-35.[7] This is done to support decision makers need to know more detailed characterization of the selected site and all items that will have an impact on cost, such as geology and hydrogeology, seismicity, site preparation work (including excavation, internal and external access routes), emergency preparedness, security facilities, construction laydown and storage areas, all utilities and facilities necessary to support construction (power, compressed air and other gases, service and drinking water, administration and technical support buildings) and any other cost related items.[6]

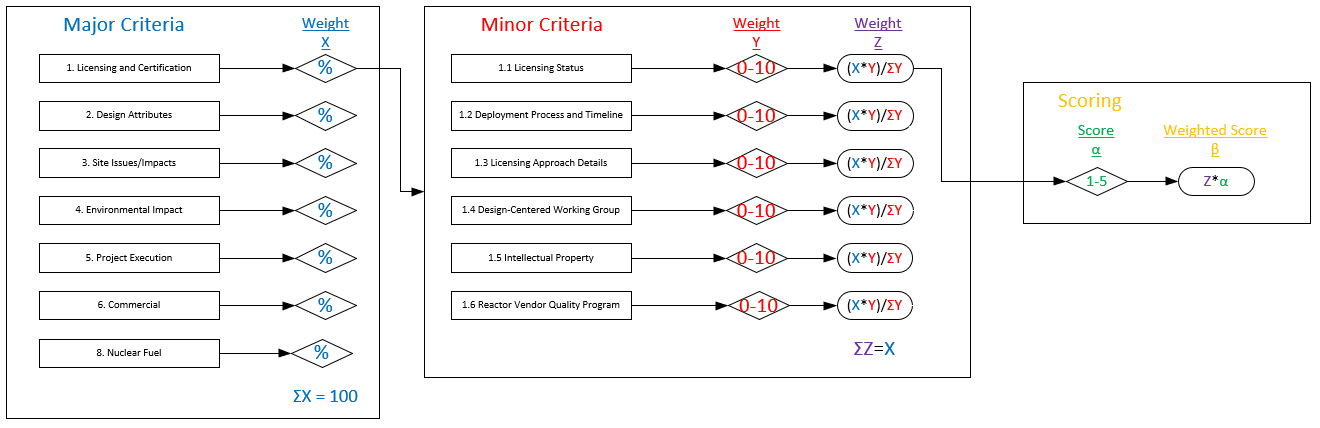
Candidate sites which remained after completion of Phase 1 will be examined in detail to determine whether any have significant or unique infrastructure, engineering, environmental, or socioeconomic issues that would make them impractical or otherwise less desirable for development of the SMR. Candidate sites were evaluated for project development considerations, including:

* Safety-Related Criteria – Natural Hazards
* Safety-Related Criteria – Human-Induced Hazards and Nuclear Security
* Safety-Related Criteria – Radioactive Material and Emergency Planning
* Non-Safety-Related Criteria

The ranking criteria in the above four categories include approximately 50 site characteristics related to public safety, nuclear security, nuclear fuel production licensing requirements, environmental impact, and engineering requirements. Each characteristic is defined as part of the exclusionary criteria (required) or discretionary criteria (desired). In addition, the ranking criteria evaluated were primarily technical and environmental, combined with some qualitative assessments of the nuclear regulatory and social impacts.

Quantitative criteria were developed to generate numerical scores that reflect how well each site satisfied the discretionary criteria for each of the 50 site characteristics. The criteria included both an objective means of assigning a numerical score for each site characteristic and importance weighting factors, which were used to adjust the numerical scores based on the relative importance of the site characteristics. The possible score on each site characteristic ranged from 1 to 5, and each importance weighting factor ranged from 1 to 10. Fig 3 below details the process of applying weighting and scoring to develop the weighted score.

*FIG. 3. Weighting and Scoring Approach.*



1. Criteria

2. Criteria

3. Criteria

4. Criteria

5. Criteria

6. Criteria

7. Criteria

1.1 Minor Criterion

1.2 Minor Criterion

1.3 Minor Criterion

1.4 Minor Criterion

1.5 Minor Criterion

1.6 Minor Criterion

Detailed information was collected on environmental and technical conditions at each site and assessed and scored based on an evaluation of selected site criteria. Potential site locations that failed to meet one or more exclusionary criterion were subjected to further consideration; whereas discretionary criteria included within the ranking criteria were evaluated for significance. In general, discretionary criteria were evaluated to determine whether they had the potential to introduce adverse technical, safety, environmental, or licensing impacts.

The sites were ranked based on the weighted scores determined for each of the 50 criteria. The scores will range between 0 and 100% of the maximum possible score and the report will identify the preferred sites.

Additionally, a SMR technology assessment will be performed in accordance with IAEA NR-T-1.10, Nuclear Reactor Technology Assessment for Near Term Deployment.[8] expanded to assist Slovakia in evaluating SMR technologies based on commercial, contractual, and technical criteria currently deemed important to Slovakia and based on the current status of SMR technologies. Sargent & Lundy will work with Slovak stakeholders to develop at least six (6) categories and approximately 60 criteria for evaluation along with inquiries to each of the vendors related to each of the criterion. These inquiries will be submitted via an RFI to the SMR technology vendors. Based on previous experience, each of the vendors, will require an executed three-way Non-Disclosure Agreement (NDA) with Slovak stakeholders and Sargent & Lundy prior to response to the RFI.

Prior to receiving RFI responses from the vendors, Sargent & Lundy and Slovak stakeholders will work collaboratively to establish criteria weighting and scoring guidelines. Upon receipt of vendor responses on, Sargent & Lundy will utilize its SMEs to evaluate the responses from each of the vendors and score their responses per the established scoring guidelines. The overall ranking for the SMR technologies will then be computed as the sum of the weighted average of the composite rankings for the technology assessment criteria. The criteria will include both an objective means of assigning a numerical score for each criterion and importance weighting factors, which were used to adjust the numerical scores based on the relative importance of the specific criteria. The possible score on each criterion will range from 1 to 5, and each importance weighting factor range from 1 to 10. Sargent & Lundy will collaborate the scoring with Slovak stakeholders to ensure alignment with final technology assessment scores.

Sargent & Lundy will then prepare the NPP technology assessment section of the feasibly report that contains the findings and a detailed account of work performed. The purpose of the activity is not to select or recommend a final SMR technology, but rather to evaluate the technologies available to determine which SMR technologies may be more favourable than others, based on the criteria identified by Slovak stakeholders in collaboration with Sargent & Lundy SMEs.

In parallel to the technology assessment the following topics will also be addressed:

* A description of the Slovak fuel cycle to convey the current Slovak national participation programme goals in areas such as radioactive and conventional waste management, spent fuel management, safety during operation and accident conditions, spent fuel pool facilities and radioactive waste storage and control.
* The licensing process for new reactors will be described based on current Slovak regulatory requirements including identifying a milestone schedule and an estimated cost of the licensing documentation and safety analyses required.
* Possible project financing options will be explored, including various partnership models and capital injection potentials. In addition, possible contractual approaches will be examined, together with procurement models and project management models.
* Description of the Slovak overall national strategy goals for use of SMRs as part of its energy mix.
* A description of the Slovak accident preparedness and emergency planning requirements.
* The study will maintain a project risk matrix and its implications, followed by a risk assessment and management plan. This will include recent lessons learned from Slovakia’s construction of Mochovce Units 3 and 4.
* An overall AACE International Class 5 project overnight cost estimate will be developed based on technology vendor inputs and publicly available data sets including licensing and site preparation including demolition, remediation, and other associated costs. Additionally, operation and maintenance (O&M), waste management, and decommissioning costs will be estimated based on publicly available data sets, Slovak experience, and technology vendor inputs.
* A description on the options for preparation of the invitation to bid will be developed, in which the various requirements in the future BIS will be described.

## Conclusions:

At the conclusion of Phase 1 of the project, anticipated in the summer 2024, Slovak stakeholders will have a confirmed subset of sites and technologies for further assessment in Phase 2 of the project. Consequently, at the conclusion of Phase 2 of the project, anticipated in the spring 2024, Slovak stakeholders will be able to identify the highest priority site(s) and technology(ies) for further development.

## Next Steps:

Upon completion of the feasibility study, the next crucial phase involves engaging with Slovak shareholders and key decision-makers to formally determine the priority site(s) and preferred technology(ies). A project management organization will be established to manage the new construction project and initial procurement activities will proceed. Detailed site surveys and environmental impact assessments will take place. Additionally, a thorough analysis pertaining to Slovak regulatory requirements vs the country of origin of the preferred technology(ies) and permitting processes will be conducted to identify gaps and streamline deployment.

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