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Elements of a Swedish Safeguards Policy for a Spent Fuel Disposal System

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Abstract:

This paper presents an outline of a proposed Swedish encapsulation and deposition system for spent nuclear fuel, possible national measures in support of international safeguards, and possible national measures implemented for domestic purposes. All these measures are only in support of nuclear material accountancy and are not in any way aimed at other scenarios that would be in violation of Swedish law, e.g., theft, falsification, sabotage, etc. Only the operational phase of the geological repository is considered in this paper.

The IAEA has developed safeguards approaches under integrated safeguards for encapsulation plants and geological repositories. The approaches are very generic for these two facility types and cannot be used for devising detailed safeguards approaches. In this context, a compatibility evaluation of the generic IAEA approaches vis-à-vis the proposed Swedish system has been conducted. This evaluation also takes into account the conclusion drawn under the Additional Protocol, i.e., the confirmed State-wide absence of undeclared nuclear activities.

Two elements of the proposed Swedish system that will need careful consideration are: (1) the high throughput encapsulation process–which may limit the time available for safeguards measurements; and (2) the unavailability of the copper canisters for measurement and evaluation of C/S once they have been loaded into transport casks. While also taking into consideration that ongoing daily operations over a period of several decades is expected at both facilities, there is apparent justification to develop very robust techniques for unattended verification and monitoring involving remote data transition capabilities.

For the proposed Swedish system, it appears imperative that the transport casks containing the canisters are covered by robust C/S measures from the time of canister loading at the encapsulation plant up to the time of entering the underground areas of the geological repository. It is considered undesirable to have routine inspection activities (including C/S activities) conducted underground.

Lastly, due to safety requirements, the operator is expected to perform comprehensive measurements on all individual fuel elements. These measurement results, in addition to equipment, may also be used by the IAEA. Consequently, authentication and sharing issues may need to be addressed.

Keywords: Final disposal; spent nuclear fuel; safeguards.

1. Introduction

Spent nuclear fuel from reactors must be managed and disposed of in a safe manner, including safeguards. A Swedish system for handling spent nuclear fuel has been developed and proposed by the Swedish Nuclear Fuel and Waste Management Company (SKB). In brief, the system is based on encapsulating the spent fuel in copper canisters and depositing them in granite bedrock about 500 m below ground. In 2011 SKB formally submitted licence applications for an encapsulation plant and a final repository.[1]

Spent fuel from Swedish reactors is shipped to Clab, an interim storage facility located in Oskarshamn. Here, the spent fuel is placed in storage pools in the bedrock about 30 m underground. Clab has been in operation since 1985 and is used to store spent fuel from all the nuclear power plants in Sweden.[2] Today there are about 33,000 spent fuel assemblies, at Clab corresponding to 6,500 tonnes of uranium and 61 tonnes of plutonium.[3] . The spent fuel stored at Clab consists primarily of BWR and PWR fuel with a few additions of older experimental fuel and spent fuel debris.[4] The flow of spent nuclear fuel in Sweden is illustrated schematically by Figure 1. A proposed encapsulation plant and a geological repository are also included in the figure.

[1] SKB's licence applications under two separate legal instruments have been reviewed by the Swedish Radiation Safety Authority and by the Land and Environmental Court. The Swedish Radiation Safety Authority supports licensing under the Act on Nuclear Activities on condition that a step-wise authorisation process is followed for key future phases of development. The conclusion from the Land and Environment Court is that some identified uncertainties in the long term stability of the copper canisters need to be further addressed by SKB before a licence under the Environmental Code can be considered. It is the Swedish government that takes the final decision.

[2] The NPPs at Forsmark, Oskarshamn, Ringhals and Barsebäck (the latter undergoing decommissioning).

[3] As of March 2017.

[4] This is fuel from the closed, experimental Ågesta reactor and some German fuel obtained in a swap with Swedish fuel that was intended to be reprocessed. The fuel debris consists of parts of spent fuel rods from the Studsvik Hot Cell laboratory. This is debris from examination of the fuel or leaking fuel rods that have been cut in smaller parts. The fuel debris is stored in closed containers.

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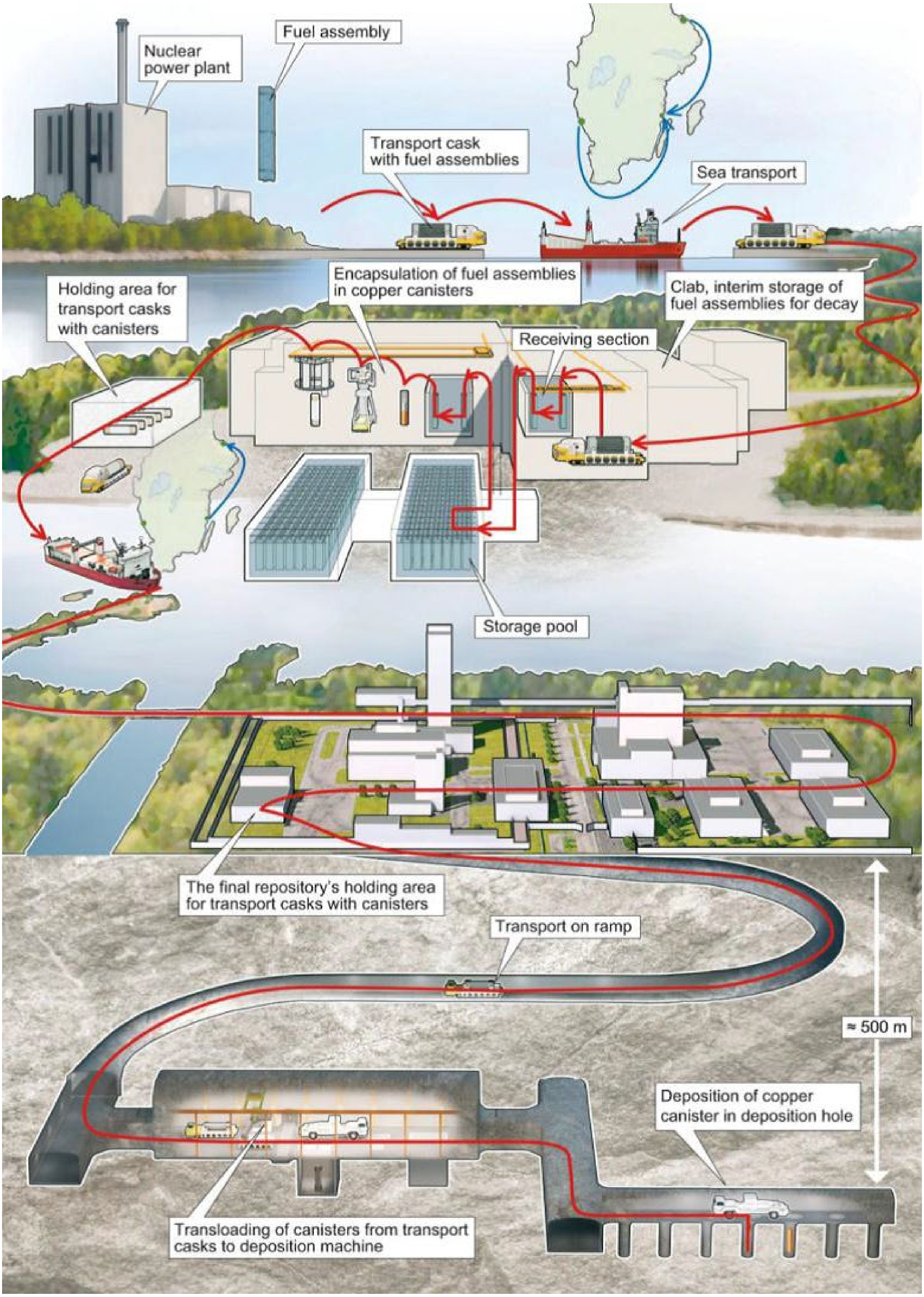

Figure 1. Schematic illustration of the flow of spent fuel in Sweden, from nuclear power plants to final deposition. Source: SKB and LAJ Illustration.

2. The encapsulation plant

SKB has applied for permission to build the encapsulation plant, which is to be co-located with the existing interim storage facility Clab as an extension above ground. Thus there will be no need for transports between the interim storage and the encapsulation plant. The combined facility will be named 'Clink'.[5] Cooling times of the spent fuel that will be encapsulated will typically be 40 years, but it may vary from 10 to 60 years. Burn-up will range from a few GWh/tU up to 60 GWh/tU.

Fuel to be encapsulated will be moved to a measuring position where the operator will verify important parameters of the fuel, such as thermal residual power and burn-up. After the operator's verification, the fuel will be moved to a transfer canister, which will be moved to the handling cell where the assemblies will be dried and placed in a copper canister. In a series of steps, a copper lid will be put on and stir welded to the copper canister. The weld will be quality checked by the operator and the surface of the canister will be polished and decontaminated. Lastly, the canister will be placed in a transport cask and temporarily stored at the facility before being shipped to the geological repository site.

Each copper canister will have an insert of cast iron with positions for 12 BWR fuel assemblies or four PWR fuel assemblies. Fuel will be encapsulated during campaigns arranged separately for BWR and PWR fuel. It is envisaged that 150 canisters will be treated per year. During routine operation, this means loading one canister per workday, corresponding to a flow of 12 BWR assemblies, or four PWR assemblies, per day.

3. The geological repository

The plan is to build the geological repository at Forsmark, about 360 km north of the encapsulation plant. The repository will be close to, though separated from, the Forsmark NPP and the final storage facility for low and intermediate level radioactive waste, SFR, located there.

The geological repository will consist of a surface area and an underground deposition part, about 500 m below ground. The surface area will encompass a terminal and buildings for elevators, ventilation and backfill materials. There will be a transport ramp for vehicles connecting the above ground area with the underground repository; this will include the vehicle for transporting the transport casks containing the copper canisters. Copper canisters from the transport vehicle will be reloaded to a deposition machine in the underground Central Area. Transport tunnels will lead from the Central Area to the deposition tunnels, each having about 30 drilled vertical holes for one copper canister each. When all positions in a deposition tunnel have been filled, the tunnel will be backfilled and sealed with a concrete plug. A schematic illustration of the geological repository site is shown in Figure 2.

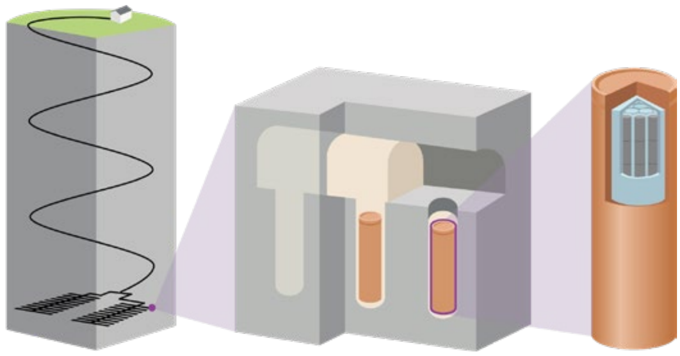

Figure 2. A schematic illustration of the geological repository's proposed layout.

Deposition tunnels will be excavated in a rock excavation zone, separated from the deposition and backfilling zones by a protection zone (with no blasting) and a separation wall. Excavation, deposition and backfilling can thus take place simultaneously, although physically separated. When the deposition tunnels have been backfilled, the separation wall will be moved, and the next step of excavation, deposition and backfilling can begin. One such step will take at least one year.

A specially designed ship will deliver transport casks containing filled copper canisters from the encapsulation plant to the geological repository. The transport casks will be temporarily stored at surface level in a terminal building before being transported by a ramp vehicle underground to the Central Area. The copper canisters will then be transferred from the transport cask into a radiation shield of the deposition vehicle. The deposition vehicle will bring the copper canister from the Central Area to its final deposition position. Lastly, the ramp vehicle will return to the surface with the empty transport cask. The facility will deposit 150 canisters per year during normal operation. This means an average of one transport cask with copper canisters will be transported each workday from the surface terminal building to the subsurface Central Area and deposited.

Both the encapsulation plant and the geological repository will be in operation for about 45 years. After this period of operations, the surface buildings will be removed and the repository sealed. More details on the proposed encapsulation plant and the geological repository can be found in [1].

4. Legal requirements and national policy

One basic national legal requirement is that operators of nuclear facilities are responsible for ensuring that all the necessary measures are taken for safe management and

[5] An acronym for the Swedish term Clab and *inkapslingsanläggning (Swedish for encapsulation).*

disposal of spent nuclear fuel. This includes fulfilling all obligations as prescribed by Sweden's agreements aimed at preventing the proliferation of nuclear weapons [2]. As the licensees have assigned management and disposal of spent fuel to the Swedish Nuclear Fuel and Waste Management Company, SKB, the responsibility rests with SKB.

Insofar as a geological repository is concerned, the main national policy in Sweden with regard to nuclear material accountancy is to provide assurance domestically and internationally that all deposited nuclear fuel is as declared. According to national regulations [3], SKB must ensure that sufficient and correct nuclear material accountancy information and knowledge are in place and available on the part of the spent fuel prior to its deposition. This can be carried out by verifying that the documentation accompanying the nuclear material is complete and correct, for example by using a specially designed "paper trail" (e.g., source and operating documents) verification procedure covering the entire fuel history. In the event of uncertainty, SKB should perform the necessary measurements or analyses. SKB is also required to have a system in place guaranteeing that necessary and correct information about the nuclear material is documented and retained following the material's disposal.

As a consequence of Sweden's international safeguards obligations, all requirements must be met as effectively and efficiently as possible. This should involve the inclusion of design features that further facilitate the implementation of international safeguards. In order to achieve this, early discussions between the parties involved will be necessary. Therefore, early provision of the required documentation is of importance for fostering efficient and cost-effective safeguards.

5. Safeguards models

The IAEA model integrated safeguards approach for an encapsulation plant [4] assumes that the encapsulation plant is a separate facility and that the spent fuel will be transferred from an interim storage facility in a transportation cask to an assembly handling cell of the encapsulation facility. The proposed Swedish encapsulation plant will, however, be co-located with the spent fuel interim storage facility and form a combined facility. The encapsulation part of the facility will not have an area for receiving and storing spent fuel transport casks. The spent fuel from the NPPs will be stored in the interim storage area and stored in pools for several years before being moved internally to the encapsulation plant.

The IAEA model integrated safeguards approach for a geological repository [5] assumes a separate facility similar to the proposed Swedish system. However, there are a few differences. The IAEA model assumes that the copper canister can be identified upon receipt at the geological repository and that canister identification can be performed when a canister is transferred between the above ground area and the geological repository at the entrance of the repository. In the proposed Swedish system, however, the copper canisters will be shielded by a transport cask until they reach the underground central area.

These models [4], [5] assumes that during temporary canister storage above ground, dual C/S systems should be applied. A redundant C/S system is to be applied to the disposal canister during transport from the encapsulation plant to the repository [5]. In this context, we want to stress the importance of having robust C/S systems on the transport cask, e.g., systems that can be fully operated by facility employees while also providing credible assurance for the international community.

However, these model approaches are partly outdated and do not fully reflect the current (not yet finally formulated) policy of the IAEA, the findings of SAGOR I-II or the provisions of the Additional Protocol. They can therefore not be used directly as a basis for any detailed technical preparations by Sweden.

6. Safeguards considerations

6.1 General

On the basis of, inter alia, IAEA GOV/2002/8 [6], IAEA Model Integrated Safeguards Approaches for Spent Fuel Encapsulation Plants [4] and the IAEA Safeguards Glossary (2001) [7], in the absence of finally issued formulated guidance, it is our understanding that the basic international verification requirements for an encapsulation plant are:

- Yearly verification for "gross defects" (yes/no test whether or not all declared fissile material is missing) with "low detection probability" (20%) for spent fuel elements which are available for measurement and which are "difficult to dismantle"; [4]
- Verification for "partial defects" (at least a yes/no test whether or not 50% of the declared fissile material is missing) for each spent fuel element which is being placed in a copper canister and for yearly verification of spent fuel elements which are available for measurement and which are not "difficult to dismantle"; [4]
- Maintaining "dual C/S" or an equivalent system for spent fuel elements which are not available for measurement. [4]

There is no completely clear definition of the concept "difficult to dismantle". Rod exchange has been performed earlier on both BWR and PWR fuel in the ponds of Swedish nuclear power plants. However, with the absence of the required equipment for dismantlement at the Clab and Clink sites, it is reasonable to assume that all fuel that will be deposited can be classified as "difficult to dismantle".

With the above requirements and assumption, it is expected that the nuclear material at Clink will be verified with low detection probability for gross defects on an annual basis. Spent fuel will be verified for partial defects immediately prior to encapsulation. After encapsulation, canisters will be placed in transport casts and temporarily stored at the site under dual C/S before shipment.

Thereafter a robust C/S system should be applied to the transport cask. This C/S should be evaluated upon entry into the underground area at the geological repository.

The activities under the Additional Protocol are not fully credited for in the two IAEA approaches mentioned above. The confirmed state-wide absence of undeclared activities should render unnecessary certain proposed monitoring and verification activities. In this context, we would refer to an excerpt from the Minutes of the Experts' Group on Safeguards for Final Disposal of Spent Fuel in Geological Repositories [8] and also the statement from DG to the IAEA Board of Governors in February 2002 [9].

"The important difference is that under Integrated Safeguards, geophysical methods may not be needed to detect excavations or excavation activities. For this purpose, geophysical tools could be replaced with Complementary Access and information analysis. Ground Penetrating Radar (GPR) may still be required for DIV purposes (i.e. detection of undeclared tunnels, rooms and boreholes, such as any permanent underground equipment and installations)." [8]

"The measures of the Model Additional Protocol were never intended to be simply superimposed as a new 'layer' of activity on top of safeguards as implemented under INFCIRC/153 (Corrected) and earlier strengthening measures. Given the additional assurances provided under an additional protocol, the need to avoid undue burden on States and facility operators, and the need for maximum efficiency in the light of the prevailing resource constraints, the new measures were to be 'integrated' with existing ones." [9]

Periodic DIVs and CAs under and above ground will provide sufficient assurance of the integrity of the site declarations and the absence of undeclared activities for both areas. The implementation of AP measures in the State will add more information on the nuclear capabilities.

As mentioned earlier, the last verification opportunities for the individual fuel elements exist at the encapsulation plant. The operator is expected to perform comprehensive measurements on all individual fuel elements for safety purposes. The optimal position for the operator's performance of these measurements is as early as possible in the material flow into the encapsulation process. This enables the operator to more easily reject assemblies that for safety or other reasons do not fit into the planned canister.

The IAEA (and the Euratom), on the other hand, presumably prefer to have the verification measurement performed immediately prior to the canister lid being put on and welding being started. This verification is expected to be performed according to established IAEA criteria and practice, namely, a verification for "partial defects" for the spent fuel element.

Routine inspection activities underground at the final repository are not foreseen; underground activities will be limited to DIV only. Also, see the following recommendation from SAGOR:

"The recommended safeguards approach is to use item accounting supported by a reliable and comprehensive C/S system above-ground to verify, inter alia, the flow of full casks and overpacks. DIV is recommended as the primary safeguards measure underground. DIV would include geophysical methods."[10]

6.2 Measurements and possible use of operators' results

It is not desirable to have two completely different pieces of measurement equipment and perhaps also two different measurement positions for the required final verification of the spent fuel. This takes up space and will take more time. Also, it must be kept in mind that up to 12 assemblies will be encapsulated on a daily basis. It should be investigated to what extent the operators' measurement results and equipment can be shared with the IAEA (and Euratom). It has to be assured that the operator's measurement results in principle are sufficient for the IAEA (and Euratom). Therefore, the authentication issues must also be addressed to provide the international safeguards with the required opportunities for drawing independent conclusions.

Considering the fact that daily operations are expected to take place over the course of several decades, there appears to be a need to develop unattended verification techniques by means of remote data transmission capabilities. The measurement position needs to be arranged at Clink in coordination with the IAEA (and Euratom).

After measurement at the Clink site, proper C/S measures must be applied to assure Continuity of Knowledge (CoK) from the final measurements until the closure of the copper canister. If needed, as a backup to the C/S measures, a simple unattended quality control immediately prior to the assemblies being placed in the copper canister may also be considered. Such verification could involve reading the fuel identification number, measuring the weight of the assembly, and using a gross gamma detector. After the spent fuel has been placed in the copper canister, additional C/S measures have to be applied until the canister is placed in its final position in the geological repository.

If a method is developed and approved, verification of the copper canister may also be conducted at the encapsulation plant. However, for practical reasons, there are limitations to conducting similar verification on the transport cask or on the copper canister underground at the final repository during normal operations. In exceptional cases, such verification underground could be performed in order to resolve anomalies.

6.3 Continuity of Knowledge

In the proposed Swedish system, it seems imperative that the transport casks containing the canisters are covered by robust C/S measures from canister loading at the encapsulation plant to entering the underground part of the geological repository.

The operational activities are expected to be run continuously for approximately 40-50 years with daily production of one copper canister and shipments on at least a biweekly basis, a sealing system that can be attached, also that the same seal can be detached by the operator, would be cost-efficient and enhance an efficient use of resources.

The inner walls of the underground tunnels and shafts define the primary containment of the geological repository. During construction and operation of the repository, there will be an access ramp, ventilation shaft, etc. These should be covered by C/S methods that are able to detect movements of spent fuel down to the deposition location and to detect any removal of nuclear material from the underground part. It is important to verify that a canister enters the underground part of the repository. This enables us to treat the underground part of the geological repository as a black box and there is thus no need for C/S and verification methods underground.

Also, as already discussed earlier, it is not considered desirable to have routine inspections of nuclear material accountancy activities, or verification of seals, etc. performed underground.

If the C/S is lost, specific measures determined by the IAEA will be applied [5]. A unique identifier for each copper canister resolution may contribute to its resolution, but not for routine use. Gamma and neutron measurements on the transport container may also be considered as a measure to resolve inconsistencies and re-establish C/S.

Verification of empty transport containers leaving the underground area is to be performed, e.g., weighing, gamma and neutron measurement.

6.4 Design Information Verification

The integrity of the geological repository can be verified during DIV, which may be conducted periodically. The main objectives are to confirm the following: that the excavations are performed as declared, that there are no other undeclared nuclear activities, and that there are no clandestine removal routes or excavations. In this context, Complementary Access both above and below ground, information from satellite imagery and other open sources' information provide assurance for confirming the absence of clandestine activities at the area of the site. Hence, there is no need to continuously monitor the excavation by using geo-seismic monitoring.

7. Conclusions

The conclusions drawn under the Additional Protocol are not properly credited for in the IAEA approaches mentioned above. The confirmed state-wide absence of undeclared activities should render unnecessary certain monitoring and verification activities that have been proposed. Therefore, in this context, some of the facility-specific considerations in the IAEA model may not apply.

The last verification opportunities for individual fuel elements and also for routine verification of the canisters will exist at the encapsulation plant. The final spent fuel verification prior to canister welding at the encapsulation plant is expected to be performed according to established IAEA criteria and practice.

The maximum time available for verification will depend on the material flow. In the proposed Swedish spent fuel disposal system, up to 12 assemblies will be encapsulated in one day, so the measurement times will probably be in the order of minutes. Considering the fact that daily operations over the course of several decades are expected, there is a need to develop unattended verification techniques by means of remote data transition transmission capabilities.

Due to safety requirements the operator is expected to perform comprehensive measurements on all individual fuel elements. It should be investigated if these measurement results can be shared with the IAEA. Therefore, authentication and sharing issues have to be addressed.

Inspections for DIV purposes are essential to confirm that the repository is constructed as declared and to confirm the absence of any undeclared activities. It is considered undesirable to have other routine and verification activities, including C/S, performed underground.

In the proposed Swedish spent fuel disposal system, it seems imperative that the transport casks containing the canisters are covered by robust C/S measures from the time of canister loading at the encapsulation plant up to the time of entering the underground part of the geological repository. It is considered undesirable to have routine inspection activities (including C/S activities) performed underground.

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9. Legal matters

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