Achieving Safeguards Objectives for the Encapsulation Plant and Geological Repository in Finland

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ABSTRACT

In order to maintain effective and efficient safeguards, the International Atomic Energy Agency (IAEA), in cooperation with European Atomic Energy Community (Euratom) and the Finnish Radiation and Nuclear Safety Authority (STUK), continues to evolve its safeguards system by taking advantage of new techniques and technologies, and the development or adaptation of new and existing safeguards concepts and approaches.

By 2025, the spent fuel encapsulation plant and geological repository (EPGR) in Finland will become the first operational facilities of their type in the EU under the Euratom Treaty, and in the world under a comprehensive safeguards agreement (CSA) with the IAEA. In response to the need to establish an effective safeguards approach for the future EPGR, Euratom, the IAEA and STUK are jointly working on identifying safeguards measures and techniques that will be implemented before operational start to efficiently meet the safeguards technical objectives relevant to these facilities.

The identification of possible safeguards measures has been carried out within the framework of the Safeguards by Design (SbD) concept that enables each of the international safeguards inspectorates (Euratom and IAEA), as well as the national authority (STUK), to effectively and efficiently fulfil their mandates related to the implementation of safeguards, while at the same time minimising the burden of safeguards implementation on operation of the EPGR.

This paper will use the EPGR Project in Finland as a case study to demonstrate how the need to achieve safeguards objectives drives the implementation and development of both traditional and innovative safeguards measures and techniques, with SbD supporting the effective and efficient use of available resources.

INTRODUCTION: THE GENERIC SAFEGUARDS OBJECTIVES AND ROLE OF THE INSPECTORATES

The encapsulation plant (EP) and geological repository (GR) in Finland are the first facilities of their type to be included under a comprehensive safeguards agreement (CSA) between

Euratom and the IAEA. This evolution in spent fuel management requires an evolution of the international safeguards system to accommodate new approaches and concepts, supported by the innovative application of proven and reliable safeguards techniques and new methods such as seismic monitoring and laser-based containment systems.

The EP and GR in Finland pose unique safeguards challenges due to their operational complexities, in particular the GR due to its extensive depth underground, and ongoing construction of deposition tunnels and holes during emplacement operations over the next approximately 100 years. Within the context of the State-level approach (SLA) for Finland, the IAEA, in cooperation with Euratom and STUK, aims to meet its safeguards objectives whilst addressing these challenges. Facility-level approaches for the EP and GR were developed by careful analysis of potential acquisition pathways and the risks and opportunities afforded by a variety of feasible safeguards measures. The resulting approaches consider the operational needs and challenges of the facilities, with sufficient robustness to address operational restrictions should they arise. A blend of existing safeguards measures, such as containment and surveillance, unattended monitoring systems, and remote data transmission, complemented by emerging concepts, such as geological containment, form the backbone of this approach.

In general, three generic safeguards objectives are applied to verify a State's compliance with its international obligations under a comprehensive safeguards agreement with the IAEA [1]:

a) The timely detection of diversion of nuclear material from peaceful nuclear activities;
b) The detection of undeclared processing of nuclear material at declared facilities;
c) The detection of undeclared nuclear material or activities in the State as a whole.

These objectives are applied for each State and facility to draw safeguards conclusions, in accordance with the State's customised State-level safeguards approach (SLA). An SLA is a customised approach to implementing safeguards for an individual State, detailed in an internal document developed by the IAEA, and consisting of specific safeguards objectives and measures for the State [2]. A facility-specific safeguards approach is based on the State-level safeguards approach, and consists of a "*set of safeguards measures chosen for the implementation of safeguards in a given situation in order to meet the applicable safeguards objectives* [1]. These objectives differ in some instances to those of Euratom, in particular, concerning the detection of undeclared nuclear material and activities [3]. As defined by Article 77 of the Euratom Treaty, Euratom safeguards shall verify that special fissile material is not diverted from its intended use but also to satisfy itself that in the territories of Member States the supply provisions and any particular safeguards obligations assumed by the Community are complied with. To fulfil this obligation Euratom and IAEA worked on a set of relevant safeguards measures for the EP and GR.

Both the IAEA and Euratom work with the Radiation and Nuclear Safety Authority of Finland (STUK), the national regulatory body responsible for maintaining the national nuclear safeguards system in Finland. Like the IAEA and Euratom, STUK also has a separate legal basis underpinning the organisation's responsibilities and objectives from a safeguards perspective [4]. This legal basis is written in mind to fulfil Finland's international safeguards commitments and it establishes Finnish state system of accountancy and control (SSAC).

This paper will focus on the aforementioned safeguards objectives that the IAEA meets in order to draw its safeguards conclusions for a State. It is important that the IAEA maintains its independence and impartiality whilst also working with Euratom and STUK to streamline safeguards activities and reduce the burden of three separate inspectorates on the operator. As a result, the three inspectorates have worked together, in an SbD process of early discussion and collaboration, to develop the necessary activities and tools to enable data sharing, authentication and independent evaluation.

FEATURES OF THE ENCAPSULATION PLANT AND GEOLOGICAL REPOSITORY THAT POSE SAFEGUARDS CHALLENGES

The overarching purpose of the encapsulation plant (EP) and geological repository (GR) in Finland is to safely and permanently contain spent fuel from Finland's existing nuclear power plants, via a layered system of engineered and natural barriers [5]. Given that physical access to nuclear material, safeguards equipment and the process areas/deposition tunnels is very limited, new concepts, measures and equipment are required to help meet the generic safeguards objectives and inspectorate's requirements.

The EP will receive the spent fuel in casks from the wet storages, dock the cask in a fuel handling cell and transfer each fuel assembly into a copper canister, which will then be undocked from the handling cell and welded shut. The filled and welded canisters will then be placed in a buffer storage prior to transfer to the GR. Figure 1 depicts a generic process diagram for the EP. From an operational perspective, this process is planned to be conducted continuously, however given the limited storage space, the rate of emplacement is determined by campaign operations at the GR. Once the spent fuel is welded inside the canister, it cannot be easily accessed or accurately verified, limiting the effectiveness of a traditional physical inventory verification (PIV) that would normally be carried out by the inspectorates. Furthermore, access to the process and storage areas in general is limited in the presence of the spent fuel canisters due to radioactivity levels, further making traditional in-person safeguards activities difficult to carry out.

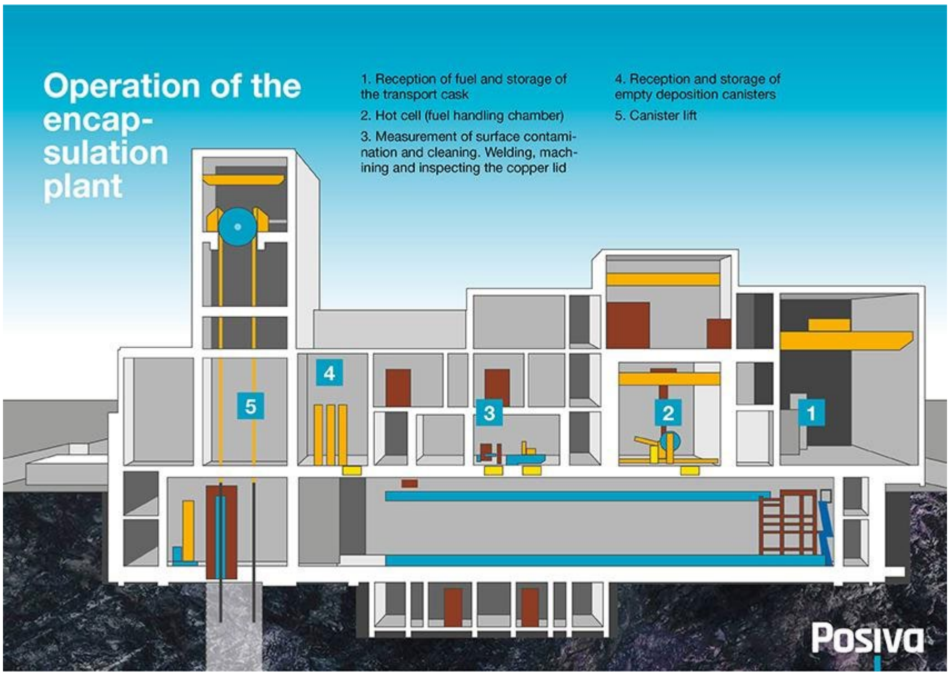

Figure 1: General process diagram for the encapsulation plant (EP) in Finland [6]

The GR will receive the spent fuel canisters directly from the EP via a connected canister shaft, reaching a depth of 437m underground. The canister will be transferred to a canister buffer storage and reception area, where it will be stored until the deposition tunnel is ready for a campaign. The canisters for one campaign (approximately 30) will then be transported one by one with a canister deposition vehicle and emplaced in the deposition hole. This process will repeat until one tunnel is full. The deposition holes and the deposition tunnel will be backfilled with bentonite, and the entrance to the deposition tunnel will be plugged with a thick concrete structure. The plug installed by the operator may be scanned by the safeguards inspectorates using precise 3D laser technology. The resultant surface map has the potential to provide a long-lasting identity and integrity check of the installed plug. Figure 2 shows a generic layout and process diagram for the GR.

A number of unique challenges have been identified that could affect safeguards implementation in a GR, primarily related to access and operational restrictions, risk of damage to safeguards equipment, and size of the tunnel network. Among other challenges, access to the canisters is restricted before emplacement due to the high dose rate. As tunnel blasting and excavation will continue throughout the approximately 100-year operational timeline of the repository, physical access in these areas will be limited. Because of excavations and backfilling, huge amounts of rock is transferred up and buffer material down in the tunnel. Material transfers are a priority for plant operations, but they are also one of the diversion routes. Dense traffic also creates environmental hazards, like dust, vibrations and shock. Access to safeguards equipment, should it require servicing or maintenance, can be hampered by both the presence and movement of spent fuel canisters or other operational activities. As such, if timely access is required for safeguards reasons, this has the potential to adversely impact operations. Furthermore, access to equipment, such as surveillance cameras, may be more urgent if there is an increased risk of damage due to ongoing blasting, excavation and construction work. Finally, the sheer length of the extensive and expanding tunnels underground poses a challenge to achieving safeguards objectives, as it creates a far more intensive requirement for physical access in order to perform design information verification (DIV) and interim inspections to ensure the facility is operated as declared, and that there are no indications of undeclared activities.

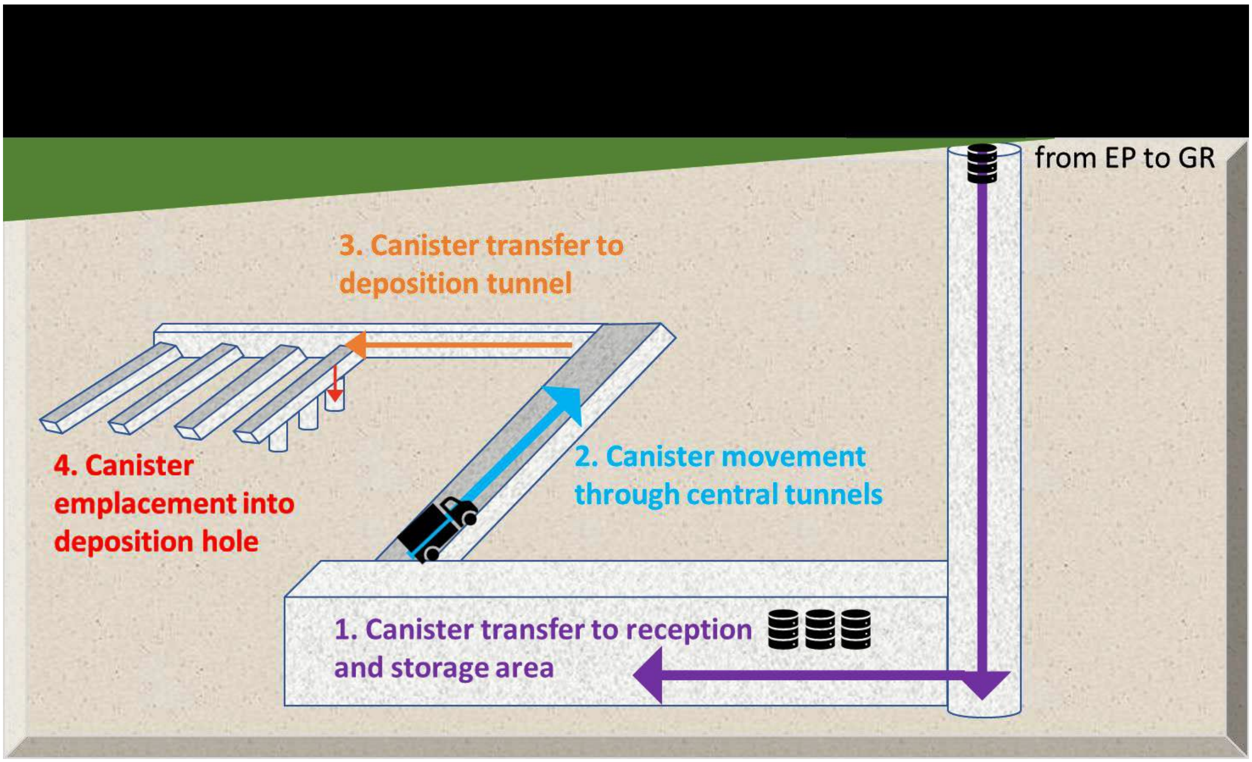

Figure 2: General process diagram for the geological repository in Finland

METHODOLOGY FOR DEVELOPING SAFEGUARDS APPROACHES

To overcome these unique challenges, the IAEA and Euratom employed a structured and analytical methodology to develop robust safeguards approaches. The methodology can be summarised in five basic steps:

a) **Identify proliferation scenarios:** A facilitated expert team exercise identified proliferation scenarios based on the IAEA's safeguards objectives, using structured analytical techniques. The scenarios were then prioritised according to their feasibility in the context of the State -level approach (SLA.

b) **Assess timeliness of each scenario:** Each feasible scenario was then applied to the proliferation pathways identified in the SLA, which then led to further prioritisation or elimination of scenarios based on the timeliness in which they could be carried out.

c) **Identify safeguards measures to address each scenario:** Various options for different safeguards measures were identified. They were then grouped into different overall approaches, in order to further test and compare efficiency, cost and risk in later steps.

d) **Cost assessment and comparison:** The cost was then estimated for each approach, and compared between different approaches to determine feasibility and any potential impact on resources. This was later refined in detail following agreement on the final approach.

e) **Identify and mitigate risks to determine the final approach:** A risk-based assessment was performed on the proposed measures in order to focus the allocation of safeguards resources. Risks were identified for the different approach options to select the most suitable approach. The risks identified in the chosen approach were then further mitigated to determine the final set of safeguards measures and activities. In conducting this analysis, the risk in achieving the generic safeguards objectives for the IAEA and Euratom, and the risks to safeguards implementation were assessed.

SAFEGUARDS CONCEPTS AND MEASURES TO ADDRESS EPGR CHALLENGES

The EPGR Project in Finland demonstrates how a need to achieve safeguards objectives can drive innovation, through the development and implementation of new techniques and their integration with traditional techniques. More recently-developed concepts and measures that were used to address the challenges identified in the EPGR Project include geological containment, flow monitoring, and remote data transmission of unattended monitoring systems, within the context of Safeguards-by-Design (SbD).

Safeguards by Design involves the integration of safeguards considerations early in the planning and design phase of a facility, and continuing this integration throughout construction, operation, and decommissioning [7]. This in turn reduces the need to retrofit the facility, thereby saving resources. It also reduces the burden on operators and safeguards staff by optimising inspections and facilitating joint-use equipment, while also potentially reducing the risks associated with licensing, budgeting and construction/operation schedules, with increased flexibility for future safeguards equipment maintenance and/or installation. In the case of the

EP and GR in Finland, SbD has been essential in enabling Euratom and the IAEA to identify needed infrastructure for safeguards equipment during the construction phase, and developing efficient measures to meet the requirements of the safeguards approach. For example, the provision of detailed design information of the canister deposition vehicle and description of the method by the operator has enabled a reduction in the number and locations of safeguards equipment underground.

'Geological containment' applies the concept of facility containment to the natural barrier of the underground component of the GR, and supports the objective of detecting the diversion of nuclear material [8]. This concept is defined by a notional boundary from the declared excavations underground out to a set distance, from which no excavations or movement of nuclear material can occur. The underground area outside the declared tunnels is a restricted zone where it is expected that no nuclear material should be located. Once the spent fuel canisters enter the containment, the spent fuel cannot be easily retrieved and is therefore designated as 'Difficult to Access [9]. This means that the integrity of the containment must be maintained, which is achieved via the use of seismic monitoring to detect any undeclared penetrations of the rock, and containment and surveillance (C/S) on the declared penetrations [9].[i]

By applying the concept of geological containment, continuity of knowledge (CoK) can be more effectively kept on 'Difficult to Access' spent fuel to meet diversion objectives. This would prevent the requirement to verify the spent fuel in the canisters, which would be physically challenging within the GR, in case of loss of CoK.

Inside the GR, flow monitoring is performed to observe the flow of nuclear material through a facility. It is less rigorous than maintaining CoK, which must be re-established if lost [10].[ii] However, evaluation of flow monitoring data within the geological repository is necessary to provide the inspectorates with a high confidence of the absence of misuse or undeclared activities and materials, within a reasonable time-frame. It will also enable the clarification of erroneous events and faster resolution of possible issues and inconsistencies if they occur, and comparison against operator declarations to ensure the facility is operating as declared. Risks to the reliability of safeguards equipment underground and the risk of restricted access to this equipment due to operational and radiation hazards will be mitigated via the use of existing operator equipment and network where possible, in particular safety-essential equipment that would require the cessation of operations until the issue is rectified, as a national regulatory requirement. In this way, the inspectorates can monitor the flow of nuclear material, and if that monitoring is interrupted, the movement of nuclear material is generally frozen until monitoring capabilities are regained. Furthermore, the use of operator equipment for flow monitoring will assist in the reduction of common-mode failures as part of a layered safeguards approach.

Remote data transmission (RDT) refers to data collected by unattended monitoring and measurement systems which are then transmitted electronically to inspectorate headquarters for review. These systems include surveillance systems, seals, NDA instruments, sensors and radiation monitors, and may have automated data collection and computer-assisted data review capabilities [1].[iii] RDT is already in place at a number of facilities around the world, and the IAEA's Division of Technical Services (SGTS) in collaboration with Euratom is currently developing an automated system to compare electronically-submitted operator declarations with sensor observations. This system will enable online process monitoring based multi-sensor data with very short delay feedback to the operator. The comprehensive use of RDT inside the EP and GR will reduce inspector presence at the facilities and provide virtual access to the nuclear material that would not be physically possible without significantly interrupting operations. Furthermore, it will reduce detection time of equipment failure. Whilst some physical inspection presence will be required, it is envisaged that some safeguards verification activities at the EP and GR will be performed entirely remotely, further reducing the burden on resources for both the inspectorates and the facility operator. In order to ensure successful implementation of these concepts, the IAEA, Euratom and Finland are working together to develop systems for implementation within the EP and GR.

CONCLUSION

The construction of two of the first facilities of their type to come under international safeguards requires an innovative and collaborative approach in formulating an efficient and effective safeguards regime, whilst minimising the impact on operations. At future encapsulation plants and geological repositories, physical access to nuclear material, safeguards equipment and tunnels will be very limited. This challenge requires effective use of Safeguards by Design, and new and emerging concepts such as geological containment, and RDT on unattended monitoring systems, in combination with traditional measures and novel use of reliable and proven technologies. The case of the EPGR in Finland has shown that through collaborative innovation, the IAEA, Euratom and STUK can work with the operator to implement efficient and effective safeguards in a manner that meets the needs of all stakeholders – for the operational period of one century and beyond.

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[i] Containment and surveillance (C/S) is applied to completement nuclear material accountancy, and is aimed at verifying information on the movement of nuclear or other material, equipment and sampled, or preservation of the integrity of safeguards-relevant data. Dual C/S refers to a system with two separate and independent C/S devices.

[ii] 'CoK is a system of data or information regarding an item that is uninterrupted and authentic and provides the IAEA with adequate insight to draw definitive conclusions that nuclear material is not being diverted from peaceful purposes'.
[iii] The term 'remote data transmission' replaces 'remote monitoring.'