



**Claudia Gonzalez**

gonzalez.claudia@laurentisenergy.com  
Oshawa, Ontario - Canada

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ORCID ID	0000-0001-9073-0178
Corresponding Author	Claudia Gonzalez

## GEOTECHNICAL ASPECTS FOR NUCLEAR POWER PLANTS

### ABSTRACT

Today, global awareness about preserving the planet is pushing mankind towards net-zero carbon emissions. This new perspective invites evaluation of the nuclear option as an attractive source of clean energy. In this context, small modular reactors (SMRs) integrated into deep-embedded nuclear power plants have great potential. An SMR has a smaller environmental footprint and is equipped with advanced features that make it safer to operate than larger conventional reactors. Following the Fukushima accident, the International Society for Rock Mechanics and Engineering (ISRM) Commission on Underground Nuclear Power Plant assessed that the disaster could have been avoided if the Fukushima NPP had been built underground based on the concepts presented in the commission's report. Since then, the Geotechnical discipline has become a key contributor to SMR engineering design. At Laurentis Energy Partners (Laurentis), in Canada, engineers have advanced their expertise in geotechnical analysis for nuclear facilities, including SMRs, and this paper will comment on some of the key aspects of such a challenging design.

**Keywords:** Nuclear, Small Modular Reactors, Geotechnical Analysis, Deeply Embedded Nuclear Structures, Geotechnical

### 1. INTRODUCTION - LAURENTIS ENERGY PARTNERS

Laurentis Energy Partners (Laurentis) delivers innovative nuclear solutions that power communities, advance healthcare, and support a cleaner future. Laurentis helps clients around the world bring that vision to life by supporting early assessment work for building new nuclear power reactors.

Laurentis also delivers radioisotopes for both medical and non-medical applications:

- **Molybdenum-99 (Mo-99):** Mo-99 is one of the world's most important medical isotopes and is used in millions of diagnostic imaging procedures annually. Once into commercial Mo-99 production, Darlington NPP (Canada) will be the first commercial power reactor source of Mo-99 in the world.
- **Yttrium-90 (Y-90):** Laurentis is preparing to produce yttrium-90 (Y-90) using its Target Delivery System at Darlington. Y-90 is used in targeted radiation therapies for the treatment of liver cancer and other inoperable tumours. Laurentis's entry into Y-90 production represents an important expansion into therapeutic medical isotopes.
- **Lutetium-177 (Lu-177):** Lu-177 is a rapidly growing medical isotope used in targeted radiotherapeutics for cancers,

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including neuroendocrine tumours and prostate cancer. Laurentis plans to use its Target Delivery System at Ontario Power Generation's Darlington to support commercial-scale Lu-177 production.

- **Helium-3 (He-3):** Stable, non-radioactive, inert and in global demand, He-3 is a rare isotope that Laurentis provides to clients around the world. To extract the He-3, Laurentis developed a new, custom-designed tool. When extraction began in late 2021, Laurentis became the world's first non-military source of He-3. Laurentis is now one of the world's largest suppliers of this critical and in-demand isotope.

**Relevant projects at Laurentis are:**

- **Target Delivery System:** Laurentis and BWXT Medical have deployed a first-of-its-kind isotope irradiation system, known as the Target Delivery System (TDS), at Ontario Power Generation's Darlington Nuclear Generating Station on Unit 2. The system was installed in 2023. Because of the unique design of Darlington's CANDU reactors, medical isotopes can be removed while the reactor is still online, and without interrupting the station's generation of clean energy. The system represents a major advancement in commercial isotope production capacity as the single largest isotope irradiation system in North America. A second TDS is being installed at Darlington Unit 3, which is expected to expand Laurentis's isotope production capacity significantly. Installation is expected in 2026. The TDS platform supports the production of multiple medical isotopes used in both diagnostic imaging and targeted therapies.
- **Small Modular Reactors:** Bringing SMR projects to life: As demand for safe, clean, reliable power grows, small modular reactors (SMRs) are set to play a big role in the future of nuclear—and the energy industry at large. With extensive expertise in nuclear power and a commitment to helping clients unlock the promise of this low-carbon, high-impact technology, Laurentis is uniquely positioned to help support this energy transition. Laurentis provides feasibility early assessment work support to help clients meet a diverse range of energy needs and bring new nuclear projects to life.
- **Cernavodă NPP Unit 1 Refurbishment:** Through its European subsidiary, Canadian Nuclear Partners SA (CNPSA), Laurentis is delivering Project Management Organization (PMO) services to support the preparation and execution of Societatea Nationala Nuclearelectrica's (SNN) Cernavodă Nuclear Power Plant Unit 1 refurbishment project in Romania:
  - o Project management services
  - o Technical and engineering support
  - o Consulting services
  - o Specialized training for CANDU refurbishment
  - o Outage management, and
  - o Coordination and oversight of restart - return to commercial operation

## **2. RESEARCH SIGNIFICANCE**

This study highlights the critical role of geotechnical engineering in achieving net-zero carbon goals through the safe design of Small Modular Reactors (SMRs) and deeply embedded structures, using lessons from the Fukushima disaster to enhance subsurface safety. The analysis provides crucial insights for the nuclear energy sector by

establishing SMRs as a secure, low-carbon energy source and advances the healthcare sector by demonstrating the uninterrupted, high-capacity production of medical isotopes via online target delivery systems.

**Highlights:**

- o **Geotechnical Importance:** Geotechnical discipline stands out as a fundamental engineering component in SMR design and nuclear safety.
- o **Fukushima Lesson:** It is stated that similar disasters can be prevented by building nuclear power plants underground.
- o **Medical Isotope Leadership:** The Darlington Plant has North America's largest system (TDS) capable of producing medical isotopes while the reactor is operating.

**3. FUKUSHIMA ACCIDENT (JAPAN) - LESSONS LEARNED**

Located in Ōkuma, Japan, the Fukushima Daiichi Nuclear Power Plant was once one of the largest nuclear power stations in the world.

On March 11, 2011, at 2:46 p.m., the facility sustained severe damage from the Great East Japan Earthquake. This seismic event, which registered a moment magnitude of 9.0 ( $M_w = 9.0$ ), was caused by the Pacific plate subducting beneath the Eurasian plate and forcing it to catapult upward.

As a direct result of this earthquake, a massive tsunami with a run-up height exceeding 20 meters was triggered [7]. When the tsunami struck the nuclear power plant, the resulting flooding caused a catastrophic functional loss of the station's emergency power supply system.

This accident caused the loss of reactor cooling water, resulting in a hydrogen explosion of the plant and a core meltdown. As a result, radioactive materials were scattered, and a vast area of the region was contaminated by radioactivity. Tens of thousands of people were forced to evacuate, and even now, many people cannot go back because of radioactive contamination.

Once a serious nuclear power plant (NPP) accident occurs, like the Fukushima Daiichi disaster, significant resources are required, not only for decommissioning the nuclear reactor, but also for decontaminating the radioactive environmental destruction around the NPPs. Thus, a lesson learned from the Fukushima Daiichi disaster is: We cannot prevent seismicity or/and tsunamis, but we can prevent, control, and mitigate the impact of those events on the NPP. Thus, the question is: how to mitigate the impact of a natural phenomenon in a nuclear reactor plant?

As far as the security of NPPs is concerned, one of the crucial issues is to prevent disasters due to earthquakes, tsunamis, human errors, and even unpredictable causes, including the threat of terrorism. To prevent serious accidents of NPPs triggered by those natural or human-made catastrophes, siting NPPs underground must be one of the potential options.

**4. SMALL MODULAR REACTORS (SMR)**

The concept of underground nuclear power plants (UNPPs) is not new; studies began in the 1950s, and there is a history of UNPPs built in various countries. The first underground nuclear reactors were built in the 1960s in Russia and Sweden. After that, other countries, including Norway, France, Switzerland, and Sweden, also developed underground nuclear reactor projects that were active for many years, in some cases. However, it was not until 1981 that the world talked about UNPPs - the "Hanover Conference."

In 2004, the idea of a large underground nuclear facility was presented by Myers & Elkins. They proposed to install many reactors and generators, facilities for used fuel storage and treatment, and a repository for the final waste disposal in a large underground cavern. The concept is called Underground Nuclear Park [[9]]. The key component is safety since radionuclides in the reactors, as well as in the used fuel and nuclear waste, would be protected against threats from outside.

Following the Fukushima accident, the International Society for Rock Mechanics and Engineering (ISRM) Commission on Underground Nuclear Power Plant concluded [[5]] that the disaster could have been avoided if the Fukushima NPP had been built underground based on the concepts presented in the commission's report.

The study further suggested that an underground NPP could have withstood the damaging effects of the tsunami and significantly reduced environmental contamination. It also indicated that if plants' backup power systems had been sited underground, they would have been protected from flooding, potentially preventing the meltdown of the reactor and subsequent explosion.

Today, growing global awareness of the need to preserve the planet is driving humanity toward achieving net-zero carbon emissions. Within this context [11], nuclear energy is increasingly being reconsidered as an attractive and reliable source of clean power. In this context, the SMR, using a below-grade Reactor Building (e.g., GE Vernova's BWRX-300 reactor), offers great potential.

SMRs are [[11]] advanced nuclear reactors that have a power capacity of up to 300 MW(e) per unit [[6]], which is about one-third of the generating capacity of traditional nuclear power reactors. SMRs, which can produce a large amount of low-carbon electricity, are:

- **Small:** Physically a fraction of the size of a conventional nuclear power reactor. Smaller environmental footprint and is equipped with advanced features that make it safer to operate than larger conventional reactors. An SMR is small because the size of the facility can be limited to just a few acres compared to a conventional plant that can span hundreds of acres.
- **Modular:** Since it is designed for cost-effective fabrication under controlled factory conditions and subsequent deployment on site, multiple units can be produced and installed simultaneously. This new manufacturing process for nuclear reactors will speed up their deployment to meet the urgent need for low-carbon electricity sources [[6]].
- **Reactors:** Harnessing nuclear fission to generate heat to produce energy.

SMRs create the potential for flexible power generation, i.e., the capacity to add more reactors to ramp up output as needed.

SMRs also have broader industrial applications, such as desalination or hydrogen production.

Based on the global experience in Underground Hydropower Plants, it is approximately [[8]] 600 to 700 of the more than 45,000 hydroelectric plants in operation have their powerhouses sited underground. This highlights the already well-established expertise in engineering, supported by a strong community of engineers with extensive experience in underground hydropower plants.

Similarities between Underground Hydropower Plants and SMR-UNPPs [[8]]:

- o Generation of Electrical Power
- o Proximity to Electrical Grid
- o Cavern Type and Dimensions

- o Large equipment size and weight
- o Overall Operations
- o Workforce Skills---in part

**Other advantages of UNPP:**

- Underground NPPs (or having important structures below-grade) offer better protection against natural hazards. Contrary to conventional thinking, the seismic performance of an underground structure is more robust compared to aboveground structures. This is because, during an earthquake, ground-level structures experience stronger motion; being located underground provides increased protection against both earthquakes and volcanic eruptions:
  - o Below-grade reactors are safer (for surface explosions, surface vibration can decrease with depth)
- Leakage of water contaminated by radioactive substances:
  - o By design: water pressure outside (depth) is larger than the pressure inside
- In addition, the surrounding mass of very low permeability increases the time for intervention.
- Structures and facilities built below-grade have the best protection from conventional military attacks.

**5. GUIDELINES AND REGULATIONS**

A Preliminary Safety Analysis Report (PSAR) is one of the key technical documents to be submitted as part of the Licence to Construct (LTC) application. The PSAR also summarizes the Site Evaluation, and this is a key component of licence applications for site preparation, construction, operation, and decommissioning of a nuclear facility. Additionally, it demonstrates the adequacy of the design and results of the safety assessment.

Laurentis has extensive experience in Europe and Canada in applying International Atomic Energy Agency (IAEA) guidelines and standards, including:

IAEA SSG-61 Chapter 2 guidance related to [[1]]:

- Plant design site reference data for seismological, hydrological, meteorological, hydrogeological and geotechnical features of the site and the surrounding region;
- characteristics of site-specific human-induced external hazards;
- Radiological dispersion characteristics of the site and surrounding environment,
- present and projected population distribution and land use relevant to the safe design and operation of the facility; and
- identification, characterization and results of assessment of site characteristics that might affect facility safety.

The objective of the IAEA SSG-61 Safety Guide is to provide recommendations on the structure and content of the safety analysis report to be submitted by the operating organization in support of an application to the regulatory body for authorization of the siting, construction, commissioning, operation, and decommissioning of a Nuclear Power Plant (NPP). The Safety Guide is intended to facilitate both the development of the safety analysis report by the operating organization and the evaluation of the completeness and adequacy of the safety analysis report by the regulatory body.

The most relevant international standard guidance that focuses on geotechnical engineering serving SMR nuclear projects is currently the IAEA SSG-93, released in 2026, titled "Geotechnical Aspects in the

Siting and Design of Nuclear Installations.” This Safety Guide supersedes IAEA Safety Standards Series No. NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants.1 The revision ensures [[2]] consistency with the requirements established in SSR-1 [[3]], in particular with sections 21 and 22. The guidance also incorporates the latest knowledge, experience, and lessons learned from significant geotechnical events in Member States.

Also, relevant recommendations are provided in the IAEA Safety Standards Series No. SSG-9 (Rev. 1) [[4]], Seismic Hazards in Site Evaluation for Nuclear Installations, relates to seismic aspects that play an important role in this field.

If we focus on the title of SSG-93, “Geotechnical Aspects,” this refers to aspects of geotechnical site investigation, methods of analysis, evaluation, engineering design, and safety assessment relating to the subsurface conditions at nuclear installation sites (SSG-93).

This Safety Guide does not include recommendations specific to subsurface nuclear installations, which necessitate a higher level of effort and greater focus on subsurface exploration, tunnel construction, and site-specific considerations. However, it applies to SMR facilities where the reactor is built below grade, and in-depth expertise is called into action.

## 6. GEOTECHNICAL DESIGN ROAD MAP

At Laurentis, we fulfill the geotechnical requirements by guiding the clients to perform six interactive reports. Each of them scopes key site-specific studies that focus on geotechnical hazards and geotechnical design for SMR Nuclear Plants, under the guidance of international standards.

The five Geotechnical reports are:

- o Geotechnical Investigations
  - o Nuclear Site Subgrade Properties
  - o Probabilistic Seismic Hazard Analysis (PSHA)
  - o Soil Liquefaction Assessment
  - o Foundation Interface Analysis (FIA)
  - o Soil Structure Interaction
- **Geotechnical Investigations:** This report provides factual data and raw data collected by site and laboratory testing. The study includes site campaigns with boreholes, mapping, and core logging. Following the IAEA SSG-93, this report should provide the geotechnical investigation program, which includes the data necessary for an appropriate characterization of the subsurface at each stage of the site evaluation of a nuclear installation. The various methods of investigation (i.e., the use of current and historical documents, geological data, geophysical and geotechnical investigations, and in situ and laboratory testing) are typically applicable to all stages of the site evaluation process but vary from stage to stage, as necessary. In general, the investigations should become more detailed in character when approaching the later stages of the investigation program. Furthermore, some analysis-specific considerations may apply only to data sets used as input data in soil and rock characterization and analysis.
  - **Nuclear Site Subgrade Properties:** This report takes data from Factual Geotech Studies and interprets data via statistics and engineering judgement. It also defines properties for engineered fillings and delivers sets of data or ranges (BE, LB, UB) to FIA. For this report, the input is the Geotech Report, and the

output is the range of values for each parameter after interpretation and statistical treatment. This report can be integrated into the Geotech report as a Chapter that interprets all the Factual Data.

These two studies together provide a range of set of parameters included engineered fill materials, that will be the input parameters to the Foundation Interface Analysis (FIA) and for Soil Structure Interaction Analysis.

- **Probabilistic Seismic Analysis:** This analysis provides demands for seismic design. This analysis estimates the probability of different levels of earthquake-induced ground shaking at a site over a specified period of time, accounting for uncertainties in earthquake occurrence and ground motion.
- **Soil Liquefaction Assessment:** This is a seismically induced soil liquefaction site-specific study. According to IAEA SSG-9, liquefaction is a behaviour that can be developed by non-cohesive soils in loosely deposited conditions below the water table. If this is the case, the bearing capacity (strength and stiffness) of the soil is reduced when subjected to vibratory ground motions. Therefore, careful geotechnical investigations should be carried out in the site area to assess the liquefaction potential of the soil, including non-cohesive backfill materials, which might affect the safety of the structures, systems and components of the nuclear installation.  
 For soils susceptible to liquefaction, detailed information on the modelled soil profile is needed. To assess the liquefaction potential, specific characteristics of the seismic design basis or the seismic hazards at the site should be provided, which link this study to PSHA. Also, close coordination should be established with the geotechnical engineering experts performing the liquefaction analysis and foundation design. The selection of a site with potential for massive liquefaction should be avoided (see Annex I to SSG-35 [13]). [1]
- **Foundation Interface Analysis (FIA):** This analysis may involve numerical models in 2D or 3D and is aimed at calibrating those parameters and delivering reliable values to be used in the Soil Structure Interaction. As an example, for the deeply embedded BWRX-300 reactor (GVH), this report would estimate:
  - Earth pressures load for the RB shaft and surrounding power block foundations.
  - Settlements of deeply embedded RB and the surrounding power block foundations.
  - Bearing capacity evaluations of the RB and the surrounding power block foundations.
  - Kinematic stability evaluations of the subgrade materials surrounding the RB.
  - Ground reaction against the excavation and construction stages of the RB shaft.
- **Soil Structure Interaction:** captures the effects of soil-structure interaction (SSI) via numerical modelling for the deeply embedded RB with adjacent structures and foundations. SSI will calculate the seismic demand on individual structures, systems, and components for design and assessment purposes. This is needed not only for different site-specific levels of seismicity but also for Beyond Design basis dynamic ground motions (due to natural earthquakes or human activity dynamic inputs in the ground).  
 SSI is a guide for:

- o Foundation work design
- o Improvement of the foundation conditions
- o Assist with the choice of foundation system and construction

## **7. CONCLUSIONS**

Small modular reactors (SMRs), being one of the most promising, versatile, and adaptable low-carbon energy technologies of tomorrow, are set to play a big role in the future of the nuclear energy industry.

SMR technology opened the door to experts in geotechnical engineering and other earth and environmental science fields. These disciplines find applications in the nuclear industry, given the site-specific nature of the required studies.

Even more, these geotechnical studies gained fundamental importance from the lessons learned after nuclear world disasters.

With its extensive expertise in nuclear operations and applications, Laurentis is helping to lead the change. Solid knowledge and expertise in site-specific hazard analysis are the path to match the SMR advanced technology and provide a reliable service in nuclear energy.

### **NOTICE**

This work is derived from an oral presentation given at CIVIL2026 (Global Summit on Civil, Structural and Environmental Engineering) in Madrid, Spain, from May 28-30, 2026.

### **CONFLICT OF INTEREST**

The author declares that they have no potential conflict of interest.

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This research received no financial support.

### **DECLARATION OF ETHICAL STANDARDS**

The author of the article declare that the materials and methods used did not require ethics committee approval and/or regulatory approval.

## **REFERENCES**

- [1] IAEA Safety Standards Series No. SSG-61., (2021) Format and content of the safety analysis report for nuclear power plants. International Atomic Energy Agency.
- [2] CNSC, REGDOC-1.1.2., (2022) Licence Application Guide: Licence to Construct a Nuclear Power Plant, version 2.
- [3] IAEA Safety Standards Series No.SSG-93., (2026). Geotechnical aspects in the siting and design of nuclear installations. Austria.
- [4] IAEA Safety Standards Series No. SSG-1., (2019) Site evaluation for nuclear installations. International Atomic Energy Agency.
- [5] IAEA Safety Standards Series No. SSG-9., (2022) Seismic hazards in site evaluation for nuclear installations. International Atomic Energy Agency.
- [6] Chew, A. and Yingxin, Z., (2024). CO24180 | why small modular reactors are suitable underground. Rajaratnam School of International Studies (RSIS). Nanyang Technological University, Singapore.
- [7] Canadian Small Modular Reactor (SMR) Roadmap Steering Committee., (2018). A Call to Action: A Canadian Roadmap for Small Modular Reactors.
- [8] Cetin, K.O., (2023). Geotechnical Aspects in Site Evaluation and GeoHazards for Nuclear Installations. IAEA Asian Nuclear Safety

- Network (ANSN) Regional Workshop on Site Evaluation for Small Modular Reactors (SMRs). China.
- [9] Sakurai, S., (2019) SMR: a good idea for Underground Nuclear Power Plants? IAEA Technical Meeting on Fast SMRs. President of the UNPP Commission for the International Society for Rock Mechanics & Rock Engineering (ISRM).
- [10] Myers, C., Mahar, J., Kunze, J., and Elkins, N., (2008) Underground nuclear parks: new approach for the deployment of nuclear energy systems. WIT Transactions on the Built Environment, Vol 102, © 2008 WIT Press [www.witpress.com](http://www.witpress.com), ISSN 1743-3509 (on-line) Underground Spaces I 63. doi:10.2495/US080071.
- [11] Ritch, J., (2008). The necessity of nuclear power: a global human and environmental imperative. Bulgaria.
- [12] IAEA., (2023). What are Small Modular Reactors (SMRs)? <https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs>, accessed on 23-May-2026.
- [13] Myers, W. and Elkins, N., (2004). Siting nuclear power plants underground: Old idea, new circumstances," Nuclear News, 47(3):33-38.
- [14] Fukushima Daiichi nuclear disaster - Wikipedia (2021), [En.wikipedia.org](https://en.wikipedia.org). Available from: [https://en.wikipedia.org/wiki/Fukushima\\_Daiichi\\_nuclear\\_disaste](https://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaste), accessed on 23-May-2026.
- [15] Britannica Editors. "Fukushima accident". Encyclopedia Britannica, 17 Apr. 2026, <https://www.britannica.com/event/Fukushima-accident>. Accessed 25 May 2026.
- [16] Fukushima Daiichi Accident - World Nuclear Association., (2021), [World-nuclear.org](https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.aspx). Available from: <https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.aspx>, accessed on 23-May-2026
- [17] Willis, C., (2026). Ensuring the Safety of Nuclear Installations: Lessons Learned from the Fukushima Daiichi Accident | IAEA, [Iaea.org](https://www.iaea.org). Available from: <https://www.iaea.org/a-decade-of-progress-after-fukushima-daiichi/ensuring-the-safety-of-nuclear-installations-lessons-learned-from-the-fukushima-daiichi-accident>, accessed on 23-May-2026.
- [18] BBC., (2021) The tsunami overcame the sea wall and hit the plant. Available from: <https://www.bbc.co.uk/news/world-asia-56252695>, accessed on 23-May-2026.