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The Back-End of the Nuclear Fuel Cycle in Sweden

Considerations for safeguards and data handling

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SSM perspective

Background

According to the Non-Proliferation Treaty (NPT) and other Treaties signed by Sweden, all nuclear facilities and activities in Sweden are under safeguards - an international monitoring system for all nuclear material. In order to close the back-end fuel cycle, the industry´s plan in Sweden is to construct an encapsulation facility and a geological repository to take care of all the spent fuel. The canisters with spent fuel is planned to be disposed of 500 m below the ground surface in crystalline rock. These new facilities will also have to be under safeguards supervision. However, as the nuclear material will be inaccessible after encapsulation and emplacement it is not possible to verify that the nuclear material is as declared. This means that the safeguards system will phase new challenges. Currently, on the international level, there are ongoing discussions and work to specify safeguard requirements for the final disposal of spent fuel.

Objectives

The aim of this project has been to discuss and analyze various aspects of how the safeguarding of an encapsulation plant and a deep repository can be accomplished. The result will be one input for SSM in the formulation of safeguard requirements that have to be fulfilled in the final disposal of nuclear spent fuel. The result may also be used in an international context to show how Sweden can fulfil existing/future safeguard requirements for the encapsulation plant and the geological repository.

Results

The report is a compilation report consisting of three papers.

A safeguards approach for the planned encapsulation facility and the operating final repository is presented in paper 1. Special considerations concerning safeguards for the final disposal process have been discussed and incorporated into the approach.

Paper 2 defines the spent fuel data that must be secured, for safeguards purposes and for national purposes, prior to when the spent fuel assemblies become inaccessible in the final disposal process. A finding according to the paper is that the safeguards approach for the final disposal process should include a gross defect measurement. Furthermore, it is concluded in the paper that the information categories that are sufficient for a national record are available today, but that the information should be completed with the data uncertainties.

In paper 3 a diversion path analysis has been performed for the interim storage and encapsulation facility in the back-end of the Swedish fuel cycle. The diversion path analysis is necessary for defining the safeguards system that can cover all feasible diversion paths.

The objective of this particular diversion path analysis was to form a basis for identifying the safeguards system's need for fuel data.

A conclusion from the diversion path analysis is that it is possible to allow a back-flow of material through the facility without losing the ability to safeguard the nuclear material in the building.

Project information

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Reference: SSM 2008/346/1301

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SUMMARY

All nuclear facilities and activities in Sweden are under safeguards - an international monitoring system for all nuclear material. When the planned facilities for encapsulation and final disposal of spent nuclear fuel are constructed, they will also be covered by the safeguards system. The Swedish plans for final disposal is to emplace all spent fuel in a geological repository. The new facility type, the geological repository, will mean that the safeguards system is faced with new challenges, mainly since the nuclear material will be inaccessible after encapsulation and emplacement. This implies that, unlike for existing facilities, it is not possible to verify that the nuclear material is where it is declared to be or that it has the declared characteristics.

This report consists of three parts, where each part investigates one aspect of safeguards for encapsulation and final disposal of spent nuclear fuel.

The first part, Paper 1, presents a plausible safeguards approach for the two new facilities. The paper starts with an introduction to international safeguards and to the facilities. The facility layouts and processes are comprehensively described. The main part of Paper 1 is spent describing a safeguards system that covers all diversion paths for fissile material. The diversion paths are identified in the diversion path analysis which is the basis for Paper 3. A strategy to detect diversion is presented for each diversion path.

The safeguards system comprises three main measures:

1. Verification of Nuclear Material Accountancy using, for example, verifying measurements and comparisons between shipment documents and receipt documents for transports.

2. Containment and Surveillance which are methods used to maintain continuity of knowledge of the nuclear material during periods between inspections.

3. Design Information Verification which is methods to verify that nuclear facilities are designed and operated according to declarations.

The second part of the report, Paper 2, describes which data must be secured prior to encapsulation and disposal of the nuclear material. Fuel data is needed for safeguards reasons and for future national needs. The conclusions include a summary of the data types that cannot be recreated once the fuel assembly is encapsulated.

The safeguards system needs data from a measurement showing that the fuel assembly to be encapsulated actually contains spent nuclear fuel, i.e. is not a

dummy. Furthermore, each assembly must be undisputedly identified. These conclusions are supported by the diversion path analysis presented in Paper 3.

Fuel data for national needs should cover all future needs that the State (which will assume responsibility for the repository and its contents after its closure) may have. Data that must be secured prior to encapsulation is the isotopic composition of the fuel including the uncertainties for the computed or measured data.

The third and final part of the report, Paper 3, includes an analysis of possible paths from the encapsulation plant along which nuclear material could be diverted. The diversion path analysis is the basis for discussions on which data the safeguards system must have access to (see Paper 2) and on how a comprehensive safeguards system for the encapsulation plant could be designed (see Paper 1). The diversion path analysis includes a summary of identified diversion paths from the encapsulation process and detection points, i.e. points in the process where diversion can be detected.

SVENSK SAMMANFATTNING

Alla kärntekniska anläggningar och aktiviteter i Sverige omfattas av en internationell kärnämneskontroll, även kallad safeguards. Kärnämneskontrollen kommer också att omfatta de planerade anläggningarna för inkapsling och slutförvar av använt kärnbränsle. Slutförvarsanläggningen kommer att ställa kärnämneskontrollen inför helt nya situationer, i första hand beroende på att kärnbränslet kommer att bli helt oåtkomligt efter inkapsling och deponering. Man kan alltså inte, som i befintliga anläggningar, kontrollera att kärnämnet finns där det deklareras vara eller har de deklarerade egenskaperna.

Denna rapport består av tre delar, där varje del för sig belyser en aspekt av kärnämneskontroll för inkapsling och slutförvaring av använt kärnbränsle.

Den första delen, Paper 1, ger en övergripande bild av ett tänkbart system för kärnämneskonstroll för de planerade anläggningarna. Paper 1 börjar med en introduktion till internationell kärnämneskontroll och till de planerade anläggningarna. Dessa beskrivs övergripande till både layout och anläggningsprocess. Huvuddelen av Paper 1 ägnas åt att beskriva ett system för kärnämneskontroll som täcker samtliga avledningsvägar för klyvbart material. Avledningsvägarna har identifierats genom den analys som ligger till grund för Paper 3. För varje avledningsväg beskrivs strategier för att upptäcka avledning via just den vägen.

Systemet baseras på tre huvudsakliga metoder:

1. Kontroll av bokföring av kärnämnet genom bland annat mätningar och jämförelser mellan sänddokument och mottagardokument vid transporter.
2. Containment and Surveillance vilket är metoder för att säkerställa att den kunskap man byggt upp om kärnämnet bibehålls under den tid då det inte är under direkt kontroll av en inspektör.
3. Design Information Verification vilket är metoder för att kontrollera att kärntekniska anläggningar ser ut och drivs enligt statens deklarationer.

Rapportens andra del, Paper 2, beskriver vilka data som måste inhämtas innan kärnämnet blir oåtkomligt vid inkapsling och deponering. Bränsledata behövs både med tanke på kärnämneskontroll och med tanke på framtida nationella behov. Slutsatserna inkluderar en sammanställning av de data som inte kan återskapas då bränsleelementet är inkapslat.

För kärnämneskontrollen finns behov av data från en mätning som visar att bränsleelementet faktiskt innehåller använt kärnbränsle och inte är ett förfalskat bränsleelement, en så kallad dummy. Dessutom måste varje bränsleelements identitet vara säkerställd. Dessa slutsatser har kunnat dras med stöd av den analys av avledningsvägar som utförts i Paper 3.

Bränsledata för nationella behov ska täcka alla framtida behov som staten (som tar över ägandet av slutförvaret då det är fyllt och förslutet) kan tänkas ha. Data som måste tas fram innan inkapsling är bränslets isotopsammansättning inklusive de beräkningsosäkerheter som är förknippade med dessa data.

Den tredje och sista delen av rapporten, Paper 3, innehåller en analys av möjliga avledningsvägar från inkapslingsanläggningen, längs vilka kärnämne skulle kunna föras bort. Analysen är nödvändig som underlag för diskussioner dels om vilka data som safeguardssystemet måste ha tillgång till (se Paper 2), dels om hur ett heltäckande safeguardssystem för inkapslingsanläggningen kan utformas (se Paper 1). Avledningsvägsanalysen innehåller en sammanställning av de avledningsvägar som identifierats från inkapslingsprocessen samt så kallade detection points, det vill säga punkter i processen där avledning kan upptäckas.

REPORT STRUCTURE

This report is a compilation of three papers:

Paper 1 *A safeguards approach for the Swedish encapsulation plant and final repository for spent nuclear fuel*

Paper 2 *Fuel data in preparation for the final disposal of spent nuclear fuel*

Paper 3 *Diversion path analysis for Clab and the encapsulation facility*

The papers are interrelated but can be read separately.

Safeguards cover all nuclear activities in Sweden to show the international community that the Swedish nuclear fuel cycle is strictly aimed at civil power production. As new facilities and processes are added to the nuclear activities, in order to handle the spent nuclear fuel from the power plants, the safeguards system must be extended to cover the new parts.

The Swedish strategy to handle the spent fuel is to place the fuel in copper canisters which in their turn are placed in a geological repository.

In **Paper 1** a safeguards approach for the planned encapsulation facility and the operating final repository is presented. Special considerations that concern safeguards for the final disposal process have been discussed and incorporated into the approach. The paper elaborates further on **Paper 3**.

Paper 2 contains a definition of the spent fuel data that must be secured, for safeguards purposes and for national purposes, prior to when the spent fuel assemblies become inaccessible in the final disposal process. The paper elaborates further on **Paper 3**.

Paper 3 presents a diversion path analysis for the combined interim storage and encapsulation facility that will be constructed in Oskarshamn in the south-west of Sweden. The diversion path analysis has provided a basis for the safeguards related parts of **Paper 1** and **Paper 2**.

DEFINITIONS

Containment and surveillance

Containment and surveillance, C/S, is used to complement nuclear material accountancy through maintenance of the continuity of knowledge between verifications of the accountancy. The most common C/S measures are seals (containment) and optical surveillance. For example, seals are used on containers of nuclear material to ensure that no material has been added or removed from the container since the last verification of its contents. Optical surveillance is typically used in storage areas to verify that the movements of nuclear material in and out of the area are as declared.

Gross and partial defect level verification

Defect denotes a difference between the declared amount of nuclear material and the material actually present.

Gross defect refers to an item or a batch that has been falsified to the maximum extent possible so that all or most of the declared material is missing. To perform gross defect level verification refers to verification that the item is present and contains nuclear material.

Partial defect refers to an item or a batch that has been falsified to such an extent that some fraction of the declared amount of material is actually present. To perform partial defect level verification is defined, in the context of spent nuclear fuel assemblies, as verification capable of verifying that at least 50 % of the fuel pins are present in the assembly.

Non-destructive analysis

Non-destructive analysis, NDA, is a measurement of the nuclear material content or of the element or isotopic concentration of an item without producing significant physical or chemical changes in the item. An example of NDA equipment is a gamma spectrometer that detects the emitted gamma radiation from a spent nuclear fuel assembly.

Significant quantity

A significant quantity is the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded. For example, a significant quantity of plutonium is 8 kg while a significant quantity of natural uranium is 10 t.

Timeliness

The IAEA safeguards objective is to detect diversion of nuclear material in a *timely* manner. Different nuclear material categories are connected to different timeliness detection goals referring to the time passed between the diversion act and the detection of the diversion. These goals are used for establishing the frequency of inspections.

PAPER 1

A SAFEGUARDS APPROACH FOR THE SWEDISH ENCAPSULATION PLANT AND FINAL REPOSITORY FOR SPENT NUCLEAR FUEL

Abstract:

Safeguards cover all nuclear activities in Sweden to show the international community that the Swedish nuclear fuel cycle is strictly aimed at civil power production. As new facilities and processes are added to the nuclear activities, in order to handle the spent nuclear fuel from the power plants, the safeguards system must be extended to cover the new parts.

The Swedish strategy to handle the spent fuel is to place the fuel in copper canisters which in their turn are placed in a geological repository.

A safeguards approach for the planned encapsulation facility and the operating final repository is presented in this report. Special considerations that concern safeguards for the final disposal process have been discussed and incorporated into the approach.

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1 INTRODUCTION

This report summarizes the work performed during 2009 in a research project initiated by the Swedish Radiation Safety Authority, SSM. The work aims at resolving issues related to safeguarding the back-end of the Swedish fuel cycle.

Although the Swedish fuel cycle is under safeguards today, there are a number of issues that are unique for the back-end of the fuel cycle, which calls for special attention. These issues include e.g. that the repository perimeter is not visible other than from the inside; and that the nuclear material will become unavailable for verification after emplacement in the repository.

Considering the issues mentioned above, a safeguards approach has been suggested. The approach is based on diversion path analyses for the combined interim storage and encapsulation facility and for the final repository. Furthermore, needs for fuel data, as described in **Paper 2** have been considered in the safeguards approach. The ambition has been to create a minimal safeguards approach that still covers all feasible diversion paths, with even emphasis on all phases of the fuel cycle.

Only operating facilities are included in the approach, i.e. safeguards for the closed repository is not investigated here.

2 INTRODUCTION TO SAFEGUARDS

2.1 INTERNATIONAL SAFEGUARDS

Safeguards constitute a control system put into place by the International Atomic Energy Agency, IAEA in order to timely detect if a state is diverting nuclear material from peaceful activities to the production of nuclear weapons. The legal basis for IAEA to apply safeguards is the non-proliferation treaty [1]. The non-proliferation treaty binds the signatory states to not produce nuclear weapons. Furthermore, it allows for IAEA to apply safeguards measures to the state's nuclear facilities.

Sweden has signed the Non-Proliferation Treaty. Furthermore, Sweden has signed a Comprehensive Safeguards Agreement with the IAEA and has signed and ratified the Additional Protocol to the Comprehensive Safeguards Agreement. When a state has signed and ratified the Additional Protocol, the IAEA can use a new set of activities to evaluate the state as a whole. For example, IAEA can perform inspections at facilities that do not hold nuclear material in addition of declared nuclear facilities. IAEA can also use open source material such as research articles etc. If the IAEA finds a positive result of the evaluation, i.e. a conclusion that there are no undeclared facilities and no undeclared material, Integrated Safeguards can replace the traditional safeguards system in the state. In Sweden, the implementation of Integrated Safeguards started January 15 2009. Integrated Safeguards are described as an optimum combination of the safeguards measures available in the traditional safeguards agreement (Comprehensive Safeguards Agreement) and in the Additional Protocol. Integrated Safeguards require fewer verification and inspection activities since a measure of confidence is acquired, that the state will not pursue nuclear weapons production. For example, in principle, the IAEA can replace planned inspections with fewer unannounced inspections and short notice random inspections. This approach could therefore be more resource efficient than traditional safeguards.

The objective of international safeguards is to detect if a signatory state to the Non-Proliferation Treaty violates the treaty by diverting nuclear material to the production of nuclear weapons. This objective has been further defined in a technical objective: *"the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection"* [1]. A significant quantity is the amount of nuclear material sufficient for the production of a nuclear weapon. The goal regarding the amount of nuclear material is connected to a timeliness goal referring to the time passed between the diversion act and the detection of the diversion. The timeliness goal depends on the sensitivity of the nuclear material, i.e. how easily it can be transformed to the metal component of a nuclear weapon. For irradiated material, such as the spent nuclear fuel inventory in Clab, the timeliness goal is three months under traditional safeguards, and one year under Integrated Safeguards.

As a member of the European Union, Sweden has also acceded to the Euratom treaty, giving the European Commission the right to apply safeguards at the nuclear facilities in Sweden. DG-ENER performs the Commissions' safeguards activities.

2.2 NATIONAL SAFEGUARDS

The national safeguards authority in Sweden is SSM, which has the task to see to that Sweden is in compliance with the international agreements mentioned in section 2.1. This is the main purpose of SSM's safeguards activities. In addition, SSM contributes to the strengthening of the international safeguards regime through research efforts and confidence building actions. The SSM safeguards for the final disposal process should also be performed in such a manner that public acceptance of the final disposal process, and the connected safeguards activities, is achieved. It is the state, through an appropriate authority, that will be responsible for the repository once the operator has completed the deposition and closed the facility.

2.3 PREVIOUS WORK

The safeguards challenges of spent nuclear fuel disposal were identified by the IAEA already in the end of the 1980's. Since then, work on safeguards for geological repositories and final disposal has been carried out and presented in several fora, including the following:

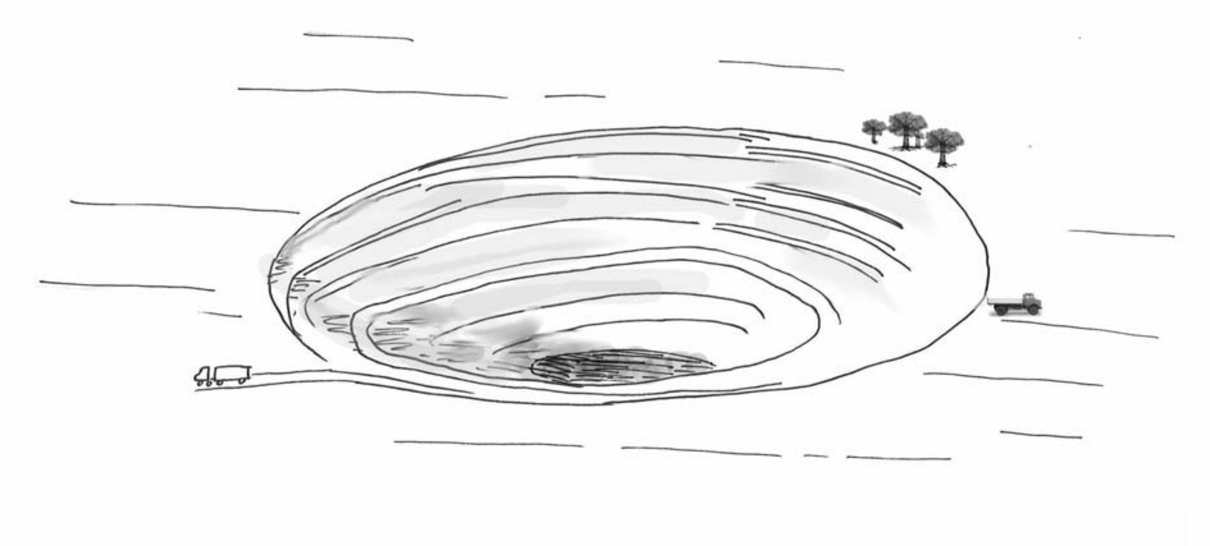
- Consultants meetings
- Advisory group meetings
- State Support Programmes to IAEA safeguards, for example
    - SAGOR – Programme for Development of Safeguards for the Final Disposal of Spent Fuel in Geological Repositories. An IAEA convened programme with participants from many member states, including Sweden, with the purpose of developing international safeguards approaches for spent fuel in conditioning plants and geological repositories.
    - ASTOR – Application of Safeguards to Geological Repositories. An IAEA convened experts group with the purpose of continuing the work started within the SAGOR programme.
    - Other State Support Programmes: Germany and Finland, among others.
- European Safeguards Research and Development Association (ESARDA) working group: Back-end of Fuel Cycle
- SAGSI – Standing Advisory Group on Safeguards Implementation. An advisory group to IAEA
- IAEA Policy Paper for safeguarding geological repositories.

Conclusions from previous work are summarised below. It should be noted that these are not formal requirements on the safeguards system:

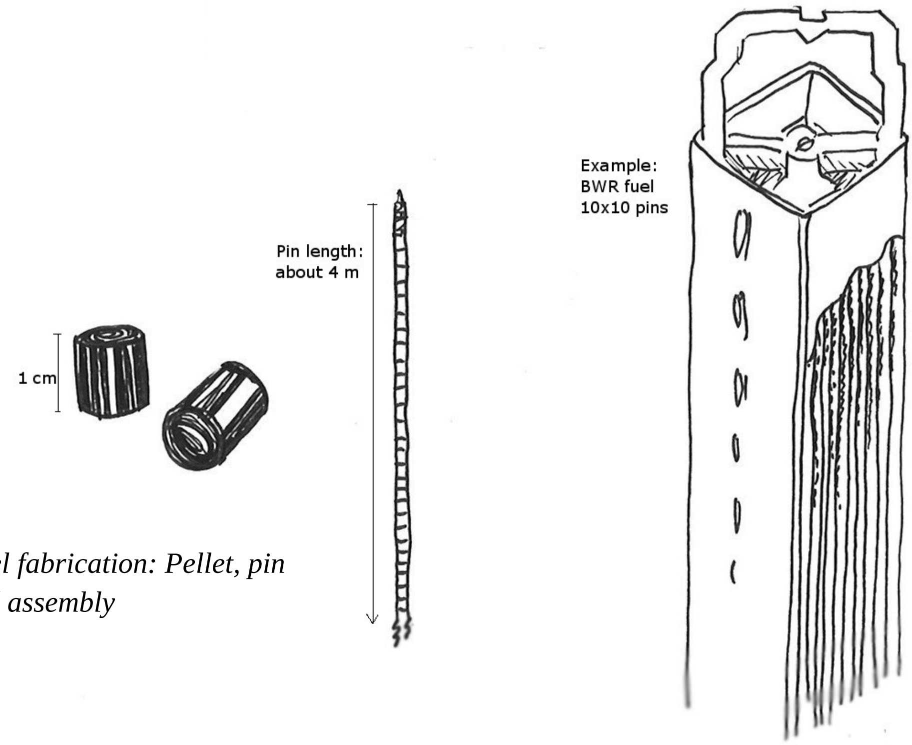
- The fuel should be disposed of only as verified nuclear material fulfilling the demand on continuity of knowledge kept [2].
- The safeguards applied should give the same level of assurance of non-diversion of nuclear material from peaceful use throughout the fuel cycle [3].
- Nuclear material transferred to a final repository should be verified at the same level as is required by the IAEA for material in difficult-to-access storage [3]. This implies that the fuel should be verified with a NDA technique providing a high probability of detection of a partial defect. The partial defect referred to here is 50 % meaning that the NDA technique should be able to detect if half of the fuel pins in an assembly is missing.
- Safeguards information should be retained for as long as the material in the repository is under a safeguards agreement [4].

The work mentioned above is mainly concerned with international safeguards. National safeguards are included in the work of the Finnish State Support Program to IAEA safeguards [5]. Furthermore, these recommendations were formulated with the traditional safeguards system as a prerequisite, with exception for the work carried out in the ASTOR group.

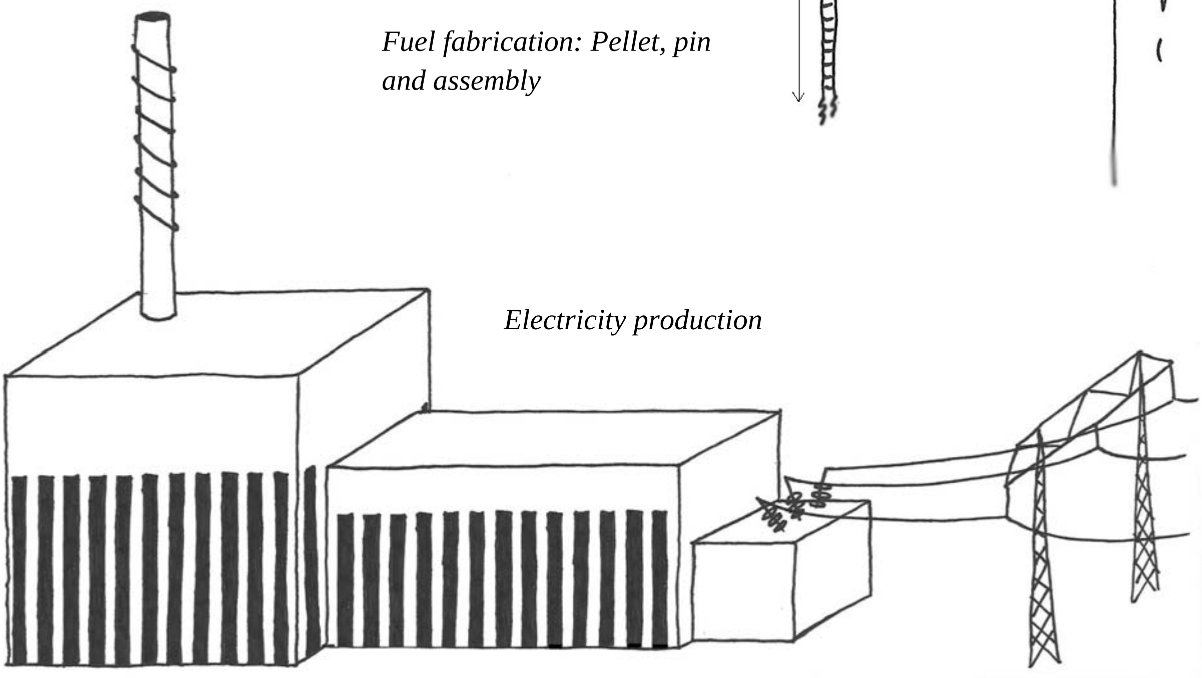
Figure 1 The nuclear fuel cycle



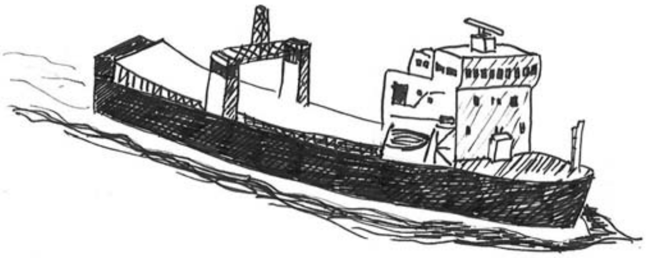
Uranium mining; open pit mine



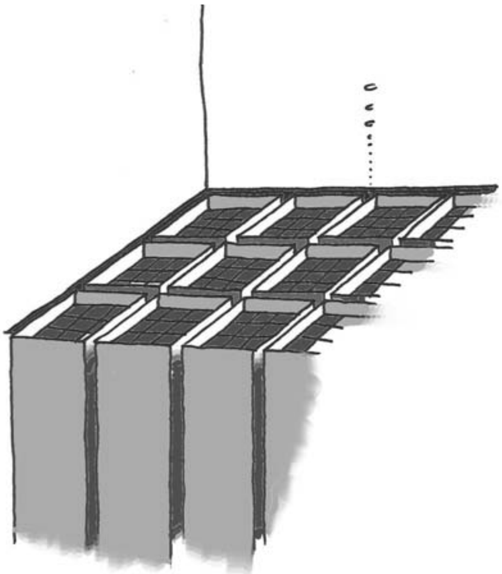
Fuel fabrication: Pellet, pin and assembly

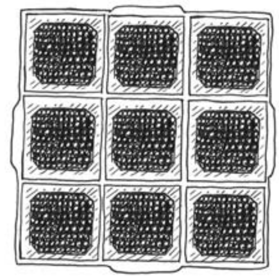


Electricity production

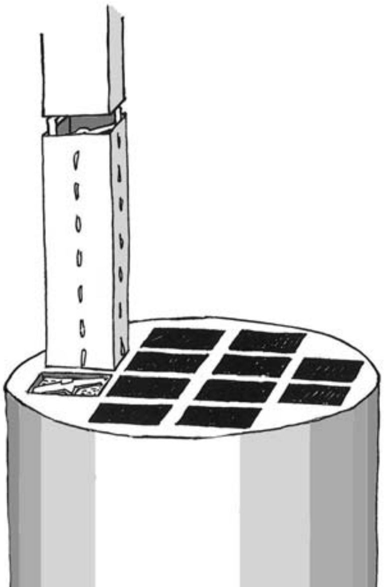


Transport to intermediate and final storage

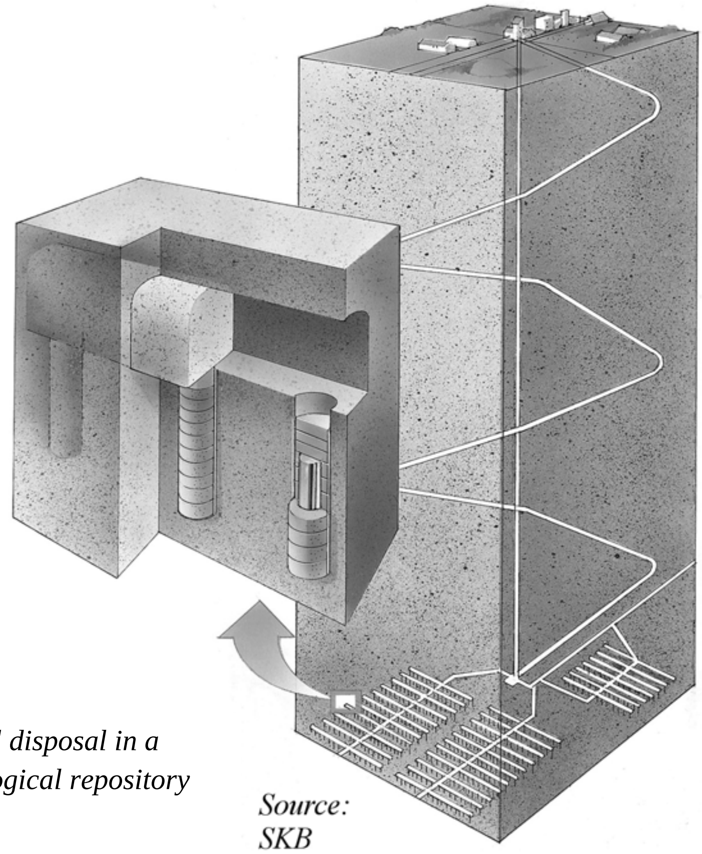




Intermediate storage. The fuel assemblies are placed in cassettes (PWR fuel storage cassette above) which are stored in pools (a corner of the storage pool to the left).



Encapsulation



Final disposal in a geological repository

3 THE SWEDISH NUCLEAR FUEL CYCLE

The complete nuclear fuel cycle is presented in figure 1. Safeguards are applied throughout the entire cycle.

Uranium mining is not carried out in Sweden, so the uranium needed for fuel fabrication is imported. Fuel fabrication takes place in Västerås in Sweden. The raw material from the mines is imported in the form of UF_6, which is converted to uranium dioxide for use in the fuel, is accounted for as bulk material. The accountancy is based on material weight. The uranium dioxide is pressed into pellets; small cylinders that are about 1 cm in both height and diameter. When the pellets are assembled into fuel pins, and subsequently to assemblies, the safeguards system is concerned with the pin or assembly as items. Nevertheless, records of material weights are maintained.

The electricity production is the purpose of the fuel cycle. There are ten nuclear reactors in operation at three sites in Sweden today: Forsmark, Ringhals and Oskarshamn. The Barsebäck site had two reactors which were in operation for several decades, but these are now closed down. In the nuclear power plant, NPP, the fuel is irradiated by neutron radiation which induces fission in the fissile material in the fuel. In the fission process, the heavy uranium nuclei split into lighter nuclei which often are radioactive. The radioactive fission products produce energy, decay heat, long after the fuel is removed from the reactor. The decay heat is reduced over time, and is highest directly after reactor shut down. Therefore, the spent fuel must cool for several years before it can be placed in a final repository. First, the spent fuel cools for at least one year at the NPPs. Then, the fuel is transferred to the interim storage Clab where it is stored in cooled storage pools. These steps exist in the Swedish fuel cycle today. In order to handle the spent fuel in such a way that it does not impose undue burden on future generations, the nuclear power companies have founded a jointly owned company, Swedish Nuclear Fuel and Waste Management Co, SKB. SKB has worked out a strategy for the final disposal of spent nuclear fuel which is illustrated in the reference concept called KBS-3. The KBS-3 concept is a multi-barrier system designed to keep the radioactive contents of the spent fuel away from the environment and the human society. KBS-3 includes the following parts:

1. Wet interim storage of the spent fuel in Clab for around thirty years, see figure 2.
2. Encapsulation of spent fuel in disposal canisters. The disposal canisters are made of corrosion resistant copper, with a shock resistant insert made of cast iron, see figure 3.
3. Emplacement of the disposal canisters in a geological repository in the granite bedrock near the Forsmark NPP. The canister will be surrounded by a bentonite buffer. The bentonite is a volcanic clay which swells in contact with water. When saturated with water, the clay will absorb shocks from bedrock movement, see figure 3. The repository is designed as a multi-barrier system with the purpose of keeping the radioactive contents of the spent fuel away from the environment and the human society.

The barriers are the following: The fuel itself which is practically insoluble in ground water, the copper canister, the bentonite buffer and the bentonite backfill (which is used to fill the deposition tunnels after completed deposition) and finally the host rock.

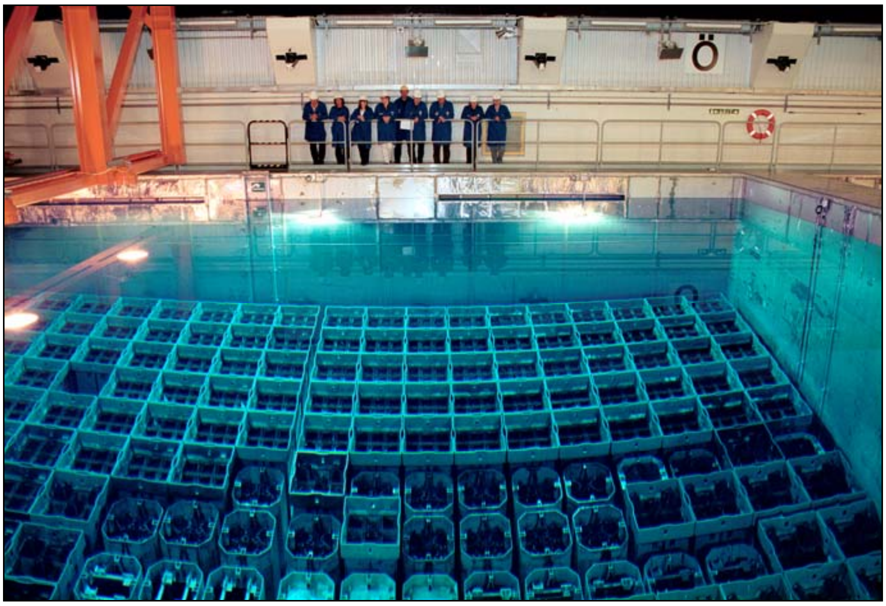


Figure 2 One of the two storage pools at Clab. Photo: Curt-Robert Lindqvist, SKB

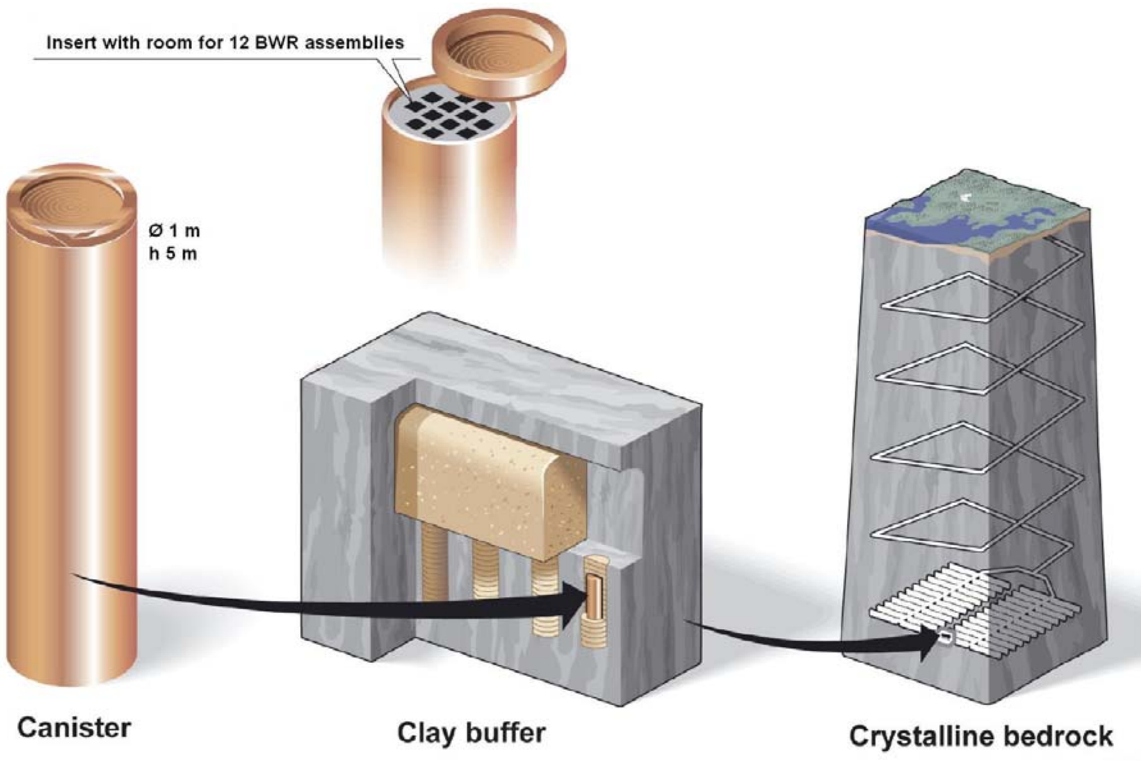


Figure 3 Disposal canisters and final repository for spent nuclear fuel in the KBS-3 method. Graphics: Mats Jerndahl, SKB

4 FACILITIES AT THE BACK-END OF THE FUEL CYCLE

This chapter presents SKB's present plans, which may be changed during detailed design and construction of the facilities.

4.1 CLINK

Clink is the working name for the combined interim storage facility and encapsulation plant. It will be situated in Oskarshamn in the southeast of Sweden, around 350 km south of Stockholm, see figure 4.

The interim storage, Clab, is already in operation since 1985. All spent fuel from the Swedish NPPs, dating back to the mid 1960's is stored in pools in Clab.

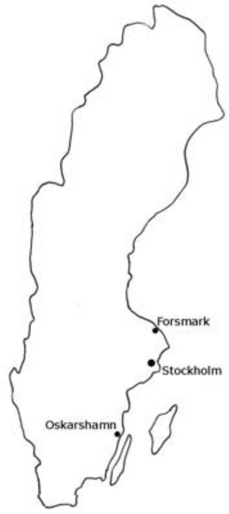


Figure 4 Facility locations

4.1.1 FACILITY DESIGN

SKB plans to expand and convert Clab into the new facility Clink.

The facility will include the following steps:

- A reception area where spent fuel transports from the Swedish NPPs are unloaded (existing area in Clab).
- A storage area consisting of two underground pools where the spent fuel is stored for around 30 years awaiting encapsulation and final disposal (existing area in Clab).
- An encapsulation area where the spent fuel is placed in disposal canisters made of copper (future area in Clink).
- A loading area where the disposal canisters are placed in transport casks (future area in Clink).
- A terminal building where the filled transport casks await transport to the repository. The terminal building will also be used as buffer storage for the filled transport casks. (Future building in close proximity to Clink.)

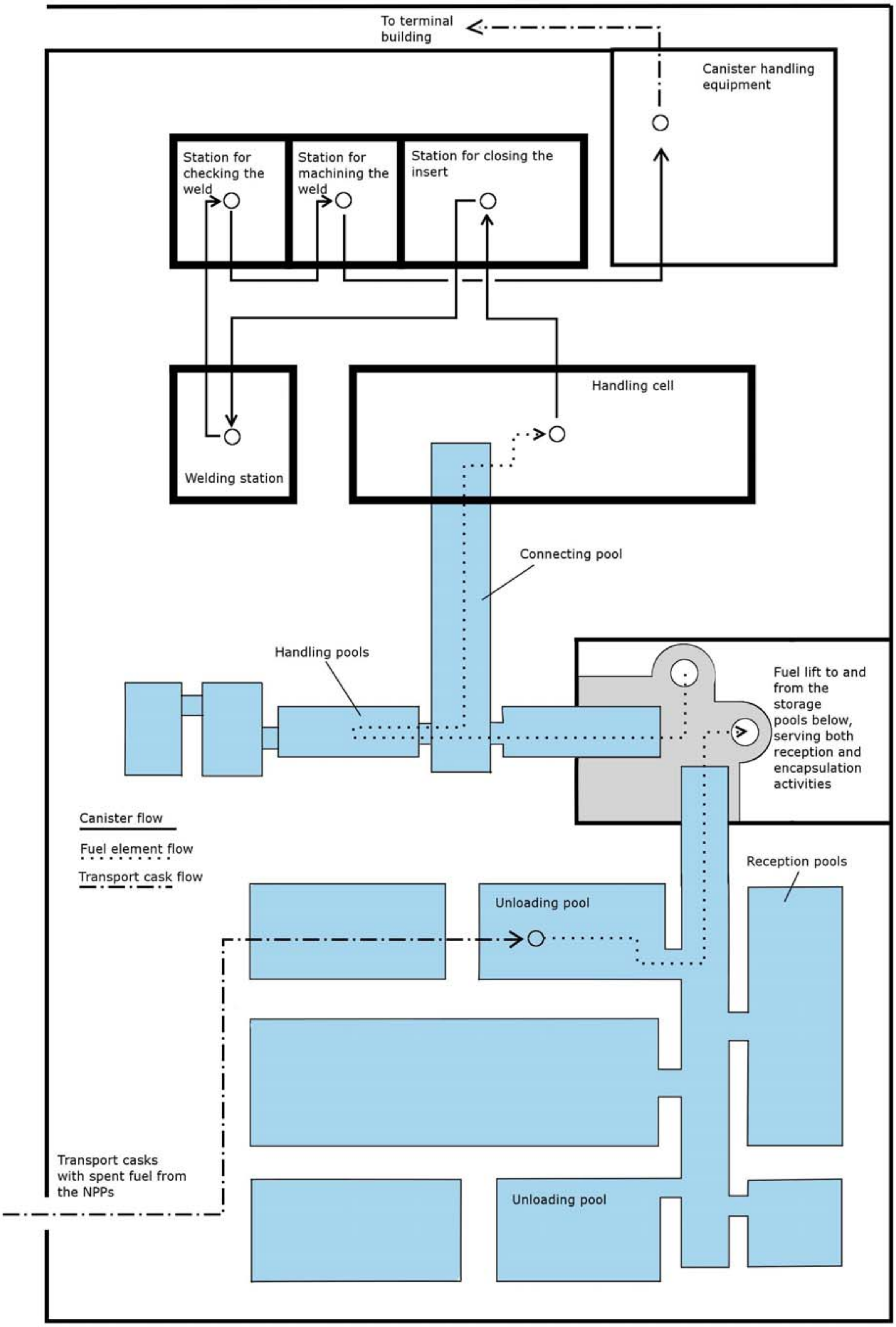


Figure 5 Facility process in Clink. The reception pools and the fuel lift exist in Clab. The other areas will be constructed as parts of Clink.

4.1.2 FACILITY PROCESS

The facility process is showed in figure 5. This description applies to BWR fuel assemblies. PWR assemblies are handled in the same manner with the difference that only four PWR assemblies are placed in a disposal canister. The process contains the following steps:

- Transport casks containing spent fuel from the Swedish NPPs are lifted into the reception pools. The fuel assemblies are unloaded into storage cassettes.
- The storage cassettes are transported down to the storage pools by the fuel lift.
- The fuel assemblies are stored in the storage pools for around 30 years while the decay heat declines.
- Selected storage cassettes are taken to the handling pool by the fuel lift. In the handling pool, twelve BWR fuel assemblies are lifted into a transport cassette. The transport cassette is lifted into the handling cell.
- In the handling cell the assemblies in the cassette are dried. When dry, the twelve assemblies are transferred into an open disposal canister. The insert steel lid is fastened.
- The filled disposal canister is taken from the handling cell by a shielded transporter, to a hot cell where the insert atmosphere is changed and the insert is closed.
- The transporter then takes the canister to a welding station (in a hot cell) where a copper lid is welded to the canister.
- Two more hot cells are used for inspection and machining of the weld. Finally, the canister is placed in a transport cask and is taken to the terminal building awaiting sea transport to the final repository.

4.2 FINAL REPOSITORY

This section describes the final repository design and operation briefly. A more elaborate and complete description can be found in [6].

4.2.1 FACILITY DESIGN

The geological repository will be situated in the granite bedrock in Forsmark, 150 km north of Stockholm, see figure 4. The repository level, around 500 m below ground, will consist of a central area and a repository area. The central area, see figure 6, includes eight halls with different functions necessary for the operation of the repository, such as a ventilation hall and a hall for lifts and the reception of visitors. There is also a station for loading masses of rock onto a skip that will be used to transport rock residue from the tunnel excavations to the surface. A central place from a safeguards perspective is the reloading hall.

In this hall the spent fuel arrives carried by a cask transport vehicle and is reloaded to the emplacement vehicle. The reloading hall is therefore the first and only location since the encapsulation plant where the canister is available for identification and other types of verification.

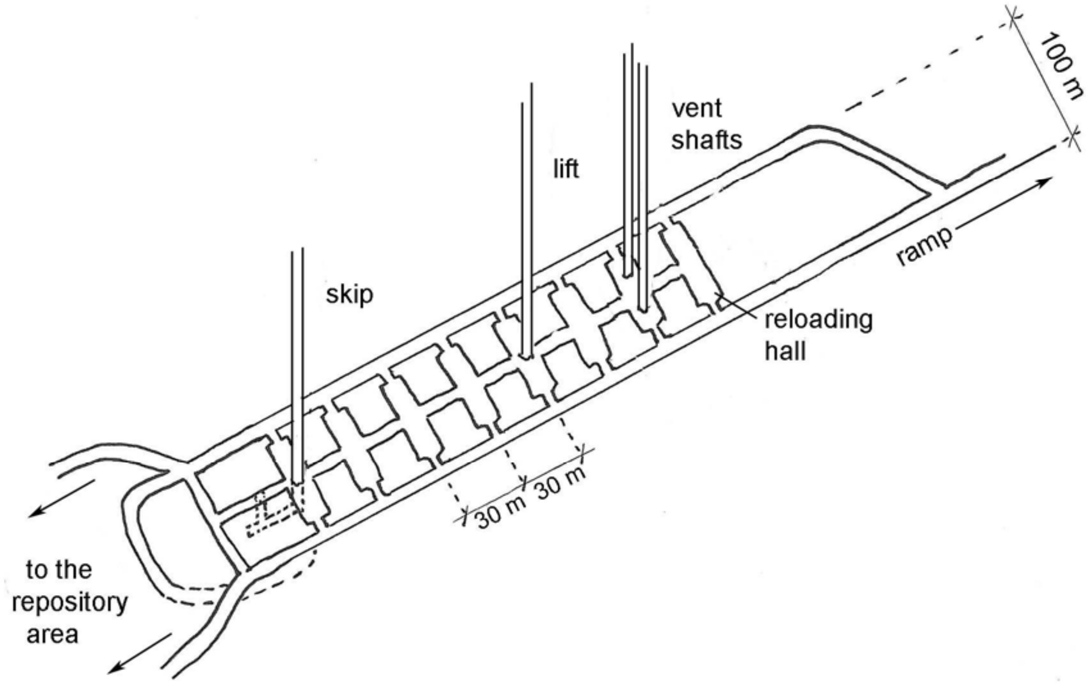


Figure 6 The central area

The central area is connected to the surface by a transport ramp that will be used by dumpers, trucks and vehicles carrying transport casks containing the disposal canisters. A number of shafts will be constructed leading from the surface to the repository level. These are a lift shaft, a skip shaft and ventilation shafts.

Tunnels connect the central area and the repository area, see figure 7. In the repository area concurrent excavation, deposition and backfilling of disposal tunnels will occur. The disposal tunnels branches out from two parallel main tunnels. Excavation will be carried out from one main tunnel and the emplacement of disposal canisters in the other at each point in time, with an exchange of the two operations at regular intervals. The disposal canisters will be emplaced in vertical holes drilled in the floor of the disposal tunnels.

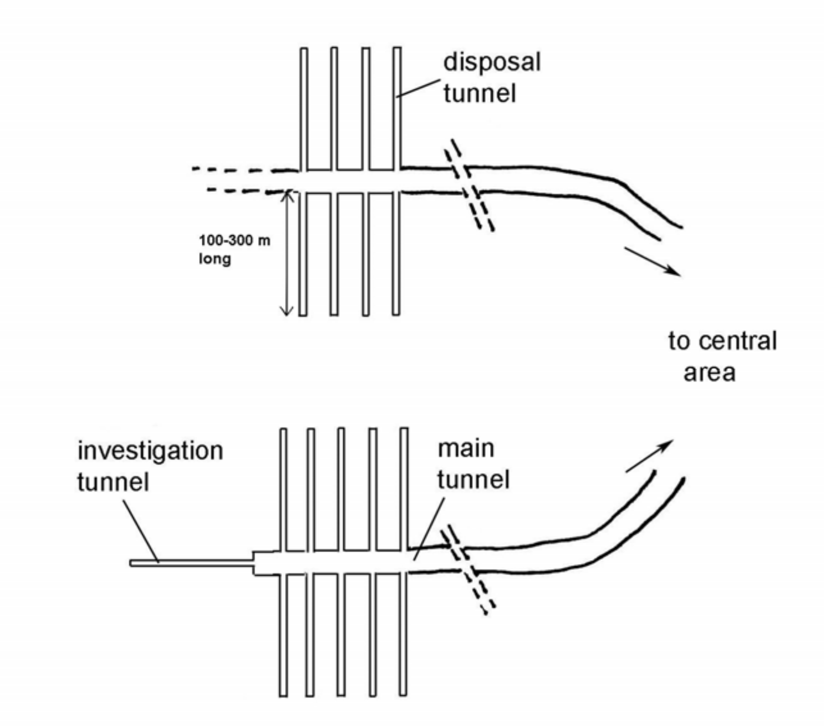


Figure 7 The repository area

4.2.2 FACILITY PROCESS

The full disposal canisters are transported to the repository level in transport casks via the ramp. On the repository level they are taken to the reloading hall (see figure 6) where the canisters are transferred to a shielded emplacement vehicle. The emplacement vehicle takes the disposal canister to a prepared hole in a disposal tunnel where emplacement is remotely conducted. After emplacement the tunnel is backfilled with bentonite. When a tunnel is completely backfilled it is sealed by a concrete plug.

The main process for the final repository is separated in an excavation process and a disposal process. Both processes occur concurrently. The excavation process includes the following steps:

- Excavation of tunnels by drilling and blasting
- Removal of rock material. Inspection of the host rock. Enforcement of the tunnel if necessary.
- Investigating drilling to inspect the planned positions for holes. Installation of power, ventilation etc. in the tunnel. Drilling of the disposal holes.

The disposal process includes the following steps:

- The hole with the innermost position is prepared for disposal: It is drained, cleaned, inspected and lined with bentonite buffer.
- The canister is collected in the reloading hall and taken to the tunnel by the emplacement vehicle.
- The canister is emplaced in the prepared hole and is then covered by a bentonite lid.

5 DIVERSION PATHS IN THE FACILITIES

From all facilities containing nuclear material there are paths through which the material could be diverted. These diversion paths must all be covered by the safeguards system so that there is credible assurance that diversion of nuclear material will be detected in a timely manner.

Diversion path analyses have been performed for Clink and the final repository, **Paper 3** and [7]. The analyses include identification and description of the feasible diversion paths from the facilities. A listing of the identified diversion path analyses follows:

1. Diversion during transport or storage of transport casks at Clink
2. Diversion of an assembly from the unloading pool
3. Diversion of an assembly from the storage pool
4. Diversion of an assembly from the handling pool
5. Diversion of an assembly or a full disposal canister from a hot cell
6. Diversion of individual fuel pins from dismantled assemblies
7. Diversion of a full transport cask from below ground
8. Diversion of a full canister from below ground
9. Diversion of fuel from a breached canister from below ground
10. Diversion of separated uranium or plutonium from below ground

Connected to all diversion paths are detection points which are points where safeguards authorities can detect diversion. The detection points and safeguards measures that should be applied to cover all diversion paths are presented in section 6.3 and 6.4.

6 SAFEGUARDS APPROACH

6.1 OBJECTIVES

Comprehensive safeguards objectives are presented in chapter 2. Specifically for the final disposal process, the following objectives should be met:

The safeguards system should give credible assurance, concerning spent nuclear fuel designated for final disposal, that

- all nuclear material is contained in the fuel;
- all spent nuclear fuel is placed in disposal canisters (i.e. all spent fuel assemblies are as declared and encapsulated);
- all disposal canisters are emplaced in the repository; and that
- all disposal canisters remain in the repository.

In order to give credible assurance that the items above are fulfilled all feasible diversion paths (see chapter 5) from the facilities in the back-end of the fuel cycle must be covered by the safeguards system.

Furthermore, an objective for the safeguards system is to generate all necessary safeguards information about the fuel assemblies, since they become inaccessible when placed in disposal canisters. The needed information is gross defect measurement data proving that the assemblies contain spent fuel and positive identification of all fuel assemblies that are placed in disposal canisters, see **Paper 2**.

6.2 ELEMENTS OF THE SAFEGUARDS APPROACH

In the following sections the main parts of the proposed safeguards approach are described. A more elaborate description can be found in e.g. IAEA’s safeguards glossary [8].

6.2.1 NUCLEAR MATERIAL ACCOUNTANCY

Nuclear material accountancy, NMA, is the practice to verify the correctness of the nuclear material accounting in the records for a facility or a state. NMA activities could be to compare records from the sender of a transport to records from the receiver to see that they match, or to measure the characteristics of a nuclear fuel assembly in order to verify that its contents are as declared.

NMA is concerned with material balance areas, MBA:s. A MBA is an area in or outside a facility chosen so that the quantity of nuclear material into or out of the area can be determined, and that the physical inventory in the area can be determined. All transfers to or from a MBA shall be reported to IAEA. Therefore, the division of facilities into MBAs should be made carefully so that accountancy routines are facilitated and important transfers can be easily followed. The issue of MBA structure is further discussed in chapter 8 below.

6.2.2 CONTAINMENT AND SURVEILLANCE

Containment and surveillance, C/S, are safeguards measures applied to verify that the integrity and knowledge of nuclear material items are maintained between NMA activities, i.e. to maintain the so called *continuity of knowledge* of the nuclear material items. C/S activities can be the application of seals on a nuclear material container or the surveillance (by video camera) of a storage room in a facility, for example.

6.2.3 DESIGN INFORMATION VERIFICATION

Design information verification, DIV, is used to verify that nuclear facilities are constructed and operated as declared. DIV is used to find undeclared structures and features, and structures for which there is no apparent justification. DIV is mainly performed at inspections where the facility for example could be measured and geophysical methods could be used to find cavities behind walls and beneath floors. Findings are compared with declarations and results of earlier DIV inspections to find changes and inconsistencies.

6.3 DETECTION POINTS AND STRATEGIC POINTS TO COVER DIVERSION PATHS

The feasible diversion paths from Clink and the final repository are described in chapter 5. The diversion paths are summarized in figure 8 and 9 together with detection points where diversion through the paths can be detected if safeguards measures are applied.

However, if safeguards measure were implemented on all detection points, some would be redundant. The smallest set of detection point that covers all diversion paths is called a set of strategic points. The strategic points are coloured in figure 8 and 9 to distinguish them from the other detection points.

The proposed safeguards approach is based on the strategic points, i.e. without redundancy. Additional safeguards measures can be applied for increased strength and redundancy, but it is judged that the proposed approach in itself could cover all diversion paths.

From the figures, it is evident that DIV measures are crucial in order to detect diversion of individual fuel pins. The safeguards measures applied at each strategic point, and the needed DIV measures, are presented in section 6.4.6 below.

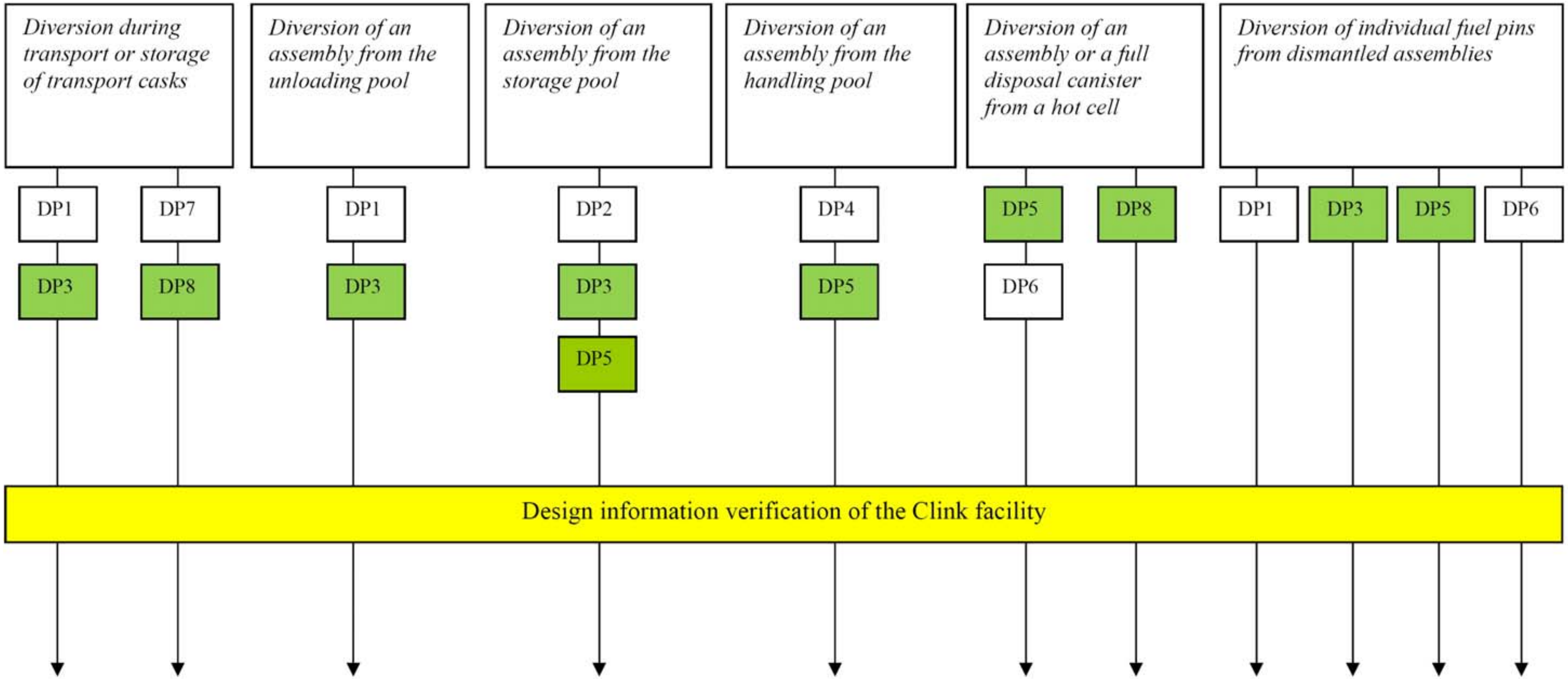


Figure 8 Diversion paths and detection points in the Clink facility

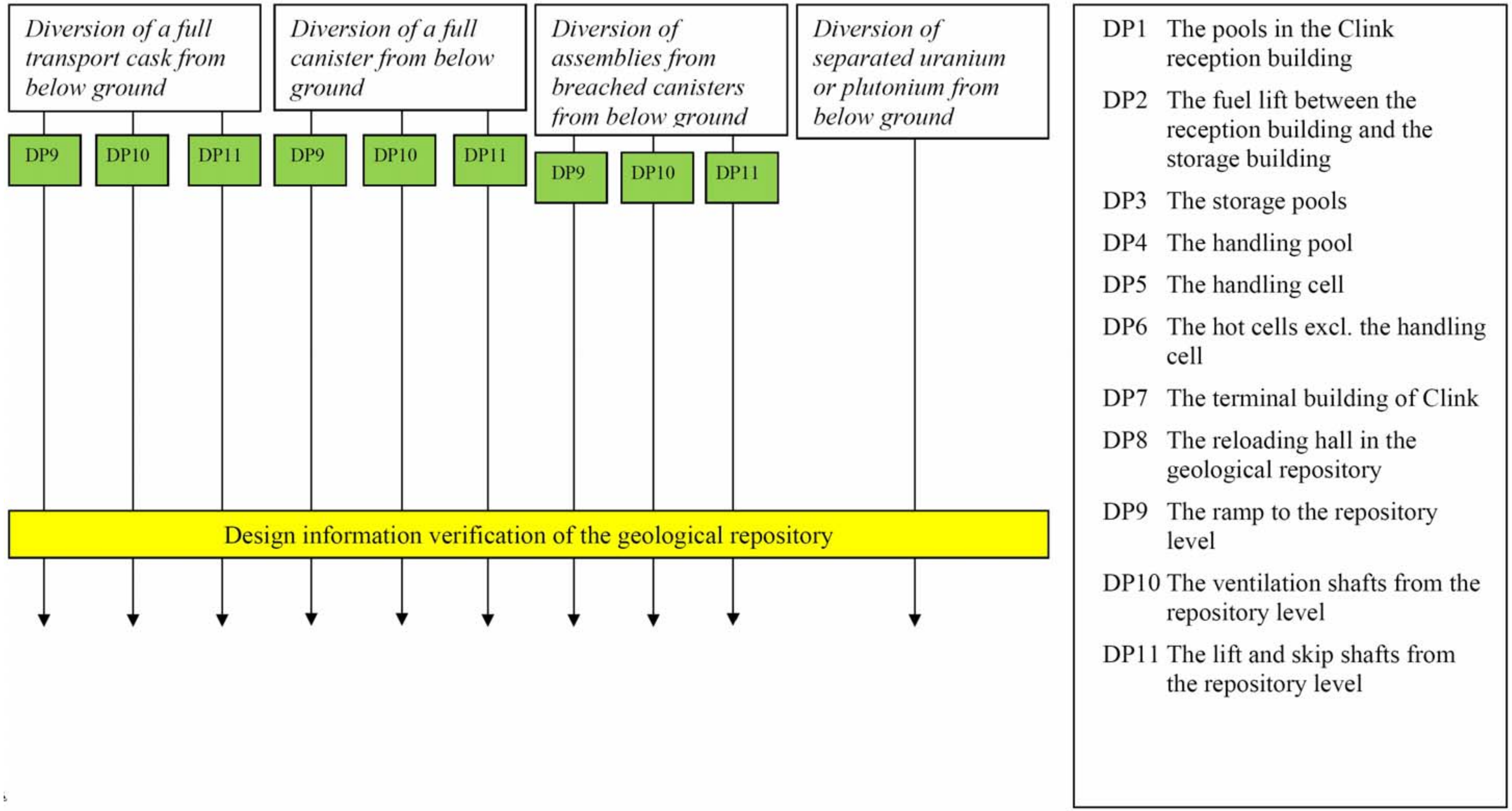


Figure 9 Diversion paths and detection points in the final repository

6.4 SAFEGUARDS MEASURES

6.4.1 STORAGE POOLS

The inventory in the storage pools should be verified each year by means of a gross defect level measurement. The inventory verification can detect removal of assemblies and if assemblies have been exchange for dummies.

Such inventory verification can detect diversion of fuel assemblies that have occurred during transport to Clink, at unloading in the reception pools or from the storage pools.

6.4.2 HANDLING CELL

The handling cell is the last place where the individual fuel assemblies are visible and accessible for measurement or other individual verification. From the handling cell no flow of assemblies back to the storage pool is planned.

To detect diversion since the last inventory verification in the storage pools, a simple gross defect measurement, such as a bundle counter or similar, should be applied. The measurement detects replacements of assemblies for dummies and gives assurance that the assembly that is placed in the canister is a spent nuclear fuel assembly. The measurement detects diversion from the storage pools or from the handling pool.

The handling cell activities should be monitored using video surveillance. Video surveillance detects undeclared activities in the handling cell, such as removal of assemblies through a transfer port, or dismantling of fuel assemblies.

A strengthening measure could be to apply monitors that register movement direction on all transfer ports

6.4.3 RELOADING HALL

The reloading hall is the first place after transport from Clink where the disposal canister is taken out of the transport cask, i.e. is accessible for verification of identity or contents.

In the reloading hall the identity of the disposal canister should be checked. Also, a gross defect measurement utilizing the neutron radiation could be applied. Any C/S measures applied during transport should be evaluated.

In the reloading hall the diversion of full disposal canisters from Clink or during transport can be detected.

6.4.4 RAMP

A radiation monitor should be applied in the ramp in order to detect diversion of full casks or canisters from below ground. It is judged that the amount of shielding that fits in the ramp cross section is incapable of reducing the radiation from a full cask or canister below a monitor’s detection threshold.

The amount of shielding sufficient to shield a single assembly from a breached canister below the detection threshold of a radiation monitor is not known presently. Therefore, this safeguards approach plans for the detection of canister opening equipment, in order to be able to detect diversion of spent fuel from breached canisters.

6.4.5 SHAFTS

The ventilation shafts will not be used for transport and can therefore be sealed in a manner that does not impair the ventilating function, e.g. using wires.

The lift and skip shafts should be equipped with radiation monitors so that undeclared use of the shafts can be detected.

6.4.6 DIV MEASURES

DIV measures in Clink

Diversion of individual fuel pins from a dismantled fuel assembly should be possible to detect. However, as shown in figure 8 and 9, safeguards measures are not planned for all points where dismantling can be carried out. Therefore, design information verification is necessary to give assurance that dismantling cannot be carried out within the facility.

The places in Clink requiring the smallest installation for dismantling are the areas where fuel handling equipment already is installed, i.e. the reception pool, the storage pools, the handling pool and the handling cell.

In the pools, shielding from the water is also available. The hot cells are also shielded but no fuel handling equipment is planned to be installed.

Design information verification should be used to find installations of dismantling equipment, and also areas where equipment or shielding material could be cached. If DIV is judged as not giving enough assurance that fuel dismantling cannot be carried out, additional measures should be applied at the detection points, thereby redefining the detection points as strategic points. Such measures can be e.g. video surveillance that can register adjustments to the declared equipment.

DIV measures in the final repository

In figure 8 and 9 it is shown that diversion of separated nuclear material only can be detected using design information verification. Furthermore, the removal of fuel assemblies from a breached canister through the ramp may not be possible to detect using radiation detectors. This diversion scenario should therefore also be detectable by DIV.

Consequently, the DIV regime should be capable of detecting hot-cell installations and reprocessing installations in the repository. Environmental monitoring could be used to strengthen the DIV by detecting nitric gases from reprocessing activities or Kr-85 from damaged fuel pins in breached canisters.

7 CONTINUITY OF KNOWLEDGE

7.1 CONTINUITY OF KNOWLEDGE IN THE FINAL DISPOSAL PROCESS

As stated in section 2.3, an advisory group to the IAEA has recommended that spent fuel should only be disposed of as verified nuclear material on which continuity of knowledge has been kept.

The concept “continuity of knowledge” denotes the assurance that the safeguards knowledge acquired, at e.g. an inventory taking or a measurement, is still correct at a later point in time although it has not been directly verified. An example is a spent fuel assembly which is verified as being spent fuel by a gross defect measurement. By attaching a seal to the assembly, or placing it under video surveillance, assurance is given that the assembly has not been disassembled or replaced with a dummy, i.e. that its characteristics have not changed. This means that the continuity of knowledge has been kept. However, if the seal shows signs of tampering, or the surveillance footage is inconclusive, continuity of knowledge is not kept.

In the final disposal process, it is of paramount importance that continuity of knowledge is maintained after the final physical verification of the fuel. Should the continuity of knowledge be lost after the encapsulation of the fuel assembly, it cannot be re-established without seriously disrupting the final disposal operations. After emplacement of the canister and backfilling of the disposal tunnel, re-verification may be practically impossible. Therefore the safeguards system should be designed with redundancy and robustness so that assurance is given that continuity of knowledge is maintained after the final physical verification.

7.2 THE FINAL VERIFICATION

The final physical verification will be performed in the Clink facility. As proposed in the safeguards approach in chapter 6, the final verification that the fuel assemblies are spent fuel takes place as the assemblies are lifted into the handling cell where they are placed into disposal canisters.

During interim storage a physical inventory verification of the storage pools is carried out annually. The declarations of pool inventory are compared to the actual placing of assemblies in the pools. As a strengthening measure, a gross defect measurement is carried out using a cherenkov viewing device, the ICVD or a Spent Fuel Attribute Tester, the SFAT. In the safeguards approach for the final disposal process, see chapter 6, the annual physical inventory verification with a gross defect measurement is an integral part.

A possible extension to the present physical inventory verification scheme is to perform measurement campaigns using neutron detection in addition to gamma radiation detection. The ICVD detects cherenkov radiation produced by gamma and beta radiation from decaying fission products in the fuel. In order to acquire an indication of the fissile content in the assemblies, a neutron detector can be used. Such verification is also a gross defect level verification, but has the capability of detecting dummies made from vitrified high level waste which have a gamma signature. It is difficult for Sweden to produce dummies from high level waste since no reprocessing is carried out in the state. However, a neutron measurement may be viewed as a strengthening of the safeguards system.

Since the storage facility in Clink has two pools, whereof one is only partly filled, it is possible to perform measurements on a number of fuel assemblies which can be placed in separate, sealed parts of a storage pool. This possibility gives an easy way of preserving the continuity of knowledge of the extended physical inventory verification.

7.3 C/S TO MAINTAIN CONTINUITY OF KNOWLEDGE

Continuity of knowledge is maintained by the use of containment and surveillance measures. In the IAEA safeguards glossary, the following is stated:

The use of C/S measures is aimed at [among other purposes] the preservation of the integrity of safeguards relevant data. In many instances C/S measures cover the periods when the inspector is absent, thus ensuring the continuity of knowledge for the IAEA and contributing to cost effectiveness [8].

Continuity of knowledge can be viewed as kept, if the C/S system designed to maintain it, is evaluated as acceptable. In the IAEA safeguards criteria, annex 3, acceptable C/S is defined: the C/S system is evaluated with a conclusive positive result, implying that the system for example has not been defeated or tampered with.

For applications where C/S system robustness is important, such as after the last verification in the final disposal process, dual C/S can be used. A dual C/S system is a system where all diversion paths are covered by two C/S devices which are functionally independent and do not have a common tampering or failure mode. An example is a surveillance camera in combination with any type of seal. For an acceptable dual C/S result, both devices should yield a conclusive positive result. Should a C/S system be evaluated as inconclusive or conclusive negative, re-verification by a non-destructive measurement is normally used to regain knowledge. However, this is not feasible in the final disposal process after the canister is emplaced in the repository.

If continuity of knowledge is lost prior to emplacement, a remedial action could be to perform a gross defect measurement of neutron radiation from the canister. Such measurement cannot detect removal of individual assemblies but is able to detect the replacement of a canister with a dummy.

The C/S strategy to maintain continuity of knowledge in the final disposal process is described in the items below. The C/S measures are also presented in the safeguards approach in chapter 6.

- If it is decided that the extended physical inventory verification should be performed, single C/S should be applied after verification campaigns in the storage pools. For example, a part of the storage pool, where measured assemblies is placed, can be sealed.

- Bundle counting should be applied when the assemblies are going in to the handling cell. If no other measurement than gross defect measurements using gamma radiation has been performed there is no need for extra C/S measures between the annual physical inventory verification and the bundle count.
- Surveillance cameras covering the activities in the handling cell should be installed. If dual C/S is required also in the handling cell, monitors detecting movement direction can be applied on all transfer ports to the handling cell. No back-flow of material from the handling cell is planned as part of normal operations.
- Fuel identification should be performed when the assemblies are placed in the canister, but before the insert lid is mounted. (The operator, SKB, is planning a digital photo of all assembly handles, where the IDs are visible.)
- Dual C/S should cover the full canisters until the reloading hall in the final repository. In the reloading hall the C/S measures attached to the transport cask should be removed and evaluated. It is also possible to perform a neutron radiation measurement that could detect replacements of the canister during transport or storage. Possibly, one of the C/S measures could be replaced by such measurement.
- Dual C/S should cover all exits from the repository. When designing the C/S system for the repository exits, it is possible to utilize the fact that radiating loads only is planned to go downwards in the ramp.

The best way to put the canisters under dual C/S is under discussion. It should be considered that the process is planned for filling and closing approximately one canister per working day. This means that applied C/S measures should be possible to evaluate remotely (in order to reduce the need for constant inspector presence). It should also be investigated if operators could apply e.g. seals under some kind of control that they are applied properly.

The most difficult part of the process to place under dual C/S is after filling of the disposal canister. When the canister is filled the insert steel lid is applied. Then the canister is transferred to another hot cell where the insert atmosphere is changed and the insert lid is completely closed. Only after that is the canister transferred to the welding station, where the canister lid is welded into place.

When the canister is placed in a transport cask, application of dual C/S is more straight-forward. For example two different kinds of seals could be used on the transport cask.

8 MATERIAL BALANCE AREAS

8.1 BACKGROUND

The nuclear material accountancy activities are based on a division of each state into material balance areas, MBA. The safeguards information collected by IAEA is to large extent information on transfers into and out of MBAs and the inventory within each MBA. All changes in the inventory of a MBA shall be reported to the IAEA.

The final disposal process should be divided into MBAs so that it is evident that all fuel assemblies are placed in disposal canisters and subsequently placed in the repository.

Presently, Clab constitutes one MBA. It is reasonable to let the final repository constitute a MBA since the site will be geographically separated from the other parts of the final disposal process, and since the other parts will be decommissioned when all (present and future) Swedish spent fuel is encapsulated. After decommissioning, safeguards will be terminated on the old facility sites. Safeguards will however not be terminated for the final repository for as long as the nuclear material in the repository is covered by a safeguards agreement.

The remaining question is how to determine the MBA structure of Clink. The MBA structure should be such that inventory taking is easy and that reporting on transfers between MBAs is not unreasonably extensive.

As described above in section 4.1 the encapsulation plant will be integrated with Clab so that the two facilities will be within the same building and form the new facility Clink. The new and old part will be connected with a fuel lift. The process is planned with many (several each day) movements of fuel between the storage pools and the handling pool. The encapsulation of spent fuel will probably be viewed by IAEA and DG-ENER as a re-batching operation. The re-batching implies that the item in the safeguards accountancy changes from the individual fuel assemblies to the disposal canister.

8.2 ALTERNATIVE MBA STRUCTURES

Three alternative MBA divisions for Clab and the encapsulation plant have been identified. The final repository is assumed to be a separate MBA in all three alternatives. The alternatives are shown in figure 10.

Alternative 1

In alternative 1 the MBA boundary is drawn in the lift shaft between the old and new building parts. The lift shaft will be used often, probably several times a day. This MBA structure is judged to be inconvenient due to the requirement that each movement between MBAs should be reported. It is also judged, based on the diversion path analysis in **Paper 3** that a monitoring of the lift movement is not necessary to cover all diversion paths.

Alternative 2

An alternative could be to have Clab and the encapsulation plant within one single MBA. This makes the reporting less burdensome for the operator SKB.

Inventory taking would be concerned with both fuel assemblies and disposal canisters. The process cannot easily be followed by a review of the accountancy which makes a comprehensive NDA and C/S regime necessary. If a re-batching will be introduced by the safeguards authorities, the process may be easier to follow since there will be a clear distinction of where the fuel assemblies are encapsulated. However, inventory taking may be complicated for a facility with as many different functions as Clink if it is contained within a single MBA.

Alternative 3

A third alternative is to make a separate MBA when the new item, the disposal canister, is formed. This could be defined as the step when the individual fuel assemblies are lifted into the canister. This means that it is made clear which fuel assemblies are encapsulated at what time. A clear distinction is made between individual assemblies and the new nuclear material item. At this stage of the process no back-flow is foreseen so inventory change reporting should only be required once for each assembly, i.e. the reporting is not very burdensome for the operator. Nevertheless, the reporting will be more extensive compared to alternative 2 above: For each assembly passing between the two MBAs, two inventory change documents must be issued: one for the sending MBA and one for the receiving MBA. This means that for a canister with 12 BWR assemblies 24 more reports must be made compared to alternative 2 (both alternatives require the same amount of documentation for the rebatching operation).

This option is judged by this report to be the most advantageous since it is easy to follow the process based on safeguards documentation and since inventory taking is facilitated.

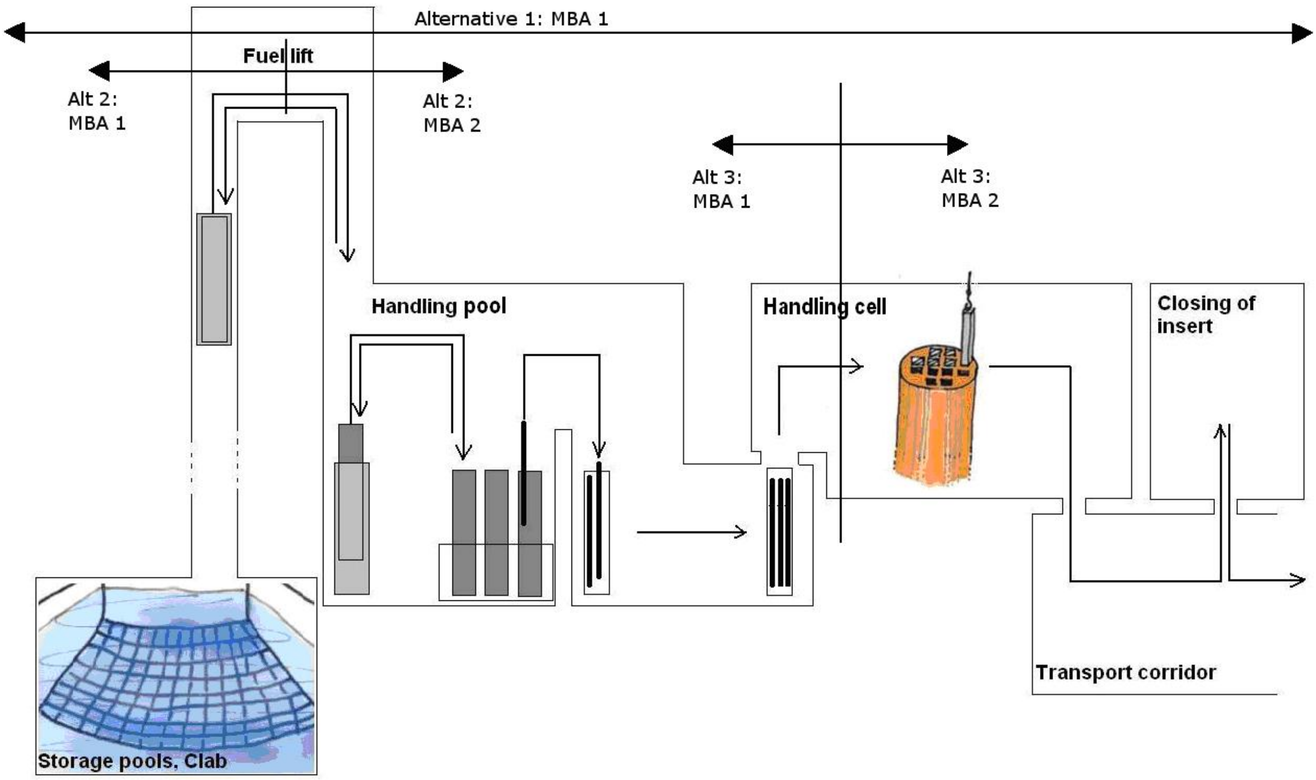


Figure 10 MBA division alternatives

9 PARTIAL DEFECT VERIFICATION

As stated in section 2.3, [3] recommends that nuclear material transferred to a final repository should be verified at the same level as is required by the IAEA for material in difficult-to-access storage. This implies that the fuel should be verified with a measurement technique providing a high probability of detection of partial defects, or with the best available technique. (Presently, no measurement technique capable of partial defect level verification is approved for inspection use.) However, in the safeguards approach presented in chapter 6, partial defect verification is not included as a prerequisite. In the following, this position is motivated.

It is also recommended in [3] that safeguards should give the same level of assurance of non-diversion throughout the fuel cycle. This is interpreted here as a recommendation that all diversion paths throughout the fuel cycle should be covered, without the safeguards system being neither front- nor back-heavy.

A safeguards objective (see section 6.1) is to verify that all fuel assemblies are complete (or as declared). The possible diversion scenario that could result in an incomplete assembly is a scenario where individual fuel pins are removed. Partial defect verification has a better chance of discovering removed pins than gross defect verification. (Partial defect verification for spent fuel assemblies is defined as 50 % of the fuel pins being removed or replaced with dummy pins [9].)

Two pin-removal scenarios could be considered:

The first scenario is that pin removal takes place at the NPPs with declared dismantling equipment. If this is considered as an important diversion path safeguards measures should be applied so that detection within the timeliness period is possible, i.e. at the NPPs. A detection of diversion in connection with the final disposal process would probably not be contained by the timeliness goal.

The second scenario is that pin removal takes place at Clink using undeclared dismantling equipment. Such diversion could possibly be detected using partial defect verification if more than 50 % of the fuel pins are removed. However, if a smaller amount of pins are removed, a partial defect measurement may not suffice. (If pin level verification is developed and approved for use, such verification could detect diversion of a small number of fuel pins). An alternative detection strategy is to target the dismantling equipment (using DIV) or the dismantling activity (using C/S). If DIV or C/S activities can show that pin removal is not feasible, partial defect verification becomes obsolete.

To sum up, partial defect verification is not necessary to meet the safeguards objectives, as long as DIV can exclude the use of dismantling equipment or C/S can exclude the dismantling activity.

10 DISCUSSION AND OUTLOOK

A safeguards approach for the encapsulation facility and the operating final repository in Sweden has been presented. The approach has considered the special traits of final disposal, such as the inaccessibility of the nuclear material after encapsulation and that the final disposal process is continuous. Previous work in the area has been considered, but has not been used as prerequisites.

The ambition has been to create a minimal safeguards approach that still covers all feasible diversion paths, with even emphasis on all phases of the fuel cycle. Some strengthening measures that could be added to the minimal approach have also been suggested.

Efforts have been made not to make the safeguards system more extensive in the back-end than in the front-end. Therefore, the final verification that the spent fuel is as declared, has been given special attention. Previous working groups supporting IAEA have recommended that partial defect measurements should be performed prior to final disposal. However, this level of verification is not applied in the present fuel cycle after the fuel fabrication phase. Furthermore, no available measurement technique is presently able to perform a partial defect measurement. A conclusion from chapter 6 is that it is possible to cover all diversion paths associated to the final disposal process without performing partial defect level verification.

The work carried out has revealed the following questions that need further attention:

- How could a dual C/S system be arranged, after the final verification that the spent fuel is as declared?
- Are there more purposes of a partial defect measurement, than covering diversion paths, which need to be fulfilled?

The research project is planned to investigate these issues, among other, during 2010.

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PAPER 2

FUEL DATA IN PREPARATION FOR THE FINAL DISPOSAL OF SPENT NUCLEAR FUEL

Abstract:

This report defines the spent fuel data that must be secured, for safeguards purposes and for national purposes, prior to when the spent fuel assemblies become inaccessible in the final disposal process.

A finding is that the safeguards approach for the final disposal process should include a gross defect measurement. Furthermore, it is concluded that the information categories that are sufficient for a national record are available today, but that the information should be completed with the data uncertainties.

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1 INTRODUCTION

As a natural consequence of the operation of the Swedish nuclear power plants, operation of a final repository for the spent nuclear fuel is planned to start within the next decade.

The material that will be deposited in the repository is potentially hazardous as its radiation is harmful to humans and the environment and it can be transformed into an extremely destructive weapon. Furthermore, it is of economic value due to the heavy metal content.

The value and the hazard, in combination with it becoming inaccessible as it is placed in the repository, make it important to have a complete record of all material in the repository. The work presented here is a part of the preparation of creating such a record.

1.1 BACKGROUND

The Swedish Nuclear Fuel and Waste Management Co (SKB), is responsible for the spent nuclear fuel from the Swedish nuclear power plants. In the year 2006 SKB submitted an application to construct an encapsulation plant for spent nuclear fuel and in 2011 a corresponding application for the construction of a geological repository is expected to be submitted. These applications will be reviewed by the Swedish Radiation Safety Authority (SSM), in accordance with the Nuclear Activities Act. As part of the review SSM will verify that safeguards can be applied in the facilities in a manner that satisfies national and international safeguards objectives.

Furthermore, SSM, as the representative for the state of Sweden, must secure the knowledge about the repository and its contents for future needs. The reason is that once the repository operations are finished and the repository is closed, the ownership will be transferred from SKB to the state of Sweden.

1.2 PURPOSE

The purpose is to investigate and define what types of fuel data must be collected in order for SSM to be able to secure the required knowledge about the repository contents. The knowledge needs are sorted into two categories:

- Knowledge for international and national safeguards needs (presented in chapter 2)
- Knowledge for national administration needs (presented in chapter 3)

The knowledge needs are separated on the two chapters because the backgrounds for the needs are completely different. For example; the safeguards system is only concerned with fissile material that could be used for nuclear weapons production.

The national needs, on the other hand, concern the administration of the repository and the health and security of the Swedish citizens.

The focus is primarily SSM’s needs. However, the results can also be used as an input to the international safeguards work carried out by the European

Commission’s safeguards authority (DG-ENER) and the International Atomic Energy Agency (IAEA).

The results will also be used as a basis for SSM’s discussions with SKB about the terms for operation of the new facilities.

1.3 A BRIEF PHILOSOPHICAL BACKGROUND

The purpose of gathering fuel data is to gain knowledge of Sweden’s spent nuclear fuel, whether it is about fuel properties or its presence within the safeguards system.

Knowledge can be described as information that is absorbed, understood and evaluated through reflection and on the basis of experience. This implies that information is necessary in order to gain knowledge, but information is not knowledge in itself.

Information on the other hand can be described as interpreted *data*.

Data are flat facts: numbers, diagrams, names etc, so data are not information. However, data form the basis of information. The information is accessed when data sets are analysed from a certain perspective.

For example, to gain knowledge of Sweden’s compliance to the international safeguards agreements, the safeguards authorities and the IAEA need information concerning a number of areas. One of these areas is the completeness of the fuel assemblies that are destined for final disposal. And, following the arguments above, the information about the fuel assemblies is accessed through the interpretation of data.

When SSM defines the needs for knowledge an important aspect should be the question of what is really needed knowledge as opposed to knowledge that is “nice to have”. Related questions concern how much information is needed to gain the required knowledge and which requirements on operators of nuclear installations are justifiable.

The needs should be derived from requirements from international agreements signed by Sweden and from applicable Swedish laws as this basis is clearly justified. Regarding the amounts of information the requirements should be the minimum amount fulfilling the knowledge needs. All information exceeding the minimum amount should be viewed as additional “nice to have” information that could be delivered on a voluntary basis from the operators if it is of use. To conclude: SSM should be able to present the traceability of all information requirements back to the laws and agreements that govern the authority’s powers and responsibilities.

2 FUEL DATA FOR SAFEGUARDS NEEDS

2.1 SAFEGUARDS NEEDS FOR KNOWLEDGE, INFORMATION AND DATA

2.1.1 KNOWLEDGE NEEDED

SSM, IAEA and the European Commission need to know that Sweden follows the word and the spirit of the Non-Proliferation Treaty and the Euratom Treaty.

With regards to the final disposal process, this means that *the nuclear material that has entered the Swedish nuclear fuel cycle, and has been produced within it, is emplaced in the repository and that it remains there*.

To know this, SSM, IAEA and the Commission also need to know that:

1. all nuclear material is contained in the fuel.
2. all spent nuclear fuel is placed in disposal canisters (i.e. all assemblies are complete and encapsulated).
3. all disposal canisters are emplaced in the repository.
4. all disposal canisters remain in the repository.

The following delimitation is applied: The basis for the knowledge needs is that diversion should be detected within a timeliness period. It is assumed that the safeguards system covering the fuel cycle prior to interim storage in Clab is able to detect diversion of spent nuclear fuel. Consequently, it is also assumed that no diversion has taken place in the Swedish fuel cycle to date. However, if a discovery indicates that diversion has taken place before the current timeliness period it needs to be addressed. Such a situation is briefly discussed in section 2.2.5.

2.1.2 INFORMATION NEEDED

In section 2.1.1 above, the knowledge needed in order to assure that Sweden complies with the international safeguards agreements, is divided into four points. In this section, the information needs derived from these four points are presented.

1. All nuclear material is contained in the fuel

The first point states that the safeguards authorities need to know that all nuclear material is contained in the fuel. This can be considered as verified if the safeguards authorities can conclude that no undeclared reprocessing is carried out. Therefore, the information needed is information from design information verification (DIV) activities or environmental monitoring showing that reprocessing is not carried out in the facilities in the back-end of the fuel cycle.

As Sweden is a state under Integrated Safeguards, it is also possible that IAEA regards the broader conclusion as enough verification that reprocessing is not carried out in Sweden. In that case, the needed information is information from activities related to the additional protocol, making it possible to draw a positive broader conclusion.

2. All spent nuclear fuel is placed in disposal canisters

The safeguards authorities also need to know that all spent fuel is placed in disposal canisters. This means that all fuel assemblies should be complete (or as declared, if reconstruction has occurred due to, for example, fuel damage during operation) and that all fuel assemblies are encapsulated.

The needed information, with reference to the diversion path analysis in **Paper 3**, is the following:

- Reliable identification of the assemblies designated for encapsulation. This information is needed for practical issues, as further information is useless if it is uncertain which assembly it belongs to. Fuel ID is stamped into the fuel assembly handle and can be checked through visual inspection.
- The assemblies designated for encapsulation should contain spent nuclear fuel. They should therefore be subject to gross defect measurements, as a minimum. A complete assay (measurement of all assemblies) is recommended. This could be carried out with a simple gamma detecting device at the port where the assemblies are lifted into the hot-cell. A back-flow from the handling cell is not envisioned as part of normal operations. The purpose of the measurement is to verify that the assemblies that are placed in the canister are spent fuel assemblies.
- There is a need for information showing that dismantling of fuel assemblies does not occur in Clink. This information could be gathered in two ways: One way is that information from DIV of Clink gives assurance that there is no equipment for dismantling fuel assemblies present. The other option is that C/S information shows that no dismantling activities are carried out in the facility. A combination of DIV and C/S measures is also plausible. If it is confirmed that dismantling does not occur, the need for partial defect measurements is reduced and a gross defect measurement may suffice.

3 and 4. All disposal canisters are emplaced in the repository and remain there

The third and fourth item that safeguards authorities need to know is that all disposal canisters are emplaced in the repository and remain there.

During operation of the final repository the deduced information needs are information from containment and surveillance showing that the disposal canisters leaving the encapsulation facility are transported to the repository. C/S information and DIV information is needed to show that no nuclear material is taken from the repository [1]. The C/S information is used as verification that no nuclear material is taken out through the repository access points (shafts and ramp). DIV information is used as verification that no undeclared exits are constructed. For safeguards purposes it is not necessary to have information of the exact location of the nuclear material within the repository. This information is however important for national purposes, see chapter 3.

After repository closure information from area monitoring of the repository site is needed to show that no nuclear material is removed from the site and that no undeclared access points to the repository level are constructed.

2.1.3 INFORMATION THAT MAY BE REQUESTED

This section presents information that is not needed to reach the knowledge needs but may be requested, by the IAEA or DG-ENER, for other reasons. Such reasons may be motivated by e.g. IAEA's intention to be non-discriminatory between states with differing strategies on how to dispose of spent nuclear fuel.

The section motivates why the information is redundant to the information in section 2.1.2 in order to fulfil knowledge needs. However, for a situation where the information is requested, the section also presents how the possibly requested information may be gathered.

Fissile content verification

From a safeguards perspective, it is crucial to verify that all fissile material that has entered the Swedish fuel cycle (or is bred within it) is encapsulated and deposited in the repository and that it remains there. In this perspective, it may seem reasonable to verify that the fissile content is as declared. The purpose of such verification would be to compare the introduced amounts of fissile material to the amounts of fissile material in the spent fuel. A direct, non-destructive measurement of the fissile material cannot be performed today since there is no capable measuring technique available. Should a measuring technique be developed, the accuracy must be exceptional to be at the same level as for the fissile material in the fresh fuel.

The remaining option is to verify that the assembly burn-up could yield the fissile content as calculated and declared by the operators. However, burn-up verification does not pin-point the fissile content, and the ability to detect diversion with this method is indirect.

Therefore, the objective should not be to verify the fissile content which in essence becomes a verification of the calculation method for fissile content – this is not the purpose of safeguards. Instead, the focus should be to verify the completeness of the fuel assemblies as described above in section 2.1.2.

Partial defect verification

Under Integrated Safeguards, a conclusion is drawn that there is credible assurance of the absence of facilities designated for nuclear weapons production. Therefore, the probability that nuclear material is diverted for weapons production within the State is low. Nevertheless, the credibility of the safeguards system is dependent on verification of every State's compliance to the Non-Proliferation Treaty. Therefore IAEA have expressed the view that all fuel assemblies should be verified on a partial defect level before final disposal. However, this has not been expressed as a requirement for a state under Integrated Safeguards. Furthermore, STUK (Radiation and Nuclear Safety Authority Finland) has expressed the view that all fuel assemblies should be verified on a partial defect level [2]. The Swedish authority SSM has not issued any statements on the extent of verification.

A knowledge need (stated above in section 2.1.1) is that all fuel assemblies are complete (or as declared). The possible diversion scenario that could result in an incomplete assembly is a scenario where individual fuel pins are removed. Partial defect verification has a better chance of discovering removed pins than gross defect verification. (Partial defect verification for spent fuel assemblies is defined as 50 % of the fuel pins being removed or replaced with dummy pins [3].)

The scenario where individual fuel pins are removed from an assembly must be assumed to occur at a facility where dismantling equipment is available. This kind of equipment is not available at Clab for the normal operation. Two pin removal scenarios could therefore be considered:

1. Pin removal could take place at the nuclear power plants (NPPs) with declared dismantling equipment. If this is considered as an important diversion path safeguards measures should be applied so that detection within the timeliness period is possible, i.e. at the NPPs. A detection of diversion in connection with the final disposal process would probably not be contained by the timeliness goal.
2. Pin removal could take place at Clab or the encapsulation plant using undeclared dismantling equipment. Such diversion could possibly be detected using partial defect verification if more than 50 % of the fuel pins are removed. However, if a smaller amount of pins are removed, a partial defect measurement may not suffice. (If pin level verification is developed and approved for use, such verification could detect diversion of a small number of fuel pins). An alternative detection strategy is to target the dismantling equipment (using DIV) or the dismantling activity (using C/S). If DIV or C/S activities can show that pin removal is not feasible, partial defect verification becomes obsolete.

To sum up, information from partial defect verification is not necessary to reach the required knowledge, as long as DIV can exclude the use of dismantling equipment or C/S can exclude the dismantling activity.

2.1.4 FUEL DATA NEEDED

Following the arguments under section 2.1.2 and 2.1.3 the required fuel data are measurement data from gross defect measurements. These data should include data from several radiating isotopes so that the production of a radiating dummy is more complicated. Furthermore, fuel ID must be known.

2.2 STRATEGY FOR A SITUATION WHERE SAFEGUARDS INFORMATION OR DATA IS INSUFFICIENT OR UNCLEAR

The measurement technique used for the gross defect measurement should be non-destructive and has a high detection probability of gross defects (or partial defects, if the DIV or C/S activities in the Clab and encapsulation facilities are not positively able to detect dismantling equipment).

Since the measuring technique is undefined it is uncertain which types of errors it can reveal. The most severe error, from a safeguards point of view, is that the number of pins is erroneously declared. Since this must be assumed to have happened at the nuclear power plants, where dismantling equipment is installed, this should have been discovered before the assembly left the NPP. If not, the safeguards system’s timeliness goal is not fulfilled. The capacity to detect pin removal should therefore be installed earlier in the safeguards system (prior to arrival at Clab, in conjunction to shipment), if it is considered that the nuclear material accountancy activities are unable to detect such a scenario.

A strategy for a situation where safeguards information or data are insufficient or unclear is only needed if the safeguards authorities have a chance to detect these inadequacies. Therefore, it is assumed that a thorough survey and compilation of all relevant safeguards information, for each fuel assembly, is carried out before the current assembly is encapsulated.

The purpose of such a survey is to assure that the safeguards information to be archived is as correct as possible. Hence, the nature of such a survey is rather quality assurance than a safeguards inspection to detect diversion. However, a discovered historical error cannot be ignored, regardless of the circumstances during which it was revealed.

With the prerequisites given in this section, the following errors can be expected to be discovered:

- The declarations for at least two assemblies have been mixed up.
- The declaration for an assembly lacks some data or information.
- The declaration for an assembly is missing.
- The declaration for an assembly is inconsistent over time.
- The declaration for an assembly is (for some reason) doubtful.

Depending on the choice of measurement technique, it is also possible that also the following errors could be revealed:

- The declarations show a different pin configuration than the existing. This could be discovered if a pin level verification is performed.
- The declarations show deviating values of spent fuel properties than what the measurement shows. This could be discovered if the NDA technique used includes an analysis of fuel properties such as cooling time, burn up etc.

In sections 2.2.1-2.2.6 strategies of how the errors may be treated are discussed. The two last points concerning deviations discovered during measurements are handled as declarations with doubtful information in section 2.2.5.

If an error is discovered in the final disposal process, the processing of the fuel assembly should be stopped. If the fuel assembly already is transferred from the storage pools in Clab when the error is discovered, it is possible to take the assembly back to the storage pools without disturbing the safeguards capabilities to detect diversion, according to the diversion path analysis, **Paper 3**. The operator can choose to take back the complete canister content (the assembly with erroneous documentation and the remaining eleven (BWR) or three (PWR) assemblies). An alternative is to exchange the assembly for another with comparable residual heat where the documentation is correct.

It should be noted that this somewhat tricky situation could be avoided if the documentation review is carried out in good time before the assemblies are introduced in the final disposal process. This implies that the operator needs to notify the safeguards authorities and IAEA of their planned encapsulation operations.

2.2.1 DECLARATIONS ARE MIXED UP

A mix up has occurred when a declaration appears to be about a different fuel assembly than it really is. This means that no information is missing: only that one (or more) declaration is wrongly named.

Correct the documentation and follow up on possible resulting errors.

In the case of a mix up, it should be relatively easy to correct the documentation since no data are missing; only wrongly named.

2.2.2 A DECLARATION LACKS DATA OR INFORMATION

Retrieval of data or information

The safeguards authorities may want to save the data on the fuel assembly properties, including the calculated fissile content. If data are missing the assemblies can be taken to the reception pools where a gamma scan can be performed to determine the burn-up, from which the fissile content can be calculated. Missing historical safeguards data should be retrievable from archives at SSM, DG-ENER or IAEA. Data and information from the nuclear power plants could also be used, if necessary. For such a situation, an agreement should be made in advance between the nuclear power plants and the safeguards authorities about the terms for use of nuclear power plant (NPP) archives.

If historical information about a fuel assembly cannot be retrieved, it is unfortunate for the safeguards authorities. However, in a wider perspective, the most important fuel data and information are the fuel properties for the purpose of the national record (see section 3.2) and verification of the completeness of the fuel (see section 2.1). Fuel properties can be attained via a gamma scan. The assembly completeness can be verified by the proposed gross defect verification in combination with DIV or C/S showing that dismantling activities are not carried out in the facility, see section 2.1.2.

An exception is the case where it is uncertain how many fuel pins the assembly contains. It is important to know the number of pins since the pins contain the nuclear material. If a pin-level verification technique is unavailable, the assembly weight could be measured. Together with information on the fuel type (from the manufacturer) the number of fuel pins could be deduced from the weight. The use of tomographic equipment could also be used to retrieve the pin configuration.

Fuel ID is stamped into the fuel assembly handle and can be checked through visual inspection.

2.2.3 A DECLARATION IS MISSING

Retrieval of data or information

See section 2.2.2

2.2.4 A DECLARATION IS INCONSISTENT OVER TIME

Correct the documentation and follow up on any resulting errors

Find the point in time where the inconsistency started, and investigate why, if possible. Possible reasons could be a mix-up of two declarations or a typing error, for example. Correct the documentation (if needed with the use of gamma scanning and archives, see section 2.2.2) and follow up on possible resulting errors.

2.2.5 THE INFORMATION IN A DECLARATION IS DOUBTFUL

Retrieval of data or information

Regardless of the reason for the doubtfulness, the situation could be handled as a situation where a declaration lacks data or information, see section 2.2.2. The purpose of the examination according to section 2.2.2 is not to detect diversion, and therefore, the best effort must be viewed as sufficient. In principle, the safeguards system has failed if the documentation is doubtful and incomplete. Therefore, the operators should not be burdened unnecessarily by this situation.

Exception: A historical diversion, that took place more than one timeliness period ago, is suspected. This situation (although unexpected) should be handled on a case by case basis by the safeguards authorities. A handling plan should be ready for such an occasion.

2.2.6 THE DOCUMENTATION PROBLEM CANNOT BE RESOLVED

The safeguards authorities should be prepared for the possible situation where the documentation issues cannot be resolved within reasonable time.

In the case where a problem is revealed during the final disposal process, the shortest time for investigation is available. In order for an investigation to be as non-intrusive as possible, a maximum available time delay for the disposal process should be discussed with SKB. It is possible to avoid delay by finding documentation issues in a survey made well in advance of the disposal process.

If the documentation is not sorted by then, data and information should be retrieved to as large extent as possible, see section 2.2.2. After that, the fuel assembly should be allowed to proceed in the final disposal process. If new information is revealed at a later time, it could be used to complete the archived information.

3 FUEL DATA FOR THE CREATION OF A NATIONAL RECORD

3.1 INTRODUCTION

Fuel data needed for a national record have been investigated separately from data for safeguards needs. The national record has nothing to do with the safeguards agreements but is a necessary prerequisite for the administration of the closed repository. Therefore, the needs for knowledge, information and data needs are completely different for the two areas.

The repository will contain large amounts of material with different properties regarding economic value, strategic value, potential harmfulness towards humans and the environment etc. If information about these properties is lost, it cannot be recreated unless the repository is opened and the material extracted. Therefore, information about the repository and its contents should be carefully created and archived for future needs, whatever they may be.

Public acceptance is another reason for creating a document with all relevant information about the repository contents, especially since the managing of the repository will reflect on the nuclear power business as a whole. The public have the right to expect the state (the authorities) to have a thorough knowledge of dangerous and sensitive material on its territory.

To sum up, both current and future generations need a sustainable and correct record of the repository and its contents. The purpose of chapter 3 is to find a reasonable level of requirements for the saved data and information - not to design a checking procedure of operator data.

3.2 THE NEEDS FOR KNOWLEDGE, INFORMATION AND DATA FOR THE CREATION OF A NATIONAL RECORD

3.2.1 KNOWLEDGE NEEDED

Knowledge cannot be saved in archives as information and data. The knowledge needed in the context of a national record is that all saved data are correct, and that the state has fulfilled its duties towards its citizens and the society to retain all relevant information.

3.2.2 INFORMATION NEEDED

As it is impossible to predict the exact future needs of information, the needs must be estimated. A suggestion of a minimum set of information categories included in a national record is as follows:

- Design information about the repository and the canisters. This information should include coordinates, dimensions, tunnels, drifts, shafts, canister positions, the method for sealing and backfilling the repository etc. This information explains the limitations of use of the repository site. It is also needed if a retrieval of the deposited materials becomes necessary.

- The amounts of material deposited in the repository. This includes both bulk material such as copper, iron and uranium, and the smaller amounts of material in the fuel and the fuel cladding. Since it is unclear what types of material will be valuable in the future, even small amounts may be important to declare. The amounts of material should be declared at least on canister level, together with associated uncertainties.
- Properties of the radioactive contents. This includes the residual heat and levels of radiation as a function of time.

3.2.3 FUEL DATA NEEDED

The data needed to obtain the information described above, with the exception of the design data, are as follows:

- Isotopic composition. The selection of isotopes to be recorded should be decided. For example, all amounts within the error limit (or another criterion) could be recorded as "miscellaneous" with an attached list of possible elements included in that grouping. Data resolution should be on canister level at least.

  The values of amounts of isotopes should be accompanied by the maximum uncertainty of each value. The accuracy requirement does not have to be very stringent, as long as the error limits are carefully recorded. For example, the value in the reports could be required to be determined with a relative uncertainty within 5 %, with a 99 % confidence interval. (With a generous accuracy requirement, the requirement on the confidence interval could be more ambitious.)
- The operating data for each assembly could also be archived, although this is not currently a requirement. The benefit of saving operating data is that, based on that data, the fuel assembly irradiation can be re-simulated with coming core simulators. Future codes may improve the accuracy of calculated values.

3.3 EXISTING DATA

3.3.1 SIMULATED DATA

The material content of the disposal canisters, the cast iron inserts and the fuel claddings is well known from the production of these items. The amounts of different materials that are produced as the fuel is irradiated in the reactor are calculated from the codes that simulate the core during operation. The calculated material contents are not verified through measurement.

The core simulation is based on control rod patterns and earlier calculations of burn-up. The neutron flux monitoring is used as a check that the core simulation reflects the actual state in the core. For example, if a fuel assembly is misplaced when loaded, there will be a clear deviation between the measurements and the simulation. At such a situation the reactor is shut down and the core is re-simulated with the new prerequisites so that reality and simulation match. To sum up, the measured data from the core are used as a check that the chosen simulator is representing reality. However, measurement data are not used as in-data to the simulators.

Validation of the core simulators are performed as new code versions are being benchmarked. During benchmarking the new code version is being tested on saved control rod patterns. The results are then compared with, among others, results from calibration measurements in order to confirm the code's capability.

When the Swedish NPPs were taken into operation two-dimensional codes were initially used. A two-dimensional code simulates the core as a plane. Therefore, the axially distributed burn-up cannot be attained from this code only. However, as three-dimensional codes were introduced and benchmarked, the previous cycles were re-simulated with the new codes. Therefore, three-dimensional simulated data have been produced for all fuel cycles. These 3D data originate from three different codes: POLCA4, POLCA7 and SIMULATE-3.

POLCA4 is a 3D core simulator that calculates the burn-up on a nodal level (25 segments along the fuel assembly height).

POLCA7 is the evolved version of POLCA4. POLCA7 calculates on pin and pellet level. Furthermore, all isotopes are directly followed by the simulator. (If POLCA4 is used, the isotopic composition can be calculated based on the axial burn-up.)

SIMULATE-3 is comparable to POLCA7 as it calculates on pin and pellet level and follows the isotopic composition of the fuel assemblies.

The core simulators produce burn-up data that are correct within 2-3 %. None of the core simulators produce uncertainty intervals or values on burn-up or amounts of isotopes.

3.3.2 ARCHIVES

In September 2008, a meeting was held with participants from SSM, SKB and all the Swedish NPPs including the closed down site Barsebäck. The purpose of the meeting was to investigate what fuel-assembly data, old and new, that are available. Clarifying interviews with some of the meeting participants were carried out at later dates. The results are summarised in this section.

Nuclear power plants

For most cycles SIMULATE-3 or POLCA7 data are created today. For the early cycles that were not re-simulated as part of a bench-marking program, POLCA4 data are archived.

More importantly, operating data (control rod patterns) are archived from all fuel cycles. This means that it is possible to re-simulate all burn-up values and corresponding isotopic compositions of all fuel assemblies. It is however unclear if these archives (kept by the NPP owners) are easily accessible and complete.

SKB

When the NPP’s send spent fuel to interim storage in Clab, an information data sheet is attached. The information reported for each fuel assembly includes the following:

- Fuel ID
- Fuel type project code
- Average burn-up [MWd/kgU]
- Discharge date
- Residual heat [kW]
- Activity [TBq]
- Control rod insert [Y/N] (PWR only)
- Number of pins
- Other information, e.g. damages or pin exchanges. If pins are exchanged, an assembly protocol is attached.

This information is available at Clab for all fuel assemblies stored in Clab.

SKB has initiated the project IDOL with the objective to create a computer-based system for collection and storage of fuel data for spent nuclear fuel. Within the IDOL project, SKB and the Swedish NPP’s have agreed on what data should be transferred to SKB from the NPP’s. The data in the system is intended to cover all data needs in connection with transport, storage, encapsulation and final disposal. The data included in the IDOL project are, among others, as follows [4], [5]:

- Initial weight Utot
- Initial weight U-235
- Initial weight Pu (MOX-fuel only)
- Irradiated weight Utot
- Irradiated weight U-235
- Irradiated weight Pu (also individual weights of the isotopes Pu-238, Pu-239, Pu-240, Pu-241, Pu-242)

3.4 ACQUISITION OF ADDITIONAL INFORMATION

As discussed in section 3.3.1 the necessary categories of fuel data can be extracted from the core-simulator results: the isotopic composition is calculated directly in the modern core simulating codes, but data from the earlier versions do not include fuel contents. From the earlier core simulators however, isotopic composition can be calculated based on burn-up data. The radioactivity can also be accessed through the burn-up.

These burn-up and isotopic content results are presented as fixed values. However, the values are the results of model, based on cross-section libraries, which in turn are based on experimental results from nuclear physics research.

Each of these steps introduces uncertainties in the core simulator results but the uncertainties are neither presented nor calculated.

For a national record, the uncertainties in the amounts of material are of importance. The correct use of the saved information relies on a correct understanding of its accuracy. Thus, the uncertainties of all reported values should be investigated and reported in order to create a fully credible national record.

3.4.1 UNCERTAINTY DETERMINATION

The uncertainty in the isotopic composition is of interest, as described in section 3.2.3.

Among the fuel assemblies whose calculated isotopic composition is available from the NPP archives, a selection of representative assemblies can be made. These representative fuel assemblies can act as a sample that is measured by e.g. gamma scanning to confirm that the burn-up values are in fact within the uncertainty limits.

For fuel assemblies where only the burn-up is calculated a similar approach can be used. The procedure would include burn-up measurement of a sample selection of fuel assemblies, and the measurement would give the maximum uncertainty. The isotopic composition can then be calculated from the burn-up with the known uncertainties. Extra uncertainties for the model used for translating burn-up, cooling-time and initial enrichment into isotopic composition should also be added.

3.4.2 INACCESSIBLE DATA AND INFORMATION

Since operation of the nuclear power plants in Sweden dates back to the mid 1960’s and the fuel assembly data seldom is requested, it cannot be ruled out that data and information concerning some fuel assemblies will not be retrievable. In this case, an independent measurement is the only way to access information on the fuel properties. Gamma scanning is an option for such a situation. It has been shown that the average assembly burn-up can be independently determined within 1.6 % if the cooling-time is less than 20 years and within 4.6 % if the cooling-time is more than 20 years [6].

4 RESULTS

The defined fuel data needs in chapters 2 and 3 are summarised in table 1 below. Defined knowledge and information needs are also presented to give the complete view of why the data are needed.

Table 1 can also be read as a strategy for knowledge defence: Needs for knowledge yields needs for information and data, which are presented in the three first columns. Where the needs cannot be satisfied today, the two last columns present remedial actions.

The needs for other types of data, apart from fuel data, have not been investigated since the purpose is to identify the data that must be secured prior to encapsulation.

The results also include a discussion of information that is judged as not needed to fulfil a knowledge need, but may be requested by IAEA or DG-ENER for other purposes, see section 2.1.3. This information includes

- the fissile content of the nuclear material; and
- information from partial defect level verification.

Table 1 Knowledge defence*

Defined knowledge need	**Derived information need**	**Derived fuel data need, to be secured prior to encapsulation**	**Gap between needed and existing fuel data**	**Strategies to recover gap data**
All nuclear material is contained in the fuel	Information from IS activities concerning the state as a whole, which shows that reprocessing is not carried out in the state	No data needed from the fuel assembly	Not applicable	Not applicable
All nuclear material is placed in disposal canisters	Verification that items contain spent nuclear fuel	Gross defect measurement data (see section 2.1.4)	A possible situation where safeguards information is insufficient or unclear	See section 2.2
		Positive identification of each fuel assembly (see section 2.1.4)	A possible situation where safeguards information is insufficient or unclear	See section 2.2
	Verification that all assemblies are complete: Information from C/S and/or DIV showing that assemblies have not been dismantled within the facility	No data needed from the fuel assembly	Not applicable	Not applicable
All disposal canisters are emplaced in the repository	C/S measures applied in the encapsulation plant are evaluated in the repository reloading hall	No data needed from the fuel assembly	Not applicable	Not applicable
All emplaced disposal canisters remain in the repository	Information from area monitoring	No data needed from the fuel assembly	Not applicable	Not applicable
All relevant information and data are retained	Design information about the repository	No data needed from the fuel assembly	Not applicable	Not applicable
	The amounts of material deposited in the repository	Isotopic composition including uncertainties (see section 3.2.3)	Uncertainty in calculated isotopic contents	See section 3.4.1
			Possibly inaccessible data and information	See section 3.4.2

*Knowledge, information and fuel data needs are presented in the area surrounded by the thick line. Gray cells present fuel data that must be secured prior to encapsulation of a fuel assembly

5 CONCLUSIONS

SSM is the national safeguards authority and also the authority that will be responsible for the Swedish final repository once the SKB operations are complete. Accordingly, it is in the hands of SSM to create a knowledge defence system where both safeguards needs and national needs are satisfied, while being non-intrusive on operations.

In order to be able to fulfil its obligations SSM should address the two problem areas that are revealed.

The first problem area concerns the completeness and quality of old archives. SSM is in need of fuel information stored at Clab and at the NPPs. The archives at Clab and the NPPs may not be complete for all assemblies. Therefore, a conclusion is that SSM should communicate their needs to SKB and the NPPs in order for them to take inventory of their archives and take actions to retrieve information that is not readily available. Information that cannot be retrieved by searching through archives may be retrievable using the strategies described in sections 2.2 and 3.4.

The second area concerns the lack of uncertainty data for calculated burn up values. The uncertainties are needed for the ability to use the information, but are not produced directly in the core simulators. Uncertainties can be estimated using the strategies presented in section 3.4.

6 REFERENCES

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PAPER 3

DIVERSION PATH ANALYSIS FOR THE SWEDISH INTERIM STORAGE AND ENCAPSULATION FACILITY FOR SPENT NUCLEAR FUEL

Abstract:

A diversion path analysis has been performed for the interim storage and encapsulation facility in the back-end of the Swedish fuel cycle. The diversion path analysis is necessary for defining the safeguards system that can cover all feasible diversion paths.

The objective of this particular diversion path analysis is to form a basis for identifying the safeguards system's need for fuel data.

A conclusion from the diversion path analysis is that it is possible to allow a back-flow of material through the facility without losing the ability to safeguard the nuclear material in the building.

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1 INTRODUCTION

This diversion path analysis has been performed as part of a comprehensive research project initiated by the Swedish Radiation Safety authority, SSM. The comprehensive project aims at defining the fuel data that must be secured before spent fuel becomes inaccessible through encapsulation and final disposal. As a basis for the work, a diversion path analysis has been carried out. A secondary objective is to determine if the safeguards system can cover all diversion paths if a back-flow of nuclear material through the final disposal process is allowed.

Diversion of nuclear material is defined as *"the undeclared removal of declared nuclear material from a safeguarded facility; or the use of a safeguarded facility for the introduction, production or processing of undeclared material"* [1]. The objective of diversion is expected to be the acquisition of an amount of fissile material that is sufficient for the production of a nuclear weapon: *a significant quantity*.

A diversion path analysis includes an identification of the potential points of diversion within the analysed facility; a description of potential methods of concealment of the diverted fuel; and an identification of potential routes available for diverting the fuel from the facility. In identifying these potential diversion paths, it is assumed that a significant quantity of nuclear material can be diverted as a whole or in parts.

This report also includes an identification of detection points, where diversion can be detected, and strategic points, which constitute the smallest amount of detection points that can be used while still covering all diversion paths.

2 FACILITY DESCRIPTION

The Swedish Nuclear Fuel and Waste Management Co, SKB, is planning to construct a combined interim storage facility and encapsulation plant for spent nuclear fuel. An interim storage, Clab, is already in operation since 1985. SKB plans to expand and convert Clab into the new facility where both interim storage and encapsulation will take place.

The facility will include the following parts:

- A reception area where spent fuel transports from the Swedish NPPs are unloaded.
- A storage area consisting of two underground pools where the spent fuel is stored for around 30 years awaiting encapsulation and final disposal, see figure 1.

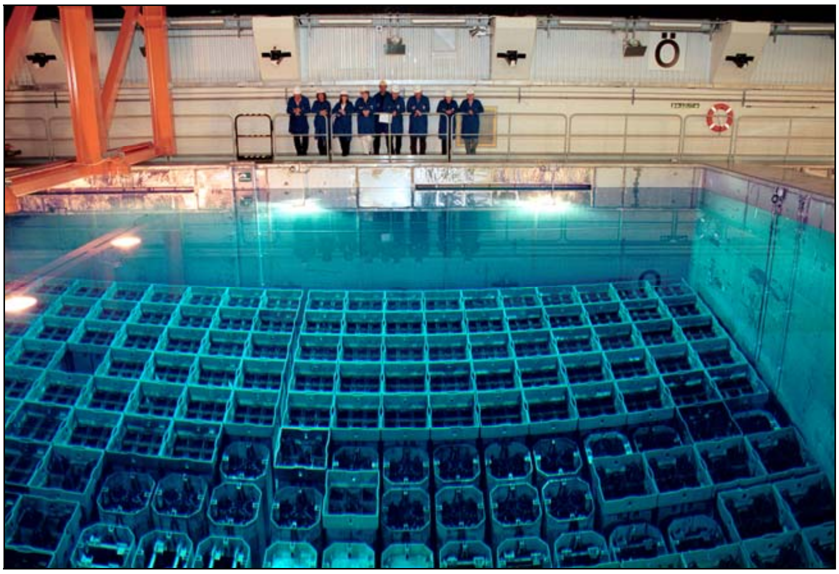

Figure 1 – a storage pool at Clab. The fuel assemblies are stored in storage cassettes. Photo: Curt-Robert Lindqvist, SKB

- An encapsulation plant where the spent fuel is placed in disposal canisters made of copper.
- A sending area where the disposal canisters are placed in transport casks and sent to the final repository.

The spent fuel is transported to the reception building in transport casks, see figure 2. The fuel assemblies are unloaded under water and transferred down to the storage pools by the fuel lift. The assemblies are planned to cool in the pools for around 30 years before encapsulation. The same lift will be used to transport fuel cassettes (rigs used for storage of fuel assemblies, containing 5 or 3×3 PWR fuel assemblies or 4×4 or 5×5 BWR fuel assemblies) from the storage pools to the handling pool in the encapsulation facility. In the handling pool, there is room for twelve fuel cassettes and four transport cassettes (16 positions in total).


Figure 2 – A transport cask is received at Clab. Photo: Curt-Robert Lindqvist, SKB

When a disposal canister shall be filled, twelve BWR assemblies or four PWR assemblies are chosen. The selection is made so that the total residual heat is as close as possible to the limit of 1700 W. The cassettes containing the chosen assemblies are transferred to the handling pool by the lift. The chosen assemblies are then lifted from the storage cassettes to a transport cassette. The transport cassette is then taken by a transporter to a position under the handling cell (one of the facility's hot cells), see figure 3 and 4.

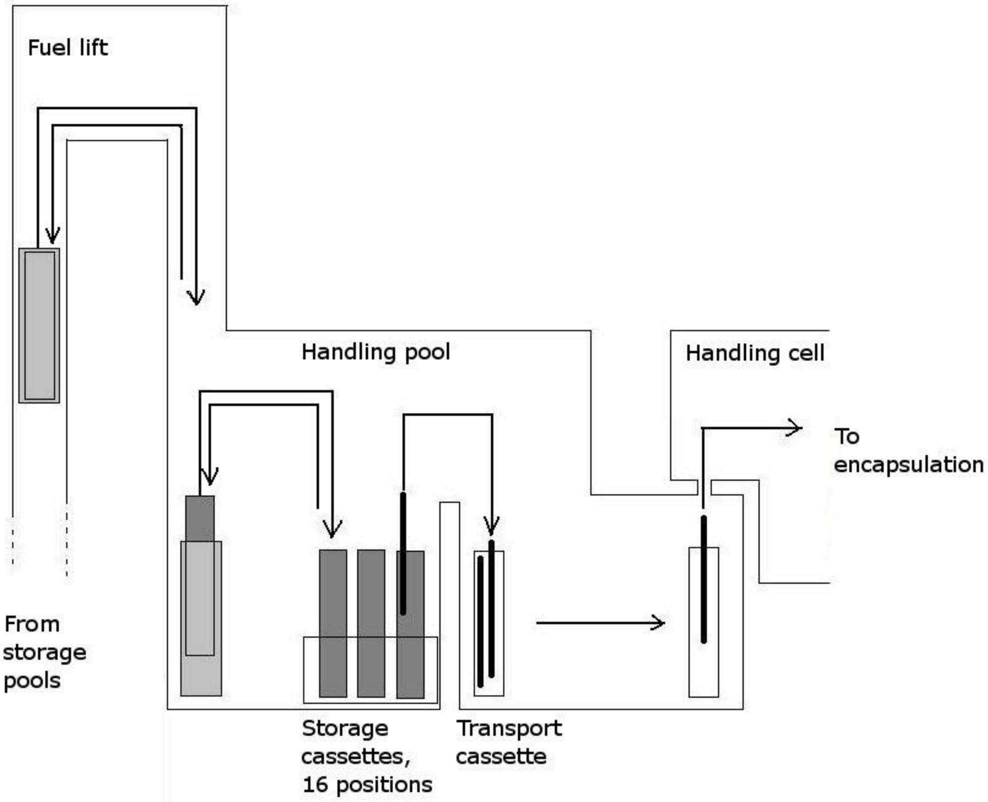

Figure 3 – the handling pool

In the handling cell, see figure 4, the following operations are carried out:

- The fuel is lifted into the handling cell from the pool.
- The fuel is dried (dripping followed by vacuum drying).
- The fuel is transferred to the disposal canister.

After filling the disposal canister is transferred to other hot cells, where work stations are installed, by a shielded load carrier. At these stations, the following tasks are carried out:

- The atmosphere inside the canister insert is changed through a valve.
- The copper lid is welded to the copper canister. The weld is smoothed by machining and checked.

If the weld quality is acceptable, the canister is removed from the load carrier so that it can be checked for external contamination. If the canister is clean, it is placed in a transport cask in a position connected to the terminal building.

Subsequently, the transport cask with the canister is transported to the final repository for disposal.

The complete process in the interim storage and encapsulation facility is presented in figure 5.

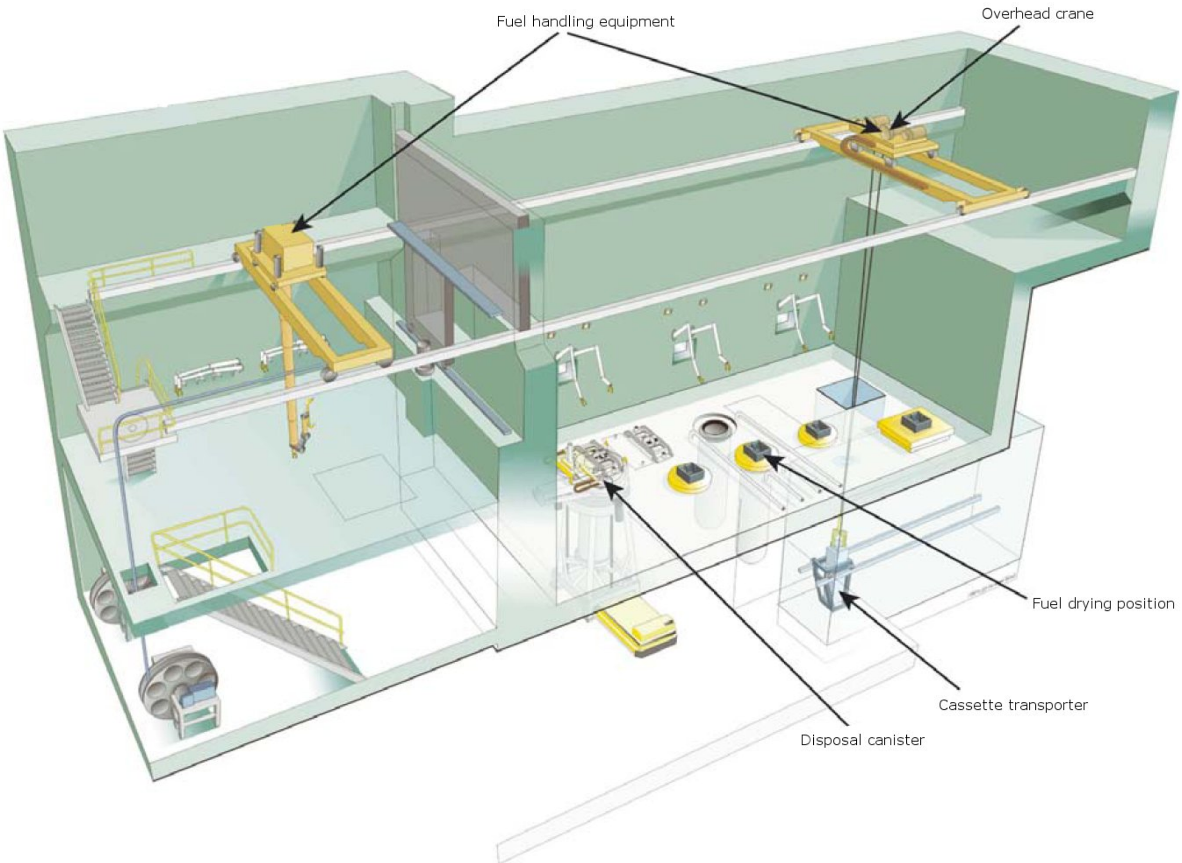

Figure 4 – The handling cell. Graphics: SKB

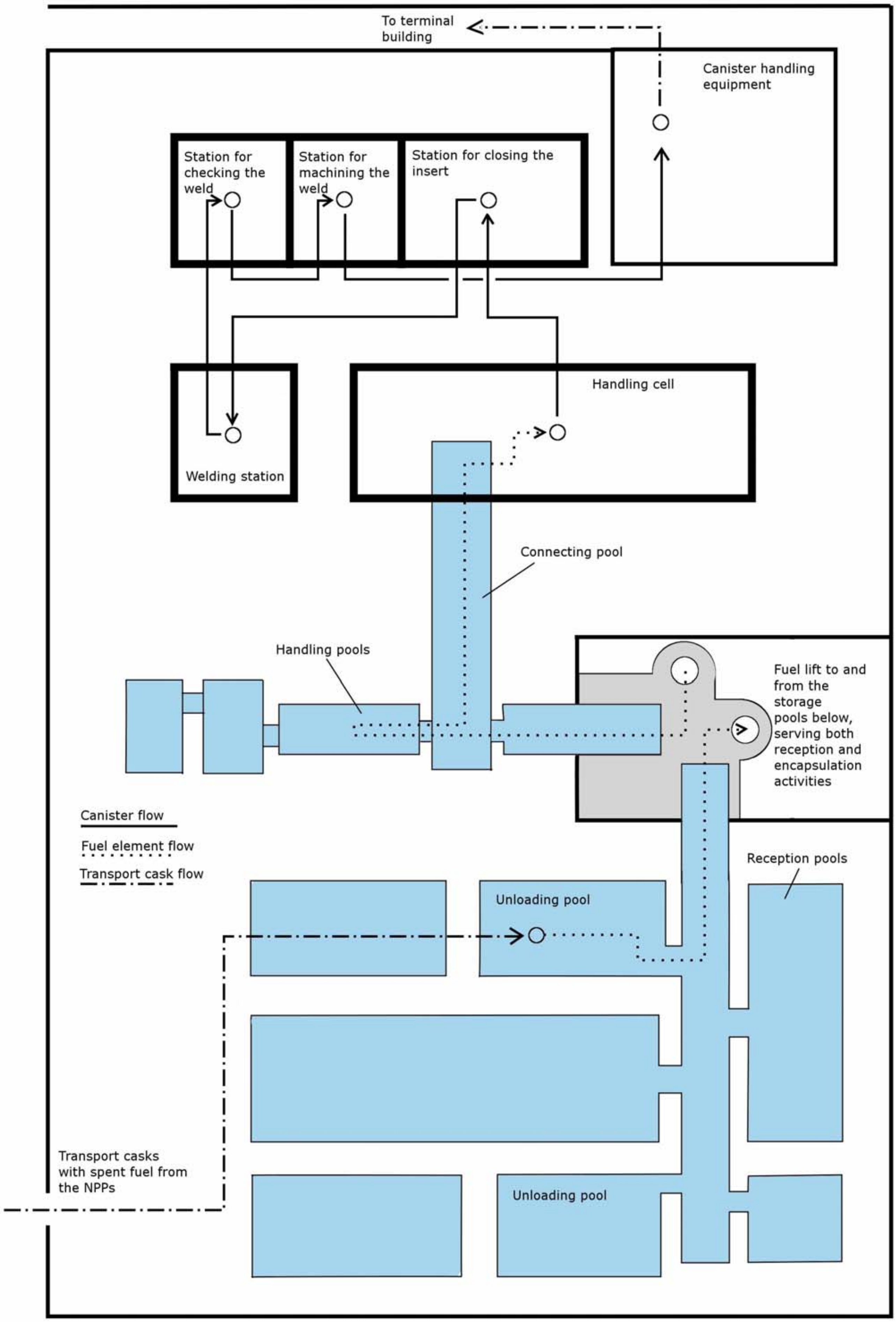

Figure 5 – The interim storage and encapsulation process. The reception pools and the fuel lift exist in Clab. The other areas will be constructed as parts of Clink.

3 DIVERSION STRATEGIES

This chapter presents strategies that a diverter may use to conceal a diversion, and their feasibility when applied to the Swedish final disposal process.

The objective of a diversion is to divert a significant quantity of nuclear material. A significant quantity of plutonium, the fissile material in spent fuel, is 8 kg. This is the approximate plutonium content of 2 PWR or 4 BWR fuel assemblies.

Diversion of a significant quantity of plutonium from spent fuel requires diversion of spent fuel transport casks, canisters, assemblies, pins or pellets followed by reprocessing of the spent fuel item.

In order to reduce the probability of detection of a diversion act, the diverting State is expected to conceal the diversion. The concealment could involve falsification of records, defeat of containment and surveillance measures such as seals and video-cameras, and the use of dummies. A dummy is an object that imitates a spent fuel item with the purpose of concealing diversion of the item. Dummies can be made with different levels of sophistication, where the imitation of appearance and ID-number is the crudest level. The next level of sophistication is to duplicate assembly/canister weight or radiation signature. The most advanced dummy would duplicate appearance, weight and radiation signature.

In the Swedish plans, the encapsulation facility is not planned to condition the fuel or to have the capability of assembly dismantling. Therefore, the credible items for diversion are fuel assemblies, final disposal canisters or transport casks. Diversion of pins from a disassembled fuel assembly requires installations of pin removal equipment. Pin diversion is also covered in the following chapters, although it is less credible than the diversion of complete assemblies, canisters or casks.

In Sweden, it is very complicated to manufacture a radiation imitating dummy. The most similar radiation signature, to the signature of spent nuclear fuel, comes from vitrified high-level waste. Vitrified high-level waste is a by-product from reprocessing of spent fuel, which is not carried out in Sweden. Therefore the acquisition of a radiation source with similar signature is more difficult here than in e.g. Great Britain or France [2]. For this reason, diversion paths that include radiation imitating dummies are not included in this diversion path analysis.

To sum up, this diversion path analysis is limited to diversion of spent fuel pins, assemblies, canisters and transport casks. Furthermore, it is assumed that diverted items are replaced with dummies replicating appearance (including ID number) and weight of spent fuel items.

4 DIVERSION PATHS

This chapter presents paths that a diverter may use to divert nuclear material from safeguards.

The place where the diversion takes place is by definition where the nuclear materials item is diverted from the safeguards system, i.e. not where it is removed from the facility.

4.1 DIVERSION DURING TRANSPORT OR STORAGE OF TRANSPORT CASKS

The assemblies are transported to the existing facility Clab in transport casks. The deliveries of assemblies have been performed since the opening of Clab in 1985. When the encapsulation facility is taken into operation, interim storage will still take place in Clab. The assemblies will cool in the storage pools for around 30 years before encapsulation. Thus, the transport of assemblies to Clab will take place many timeliness[1] periods before encapsulation. Nevertheless, transports will take place concurrently with encapsulation operations and must therefore be included in the diversion path analysis.

During transport, the transport cask could be opened and assemblies or disposal canisters could be transferred to a shielded transfer overpack. If the lid is sealed with a unique seal, the bottom of the cask could possibly be removed, the assembly or canister withdrawn, and the bottom re-welded into place.

The same strategies could be used for casks in storage. A cask can be removed from the storage position, the assemblies removed as described above, and the cask replaced in the storage area. It is possible that the diverting state removes a wall or the roof to access the spent fuel material.

Diversion of a full transport cask could be performed from a storage location or during transport. The most direct diversion would require switching the cask with a dummy item.

4.2 DIVERSION OF AN ASSEMBLY FROM THE UNLOADING POOL

In the unloading pool in the reception building, the fuel assemblies are transferred from the transport cask into fuel cassettes. Instead of being transferred to a cassette, an assembly could be put into a submerged shielded container to provide sufficient shielding when the assembly is removed from the water. Alternatively the spent fuel item could be raised from the pool by remotely controlled equipment and transferred to a shielded container on the pool deck. The container could be taken out through a declared or an undeclared exit.

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[1] A timeliness period is connected to the IAEA's detection goals. The timeliness periods are determined by the sensitivity of the safeguarded material – the easier it is to convert the material to a nuclear weapon, the shorter the timeliness period will be. The IAEA detection goal is "the timely detection of diversion of nuclear material", where timely is defined as being within the timeliness period.

The calorimetric and gamma scanning equipment is situated in the reception building pools. When an assembly is to be measured, its cassette is taken from the storage pools and brought to the reception building by the fuel lift. Diversion could take place as described above in this operation as well as while unloading a cask.

A fuel assembly could be placed in a transport cask that is declared as empty and taken out the normal exit route for transport casks.

At the unloading of assemblies from a transport cask, an assembly could be left behind in the cask and later retrieved from the "empty" cask, or taken out in the cask.

4.3 DIVERSION OF AN ASSEMBLY FROM THE STORAGE POOL

From the storage pool a fuel assembly could be placed in a shielded container under water or, if remotely controlled equipment is used, on the pool deck. The container could then be taken out through a declared or an undeclared exit.

Alternatively, the fuel lift could be used to take fuel to the reception building and diverting it from the reception pools as described above in section 4.2.

4.4 DIVERSION OF AN ASSEMBLY FROM THE HANDLING POOL

In the handling pool, the fuel assemblies are transferred from the storage cassettes to a transport cassette. If necessary, the residual effect can be measured here according to SKB's plans. For that purpose, gamma scanning equipment is included in the handling pool design. If it is decided that verification through non-destructive analysis (NDA) should be performed prior to encapsulation, this is one of the possible places for such an activity. If NDA verification is performed here, the verified assembly could be diverted after that, either by removing it from the pool system into a shielded container, or by transferring it through the pools back to a suitable place for removal as described in previous sections of chapter 4. An assembly could also be moved forward through the handling cell but instead of being placed in a declared disposal canister, it is placed in another container and removed through a transfer port.

4.5 DIVERSION OF AN ASSEMBLY OR A FULL DISPOSAL CANISTER FROM A HOT CELL

In the handling cell, the fuel assemblies are removed from the water, dried and placed in a disposal canister. The insert is closed with a steel lid.

The four other hot cells have the following functions:

1. The canister atmosphere is changed and the copper lid is placed on the canister
2. The copper lid is welded into place which closes the canister.
3. The weld is machined smooth.
4. The weld is checked.

From within the handling cell, a spent fuel assembly could be removed through a transfer port. The assembly could be placed in a shielded container within the hot cell or transferred into a shielded container as it is passed from the hot cell. A dummy could be placed in the canister in case of an ID-check of the assemblies in the canister prior to the placing of the insert lid.

In a hot cell, the insert lid can be removed and a fuel assembly could be removed from the canister. After removal of the assembly the lid could be replaced and the canister processed according to the normal disposal activities. The fuel assembly could be removed from the hot cell later through the transfer port.

A dummy canister could be placed in the transport cask that is connected to the transfer port to the terminal building, and the full canister is removed through another path, possibly through a removed wall or the like.

Another scenario is that a full and sealed canister is retaken from a transport cask and opened in the station that works the welds (which is also designed to be able to open canisters where the weld is imperfect and must be remade). The fuel assemblies could be taken back through the facility using the normal transport routes in reverse and diverted at the most suitable location. The empty disposal canister could be resealed and taken to the repository for disposal.

4.6 DIVERSION OF INDIVIDUAL FUEL PINS FROM DISMANTLED ASSEMBLIES

Equipment for dismantling fuel assemblies and removing fuel pins can be installed anywhere in the facility. To collect a significant quantity of plutonium approximately 400 fuel pins must be diverted.

The pins could be removed individually or in batches. Batches of fuel pins could be assembled in an assembly sized can that could be handled by the normal fuel handling equipment in the facility. The can could be removed through any of the paths described in sections 4.1-4.5 above.

Individual fuel pins could also be placed in lead pipes and carried out through a declared or undeclared exit. However, a calculation performed in [2] shows that it is not possible to manually carry out such pipes without receiving severe health damage. Heavier shielding requires mechanical hoist and transport.

The installing of pin removal capacity in the receiving pools or the handling pool requires the smallest installation since the fuel handling equipment could be complemented with pin removing tools.

4.7 SUMMARY OF THE DIVERSION PATHS

4.7.1 DIVERSION BY BRINGING A CANISTER OR AN ASSEMBLY THROUGH THE REVERSE PROCESS

As described in sections 4.1-4.5 a number of diversion paths include a back-flow of spent fuel items. Therefore, identified possibilities to detect these scenarios are necessary for the safeguards authorities to be able to permit operations that include a back-flow.

4.7.2 REPLACEMENT OF AN ASSEMBLY TO BE ENCAPSULATED

The most important scenario to detect is the replacement of fuel assemblies after the final verification that the fuel assembly actually is a spent fuel item. If such a replacement is conducted successfully, the evidence of the diversion may be very difficult to detect, as the canisters are not planned to ever be re-opened. The remaining options are therefore to assure that any diverted assemblies will be detected (rather than the lack of an assembly), or to assure that no spent fuel item has been replaced. To assure that no spent fuel is replaced, the following factors are necessary to have knowledge about:

1. That the encapsulated assemblies actually are spent fuel items.
2. That the canisters are deposited with all assemblies in place.

Implications of item 1 include that all assemblies must be subject to at least gross defect verification. A random selection of assemblies to be measured is not deterring enough since the encapsulation process is relatively fast. Therefore, the inspections must be numerous to be effective in this case. It is probably both more cost efficient and non-intrusive to perform a gross defect measurement on all assemblies. Another implication of item 1 is that after the final verification, the continuity of knowledge must be carefully maintained by e.g. a dual containment and surveillance (C/S) system.

Implications of item 2 includes that a dual C/S system must be implemented on the filled disposal canisters to maintain continuity of knowledge until the deposition is complete. In the geological repository, a different set of safeguards measures assure that no diversion occurs from inside the repository [3]. However, the reloading hall in the repository is a natural place for evaluation or inspection of such C/S measures that are attached to the canister, since it is inside the transport cask until that time.

The other strategy mentioned above, to assure the detection of removed spent fuel assemblies is indirect. The strategy includes a comprehensive design information verification (DIV) scheme and also radiation monitors covering all possible exits for a fuel assembly. It must be proven that the maximum amount of shielding that can cover an assembly is not able to shield the emitted radiation below the detection threshold of the radiation detectors. (The maximum amount is defined by the size of the possible exit routes.) However, a directly verifying safeguards system is judged by this report as easier to implement in a credible manner. Therefore, only the first strategy is further developed in the following sections.

5 DETECTION POINTS

The detection points are all points where a diversion through one of the diversion paths described in chapter 4 can be detected. The location of the detection points and the strategic points (see chapter 6) is shown in figure 6.

DP1 the pools in the reception building

The replacement of a spent fuel assembly for a dummy could be detected by video surveillance while unloading the transport cask (to check that all assemblies are unloaded and that no other fuel assemblies are loaded into the transport cask)

Radiation detectors could be used to trigger surveillance between unloading operations; as such detectors are expected to be able to detect assemblies in containers that are taken out of the pools.

Pin removal activities could be detected by surveillance cameras on the fuel handling equipment. DIV could also be used to detect pin removal equipment.

DP2 the fuel lift between the reception building and the storage pools

An operations log, possibly combined with video surveillance could verify that all transfer operations conducted by the lift are legitimate.

DP3 the storage pools

During the annual physical inventory verification, which is assumed to include a gross defect NDA verification, replaced or missing fuel assemblies will be detected. DIV should be used to find alternative exits than the declared ones.

Pin removal activities could be detected by surveillance cameras on the cassette handling equipment. DIV could be used to detect pin removal installations in connection to the pools.

DP4 the handling pool

Video surveillance could be used to monitor all fuel assembly transfers. This is also a possible location for NDA verification of the spent fuel assemblies.

DP5 the handling cell

NDA verification could be used here if not earlier, to assure that the assemblies destined for encapsulation are spent fuel items and not dummies. If NDA is performed earlier in the process, the applied C/S measures should be investigated here, before encapsulation, in order to detect a replacement.

Surveillance cameras could show that pin removal activities are not performed. DIV could show that pin removal equipment is not available in the handling cell.

DP6 the hot cells excluding the handling cell

DIV could show that fuel handling and pin removal equipment is not installed in the hot cells (besides the handling cell), or surveillance cameras could show that fuel handling or pin removal activities are not performed.

DP7 the terminal buildings at Clink and the repository

Motion-triggered surveillance could be used to detect illegitimate activities.

DP8 the reloading hall in the geological repository

This detection point is not situated in Clab or in the encapsulation facility. It is however an important detection point since it is the first position where the canister is taken out of the transport cask so that any C/S measures can be evaluated.

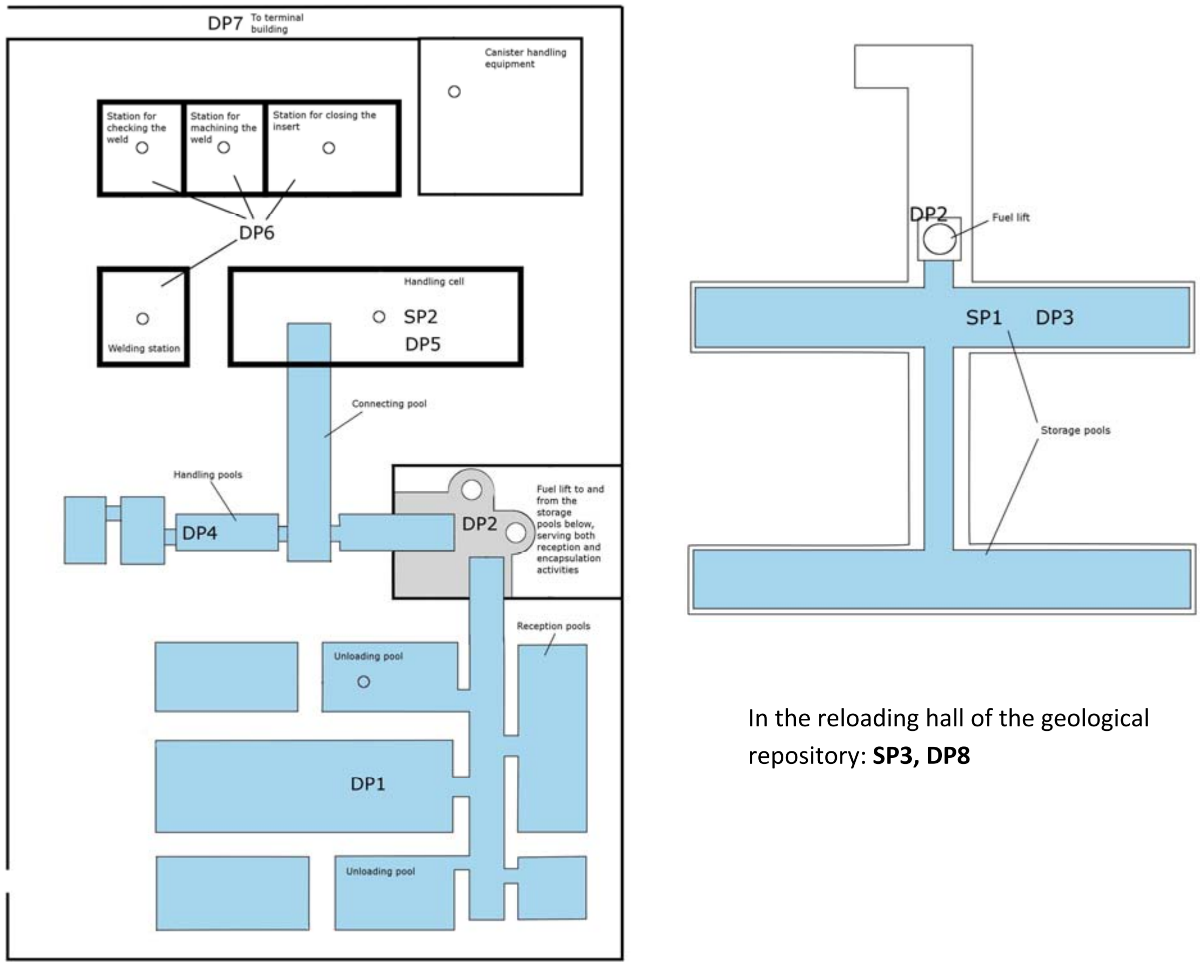

Figure 6 – The location of detection points (DP) and strategic points (SP)

6 STRATEGIC POINTS

In the SAGOR reports, activity 2A, it is stated that *"the more opportunities there are to detect a diversion path, the greater the level of confidence will become in the ability to detect diversion, and the greater will be the deterrence to diverters"* [2]. However, if safeguards measures were implemented on all detection points, some would be redundant. Redundancy increases the security of detection but at the same time, it is not resource efficient to employ more safeguards devices and activities than necessary.

To balance these two aspects is a task for the safeguards authorities, but as Integrated Safeguards are implemented in a state, it is possible that the resource efficiency will be judged as more important, as the enhanced transparency of an IS state can be viewed in itself as an opportunity to detect diversion paths.

For such a case, a set of strategic points has been identified among the detection points. A strategic point is *"A location selected during examination of design information where, under normal conditions and when combined with information from all strategic points taken together, the information necessary and sufficient for the implementation of safeguards measures is obtained and verified; a strategic point may include any location where key measurements related to the material balance accountancy are made and where containment and surveillance measures are executed"* [1].

All diversion paths can be covered if the following can be assured:

- that all spent fuel taken into the facility is encapsulated in declared disposal canisters.
- that the full disposal canisters are transported to the repository without being opened.

This assurance could be obtained by applying safeguards measures on the strategic points. The location of the strategic points is shown in figure 6 above.

SP1 the storage pools

In the storage pools, the annual physical inventory verification can give assurance that the spent fuel has not been previously diverted. To detect replacement at this point, gross defect verification is necessary. When the encapsulation operations start, C/S measures must be applied after the final verification, whether it takes place in the storage pools, or later in the handling pool.

SP2 the handling cell

The encapsulation of the fuel assemblies takes place in the handling cell. The main objective here is to verify that the assemblies have not been exchanged for dummies between the final verification and the encapsulation working station. This is accomplished by evaluation of applied C/S measures as close to encapsulation as possible. C/S measures should also be applied on the disposal canisters at this point, prior to them being transferred to the transport cask.

SP3 the reloading hall in the geological repository

In the reloading hall in the repository, the disposal canisters are taken out of the transport cask for the first time since the encapsulation facility. This opportunity should be used to verify that the disposal canisters have not been exchanged for dummies during transport or storage. A C/S measure that is practically impossible to forge, that could be useful for this verification, is an item "fingerprint", see for example the discussion in [4].

An area that should be investigated is the possibilities to verify that the spent fuel is still in the canisters (that the canister integrity has not been breached). This could possibly be performed by using a large-area laser-scanning method on the canister surface, or by using some kind of radiation measurement.

In addition to these strategic points it must also be verified (using DIV) that there is no assembly dismantling capability installed in the encapsulation plant. The DIV activities could be complemented by C/S measures in the pools. This complement could strengthen the safeguards system since pin removal equipment requires a relatively small installation in pools where fuel or cassette handling equipment already is present.

The unloading pools and the handling pools should be added as strategic points if it is judged as necessary to complement DIV with C/S measures in the pools.

If the DIV activities (possibly complemented by C/S measures) are incapable of providing sufficient assurance that no dismantling capability exists, an introduction of partial defect verification should be discussed.

7 CONCLUSIONS FROM THE DIVERSION PATH ANALYSIS

A conclusion from the diversion path analysis is that it is possible to cover all diversion paths without prohibiting a back-flow of material within the facility. This implies that it may not be feasible to monitor the material flow in the facility on a fuel-assembly level. However, the intrusiveness on operations would be high if a back-flow is not allowed. Legitimate situations that may require moving material through the reverse process include e.g. a discovery of a defect canister, or a measurement campaign where fuel from the storage pools is measured by the equipment in the reception pools.

It is also concluded that DIV, possibly complemented by C/S measures in the pools where fuel handling equipment is installed, should be able to detect pin removal from a disassembled fuel assembly, thus reducing the need for partial defect measurement to detect pin diversion from the final disposal process.

Finally, the need for verification of the integrity of the disposal canisters after transport to the repository has been identified.

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2011:02

The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 270 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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