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SPENT FUEL ENCAPSULATION AND VERIFICATION

Safeguards workshop in Helsinki, Finland, 19–20 December 2000

Phase II interim report on Task FIN C1184 of the Finnish Support Programme to IAEA Safeguards

Tapani Honkamaa (ed.)

STUK • SÄTEILYTURVAKESKUS • STRÅLSÄKERHETSCENTRALEN
RADIATION AND NUCLEAR SAFETY AUTHORITY

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Keywords: safeguards, spent fuel encapsulation, final disposal

ABSTRACT

According the present plans the final disposal of spent fuel will begin in Finland in 2020. The construction of the encapsulation facility will begin five years earlier. Preliminary design of encapsulation facility has already been presented by Finnish nuclear waste management company Posiva ltd. In order to avoid unnecessary costs and delays in implementation of safeguards regime in the facility, the safeguards-related aspects should be taken into account in early phase. This requires open communication between the operator, regulators and expert bodies.

In December 2000, Finnish Support Programme to IAEA safeguards arranged a workshop to facilitate the communication between the operators, regulators and experts. Due to the new concept, the open discussion is beneficial and necessary for all parties. One goal of the workshop was also to provide basis for further designing of the facility.

The goals for the meeting were achieved. The discussions were conducted in very good and fruitful atmosphere. The conclusions and recommendations of the workshop were discussed and written down by the chair of the final session. The draft document was distributed to the participants and all comments were taken into account, This report, representing the views of the participants, gives also recommendations for further work. It was tentatively agreed that parties will meet again in 2001 to review and discuss, in an informal atmosphere, facility design developments and potential safeguards measures. Action to convene the meeting is on the FINSP.

HONKAMAA Tapani (ed.). Käytetyn polttoaineen kapselointi ja todentaminen.Safeguards-työryhmäkokous Helsingissä 19.–20.12.2000. Vaiheen II väliraportti tehtävässä FIN C1184 Suomen IAEA-Safeguards-tukiohjelmassa. STUK-YTO-TR 177. Helsinki 2001. 10 s. + liitteet 46 s.

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Avainsanat: safeguards, käytetyn ydinpolttoaineen kapselointi, loppusijoitus

TIIVISTELMÄ

Nykyisien suunnitelmien mukaan käytetyn ydinpolttoaineen loppusijoitus Suomessa alkaa vuonna 2020. Kapselointilaitoksen rakentaminen alkaa noin 5 vuotta aiemmin. Posiva, suomalainen ydinjätehuollosta vastaava yhtiö, on esittänyt alustavan suunnitelman kapselointilaitoksen rakennesuunnitelman. Jotta ylimääräisiltä kuluilta ja viiveiltä vältyttäisiin safeguards-valvonnan asentamisen yhteydessä, safeguards-näkökulma tulisi ottaa huomioon mahdollisimman aikaisessa vaiheessa. Tämä edellyttää avointa kommunikointia valvovien organisaatioiden, operaattorien ja asiantuntijoiden välillä.

Joulukuussa 2000 Suomen tukiohjelma IAEA:n safeguardsille järjesti työkokouksen, jossa operaattorit, valvontaorganiaatiot ja asiantuntijat saattoivat keskustella saman pöydän ääressä. Koska tilanne on uusi, avoin keskustelu hyödyttää kaikkia osapuolia. Yksi kokouksen tavoite oli tarjota perustaa laitoksen jatkosuunnittelulle.

Kokouksen tavoitteet saavutettiin. Keskusteluja käytiin hyvässä ja hedelmällisessä ilmapiirissä. Kokouksen keskusteluosassa puheenjohtaja kirjasi johtopäätökset ja suositukset asiakirjaksi, joka kierrätettiin osallistujien kesken. Asiakirja antaa myös suosituksia tuleville toimenpiteille. Alustavasti sovittiin, että osallistujat tapaavat uudelleen vuonna 2001 kokouksessa, jossa tarkastellaan ja keskustellaan laitoksen suunnittelusta ja mahdollisista safeguards-menetelmistä. Kokouksen koollekutsujana toimii Suomen tukiohjelma.

CONTENTS

1 INTRODUCTION

Safeguards Workshop on Spent Fuel Encapsulation and Verification in Finland was held at STUK, Helsinki, 19–20 December 2000 under the auspices of the Finnish Support Programme to IAEA Safeguards (FINSP). The objective of the meeting was to share opinions and ideas how safeguards will be implemented in encapsultion facility. The workshop was attended by the IAEA, Euratom, STUK, Finnish nuclear power companies and the nuclear waste management company Posiva Ltd. VTT took part in the workshop as an expert body.

Posiva has made preliminary design of the encapsulation facility. In principle it has no special features compared to other existing facilities around the world. The main difference is the spent fuel usage: final disposal. The fuel at final repository will be inaccessible for reverification. Re-establishing continuity of knowledge is impossible after final disposal. This will impose extra requirements for implementation of safeguards prior and during the encapsulation process.

Most likely, additional protocol will be in force in Finland at the end of 2001. The operation of the facility will start around 2020. No-one knows, what kind of safeguards agreements are in force at that time, but it can be expected that the safeguards for the encapsulation facility will be planned and implemented in the framework of additional protocol and integrated safeguards. Also these are new concepts for safeguards community. This brings in difficulties in predicting the future. However, the Integrated Safeguards concept in general will ease the burden experienced by the operators, therefore, IS is merely an opportunity than a threat.

The present report describes the outcome of the workshop. Since the workshop was informal in nature, no detailed minutes was made. The papers or handouts of the presentations submitted to the editor are attached in appendices.

2 A SUMMATION OF THE WORKSHOP

The workshop was divided in four sessions. The first session was devoted to regulators, the second to operators and the third to expert views, respectively. The concluding session summed up the information. The Agenda of the workshop is in Appendix 1.

The IAEA representative emphasized in his presentation (Appendix 2) the importance of the continuity of knowledge. He has carefully read the design description of the facility and proposed several techniques and methods for DIV and C/S measures. He concluded, that a highly reliable safeguards system would be needed, as re-verification will be difficult. High degree of State/operator/inspector cooperation is required. Sound quality system will enhance the effectiveness.

Euratom contributed by two practical presentations:

a) The Principles of the Approach Agreed for the Pilot Conditioning Facility in Gorleben, Germany (W. Hilden)
b) Back-end fuel cycle NDA methods: Spent Fuel and Reprocessing (P. Schwalbach) (Appendix 3).

The Gorleben facility is an example for Finnish encapsulation plant and similarities exist. Unfortunately the Gorleben facility is not currently in operation. C/S systems are adequate in Gorleben at the moment, but determination of U and Pu is not really feasible at the facility.

In the Finnish SSAC's presentation (Appendix 4) the IAEA and Euratom were urged to make fuller use of the State system. Spent fuel is not specifically safeguards relevant and Integrated Safeguards will bring in the demand for cost neutrality. Finland is open, democratic and transparent society. Its nuclear fuel cycle is rather limited. Therefore in the era of Integrated Safeguards heavy safeguards system with mechanistic verification procedures can not be justified.

Posiva described its newest design option for encapsulation facility. In 1999 they presented their first design, which was described in the earlier report of this task (Honkamaa and Kukkola, 1999). The 1999 design is generic; in principle a facility of that type could be built also elsewhere. The decision to build the encapsulation facility in Olkiluoto brings in two possibilities: Firstly, they can construct a separate encapsulation facility as described earlier. Secondly, the encapsulation facility could be built adjacent to present TVO spent fuel storage. This would require new design, but also bring in benefits and flexibility.

The nuclear power operators described in their presentations their faclility specific safeguards systems and possibilities, when final encapsulation will begin. Fortum (operator of the Loviisa NPP) sees that verification at Loviisa, prior to the transport to the encapsulation facility in Olkiluoto, would be cumbersome and might delay their work remarkably. The paper presented by P-E. Hägg, Fortum Power and Heat, is in Appendix 5.

VTT participated as an independent expert body. VTT's the research group has been involved in development of safeuards measuring technology in several projects since 1980's. VTT described several verification options, which could be used in the encapsulation facility (Appendix 6). If partial defect verification is required, the most viable options are FORK (gamma + neutron) and tomographic measurements. With FORK it is possible to check the burn-up data of the assemblies. Tomographic measuring method is not in a mature stage, yet, but it would detect the defects at a pin level without prior knowledge of the assembly.

VTT was concerned about the material flow in case the verification is either inconclusive or conclusively negative. Such an event could block the material flow in the facility. VTT also made a note that constructing the encapsulation facility adjacent to the Olkiluoto Spent Fuel Interim Storage could facilitate the implementation of verification systems, since it would provide enough buffer storage and facilitate underwater measurements.

3 CONCLUSIONS AND RECOMMENDATIONS

Based on the discussion during the workshop the chair of the concluding session wrote down a few conclusions and recommendations. The document was distributed among the participants. The document, representing the views of the participants, is quoted in this chapter.

3.1 Time schedule and status

The construction of the encapsulation facility is expected to start around the year 2015. The design of the facility has now matured to the stage in which the designers need more detailed information about safeguards measures in order to take safeguards properly into account. Especially, designers need information about how much space (and where in the facility) should be reserved for safeguards instrumentation.

3.2 Safeguards context

Finland has completed all legal instruments needed to bring the Additional Protocol into force. Since EU Member States have decided that AP is to become into force simultaneously in all EU Member States, AP implementation is expected to start in Finland in a couple of years.

Currently, there is no AP/Integrated Safeguards (AP/IS) approach under development, which would cover also encapsulation facility. Therefore, no reference or guidance is available.

It is understood that by the time Posiva encapsulation facility will be in operational phase, AP/IS framework will the framework for full-scope safeguards.

In AP/IS framework, following generic principles will also be reflected to the safeguards measures to be implemented in the Posiva encapsulation facility:

- "Finland-as-whole" considerations (fuel cycle, country profile etc.)
- More flexible safeguards criteria (from quantitative criteria to more qualitative indicators),
- STUK will regulate the whole quality system of the disposal project including independent verifications, as part of audits.
- Particularly sensitive proliferation features related to the Posiva encapsulation facility have not been identified.

Encapsulation facility, as a facility type, is technically simple and as an item facility rather straightforward to safeguard. It is understood that with currently available measures reliable safeguards can be implemented.

3.3 Recommendations

During the workshop, the following recommendation regarding the current status and future preparation of the Posiva Encapsulation Facility could be identified:

1) The designer might wish to take a conservative approach and design, at this stage, proper rooms and space for:
   - C/S and flow monitoring covering material flow paths,
   - NDA stations that allow verification of fuel assemblies for gross and partial defects,
   - methods to verify receipt/shipment of full/empty transport containers.

   Equipment should function in automated and unattended mode, if feasible.
2) Designers should also aim to combine (optimize) process controls, measurements, testing

and calibrations for safety and safeguards purposes.

3) Designers should optimized safeguards measures as an iterative process with SSAC, IAEA and Euratom.
4) IAEA and Euratom might wish to look further how to make fuller use of the Finnish SSAC; especially of the quality system approach.

3.4 Further work

The workshop recommended continuing to develop further safeguards issues regarding the Posiva Encapsulation Facility. It was tentatively agreed that parties would meet again 2001 to review and discuss, in an informal atmosphere, facility design developments and potential safeguards measures. Action to convene the meeting is on FINSP.

REFERENCE

Honkamaa T, Kukkola T. Description of Finnish spent fuel encapsulation plant and encapsulating process. Phase I interim report on Task FIN A 1184 of the Finnish support program to IAEA safeguards. STUK-YTO-TR 158. Helsinki 1999. 19 pp + Appendices 9 pp.

Appendix 1

The invitation and agenda of the workshop

Nuclear Materials
Tero Varjoranta

19.10.2000

SAFEGUARDS WORKSHOP ON FINAL DISPOSAL OF SPENT FUEL; VERIFICATION AT ENCAPSULATION

Under the auspices of Finnish Support Program for IAEA Safeguards STUK will organise a workshop "SPENT FUEL ENCAPSULATION AND VERIFICATION" from 19 to 20 December, 2000 in STUK, Helsinki. The objective of this meeting is to promote open communication and discussion on safeguards issues on disposal projects. Safeguards requirements must be taken into account in the disposal project at an early phase in order to avoid unnecessary costs and delays.

Current plans of the Finnish encapsulation facility have already been introduced to safeguards community, experts and regulatory bodies. Now it is the right time for different parties to come together and express their plans how to proceed.

All speakers are requested to give their presentation also in written form. It is proposed that presentations, including conclusions of the meeting, will be be compiled into a report.

The meeting will be chaired by Mr. Tapani Honkamaa (STUK).

ANNEX: Draft agenda of the workshop

DISTRIBUTION:
IAEA: *J.Cooley, K.Murakami, A.Fattah, A.Hamilton*
EURATOM: *W. Klöckner, W. Hilden, H. Naeckerts*
MTI, Finland: *J. Manninen, A. Tanninen*
Posiva ltd: *R.Olander, J-P.Salo, J.Vira*
TVO ltd: *Rauno Mokka, K. Sarparanta*
Fortum Power and Heat: *P-E. Hägg,*
Fortum Engineering: *T. Kukkola*
VTT: *A.Tiitta, J.Hautamäki, M.Anttila, A.Tanskanen*
SKI, Sweden (observers): *M. Eiborn, G. Dahlin*
Permanent Mission Vienna: *M. Riihonen*

Nuclear Materials
Tapani Honkamaa

26.02.01

SAFEGUARDS WORKSHOP ON SPENT FUEL ENCAPSULATION AND VERIFICATION IN FINLAND

Location: HELSINKI, STUK, Laippatie 4, meeting room 3101
Date: 19 - 20 December, 2000

Draft agenda of the workshop is as follows:

Tuesday 19.12.

9:00 - 9:30	Pick-up from hotel, transport to STUK, address: Laippatie 4, Helsinki
9:30 - 10:00	Welcoming remark, *Director Tero Varjoranta, STUK* Objectives of the meeting, *Tapani Honkamaa, FINSP Task officer*
10:00 - 10:20	Coffee

Session 1: Potential Safeguards Needs, Requirements and approaches for Encapsulation Plant (Chair: Elina Martikka, STUK)

10:20 - 10:50	IAEA viewpoints, *N. N, IAEA*
10:50 - 11:20	EURATOM viewpoints, *W. Hilden, P Schwalbach, EURATOM*
11:20 - 11:50	Finnish SSAC viewpoints, *Tero Varjoranta, STUK*
12:00 - 13:30	Lunch break (Cafeteria 1st floor)
13:30 - 14:00	Discussion

Session 2: Finnish Plans for Back-End of Fuel Cycle (Chair: Juhani Vira, Posiva)

14:00 - 14:30	Overview of Finnish spent fuel disposal project, *J-P Salo, Posiva*
14:30 -15:00	Coffee Break
15:00 - 15:15	Management of Spent Fuel at Fortum, *Per-Erik Hägg, Fortum*
15:15 - 15:30	Management of Spent Fuel at TVO, *Käthe Sarparanta, TVO*
15:30 - 15:45	Verification of Spent Fuel by STUK, *N.N, STUK*

15:45 - 16:15 POSIVA Safeguards Plan for Encapsulation Plant, *Ronnie Olander, Posiva*

16:15 - 17:00 Discussion

17:00 - 19:30 Sauna&Snack (STUK 5th floor)

19:30 Transport to hotel

Wednesday 20.12.

8:30 Pick up from hotel

Session 3. Verification options and Safety Aspects for back-end of fuel cycle (Chair: Tapani Honkamaa)

09:00 - 09:40 Technical aspects of spent fuel verification for back end of the fuel cycle, *A. Tiitta, VTT*

09:40 - 10:00 Safety requirements of encapsulation plant, *E. Ruokola, STUK*

10:00 - 10:15 Coffee break

10:15 - 11:00 Regulatory Safety Requirements for Spent Fuel Handling, *P. Liuhto, STUK*

11:00 - 11:15 Discussion

Session 4. Concluding session *(Chair Tero Varjoranta, STUK)*

11:15 - 12:00 Workshop: Elaborating conclusions and recommendations for encapsulation plant

12:00 - 12:30 Conclusions, Closing of workshop

12:30 - 14:00 Lunch *(Christmas buffet at Restaurant Kokki)*

Appendix 2
Safeguards elements for conditioning plant
(A. Fattah/IAEA)

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Safeguards elements for Conditioning Plant

A. Fattah

E-Mail A.Fattah@iaea.org

Activity No.	Activity Description	A. Conditioning Plant		B. Operating Repository		C. Closed Repository	
		Draft Report Date	MSSPs	Draft Report Date	MSSPs	Draft Report Date	MSSPs
0	Introduction	5/96	US*	5/96	US*	5/96	US*
1	Describe model facility	2/96	US*	3/96	CAN*	5/96	CAN*
2	Identify diversion paths and detection points	5/96	BEL US*	6/96	BEL CAN*	9/96	BEL* CAN
3	Identify events and conditions requiring DIV and examination procedures	7/96	UK*	8/96	UK*	10/96	UK*
4	Evaluate IAEA use of operator safeguards, safety, and process system outputs	5/96	SWE* US	5/96	SWE* US	5/96	SWE* US
5	Identify potentially applicable geophysical techniques	NA	NA	6/96	CAN* FIN FRA UK US	6/96	CAN* FIN FRA UK US
6	Evaluate NDA techniques for spent fuel verification and radiation monitoring	5/96	FIN* HUN US	5/96	FIN HUN* US	NA	NA
7	Evaluate C/S techniques and integrated verification systems for spent fuel monitoring	6/96	US*	6/96	US*	6/96	US*
8	Determine guidelines for acceptable safeguards approaches	8/96	US* All	8/96	US* All	8/96	US* All
9 (formerly activities 9-13)	Design safeguards approach and evaluate candidate approaches	5/97	US* All	5/97	CAN* All	5/97	BEL* All
	Develop redundancy and reliability requirements for verification systems						
	Select safeguards approach and identify R&D needs						
	Develop QA program for detection systems						
	Specify system design requirements for model safeguards approach						
10 (formerly 14)	Integrated final report	9/97	US* All	9/97	US* All	9/97	US* All
	AGM-SAGOR	12/97	All	12/97	All	12/97	All

BEL = Belgium; CAN = Canada; FIN = Finland; FRA = France; HUN = Hungary; SWE = Sweden; UK = United Kingdom; US = United States
* Lead responsibility

Summary of Work Plan for SAGOR (Task C799)

Activity No.	Activity Description	A. Conditioning Plant		B. Operating Repository		C. Closed Repository	
		Draft Report Date	MSSPs	Draft Report Date	MSSPs	Draft Report Date	MSSPs
0	Introduction	5/96	US*	5/96	US*	5/96	US*
1	Describe model facility	2/96	US*	5/96	CAN*	5/96	CAN*
2	Identify diversion paths and detection points	5/96	BEL US*	6/96	BEL CAN*	9/96	BEL* CAN
3	Identify events and conditions requiring DIV and examination procedures	7/96	UK*	8/96	UK*	10/96	UK*
4	Evaluate IAEA use of operator safeguards, safety, and process system outputs	5/96	SWE* US	5/96	SWE* US	5/96	SWE* US
5	Identify potentially applicable geophysical techniques	NA	NA	6/96	CAN* FIN FRA UK US	6/96	CAN* FIN FRA UK US
6	Evaluate NDA techniques for spent fuel verification and radiation monitoring	5/96	FIN* HUN US	5/96	FIN HUN* US	NA	NA
7	Evaluate C/S techniques and integrated verification systems for spent fuel monitoring	6/96	US*	6/96	US*	6/96	US*
8	Determine guidelines for acceptable safeguards approaches	8/96	US* All	8/96	US* All	8/96	US* All
9 (formerly activities 9-13)	Design safeguards approach and evaluate candidate approaches Develop redundancy and reliability requirements for verification systems Select safeguards approach and identify R&D needs Develop QA program for detection systems Specify system design requirements for model safeguards approach	5/97	US* All	5/97	CAN* All	5/97	BEL* All
10 (formerly 14)	Integrated final report	9/97	US* All	9/97	US* All	9/97	US* All
	AGM-SAGOR	12/97	All	12/97	All	12/97	All

BEL=Belgium; CAN = Canada; FIN = Finland; FRA = France; HUN = Hungary; SWE = Sweden; UK = United Kingdom; US = United States

* Lead responsibility

Process

- Receipt of SF in Transfer cask (TC)
  - Castor VVWR 84 FA / BWR 50 FA
  - Buffer store 4 BWR + 4 VVWR casks (= 536 FA)
- Receipt of Empty FD Canisters(FDC)
  - Two types/ each can take 12 FA
  - 24 storage position (=288 FA)
- TC moves through transfer channel docked to hot cell
- FA taken out by remote control manipulator : 12 at a time?
  - Dry FA cooled to 24 hrs
  - Wet FA moves to Autoclave (12 positions) ? hrs

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Process

- (Q while being dried the cask is still in the dock so FA are accessible)
- Canister moves to docking position : 1 position for BWR/VVWR (TC has 50/84 FA) One canister at a time?
- FA transferred to FDC by manipulator
  - when full , lid closed, disconnected from HC , moved to welding position in the transfer corridor, moved to buffer storage (12 positions = 144 FA)
- Damaged FA, RR FA, Waste similar process
  - Estimated Output ?

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Diversion Routes

- Diversion elsewhere prior to arrival at encapsulation plant
- Diversion at the plant
  - Diversion of transfer Casks
  - Diversion of FA from transfer cask
  - Diversion of pins / pellets
  - Diversion of FDC
  - Diversion of FA from FDC

Detection Points

- Safeguards elements to addresses all diversion concern and detection points
- DIV assures that plant design & operations are as declared
  - Design of Containment , storage area , operating area , operating equipment
  - Plant operations conducted as declared.
- NMA verification to establish & track knowledge re quantity of NM.
  - Records & Reports audit, IC, ID & NDA
- C/S preserves CoK established by NMA
  - Seals, Radiation Monitors, motion detectors, optical

Safeguards Elements

- **Objective is to provide high level of assurance that the quantity of NM contained in the SF received at the facility is as declared and leaves the facility in declared disposal container.**
- **Measures consists of DIV, NMA and C/S to provide independent verification to confirm CoK**
- **Effectiveness of detection capabilities**
- **Area : Cask Store / Transfer route / Hot cell**

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Storage Area

- **DIV measures**
  - **Cask design**
  - **Cask storage area design**
  - **Cask preparation area design**
  - **Cask handling & equipment design & operation**

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Storage Area

- NMA measures :
  - Cask ID, IC using video activated by radiation/ motion detector / smart tag for all casks/canisters/containers automatically.
  - NDA of Casks in the event of loss of CoK with high detection probability for all casks/ canisters/ containers for partial defects/ gross defects as appropriate.

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Storage Area

- C/S measure
  - Seals and weld integrity to monitor on all casks as appropriate including buffer storage.
  - Radiation monitors in cask preparation area.
  - Optical surveillance with cameras activated by radiation and motion detectors to entire area including buffer storage.

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Transfer Tunnel

- DIV measures
  - Transfer tunnel design
  - Cask handling & equipment design & operation
  - Cask lid removal/installation equipment design & operation
  - Cask welding design & operation

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Transfer Tunnel

- C/S measure
  - Seals on transfer tunnel boundary penetration
  - Radiation monitors in cask preparation area
  - Radiation monitors in cask welding area
  - Optical surveillance with cameras activated by radiation and motion detectors at all entrance/exit port to transfer tunnel area

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Hot Cell

- DIV measures
  - Transfer casks docking area design
  - Canister loading area design
  - Canister closing design
  - Canister storage area design
  - Assembly handling area design & operation
  - Remote control manipulator design & operation
  - Autoclave design & operation
  - Pin handling design
  - Waste handling design & operation

Hot Cell

- NMA verification measures
  - FA ID, IC using a video surveillance activated automatically by radiation / motion detector during unloading from cask.
  - NDA (unattended) of FA during unloading to verify NM with high detection for gross and partial defect.
  - Video surveillance activated automatically by radiation / motion detector for all FA in and out of autoclave.
  - FA ID and IC and video surveillance during loading.
  - NDA (unattended) of FA during unloading to verify NM with high detection for gross and partial defect.

Hot Cell

- Video surveillance to track the FDC to confirm final closing and sealing.
- Similar NMA for Pins / Waste container
- NDA monitoring of declared transfers of all containers : FDC, empty canister, waste canister with high detection probability for gross defect.

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Hot Cell

- C/S measures
  - Seals on hot cell boundary penetration.
  - Optical Surveillance for hot cell nuclear transfer.
  - Optical surveillance system activated by radiation and/or motion detector applied to interior or exterior.
  - Surveillance of nuclear material transfer.
  - Radiation monitor at entry / exit points to verify full / empty container receipt /shipment.

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NDA Functional Requirements

- The system should be able to verify with high detection probability for partial / gross defect as appropriate
  - Nuclear Material of all fuel assemblies/rods during unloading from the shipping cask.
  - Nuclear Material during loading into final disposal cask
  - Nuclear Material declared as waste in final disposal cask
- The System should be able to transmit data over a reasonable distance to inspectors room/IAEA HQ as appropriate.

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NDA Functional Requirements (cont.)

- The System data review capabilities should not interfere with the system when operating data acquisition mode.
- The system should incorporate diagnostic checks with an alarm to indicate when it is not functioning within acceptable bounds.
- The system should be fully automatic and operate in unattended mode.

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C/S Functional Requirements

- The system should be able to count & identify fuel assemblies/rods and other material that enters the facility.
- The system should be able to distinguish various types of material handled by the facility.
- The system should provide surveillance of storage hall / transfer tunnel / hot cell to cover all Cask /NM movements into & out of the area.

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C/S Functional Requirements (cont.)

- The system should be able to verify that all casks leaving the area are consistent with operator declaration.
- The system should be able to verify all other movements as recorded by the operator.
- The System should provide optical/electrical methods for checking & identification of weld of final disposal cask.

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C/S Functional Requirements (cont.)

- **The System should provide remote live-time observation as well as recording of all data for subsequent review.**
- **The System should be able to transmit data over a reasonable distance to inspectors room/ IAEA HQ as appropriate.**
- **The System data review capabilities should not interfere with the system when operating data acquisition mode.**

C/S Functional Requirements (cont.)

- **The system should incorporate diagnostic checks with an alarm to indicate when it is not functioning within acceptable bounds.**
- **The system should be fully automatic and operate in unattended mode.**

Conclusion

- **Require highly reliable safeguards system as re-verification will be difficult in case of anomaly / discrepancy.**
- **A sound quality assurance programme will enhance the effectiveness of applied safeguards measures.**
- **High degree of State/Operator/Inspector cooperation is required .**

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APPENDIX 3

Back-end fuel cycle NDA methods: spent fuel and reprocessing (P. Schwalbach/Euratom)

Technical Points
C/S and Measurements ?

- *Containment and Surveillance* systems available
  - cameras, seals, radiation monitors
- Remote transmission capabilities exist / are developed
- Better technology might improve situation, but o.k. today

- *Material verification:*
- Determine Pu and U contents !
  - Not really feasible !
- Partial defect measurement… how ? how good ?

Back end fuel cycle NDA methods: spent fuel and *reprocessing*

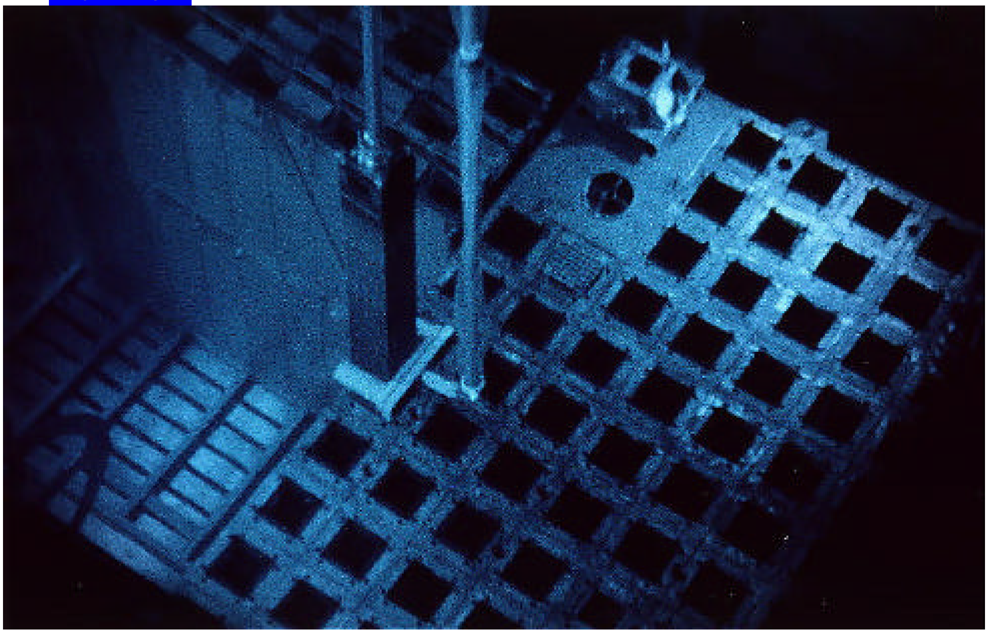
- Unloading from reactor: partial defect with Fork
- CoK until reprocessing,
- attribute testing (PIV…) NVD, SFAT...
- Partial defect testing at head end of reprocessing plant:
  - example Thorp: *Feed Pond Fuel Monitor*

    active/passive neutron interrogation(Cf source)

    high resolution gamma spectroscopy (Ge)

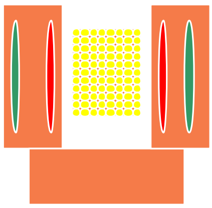
    (gives final enrichment *235U equivalent*, approx. 10% precision)

Fork



Fork

- For measurements on Spent Fuel assemblies under water
- Fission chambers to count NEUTRONS
- Ionization chambers to count integral GAMMAS
- Determines *burn up*, *cooling time*
- relative measurement, absolute calibration difficult
- combination with ORIGEN/PYVO calculations useful



- Neutrons ⓿ BU^4
- Gamma = $f(BU, T_{Cool})$

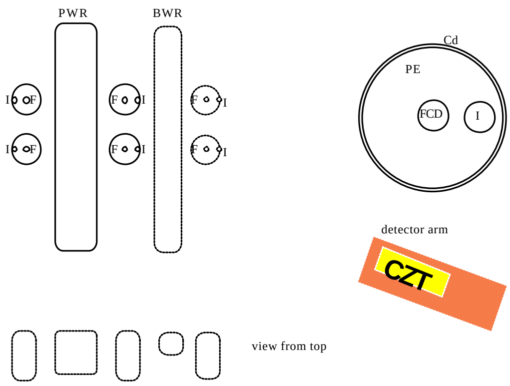
Back end fuel cycle NDA methods: Dry storage safeguards in practice

- Partial defect (Fork) at CASTOR loading at NPP
- CoK: ….C/S…seals….cameras…
- Interim storage: Reverification with DualN50 at storage
  (´partial defect´ with neutron signature -
  1-2% of Castor content with baseline measurement)
  find *one missing assembly* in a PWR Castor
  NO access to fissile mass
  (method under evaluation)
- Measurement (plan) at Conditioning facility
  (partial defect,
  Fork-type, with CZT medium resolution gamma spec.)

NDA Systems: Measurements

- Type of verification requested
  - Partial defect measurement !
- Where ?
  - NPP or intermediate storage + CoK
    OR : encapsulation plant
- How do we get the knowledge ?
  - today: Fork (~50% level) - to be improved !
- Other techniques
  - improved Fork,
    Tomography,
    active neutron interrogation,
    Feed Pond Fuel Monitor …
    others
- more development required ?
  - YES !
    - Tomography faster and in air
    - fork in air
    - discuss alternatives ?

Fork in Air



- Ionisation and Fission chambers in Polythene
- possibly extra Pb shields
- combined with CZT detector (gamma spectroscopy: burnup)

Fork in Air

- No experience with ‘Fork’ measurements in air
- Higher dose: problems of shielding
- Neutrons: no moderation >> efficiency curve flatter (simplified MCNP calculations hint at flux depression of < 20% for central rods in PWR assemblies)
- gamma measurements:
  - geometry to be optimised
  - old fuel: mainly 137 Cs - directly related to burnup (calibration)
- Eurajoki: only two principal fuel types, good calibration conditions

NDA encapsulation plant (preliminary wishlist)

- Integrate NDA instrument(s) into the encapsulation plant
- Combine

  - tomography (count all pins) with
  - improved fork (quantitative analysis)
  - active neutron interrogation and
  - good gamma spectroscopy burn-up verification (Ge)
  - measure continuously along the length of all assemblies
- Consider branching ?
- Euratom is open for discussion and cooperation

Appendix 4

Helicopter view; SSAC in Holistic Regulatory Approach for Final Disposal of Finnish Spent Fuel

(T. Varjoranta/STUK)

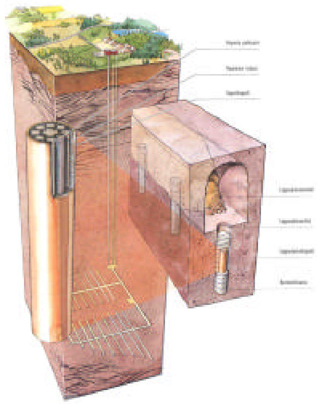
STUK

Helicopter view;

SSAC in Holistic Regulatory Approach for Final Disposal of Finnish Spent Fuel

Tero Varjoranta,Director, STUK

- Finland's national spent nuclear fuel strategy
- Holistic regulatory framework; disposal relevant fundamentals
- Finnish SSAC;
  - regulating comprehensive quality system for disposal
  - audits including independent verifications
- Finnish SSAC's possible relationship with IAEA and Euratom
  - how proliferation sensitive is Finnish disposal project?
  - disposal and "Finland-as-whole"
  - towards cost-neutrality: IAEA and Euratom can make fuller use of the Finnish SSAC



Tero

STUK

National Strategy

- strong national commitment
- limited nuclear fuel cycle
  - strong dependence on world market (materials, services)
  - active international co-operation
- open, democratic society
- transparency
  - for public (media)
  - for scientific community

Tero

STUK•SÄTEILYTURVAKESKUS•STRÅLSÄKERHETSCENTRALEN•RADIATION AND NUCLEAR SAFETY AUTHORITY

Regulatory framework; basic fundamentals

HOLISTIC MISSION of STUK

- radiation safety
- nuclear safety
- *safeguards*
- physical protection
- safety culture
- *quality system*
- co-operation (international; bi- & multilateral)

VALUES OF STUK for holistic mission

- *high competence*
- *honesty & transparency*
- *courage*

Tero

Regulatory framework; disposal relevant fundamentals

- radiation and nuclear safety 1st priority
  - binding international requirements for national legislation: Joint Convention;
  - fundamentals, requirements, recommendations: IAEA Safety Series;
  - collective opinions: OECD/NEA
    - ”no burden to future generations”
    - ”passively safe solutions”
    - ”limited periods for institutional control”
- (holistic) safety is national responsibility
  - policy: strong competence in national hands

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STUK

Regulatory framework; relevant fundamentals

Safeguards context

- considerations up to 100y
- IS-framework
  - credible assurance of non-diversion of declared materials & absence of undeclared nuclear material or activities
  - flexibility from quantitative criteria; replaced and supplemented by indicators
  - trend: less than today emphasis on direct verification
- SSAC (participates in) regulating whole quality system of the disposal system;

Tero

STUK

for disposal system
Finnish SSAC to regulate whole quality system

- management's quality policy
- organization, responsibilities
- contract review
- design control
- *document control and archieving*
- purchasing
- product identifiable and traceable
- *process control*
- *inspection and testing*
- control of non-confirming product, corrective actions
- handling, storage, packing and delivery
- *audits – independent verification*
- training
- service, maintenance

Regarding all

- activities
- decisions
- components, systems, facility

- specified methods&procedures
- documented
- followed, complied with

emphasis from "product"
to "process, conduct & product"

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Finnish SSAC's possible relationship with IAEA and Euratom

How proliferation sensitive is Finnish disposal project?

Some indicators ("+" SG friendly, "-" SG challenges) :

- SG friendly national fuel cycle
  - simplicity, int'l dependence, future development +++
- SG friendly disposal site
  - near sensitive nuclear facilities +++
  - near mines +++
  - (remote) monitoring potential of site +
- SG friendly technical disposal solutions
  - encapsulation technique ++
  - capsule --
  - disposal depth +++
  - underground SG activities ---
  - retrievable for diverter +++

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Finnish SSAC's possible relationship with IAEA and Euratom

Some indicators cont…:

- prior-encapsulation-SG +++
- host rock as extra SG barrier +++
- quality system
  - level: SG coverage&depth +
  - maturity +
  - accessability +++

Concluding indicator: Nothing special identified, low SG sensitiveness & easy to (remote) monitor compliance with declaration.

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STUK•SÄTEILYTURVAKESKUS•STRÅLSÄKERHETSCENTRALEN•RADIATION AND NUCLEAR SAFETY AUTHORITY

Finnish SSAC's possible relationship with IAEA and Euratom

- towards "Finland-as-whole"
- towards cost-neutrality: IAEA and Euratom should make fuller use of the Finnish SSAC
  - Quality-system approach analogy: operator-STUK → STUK-IAEA and Euratom
  - STUK has own documented quality system
    - independent NDA-verifications will be part of STUK's audits
  - STUK has audited Posiva's (disposal implemeter) quality system
  - IAEA and Euratom need quality audit procedures to satisfy that Finnish SSAC activities OK
    - incl. audits with independent verifications

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Where do we go from here?

- national strategy implemented as planned
- safeguards into design features
- next detailed step in quality approach
  - audit procedures
  - level of verification

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Appendix 5

Loviisa Power Plant –
Operators plans for safeguards measures
(P-E Hägg/ Fortum Power and Heat, Finland)

Per-Erik Hägg 7.12.2000

LOVIISA POWER PLANT
OPERATORS PLANS FOR SAFEGUARDS MEASURES

Background

Originally Loviisa Power Plant had an agreement that all spent fuel will be returned to the fuel supplier after a cooling time at the plant. The plant was built with one small spent fuel storage, because the idea was that the spent fuel will be returned to the supplier after a three years cooling time. Quite soon the cooling time requirement was increased to five years and a new spent fuel storage had to be built. Then in late 1994 an amendment made in the Finnish nuclear legislation prohibited the export of the nuclear waste, which after 1996 had to be stored in Finland. The last spent fuel transport to Russia took place in 1996. Again the new situation forced the company to increase the capacity of the spent fuel storage. The extension part was taken into operation in year 2000.

The Finnish parliament may make in the year 2001 the principal decision that the final repository plant will be built in Eurajoki. The construction of the plant will take place in 2010-2020 after which the operation will start.

For Loviisa Power Plant this means that the first transports to the encapsulation plant will start earliest in year 2020. The capacity of the storage with 'normal' fuel racks is enough until year 2010. After this at least part of the racks has to be replaced by 'tight' racks or the storage has to be enlarged once again.

If the life time of the power plant is 45 years, the spent fuel storage has to be in operation at least until year 2045 (at least 20 years after shut down of the plant). This means also that the spent fuel storage can not be dependent upon the plant itself and that's why the storage has to be made 'self-reliant'. In practice this means that a control room, new process systems, sea water pumps etc. has to be built before the power plant finally will be shut down and the decommissioning starts.

The final and self-reliant spent fuel storage complex in principle is shown in picture 1.

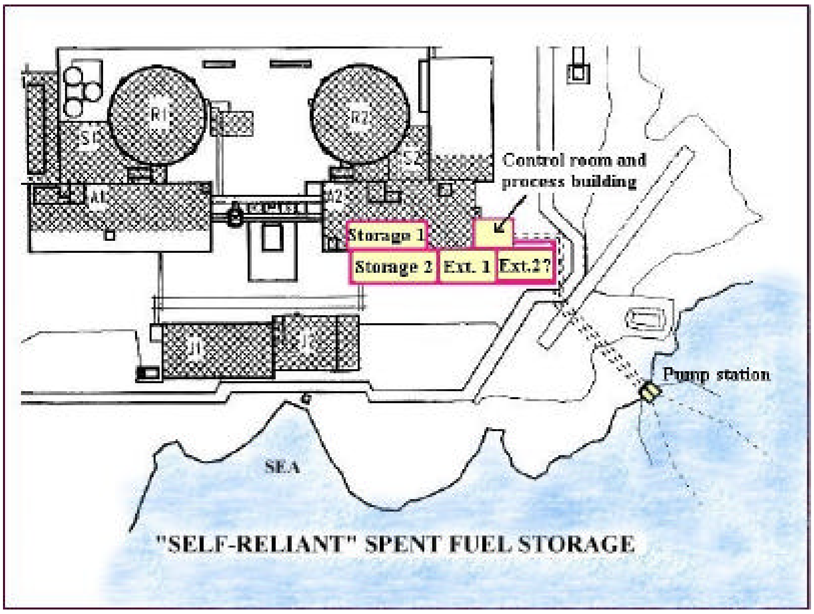

Figure 1. Spent fuel storage lay-out when the decommissioning starts.

Per-Erik Hägg

7.12.2000

Lay-out of the spent fuel storage (picture 2)

In the 'old' spent fuel storage the assemblies are stored in fuel 'baskets' – 30 assemblies in each. The baskets are brought into the storage in a transfer cask, from which the basket is lifted into the storage pond. Single assemblies can not be handled in this storage. The baskets can only be lifted into a transfer or transport cask for further transfer. The upper end of the assemblies are available for identification, CVD-verification or measurements with appropriate equipment.

Into the new storage the assemblies are transferred in a basket inside a cask. Single assemblies are moved to the storage pond with a fuel handling machine, either directly from the cask or from the 'basket corner', where the basket can be lifted from the cask.

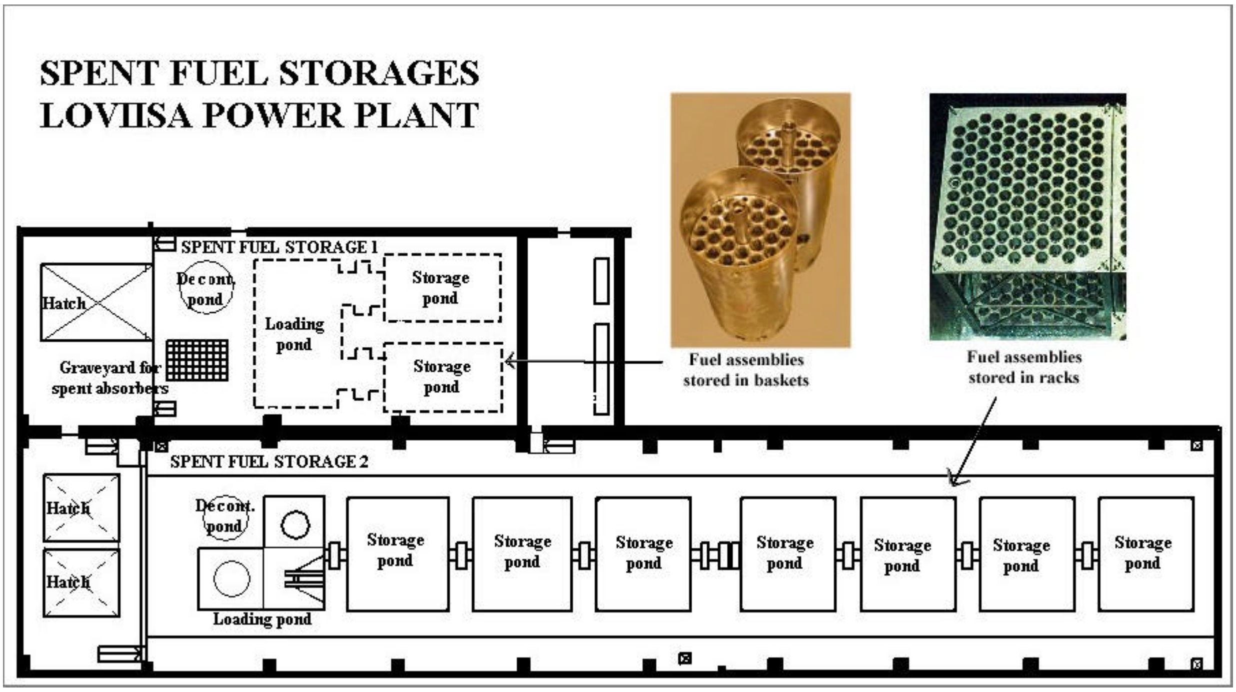

Figure 2. Lay-out of the spent fuel storage at Loviisa Power Plant (year 2000)

Safeguards measures

Water pool storage technology is the most widely used technology for storing of spent fuel. The technology is simple, the nuclear material is easily accessible for verification. The safeguards approach comprises normally item counting, identification, verification using CVD and measurements. In addition, C/S systems such as seals or continuous surveillance might be applied.

All of the above mentioned methods has been used in Loviisa during normal operation of the plant and during the loading process of the spent fuel transport casks prior to the spent fuel transport away from the plant. Based on these experiences the plant personnel has got an idea how much each kind of activities affects the normal work on the plant.

From the operators point of view, the safeguards activities connected to spent fuel shipment for final disposal should if possible be performed in a manner not to disturb the loading procedure of the transport cask. On the other hand the operator assume, that a simple and fast method, such as item counting, identification and verification by CVD, is not enough. The main technical needs are probably underwater measurements of the spent fuel assemblies. In this case the equipment has to be easy to use and the measurement time has to be reasonable. The measurement accuracy to detect gross and partial defects has to be determined in advance and not in connection with the loading process.

Loading of the casks for shipment

If the transport cask used for spent fuel shipment to the final repository plant can take the whole fuel basket with 30 assemblies the preferable place to load the cask at Loviisa Power Plant is in the 'old' spent fuel storage. The reason for this is that here the assemblies are already located in the mentioned baskets, which as such can be lifted into the transport cask. This makes the preparation time for the transport very short. The needed safeguards measures has to be performed in advance.

In the new storage only one basket can be ready loaded prior to the loading of the transport casks. If the casks are loaded here it is in principle possible to perform some measurements in a fork type equipment during the transfer of single assemblies.

From the operators point of view it is preferable that needed safeguards measures, such as measurements, are performed in advance. The area or baskets where the 'measured' assemblies are located can be sealed.

Plans for future

So far it is not decided what type of transport casks will be used during the transports from Loviisa to the final repository plant, which probably will be located in Eurajoki. In practice there are two methods of cask loading, either the whole basket will be lifted into the transport cask or the assemblies will be transferred one by one using the fuel handling machine.

If the baskets are lifted into the transport cask the safeguards measures such as measurements has to be performed in advance and the baskets, or the area where the baskets are located, can be sealed. The assembly numbers are checked before the cask is closed. This can be done also in advance.

If the assemblies are transferred one by one into the transport cask, measurements can in principle be done during the loading process, but it is desirable to do them in advance. The filling of one cask with 30 assemblies one by one will take one working day. If measurements are performed the time will increase correspondingly.

APPENDIX 6

Technical aspects of spent fuel verification for back-end of the fuel cycle

(A. Tiitta, J. Hautamäki/ VTT, Finland)

Safeguards Workshop on Spent Fuel Encapsulation and Verification in Finland
held at STUK, Helsinki, 19-20 December 2000

Technical aspects of spent fuel verification for back-end of the fuel cycle

A. Tiitta and J. Hautamäki
VTT Chemical Technology

ABSTRACT

Technical aspects regarding the verification measurements of the spent fuel assemblies from the Olkiluoto and Loviisa NPPs are considered. The spent fuel assemblies have to be verified at the partial defect level before the final disposal into the geological repository.

Developing a measurement system for partial defect verification is a complicated and time-consuming task. The Passive High Energy Gamma Emission Tomography and the Fork Detector combined with Gamma Spectrometry are the most promising measurement principles to be developed for this purpose.

The whole verification process has to be planned to be as slick as possible. An early start in the planning of the verification and developing the measurement devices is important in order to enable a smooth integration of the verification measurements into the conditioning and disposal process.

1 INTRODUCTION

There are two nuclear power stations in Finland. The Olkiluoto nuclear power plant consists of two BWR reactors, whereas the Loviisa nuclear power plant has two reactors of VVER 440 type.

Approximately 75 tonnes of spent fuel are annually removed from the reactors of the Olkiluoto and Loviisa NPPs and stored in wet storage facilities at the power plants. A total inventory of some 2600 tonnes of spent fuel will accumulate during the projected 40 years of operation of the Finnish reactor units.

Finland is among the first countries in the world to adopt the final disposal of spent fuel. A waste management company Posiva has been established for the planning and later implementation of the final disposal in the Finnish bedrock.

In order to ensure nondiversion of nuclear material, final disposal of spent fuel gives rise to demands for new safeguards approaches. Spent fuel conditioning plants and geological repositories are new facility types, where safeguards have not previously been applied. Presently, the criteria for the nuclear material accountancy and control for the final disposal are being drafted.

This paper considers technical aspects regarding the safeguards verification measurement system for spent fuel assemblies and rods before they enter the final repository in Finland. This paper is based on the report made by the authors under contract with the Radiation and Nuclear Safety Authority (STUK). [1]

2 SAFEGUARDS MEASURES AT THE CONDITIONING PLANT

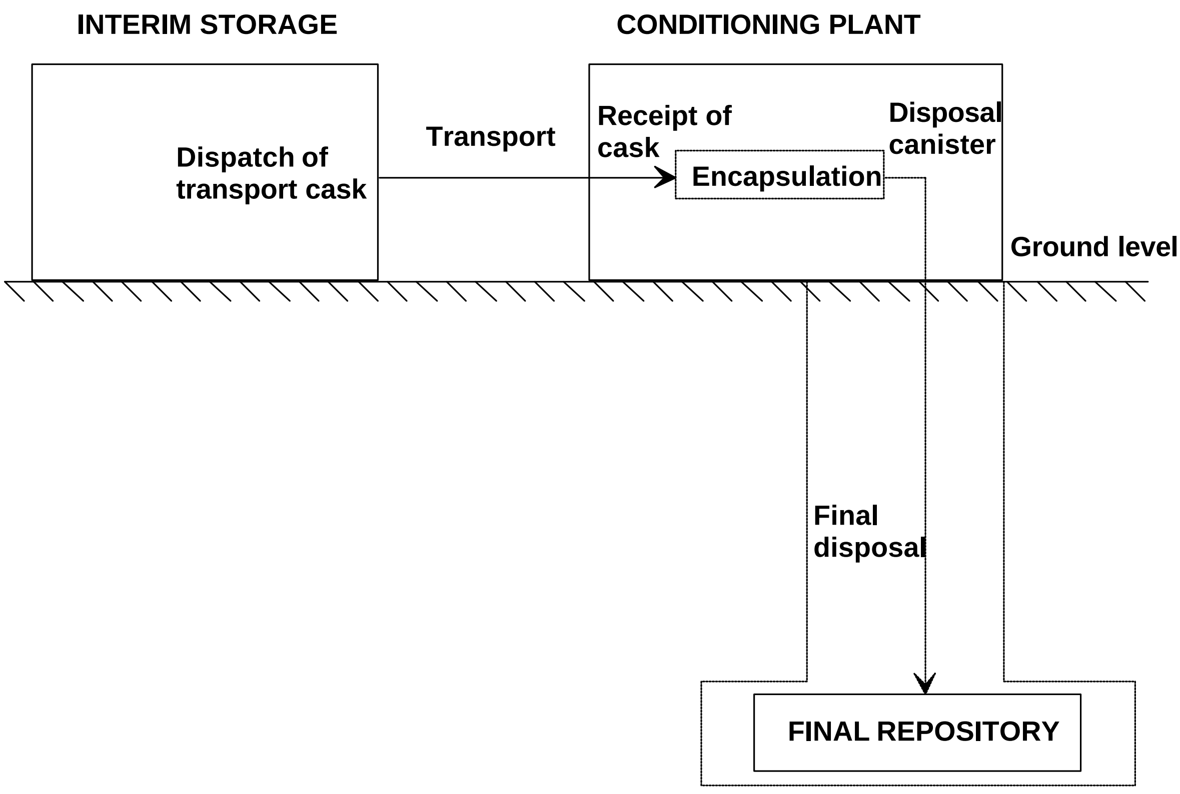

Figure 1. *The back-end of the fuel cycle in Finland.*

The Finnish approach to the back-end of the fuel cycle is represented schematically in figure 1. The safeguards measures before the final disposal concern fuel, which is in stationary state in the reactor building or in the interim storage. When the final disposal begins, the spent nuclear fuel flow shall be safeguarded.

The safeguards measures for the conditioning plant are described based on a report of the SAGOR Programme [2]. The last possible place to verify individual spent fuel assemblies and rod cassettes is the conditioning plant. The spent fuel assemblies lose their identity in the conditioning process. A new item, a disposal canister is produced. After this point, up to the emplacement into the repository, the continuity of knowledge of the material flow shall be maintained mainly by containment and surveillance (C/S) measures.

3 SAFEGUARDS REQUIREMENTS

The safeguards requirements are approached in this section based on reports of the SAGOR programme [2, 3].

Diversion of a significant quantity of nuclear material from spent light-water reactor fuel requires diversion of spent fuel casks, canisters, assemblies, cans, rods or pellets. Diversion could occur, while a spent fuel item is being transferred, in storage, undergoing conditioning or emplaced in the repository. Diverted spent fuel could be processed at a clandestine reprocessing facility or used as undeclared feed in a declared reprocessing facility. Separated nuclear material could be used in the manufacture of a nuclear explosive device.

The current safeguards criteria contain safeguards measures for spent fuel storage and handling operations at reactors, reprocessing facilities and storage facilities. However, safeguards approaches are required for new facility types i.e. spent fuel conditioning plants and geological repositories, where IAEA has not previously applied safeguards. Owing to that, the safeguards criteria for the back-end of the fuel cycle are under development.

3.1 Safeguards objective

Concerning the final disposal of spent fuel in geological repositories, the objective of the safeguards is to assure, with a high degree of confidence, that the nuclear material contained in the spent fuel is as declared, is emplaced in the repository and remains within the repository. Safeguards actions for the geological repository continue until the state declares that it is removing the nuclear material or safeguards are no longer implemented anywhere. The specific safeguards objective for a conditioning plant is to provide a high level of assurance that the quantity of nuclear material, which is contained in the spent fuel and received by the conditioning facility, leaves the facility in the declared disposal containers.

3.2 NDA verification measurements

It is generally considered that each spent fuel item to be loaded into disposal canisters should be subjected to a verification measurement at the partial defect level in advance of the final packaging operation. This requirement applies to irradiated fuel assemblies, which can be dismantled at the facility. Verification of the nuclear material content of the spent fuel should occur at that point where the spent fuel can be most effectively measured. This measurement can take place at the intermediate fuel storage or at the conditioning plant. On the other hand, after this final verification an unbreakable continuity-of-knowledge should be guaranteed. This would require high redundancy of the C/S system.

4 TECHNICAL ASPECTS IN IMPLEMENTATION OF VERIFICATION

4.1 Verification at conditioning plant

The best candidate for the location of the final verification measurement is the encapsulation plant. It would be convenient to conduct the verification measurement at the partial defect level in the encapsulation plant, because it would take place just before the spent fuel assemblies are emplaced in the disposal canister in the hot cell. This would impose less demands on the C/S system up to this point, see figure 2.

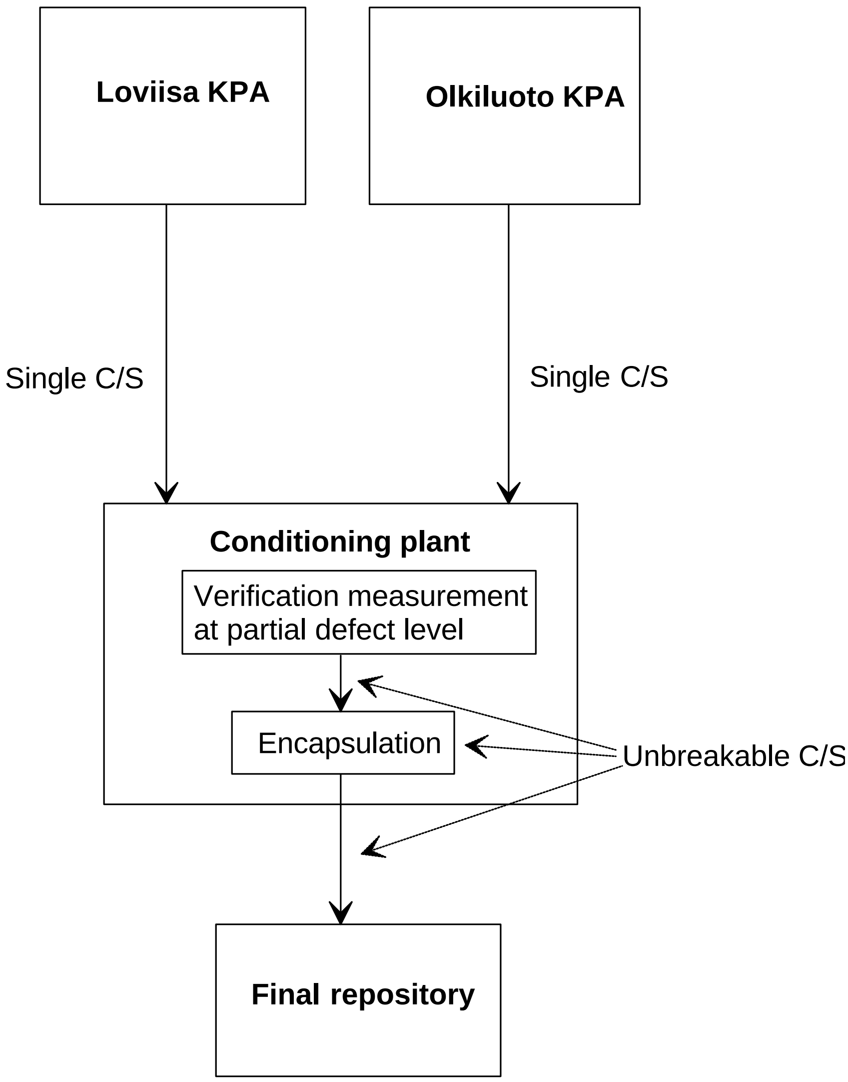

Figure 2. *A block scheme concerning the option to perform the final verification measurements in the conditioning plant.*

The hot cell is the only place inside the encapsulation plant, where assemblies are moved individually. The current plans include a shielded measurement position embedded in the floor of the hot cell. [4] The specific technical requirements for the measurement position have not yet been taken into consideration. The final design of the measurement position depends on the specifc characteristics of the verification measurement system.

Every assembly is identified by reading the fuel ID code and should be verified for consistency of cooling time and burnup data during the encapsulation. The identification and verification are important factors also in the viewpoint of safety, because the thermal load of the disposal canisters is restricted. The fuel is assumed to be transported dry. Provisions for wet transport are made. There are autoclaves in the design of the encapsulation plant originally intended for drying spent fuel assemblies after wet transportation. In the case of dry transportation, autoclaves would not be needed for drying. One option is that the room allocated for autoclaves could be used for the verification measurements. [4] The room needed for the verification measurement system can not be banked on this.

In case of accidents or mishandling, possible damages to the fuel assemblies would be more severe in air than in water. Measurements performed in air are technically more demanding as compared to measurements performed under water and there is very little experience on measurements in air. It is important to keep in mind, that the measurement position needs to be well shielded against the radiation from the assemblies in transport casks and disposal canisters. In air the measurement devices do not have to be waterproof. Because of this, it is possible to use HPGe detectors, which need liquid nitrogen cooling. On the other hand, HPGe detectors may be not the optimum solution for the gamma spectrometric measurements.

If the partial defect verification measurements are performed in the encapsulation plant, it has to be taken into consideration in the design of the plant.

4.2 Verification measurement of leaking assemblies and rejected rods

Leaking assemblies and rejected fuel rods are packed into hermetically sealed capsules at the NPP site before transport to the conditioning plant. These capsules can be handled in the same manner as the intact fuel assemblies. [5] The leaking assemblies are stored in the same way as intact assemblies at the Loviisa NPP. There is an option to package and store leaking assemblies in hermetic capsules.

Leaking assemblies packaged into hermetically sealed capsules are special cases in the verification measurements. All special cases should be identified and verified at the partial defect level already in the intermediate storages. A standard verification measurement system may not be suitable for verification measurements of special cases. A measurement system should be devised, which would be designated particularly for the verification of the special cases. This verification device could be portable. After the special cases have been verified in the intermediate storage and transported to the encapsulation plant, the same device could be used to verify no change in their nuclear material content.

Hermetic capsules are disposed of in specially manufactured canisters, which have an enlarged position. The sealed capsules will not be opened in the encapsulation plant. [20] Because of this, the verification measurement of leaking assemblies and rejected fuel rods at the partial defect level has to be performed without opening the capsule in the conditioning plant.

5 MEASUREMENT SYSTEM FOR PARTIAL DEFECT

The non-destructive assay (NDA) techniques have a firm place in the verification applications. Compared to destructive assay (DA), NDA causes less intrusiveness, no radioactive waste production and lower contamination risk.

NDA techniques are based on the measurements of radiation emitted from the samples. This radiation is emitted spontaneously or induced from outside. Neutron and gamma radiation is detected. It is generally considered that only NDA techniques should be used for the spent fuel verification measurements.

There is no validated device available for routine partial defect measurements. [6] There is even no consensus about the most suitable verification method at the partial defect level. The most promising NDA methods, which have the potential to be developed for this purpose, are the high-energy gamma emission tomography [7] and the fork detector combined with a CdZnTe detector (upgraded fork detector) [8]. These methods are discussed in this section.

It is important to keep in mind, that developing a measurement device for partial defect verification purposes is a long-term project. Evolving the methods by building test devices, making test measurements and developing the analysis of the measurement data is a demanding and time consuming process. The user interface of an operating verification system has to be constructed operator friendly i.e. easy to use. Owing to this, the development of the verification device has to be conducted concurrently with the process planning of the back-end of the fuel cycle.

5.1 High-energy gamma emission tomography

A passive high-energy gamma emission tomography device is capable of partial defect verification on rod level. It reconstructs a 2-D activity cross section map of an assembly from the measured radiation profiles, see figure 3. Measurements can be performed either in water or in air. No operator declared information on burnup, cooling time or irradiation history is needed. [6, 7] On the other hand, passive high-energy gamma emission tomography has only limited power in burnup verification.

Partial defect verification of an irradiated BWR assembly by gamma emission tomography would require about 1 hour of measurement time, if each fuel rod has to be detected using an array of 10 CdTe detectors with a 2 mm sampling interval. In order to scan one side of an assembly (318 mm), the detector array has to be moved stepwise 15 times. The assembly has to be rotated 48 times with 7.5 degrees intervals. A device with these parameters would yield high-resolution images. A measurement of one assembly would require many measures for the operator. For practical detection of a missing rod a lower resolution image could be sufficient. Such an image could be achieved by an array of 50 detectors with 4 mm spacing between them. Also the scanned linear length could be decreased to about 200 mm. This kind of detector system would not need linear movement of the detector system. Only rotation of the assembly would be needed. The measurement time could be reduced to 3 – 4 minutes for BWR assemblies using suitable means of rotating the assembly. However, the measurement head becomes heavier and very expensive, when the number of detectors is increased.

The integral of gamma intensities above a certain threshold energy level is detected in tomography measurements. The device could be enhanced by a simultaneous measurement of a complete gamma spectrum. The gamma spectroscopic measurement would reveal if the tomographic view includes contribution of isotopes, which might originate e.g. from irradiated dummy rods.

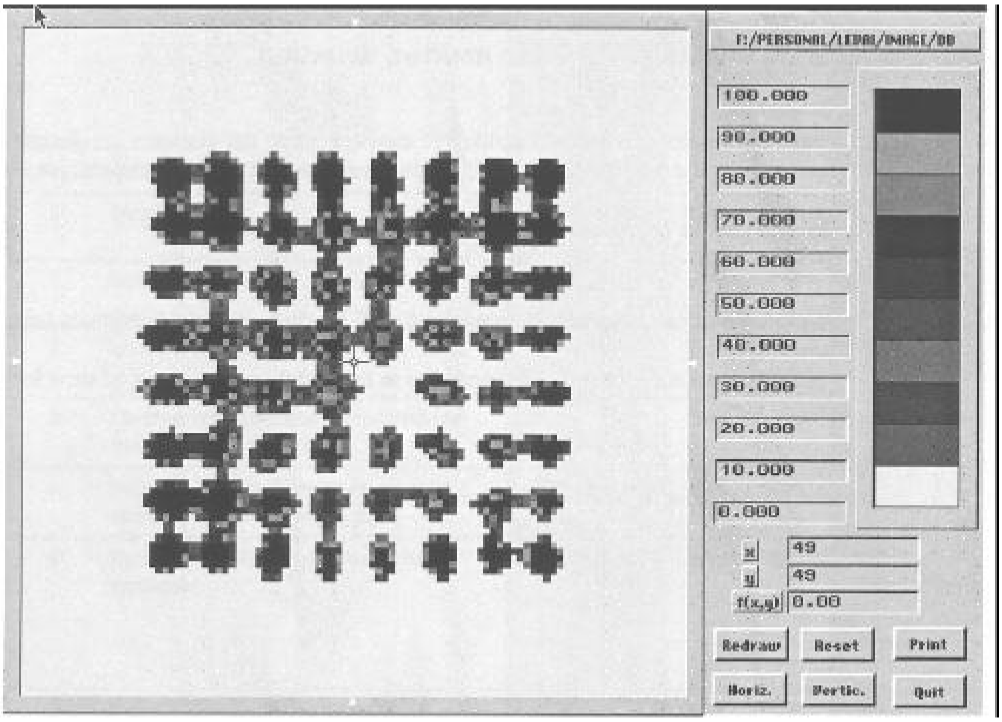

Figure 3. *A tomograph of an 8x8-1 BWR assembly showing the position of the inner water rod. [6]*

5.2 Upgraded fork detector

A conventional fork detector can be combined with a CdZnTe detector to make an upgraded fork detector. Passive total neutron count, total gamma and gamma spectroscopic measurements can be performed simultaneously. Model calculations, made with the programs PYVO or ORIGEN-S, are exploited in the analysis of the measurement data. Measurements are performed in water. [8] The upgraded fork detector has potential for partial defect verification. However, this has not yet been conclusively established by experiments. Development of the method is still going on.

The upgraded fork detector is also suitable for burnup verification, see figure 4. A reference curve, or at least one measurement of a reference assembly with certified burnup, is needed in the burnup verification measurements. The use of operator declared data is inevitable in order to calculate the necessary corrections to the measured neutron and gamma data. The parameters needed are the evacuation date from reactor, the burnup and the initial enrichment values, the irradiation time and the possible off-reactor cycles.

One measurement from one side of the assembly takes typically 100 s. Time needed for four measurements with 90º rotations is about 10 – 12 minutes.

The correlation between the neutron signal and the gamma signal should be a power function with the neutron yield proportional approximately to the fourth power of the burnup, see figures 5 and 6.

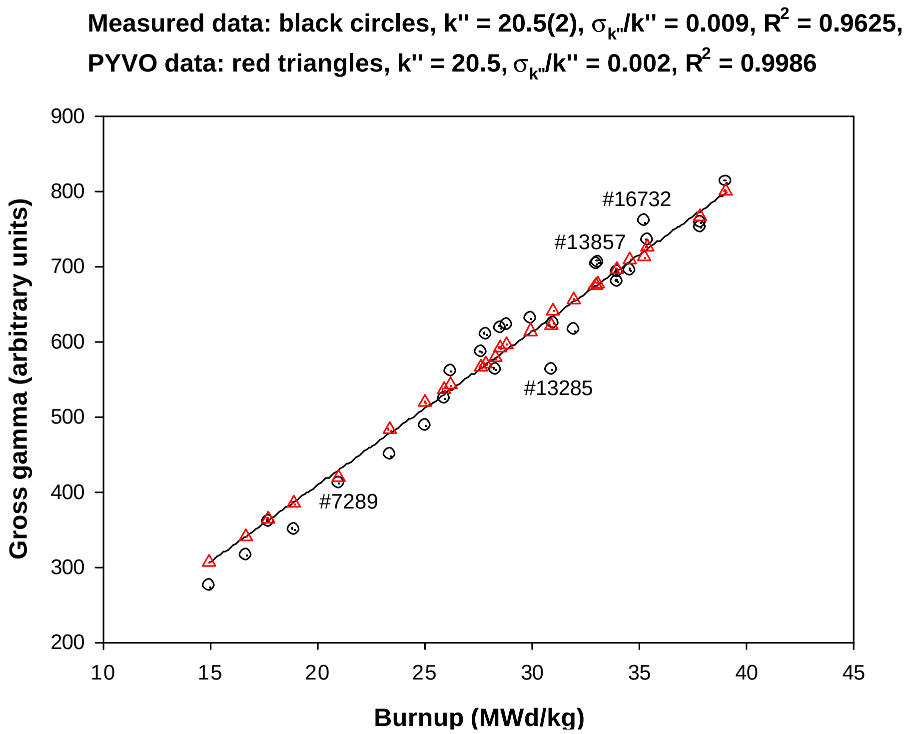

Figure 4. *Gross gamma signal versus declared burnup showing a strong linear correlation. The data obtained by evolution code calculation is shown as triangles.*

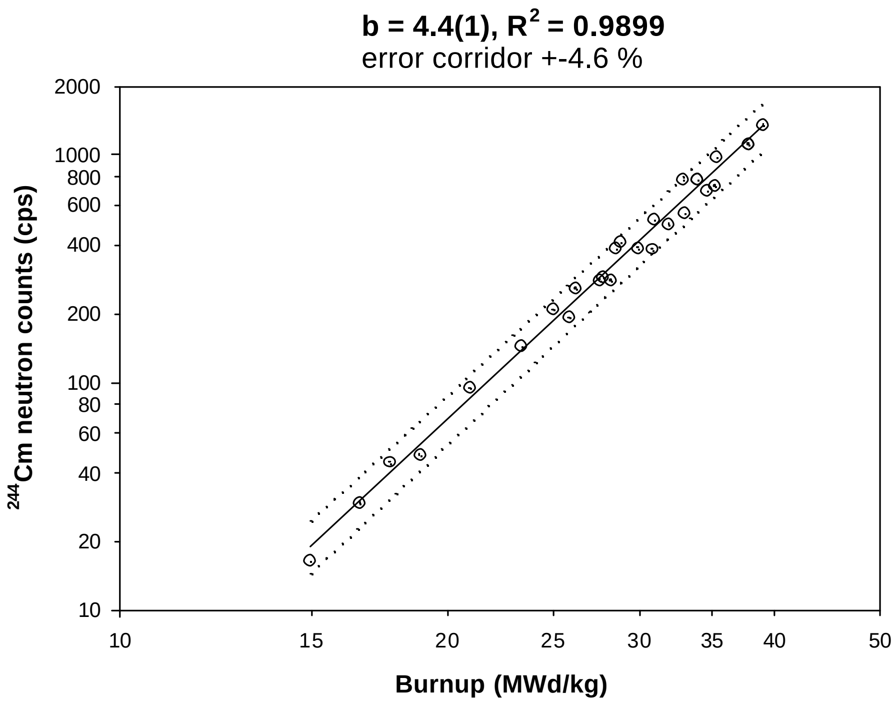

Figure 5. *^{244}Cm neutrons corrected for the enrichment as correlated with the declared burnup.*

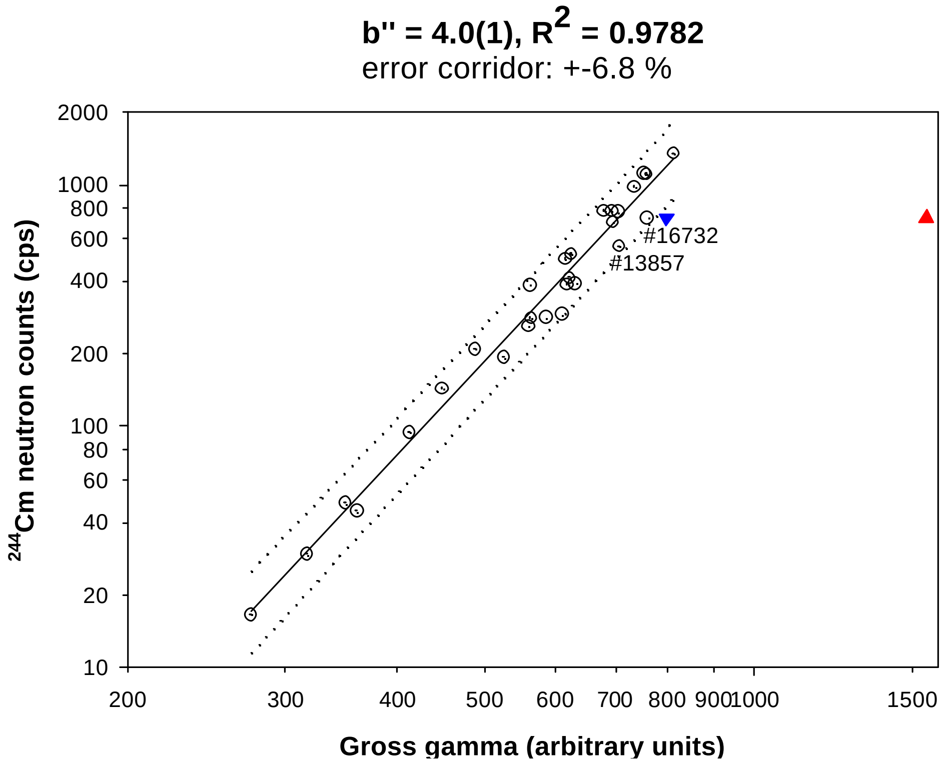

Figure 6. *Measured correlation curve in log-log scale between the ^{244}Cm neutrons and the gross gamma yield as corrected for short-lived isotopes (^{134}Cs, ^{106}Ru) as determined by gamma spectrometry. The up triangle at the right expresses the measured gamma yield of a 3.5 years cooled assembly. The down triangle to the left of the up triangle shows the effect of the correction for ^{134}Cs. Finally, the circle next to the down triangle is the final result after correction for both ^{134}Cs and ^{106}Ru.*

5.3 Selection of measurement principle

It can be concluded that the presented methods do not exclude each other but produce complementary information. Tomography produces 2-D views of the geometry of the fuel assembly, whereas the fork detector produces more quantitive but integrated type of data about the burnup and nuclear material content of the fuel assembly. Therefore a suitable combination of both methods might be the best choice. The measurement principle and the device to be chosen must, of course, comply with the requirements imposed by the competent authorities.

6 CONCLUSION

It is generally considered that all spent fuel items to be loaded into the disposal canisters should undergo verification measurement at the partial defect level in advance of packaging into the final disposal canisters.

At present there is no method or device, which could readily be applied for partial defect level verification at the back-end of the fuel cycle. At the moment the most potential devices, which could be developed for the partial defect verification purposes, are the passive high-energy gamma emission tomography device and the upgraded fork detector. It is important to understand that developing such a device into an operative level is a demanding and time-consuming project.

The planning of the whole safeguards verification process is essential. In order to minimise the costs the verification measurements of spent fuel should not unnecessarily complicate the encapsulation process. A balance should be found between the effectivity, the speed of the measurements and the investments necessary to implement the desired level of assurance.

Both for economical and safety reasons, the fuel handling operations needed during a single measurement should be minimised. The verification measurement should be integrated into the conditioning process. The measurement device should be automated with unattended operation.

Only the assemblies, which have been verified to be non-defected, should be passed to the disposal. This necessitates that there should be a special storage for potentially defected assemblies. These assemblies have to be verified with some other, yet unspecified device.

As a conclusion, it would be advisable to install the final verification system of the individual fuel assemblies at the partial defect level in the encapsulation plant.

The safeguards verification measurement of the spent fuel assemblies should be integrated in the fuel encapsulation process and it should operate in unattended and automated mode.

Due to many unsolved problems pointed out in this report it is proposed that a research programme should be started aimed at developing the methods, equipment and systems, which could be used for the verification measurements to be seen necessary for the back-end of the fuel cycle in Finland. This programme should be conducted in parallel with the research programme aiming at the achievement of the readiness to apply the construction licence for the encapsulation plant.

REFERENCES

1 Hautamäki, J. & Tiitta, A. Spent fuel verification options for final repository safeguards in Finland. STUK-YTO-TR 173. Helsinki 2000. 29 pp + Annex 1 p.

2 Safeguards for the final disposal of spent fuel in geological repositories, Volume 2, Overview of model safeguards approach for conditioning plants, IAEA, September 1998.

3 Moran, B.W., Design considerations for acceptable safeguards approaches for final disposal of spent fuel in geologic repositories (SAGOR Activity 8), K/NSP-648, Lockheed Martin Energy Systems, Oak Ridge Y-12 Plant, February 1998.

4 Kukkola, T., Encapsulation plant description, Working Report 2000-08, Posiva, July 2000.

5 Honkamaa, T. & Kukkola, T., Description of Finnish spent fuel encapsulation plant and encapsulating process. Phase I interim report on Task FIN A 1184 of the Finnish support program to IAEA safeguards. STUK-YTO-TR 158. Helsinki 1999. 19 pp + Appendices 9 pp.

6 Tarvainen, M., Lévai, F., Valentine, T., Abhold, M. & Moran, B., NDA techniques for spent fuel verification and radiation monitoring, Report on Activities 6a and 6b of Task JNT C799 (SAGOR), Finnish support program to the IAEA Safeguards, STUK-YTO-TR 133, Helsinki 1997, 23pp. + Annexes 24 pp.

7 Lévai, F., Dési, S., Tarvainen, M. & Arlt, R., Use of high energy gamma emission tomography for partial defect verification of spent fuel assemblies, Final report on the Task FIN A98 of the Finnish Support Programme to IAEA Safeguards. STUK-YTO-TR 56. Helsinki 1993. 51 pp.

8 Tiitta, A., Hautamäki, J., Turunen, A., Arlt, R., Arenas Carrasco, J., Esmailpour-Kazerouni, K. & Schwalbach, P. Spent fuel characterisation combining a fork detector with gamma spectrometry. Report on the measurements conducted with an "upgraded fork detector" at the Olkiluoto KPA Store. Espoo, November 2000. (to be printed in the report series STUK-YTO TR)