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Lessons Learned in International Safeguards—Implementation of Safeguards at the Rokkasho Reprocessing Plant

December 2009

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ACRONYMS

AEC	U.S. Atomic Energy Commission
ASAS	automatic sampling authentication system
CFE	cost-free expert
CoK	continuity of knowledge
CoT	cutoff time
CS	containment and surveillance
DC&E	data collection and evaluation
DIE	design information examination
DIQ	design information questionnaire
DIV	design information verification
HM	heavy metal
I3S	integrated inspector information system
IAEA	International Atomic Energy Agency
IAT	Input Accountability Tank
IIV	interim inventory verification
JNFL	Japan Nuclear Fuel Limited
LASCAR	Large Scale Reprocessing
MBA	Material Balance Area (as in MBA1 or MBA2)
MOX	mixed oxide (fuel)
MUF	material unaccounted for
NDA	nondestructive assay
NFS	Nuclear Fuel Services
NRTA	near-real-time accountancy
OPD	operator declaration
OSL	on-site laboratory
OSP	other strategic point
RRP	Rokkasho Reprocessing Plant
SAL	Seibersdorf Analytical Laboratory (IAEA)
SG	Department of Safeguards (IAEA)
SGOA	Department of Safeguards, Division of Operations (IAEA)
SMMS	solution measurement and monitoring system
SoH	state-of-health
SRD	shipper/receiver difference
SSAC	State System of Accounting and Control
TASTEX	Tokai Advanced Safeguards Technology Experiment
TIE	tamper indicating enclosure

TRP	Tokai Reprocessing Plant
TUI	Transuranium Institute
UK	United Kingdom
UMI	unmeasurable inventory
WAK	Wiederaufarbeitungsanlage Karlsruhe

Lessons Learned in International Safeguards—Implementation of Safeguards at the Rokkasho Reprocessing Plant

Summary

The focus of this report is lessons learned at the Rokkasho Reprocessing Plant (RRP). However, the subject of lessons learned for application of international safeguards at reprocessing plants includes a cumulative history of inspections starting at the West Valley (New York, U.S.A.) reprocessing plant in 1969 and proceeding through all of the efforts over the years. The RRP is the latest and most challenging application the International Atomic Energy Agency has faced. In many ways the challenges have remained the same, timely inspection and evaluation with limited inspector resources, with the continuing realization that planning and preparations can never start early enough in the life cycle of a facility. Lessons learned over the years have involved the challenges of using ongoing advances in technology and dealing with facilities with increased throughput and continuous operation. This report will begin with a review of historical developments and lessons learned. This will provide a basis for a discussion of the experiences and lessons learned from the implementation of international safeguards at RRP.

Introduction

The implementation of international safeguards at the Rokkasho Reprocessing Plant (RRP) in Japan has been the largest challenge the International Atomic Energy Agency (IAEA) has faced to date. A discussion of the lessons learned is presented below; however, the anticipated success of this implementation by IAEA is the culmination of experiences and lessons learned from efforts to provide effective and efficient international safeguards at reprocessing facilities over the past 30 years. This experience has contributed to the considerable advancement of technology for safeguards and has significantly impacted the way IAEA applies safeguards. Over this time frame IAEA has learned the importance of being involved early in the facility design, implementing improved verification equipment and procedures, continually improving automated data collection and evaluation (DC&E), and considering authentication measures in both facility and equipment design.

The state and operators in turn have learned that they must continue to improve their accountancy measurement systems, work with IAEA to assist in defining their verification measurement needs, and ensure that both the accountancy and the verification specifications are delivered in time for inclusion in the design and construction of the facility.

The fact that IAEA is an international organization with a continually changing multinational staff creates a challenge in maintaining continuity of interactions over the life of a project. The state and the operator must be committed to a long negotiation with IAEA to reach a consensus agreement on a safeguards approach.

History of Early Inspection Efforts—West Valley

The lessons learned experience, from the perspective of both IAEA and operators, started in 1969 with the first IAEA inspection of a reprocessing plant at the Nuclear Fuel Services, Inc. (NFS), facility known as the West Valley Reprocessing Plant in New York. Domestic safeguards requirements were in place at West Valley and the facility safeguards reports were monitored/inspected by the U.S. Atomic Energy Commission (AEC). Another very important aspect of operations at West Valley was that it was a commercial facility, and very detailed material control and accounting procedures were in place to support contractual arrangements. These were the basis of much of the regulatory reporting.

IAEA was established in 1957, and through the early years, there was an effort to gain experience and develop methods for inspection. The United States made a volunteer offer to allow IAEA to follow some early fuel cores through fabrication, irradiation, and subsequent reprocessing to help define international safeguards measures. It was in 1969 that these fuels reached the reprocessing stages of the fuel cycle.

Early on it was recognized that international safeguards must be based on declarations of the state of facility use and material movements. Agency safeguards must be based on verification of a state's declarations of movement and use of nuclear materials that in turn were based on a domestic system of requirements that has become known as the "State System of Accounting and Control" (SSAC). As the basis of the state system in the United States during the time of West Valley operations, there were requirements within the AEC rules and there was a resident AEC inspector at the site. Because a lot of the fuel processed at the facility was AEC owned, that AEC inspector was as much a contract monitor as an inspector for the AEC safeguards rules.

The facility was in commercial operation. There was a responsibility to present a "Material Report" to the customer at the end of each short campaign as the contractual requirement for financial settlement for services provided. When commercial reactor fuel was processed, the utility usually had an independent agent, in addition to the AEC representative, monitor and review measurements reported as the basis of the "Material Report". These independent agents were often involved in witnessing important measurements with independent recording of data and even independent sample analysis at times. This independent monitoring certainly influenced eventual measures implemented by IAEA

Even during commercial reprocessing campaigns, there were still the domestic safeguards requirements, administrated and monitored by AEC. The AEC representative was the agent for the contract agreement between NFS and AEC during their fuel processing contract but also served in the regulatory monitoring sense during commercial processing. Subsequent to the contractual "Material Report" developed and submitted for customer reporting, a formal "Material Balance Report" was also prepared to meet AEC regulatory requirements. The focus of the "Material Report" was to document the performance under "recovery and loss" guarantees of the contractual arrangements. The Material Balance Report focused on propagation of uncertainties and evaluation of the "material unaccounted for" (MUF) as the safeguards requirement. Data reported in the Material Balance Report were used as the mechanism to meet the requirements of the SSAC to provide information to IAEA in the regulatory application and were made available to IAEA as the basis for international inspection.

The measures developed for these contractual inspections formed the basis for procedures that would eventually be used by IAEA inspectors. IAEA followed processing of the special fuel offered by the government under the voluntary agreement between the United States and IAEA. At the time, the safeguards technology was only emerging, and the inspection was limited to IAEA inspectors simply observing the measurements by the operator and independently recording the data. The IAEA inspections were limited in scope and duration to the processing of two discrete campaigns of fuel from two reactors offered as a test case for full scope safeguards. IAEA followed the fuel from manufacture through irradiation and reprocessing. During the processing at West Valley, IAEA inspectors were in residence near the facility for the duration of each of the two campaigns and on call to be present during important measurements. This was very much patterned after processes used to meet contractual obligations.

Measurement capabilities were quite rudimentary. Nondestructive assay (NDA) development was in its infancy. Volume measurements used water manometers. Mass spectrometry was the method for input, and product measurement and waste measurements were by alpha count, requiring assumptions on isotopic composition based on input analyses. Inspectors mostly just watched measurement activities and recorded their "independent" readings from the operator instruments. But through the years of West

Valley commercial operation, the contract monitors began taking dilutions of samples and sending them to their independent laboratories. Again, this set the pattern for inspections that IAEA eventually adopted: sending samples to the IAEA laboratory at Seibersdorf and eventually implementing the "on-site laboratory" (OSL).

A significant lesson learned at West Valley was the need for a greater number of independent verification measurements, but it took many years of development to head in this direction. These were the first inspections by IAEA or customers at a reprocessing facility. The facility had been built and was operational before the inspections commenced, so there was no opportunity for submission of a design information questionnaire (DIQ) or development of a facility attachment and the safeguards design documentation that later became part of the IAEA inspection process. But the West Valley efforts, including IAEA experiences during the limited inspections, lessons learned in inspection by the commercial representatives, and operator lessons learned in addressing the demands of the inspecting organizations, provided the groundwork for development of a safeguards approach for reprocessing.

Contemporary Early IAEA Reprocessing Activities

Other large reprocessing plants, Hanford, Savannah River, and Idaho, were in operation in the United States, but they were associated with weapons programs and not subject to IAEA inspections. In fact, they were not even subject to AEC regulatory controls like the commercial plant at West Valley. Subsequent to West Valley, the French began operation at the Usine de Plutonium facility (UP1) at Marcoule, but this also was not subject to extensive IAEA safeguards as it was part of the French weapons program. Likewise for the Magnox facilities in the United Kingdom (UK) and the facilities in Russia that were in operation for weapons production and not subject to IAEA inspections.

There were a few other small scale development projects around the world. Contemporary to West Valley, a very small facility came online in Mol, Belgium. But this was a facility with kilogram quantity throughput and, like a few other research facilities in Europe, was never given much attention by IAEA.

Lessons Learned from Early Evolution of Verification Technologies

The early inspection efforts continued to draw attention to two basic shortcomings. It was becoming recognized that IAEA needed more independent verification measurements and the technologies were not necessarily available. Additionally, IAEA had not yet been involved in design of the safeguards/inspection systems at a stage when decisions could be made about equipment and procedures. At that time, any new facility being proposed for operation under IAEA safeguards was required to provide notification by submission of the DIQ only 6 months before the facility went into operation. At that point the facility was built and likely well into commissioning, and any equipment recommended had to be backfit into the facility.

NDA technology development, with an eye on verification measurements, also began in earnest in the early 1970s. Los Alamos and Lawrence Livermore National Laboratories were very active in the early development.

By the late 1970s the United States had built the Barnwell Nuclear Fuel Plant, which was the first of the next generation large scale facilities with a capacity of 5 Mt/day with continuous operation for 200 to 250 days/year. The throughputs and measurement capabilities challenged the ability to meet IAEA detection goals. And there would no longer be short campaigns that could be monitored in a timely manner to meet the timeliness goals of the agency.

Safeguards measurement and evaluation technologies advanced considerably at Barnwell through the late

1970s and early 1980's. The U.S. laboratories developed ideas and instrumentation that was deployed and tested at Barnwell. There was considerable interaction with IAEA for planned inspection activities in consideration of the need to provide information to IAEA in a timely manner and increase the amount of data provided to support more timely and sensitive evaluations. But with changes in U.S. attitudes on plutonium recycling and reprocessing and a subsequent Presidential directive in 1977 suspending commercial recycling and reprocessing of plutonium, it was becoming apparent IAEA would probably not be challenged by safeguards at this large scale facility. Development of safeguards and non-proliferation measures continued at Barnwell, but the facility was closed in 1983

First Serious Challenges to IAEA Reprocessing Plant Safeguards

Wiederaufarbeitungsanlage Karlsruhe (WAK). The first facility, and the smallest, to require an enhanced IAEA inspection regime was the WAK facility in Karlsruhe, Germany, with a throughput of around 30 t of heavy metal (HM)/year and a product of around 300 kg plutonium/year in the form of plutonium nitrate. WAK operated from 1971 to 1990, the transition years for IAEA from the first inspections at West Valley to what would be requirements for the larger facilities of the future. WAK has now been decommissioned and is being returned to a greenfield state. Although small in relative terms, its continuous operation and significant production capabilities required a continuous IAEA inspection regime with inspectors either on duty or on call 24 hours per day, 7 days per week. Because of the older process monitoring systems, in particular the analog strip-chart recorders and manually prepared logbooks, tables, and charts, the operation of the facility was actually more transparent from a safeguards point of view than more modern plants. The inspectors, at a glance, could understand the operational status of the facility or particular parts of the process by trends observed on the strip charts, rather than searching digital databases as became the requirement in later facilities. And because of its smaller physical size, it was easier for inspectors to learn their way around the plant and to be able to make observations concerning which operational activities were routine and normal and which required a closer look and further inquiries.

Although of relatively small size and throughput, there were a number of challenges that had to be met and problems to solve. These activities contributed to the improvement, and awareness of the need for improvements, in safeguarding facilities with flowing material. Following are some of the specific lessons learned from WAK that were indicative of concerns that would eventually need to be addressed at larger facilities in the future.

- Undissolved solids potentially containing plutonium are a reality in reprocessing facilities. The actual quantities of plutonium involved remain a subject of debate. They are certainly very small, and the amount of solids present and nuclear material contained remains virtually impossible to quantify. However, they must be addressed. In the early facilities such as West Valley and WAK, there was no headend clarification of dissolver solutions, and solids could be observed in samples, especially in the Input Accountancy samples and high activity waste samples. The origin of the solids is cladding fines from shearing and undissolved fuel, as well as possible in-growth of solids over time. At WAK, IAEA became aware that the operator was filtering the samples before analysis and that the undissolved fuel particles were not being measured. It was thought that the plutonium in the undissolved solids was contributing to the shipper/receiver difference (SRD) in Material Balance Area 1 (MBA1). The unmeasured solids were transferred to MBA2 and eventually into the high level waste, which also contributed to the MUF in MBA2. Experiences at WAK emphasized the need for improved headend filtering systems so that fines are not passed into the process; if they are, they must be dealt with as part of the sample analysis, even if it means filtering and dissolving the particles.
- This was a first attempt at solution monitoring with manually recording the events from the strip-chart recorders of 25 selected tanks. This large accumulation of recorded data was used on a number of

occasions to resolve discrepancies or to confirm an operator's declaration of activities. Although it was unauthenticated operator data, it would have required a great effort for the operator to manually coordinate a falsification of multiple strip-chart recorders.

- Open access for the inspectors to required files resulted in less work for the operators and faster data recording for the inspectors. These activities were always done in coordination with the Euratom inspectors and contributed to a sense of transparency.
- This was the first attempt at using computers to store, calculate, and evaluate collected inspection data. Preliminary evaluations and reports could be done on-site and the data carried back to headquarters on floppy discs, rather than in paper bags.
- To meet the need for a more rapid turnaround in analytical results, especially for inputs (dissolver solutions) and outputs (plutonium nitrate solutions), the K-edge and Hybrid K-edge Densitometers were developed at the nearby Transuranium Institute (TUI) laboratory. WAK samples were analyzed at TUI with the participation of the IAEA inspectors.

<u>Tokai Reprocessing Plant (TRP)</u>. TRP in Tokai, Japan, was the next reprocessing plant to come under international safeguards. TRP has an operating throughput of around 100 t HM/year with a product of plutonium nitrate. It began operations in 1978 and currently continues operations with a modified operating schedule. When the plant is operating, IAEA implements a continuous inspection regime of one inspector on each of three shifts with additional inspectors needed during the monthly interim inventory verification (IIV). During the more than 25 years of applying safeguards at TRP, IAEA has significantly strengthened the safeguards approach and in doing so learned how to overcome some of the inherently limiting technical factors posed by a complex flow facility. Some of these were addressed early on when the United States convened the Tokai Advanced Safeguards Technology Experiment (TASTEX) to assist IAEA with the development and implementation of safeguards techniques to meet the challenges of continuous inspection.

A number of significant new ideas resulted from the TASTEX program, including the following:

- use of electromanometers for significantly more accurate volume measurements (displacing the contemporary water manometers for the required differential pressure measurement),
- use of resin bead technology for sample preparation to allow transport of independent samples for analysis at remote IAEA laboratories,
- exploration of K-edge densitometry for plutonium concentration measurements,
- implementation of near-real-time accountancy (NRTA) for timely safeguards assessments,
- implementation of solution monitoring for additional assurance
- implementation of containment and surveillance (C/S), and
- exploration of NDA techniques.

IAEA introduced the TRP Improvement Plan, which lasted for about 10 years, in 1987. The improvement plan originally addressed 28 near- and long-term improvement needs, some of them extensions of the work done under TASTEX. In 1995, the remaining improvement areas were consolidated into 11 well defined tasks. The improvement plan highlighted the fact that IAEA had an insufficient understanding of the plant operations, that safeguards had not been a priority in either the building or the operations of the plant, and that IAEA had had little to no input in the early design of the plant. The early attempts at retrofitting safeguards into the facility had been either unusable or inadequate and in need of strengthening. The following are some of the most important lessons learned which are relevant to future facility designs.

- Design information.
    - Detailed and accurate drawings and diagrams of cell layouts and equipment design and flow routes which are associated with all inventory and inventory change key measurement points and other strategic points (OSPs) must be provided to IAEA. Sensitive documentation can be stored on-site under joint control.
    - Information must be provided on all operational procedures which affect safeguards activities, including sampling, homogenization, solution transfers, in-tank or in-line measurements, spent fuel receipt and handling, liquid and solid waste handling and storage, and accountancy data handling.
    - An accurate and complete listing of uncertainties associated with all inventory and inventory change measurements must be established by the operator and provided, including sampling, concentrations, in-tank density, level and temperature, and weighing.
    - Information is needed on the chemical and utility support systems which are relevant to the implementation of safeguards. Obtaining process related information continues to be a challenge as this information is often deemed proprietary.
    - All information provided must be verifiable.
- Design information verification (DIV).
    - Vessel calibration systems and procedures are needed that are sustainable over the lifetime of the facility. They must be reliable, accessible, consistent, and for use by both the operator and inspector.
    - Equipment and databases are needed for verification and long-term documentation of vessel construction, piping and sampling arrangements, instrumentation, and penetrations in the biological containment which could be used to transfer or control nuclear materials.
    - All initial DIV activities must either have a means to maintain continuity of knowledge (CoK) of the results or have provisions for verification throughout the lifetime of the facility.
- Solution measurement and monitoring systems (SMMSs).
    - The ability to collect information from vessels in the main process line has proven to be invaluable. The in-process measurement technology at the time the Tokai facility was built was not compatible with a computer interface for data collection. Therefore, as the technology became available the facility had to be backfit with new measurement systems. Even with these limitations, the solution monitoring applications have been of significant value to international safeguards.
    - Provisions must be incorporated in the process design to allow for independent solution measurements. If independent systems cannot be installed, then authentication of the operator's system must be achievable.
    - Methods are needed to verify the continued integrity of dip tubes and air flows. Detailed data analysis can often provide this assurance.
    - The operator must establish standard operating procedures that can be monitored and evaluated using pattern recognition methods to determine whether operations are as declared.
    - Secure data transmission must be available to the inspector's DC&E system. Installing data transmission lines in an already-built plant is nearly impossible.
    - The solution monitoring applications at Tokai were developed over the years to provide data for the improvement of the SMMSs, but the computerized evaluation technology has lagged. Much

of the early evaluation methods have used rather rudimentary graphical representations that rely on inspector experience for evaluation.

- Sample integrity.
    - The source of samples taken remotely must be verifiable.
    - Samples not under the control of inspectors must have methods applied to maintain CoK, whether it is human surveillance, standard C/S methods, or tamper indicating sample vials.
    - The facility must provide dedicated laboratory space for inspector sample preparation and storage.
- Unattended sampling systems.
    - Verifiable unattended sampling systems are needed to reduce the inspection effort.
    - For TRP, it was concluded that retrofitting with an acceptable unattended sampling system would be too intrusive and expensive.
- Waste measurement and monitoring systems.
    - Nuclear material in leached hulls and filtered fines must be established and declared by the operator as part of design information. Provisions must be made to enable measurement and verification that the design value is not exceeded. Indirect measurement of the nuclear material content by neutron measurement of the ^{244}Cm can provide adequate results only if the $Pu/^{244}Cm$ and $U/^{244}Cm$ ratios can be established. There continues to be a discussion as to whether these ratios, which are measured in the dissolved solution, are the same as those in the undissolved material in the hulls.
    - IAEA highly recommended that the leached hulls and filtered fines be cemented and made “practically irretrievable” so that safeguards could be terminated on the nuclear material. This was not done at TRP, and the accumulated leach hulls must continue to be under safeguards even though they have been removed from the book inventory as retained waste. IAEA’s right to verify this material remains, and with the construction in the early 1990s of a remote handling and storage facility, this, although difficult, could theoretically be done.
    - The liquid waste to be transferred to retained waste should be minimized and the expected waste production should be declared by the operator as part of the design information. Verification points must be provided in the design of the transfer routes to retained waste. Also, because retained waste continues to be under safeguards, verification capabilities must be provided in the design.
    - The best solution to reducing liquid retained waste is vitrification, making the waste practically irretrievable and therefore allowing for safeguards to be terminated. However, provisions must be made in the design to allow for verification of the vitrified waste canisters. This also requires the capability to establish the $Pu/^{244}Cm$ and $U/^{244}Cm$ ratios in the waste feed to the vitrification process.
- SRD.
    - SRDs are caused by both poor reactor calculations and by poor material control in the reprocessing headend. Errors in headend waste measurements and declarations and process perturbations, such as filter changes or back-flushing of filters, will contribute to the SRDs. It is therefore necessary that the headend process be clearly understood and consistent in its operations.
    - Studies of historical SRD data from TRP identified biases specific to each reactor type.

- IAEA has done extensive work in studying this problem and has implemented an SRD evaluation approach at TRP that looks at fabricator data and reprocessing data and eliminates the uncertainty and unverifiable data of the reactor.

- NRTA.
    - Although NRTA methods had been studied at TRP since 1978, they were not implemented until 1991. NRTA provided a more timely evaluation of the monthly MUF; however, the software was not "inspector friendly," and the results required regular interpretation and follow-up.
    - A major problem was the lack of reliable operator measurement uncertainties. The random and systematic errors of all accountancy and relevant operating measurements must be established and periodically updated by the operator.
    - The unmeasureable inventory (UMI) in a process must be established for various operating conditions. This includes the holdup in pipes, pumps, sampling pots, separators, evaporators, and all inventories that cannot be directly measured. UMI can be estimated based on flow and engineering design or measured indirectly in associated vessels.
    - A critical NRTA challenge for the operator during the monthly IIV was collecting and declaring all the inventory data of a flowing process at the declared cutoff time (CoT). And for the inspector, it was the capability to verify it within a given window of time. It was necessary to establish operating rules for declaring the CoT. The primary effort was to ensure a minimum of UMI and a maximum of inventory in measureable and verifiable locations, such as calibrated tanks. The installation of a reliable SMMS was useful in maintaining CoK of the flowing solutions.
- Provision of operator data.
    - To improve efficiency for both the operator and the inspector, accountancy and relevant operating data were provided in electronic form on diskettes to the inspectors. An integrated reprocessing inspection software system was developed for the inspectors to store, calculate, evaluate, and report inspection results.
    - Because the plant was relatively old and only partially converted over to digital systems, there was no direct feed of data to the operator's accountancy office. This was clearly a handicap for the operator in reporting data and results to the inspectors in a timely manner.

The work and dedication of the Japanese and IAEA have continued to improve the safeguards system at TRP. However, past experiences point to the most valuable lesson learned: establish a dialog and cooperation early on, which allows the safeguards systems to be designed with the facility and not superimposed at the end of construction and commissioning.

The Greatest Challenge to IAEA Safeguards

IAEA and the IAEA Department of Safeguards (SG) had never before been challenged with designing a credible safeguards approach for a large commercial scale reprocessing facility. This challenge was realized in the 1980s with the Japanese decision to construct RRP in northern Japan, with a throughput of 800 t HM/year. This far exceeded any previous IAEA experience. There was no model or guideline that could be used as a reference, only WAK and TRP as starting points.

IAEA began actively addressing the planned construction of RRP in 1987. The Japan Nuclear Fuel Limited (JNFL) Project Office was formally established within the appropriate operations division of the Department of Safeguards (SGOA) in 1991. It was established for the purpose of designing and introducing a safeguards approach for RRP. The project objectives were to plan, coordinate, and integrate all activities necessary to ensure that an effective and efficient safeguards system would be implemented at RRP on a schedule consistent with construction and commissioning of the plant and with resource expenditures within IAEA, JNFL, the Government of Japan, and member state funding capabilities. This posed quite a number of challenges both technical and political.

There was a concern within the international community as to whether IAEA could meet these challenges. Because of this, a multinational forum, referred to as LASCAR (Large Scale Reprocessing) was established to address the more difficult and urgent issues being raised on how an effective safeguards approach could be implemented at such a facility while maintaining an efficient use of resources. This forum, which was funded in large part by the Government of Japan during the period from 1988 through 1992, was made up of more than 50 experts in safeguards and reprocessing technologies. The participants included government, laboratory, and industry representatives from five countries—France, Germany, Japan, the U.K., and the United States—and representatives from the Commission of the European Communities and IAEA. The primary findings and recommendations were in the following areas.

1. Provision and verification of design information—Early submittal of design information by the operator/state to IAEA allows for early consultations on safeguards requirements for equipment and verification measures and allows for early determination of resource requirements. Provision of design information and DIV activities continues throughout the lifetime of a facility.

2. Advanced nuclear material accountancy methods—To meet IAEA timeliness requirements, techniques such as NRTA should be applied; however, improved accuracy and measurement uncertainties are needed. Also for timeliness, measurement methods are needed that can provide online analysis or maintain CoK of material flows. The use of unattended process monitoring systems is recommended.

3. C/S measures—Independent C/S measures should be applied wherever possible to maintain CoK of material and facility operations and to reduce remeasurement requirements, particularly in storage areas. Dual C/S should be applied to eliminate re-measurement requirements of difficult to access material.

4. Authentication of operator instruments—Although installation of independent safeguards measurement and surveillance systems is preferable, because of resource and space restrictions use of the operator’s instruments by IAEA may be desirable and sometimes unavoidable. However, proper authentication measures must be implemented.

5. Data acquisition and transmission—Data acquisition and evaluation must be computerized. A modern distributed data collection system is recommended with inclusion of access by inspectors to the operator accountancy systems.

6. OSL—To reduce sample shipping costs and provide timely analyses of safeguards samples, an on-site inspectorate analytical laboratory is recommended.

7. Research and development—IAEA, the state, and the operator should determine their ongoing needs for research and development tasks.

Although the recommendations made by LASCAR have had a great impact on the basic design of the safeguards approach, they also presented some unforeseen difficulties in their actual implementation. The cost and technological requirements for some measures have gone beyond those anticipated by the members of the forum.

The structure of the JNFL project evolved over the years between 1991 and 2006, with five different senior staff members at its head. The early years were focused on identifying measuring and monitoring systems and establishing and implementing a systematic approach to design verification. The later years brought about refinements in the safeguards approach, the methodologies and procedures to be applied, and the design and development of an integrated inspector information system (I3S). The project in its final stage used a crosscutting management scheme with a team consisting of around 35 members from various IAEA operations and support sections (SGOA, Safeguards technical Services (SGTS), Safeguards Information Technologies (SGIT), and Safeguards Concepts and Planning (SGCP) and the IAEA Seibersdorf Analytical Laboratory (SAL) and included cost-free experts (CFEs) from the United States, France, Germany, UK, and Japan; consultants; contractors; and interns. Funding for the project was shared between IAEA, the Government of Japan, and JNFL. A significant amount of development work and provision of safeguards systems was supported through the Member State Support Programs. General oversight and coordination was the responsibility of the IAEA JNFL Project Office.

The challenges and lessons learned are as follows.

- Designing and Building in Safeguards. A number of general design features could be modified or optimized to provide easier access for verification of material and operational status and to provide more transparency that the process operations are as declared. The following general design points, based on the RRP experience, are elaborated on in the following sections.
  - Permanent installation of verifiable tank calibration systems.
  - Provision of remote viewing capabilities into strategic cells.
  - Improvement of the design of accountancy vessels taking into consideration internal structures, homogenization capabilities, environmental controls, and sampling systems.
  - Re-evaluation of current sampling systems and their effects on the validity of samples taken, including factors such as tamper vulnerability, evaporation, and simultaneous sampling capabilities.
  - Provisions for transparency and minimization in recycling capabilities.
  - Clear separation and well defined waste handling and treatment areas.
  - Installation of independent inspectorate owned and controlled systems.
  - Allowance for easier inspector access to safeguards relevant operating information.

- Design Information Examination (DIE) and DIV.
  - Preliminary design features were provided to IAEA at a very early stage, which allowed for early visits to the site and resource planning for continued DIE and DIV activities. This early provision of design information should have also allowed for discussion of design changes or modification to accommodate safeguards. However, in the case of RRP, design changes were very difficult to make because of the operator’s contractual agreements. Also, IAEA was not capable at this early stage to state its safeguards requirements, nor was IAEA clear on what its safeguards approach would be. This, however, is somewhat to be expected and requires close and continuing discussions between the operator, state, and IAEA with a more intense focus on the safeguards approach early on.
  - The provision of design information that is highly sensitive due to commercial and/or proliferation concerns must be minimized. However, it should be expected that this situation will occur, in which case the information should be stored at the facility in a controlled area under both IAEA and state seal. Verification of the design can often be done indirectly during testing and by verifying the surrounding equipment.

- The extensive amount of design information and verification results must be collected and stored in an organized and retrievable manner. IAEA had software developed for electronic storage and retrieval which was a significant improvement on past practices. However, the software needs further refinements.
- The first high accuracy accountancy measurement in a reprocessing plant is of the dissolved fuel in the Input Accountability Tank (IAT). To better understand IAT operation and measurement capabilities, the Japanese built an exact copy at a demonstration facility before construction and installation in the plant.
  - After installation and during commissioning, a major design flaw was detected and had to be modified at the request of IAEA. The as-built design had sheaths around the IAT dip tubes for stability during homogenization. However, during cold commissioning it was discovered that the bubbling air collected under the sheaths, resulting in incorrect pressure readings by the electromanometers. The sheaths had to be cut away, at great cost and time, by the operator.
- It was impossible to carry out 100% verification of all the relevant safeguards design features. Therefore, priorities were established and verifications carried out at varying degrees from 100% to a low random level, depending on the importance of the safeguards.
- Great efforts were made to maintain CoK of the verification activities, although not always successfully. In-cell designs were randomly re-verified just before permanent closing of the cells. Critical pipe runs were traced and documented. Those having potential access could theoretically be re-verified in the future, although with great difficulty. New or improved verification tools are needed to access difficult to access locations, or this access need should be taken into consideration during facility design. In-cell viewing capabilities could also aid in re-verifying design features of strategic process areas.
- The three-dimensional laser rangefinder for DIV was developed by the Joint Research Centre of the European Commission in Ispra, Italy, at the request of the JNFL Project Office. This equipment provided a capability for recording the verified design in digital form and for confirming later that there had been no changes. It also allowed for dimensional measurements of piping and internal cell structures using the digital laser results. A pending need is to modify the system so that it can be taken back into the areas that are now contaminated for verification of no changes or verification of declared changes.
- After IAEA reviewed the design information for the hundreds of vessels that the operator’s control system would monitor and that the operator must calibrate, it was concluded that a little less than 100 vessels would be safeguards relevant. IAEA then participated in the calibration of these vessels as part of the design verification exercise. The vessels selected were categorized by importance. In the less important cases, IAEA used operator collected calibration data to develop its own calibration equations. For the more important vessels, at least one calibration pass was witnessed by the inspectors, with independent data recording. For the most important vessels, three calibration passes were subject to full inspection. The work was cumbersome, slow, and resource intensive. In many cases, calibration equipment was set up inside the cells that would later be sealed during operation. Incremental additions were made directly to the tank from prover vessels set up in the cell. Recalibration and calibration checks in the future will require that incremental additions be made from accessible aisles through lines that were not necessarily used in the original calibrations. The installation and use of permanent calibration systems during the initial calibrations would provide for more controlled and reproducible conditions during future calibration activities.

- Strengthened safeguards measures.
    - Enhanced safeguards measures. It was always recognized that the available verification measurements would have inadequate sensitivity and reliability to statistically detect the diversion of a significant quantity of nuclear material or the misuse of a commercial scale reprocessing plant. Therefore, enhanced safeguards measures were needed to strengthen the accountancy verification activities and to provide added assurance. A program of measures was developed to provide assurance of "Operations as Declared" at RRP.
    - Meeting timeliness goals. The sampling system installed at RRP has limited capabilities for sampling multiple vessels simultaneously. Therefore, at the declared monthly CoT for the IIV for timeliness, it is impossible to take a statistically adequate number of random samples to verify the inventory. It was therefore necessary to introduce a more frequent [about every 10 days (3 times/month)] in-process inventory verification approach that required fewer samples. The CoT is also scheduled at a time when most of the inventory is located in verifiable vessels.
    - Implementation of NRTA. To implement NRTA at a large throughput facility, the operator's accountancy system must be able to provide almost-immediate inventory declarations anytime, anyplace, even if based on process control data.
        - A critical component of the NRTA application is development of algorithms to determine the inventory in the extraction systems, such as the pulsed columns installed at RRP. To develop and qualify algorithms, the RRP operator built a scale model extraction test facility.
        - Like the pulsed-column system, a continuous plutonium evaporation system is a dynamic system for which it is difficult to determine the inventory for declaration at the closing of the NRTA material balance period or CoT. The operator again built a scale model of the evaporator to develop and qualify algorithms.
        - Taking in-process inventories to support the NRTA application is an extremely complex activity in a large scale facility like RRP. It is virtually impossible to simultaneously sample and measure all locations at CoT and to declare the inventory, particularly with the RRP automatic, pneumatic, preprogrammed sampling system. The operator conducted extensive planning and simulation tests to support the procedure for the in-process inventory taking. However, its lack of flexibility could not meet IAEA needs for simultaneous sampling.
    - Operations need to be able to accommodate high frequency random sampling or in-process analyses for IAEA inventory verification to meet timeliness requirements. The installation of in-vessel measurement and monitoring systems is critical in addressing IAEA timeliness requirements.
    - Enhanced use of OSPs. As previously stated, for IAEA to meet its quantity and timeliness goals at RRP, other measures had to be introduced to provide added assurance that the verification measures were true and correct and that the plant was being operated as declared. OSPs were identified throughout the facility for C/S, passage or process monitoring, random sampling and analyses, short notice visits, and recording of operational data. This requires that relevant and selected operating records are transparent and available for inspector access on short notice.
    - The operator needs to establish and then declare the expected waste stream components with capabilities to sample and analyze for them. This includes Np, Am, Cm, and any other signature components that would indicate that the plant is being operated as declared.
    - Evaluations of SRD. The new approach used at TRP to evaluate the safeguards significance of the difference between the spent fuel inventory declared by the reactor (shipper) and that measured in

    - Training. Although the introduction of extensive measuring and monitoring systems and an expensive integrated DC&E system was necessary, the most valuable resource was (and is) the observations of knowledgeable and well trained inspectors present in the facility.

- Verification systems. More than 50 measuring and/or monitoring systems and about 70 camera surveillance systems are installed at RRP, providing hundreds of signals. This is not only a large financial burden but a significant demand on human resources for the preparation of user requirements, installation, and testing. An overall improvement must be made in the future to make available reliable, robust online measuring and monitoring systems with increased sensitivity. Following are some criteria and lessons learned that should be considered when developing and selecting systems for installation.
    - To share the financial burden and reduce the number of installed systems, joint use by IAEA and the state, and possibly the operator, should be considered. Early consultation between all parties and system developers must start during the design phase.
    - All systems, whether solely for IAEA use or joint use, must have third party vulnerability tests to ensure that each user can reach independent conclusions.
    - The majority of installed systems at RRP had little, if any, authentication features in their original design and installation. Retrofitting or modifying systems to meet these requirements increased the total cost of systems significantly. Early consultations and valid vulnerability testing would have obviated this.
    - To reduce on-site inspector presence, unattended measuring and monitoring systems are needed which have improved reliability, robustness, and sensitivity. They must also have the capability of transmitting data, whether operator or inspector, to a central data collection computer.
    - The extensive use of installed cameras needs to be reduced. Even with the improved review software, the required inspector time is extensive. In many of the difficult surveillance areas, cameras were used where more creative and automated systems might have been developed.
    - The issue of system maintenance (repair and preventative) must be addressed in the design. Inspectors must be able to carry out diagnostic examinations of systems at locations remote from IAEA headquarters or the systems themselves must be capable of providing sufficient diagnostics in their state-of-health (SoH) information such that technicians at headquarters can provide remote instructions to the inspectors to carry out repairs. A modular design with exchangeable components, kept on-site, would also assist the inspectors in timely repairs to a system.
    - The experience at the RRP has advanced the capabilities of the IAEA to inspect as such large scale facilities through advanced instrumentation. The safeguards systems at RRP were installed with the primary purpose of continuously monitoring the flow and storage of the majority of the nuclear material from the headend of the reprocessing plant to the backend of the mixed oxide (MOX) (fuel) conversion plant. (Appendix A provides an overview of the installed safeguards systems at RRP.)

- Sampling and analysis.
    - The operator's sampling system installed at RRP is shared by the inspectorate. For the inspectorate to use the system, IAEA developed and installed an automatic sampling authentication system (ASAS) (see Appendix A). ASAS ensures the integrity of the empty and

full inspector sampling vials and tracks them from the inspectorate OSL to the sampling bench and back to the OSL. It also provides assurance that the correct vessel is being sampled.

- Although the RRP sampling system far exceeds any system previously available, it could be improved. The automated system has limited capabilities for sampling multiple vessels simultaneously, and the scheduling of samples requires significant advanced planning. This is a definite handicap when implementing random, short-notice sampling by the inspectors.
- The joint-use (IAEA/state) inspectorate OSL built at RRP provides a number of benefits, as outlined below.

  For the inspector—

  — Improved control of inspector samples and reduced chance of tampering.
  — Timely analytical results of equal quality to those of the IAEA SAL near Vienna.
  — Large sample aliquots can be handled as compared to the dried samples sent to SAL.
  — Waste can be recycled to the RRP process.
  — Reduction in the cost of shipping samples to SAL.

  For the operator—

  — Reduction of resource requirements for preparation of inspector samples.
  — Significant reduction of paperwork required for the shipping of inspector samples to SAL.
  — Reduction of operator responsibilities for handling of inspector samples and chances of mishaps.
- The roles and responsibilities of a joint-use OSL must be defined early on, including building and operating costs, which can be extensive.
- In a joint-use laboratory, procedures must be in place to ensure that all parties can reach independent results. This includes

  — CoK of samples and analyses,
  — control of all measurement systems and software, and
  — consideration of issues related to sharing data with the state.
- Safety, operating, and training issues must be addressed.
- Quality control and assurance procedures must be implemented and managed.
- Secure and timely data reporting procedures and mechanisms must be established.

- System security and authentication. To save on financial resources, physical space, and access constraints in the plant, it was recommended by LASCAR that joint-use systems, and preferably operator systems, be used by IAEA and state inspectorates. This proved to be a difficult and expensive endeavor.

  Measures must be introduced to provide—

  - Assurance that data have originated from a known source and have not been altered, removed, or substituted.
  - Assurance that data from joint-use systems cannot be used in such a way as to influence the accountancy and operational declarations of the operator to the inspectors.
  - Assurance that the state cannot use knowledge of the systems and the data in collaboration with the operator to defeat the implementation of reliable IAEA safeguards measures and investigations into possible discrepancies.

- For unattended systems, a level of assurance that is comparable with other safeguards measures. This assurance should be equal to that expected by the international finance and intelligence communities who require assurance that sensitive information has originated from a known source and has not been altered, removed, or substituted.

Methods of authentication—

- Installed technical methods.
  - Hardware: Tamper indicating enclosures (TIEs) or sealed TIEs; seals; camera surveillance; safeguards conduit; and motion, heat, or radiation sensors.
  - Software: IPsec, “sign and forward”, varying levels of password control, delayed data access for operator/state, and other methods of data encryption.
- Procedural methods.
  - Portable cable testers, optical time domain reflectometer, and portable pressure gauges.
  - Cross-correlation of data from a number of sources. This could be various sources for the same piece of data. Or it could be related data from various sources, such as adjoining vessels.
  - Sealed standard containers and sealed source.
  - Short notice random sample taking for independent analyses.
  - Short notice random visit by inspectors (observations or measurements).
- As a result of the experience gained from the implementation of joint-use systems at RRP, it is highly recommended that all parties, operator, state, and IAEA, have independent measuring and monitoring systems wherever possible.
- Data sharing. Neither the operator nor the state should normally receive IAEA verification data before receipt of the operator declaration (OPD), as receipt of that data could influence the OPD. Therefore, the operator’s accountancy measurement and reporting system must be as efficient and responsive as possible.

- DC&E. Based on experience in developing the I3S for RRP, the following requirements can be identified for consideration in developing such a DC&E system.
  - Data should be transmitted from the various inspector measuring, monitoring, and surveillance stations within the facility to a central database, possibly in the local inspector’s office and/or at IAEA headquarters.
  - Data should include SoH information from the various systems.
  - Data should also be received from the operator (OPDs) or state and from the IAEA analytical laboratory, whether it is an OSL or SAL.
  - OPDs should include not only accounting data and source details but also schedules and relevant operational information.
  - All data and information must be encrypted or secured in some manner for transmission.
  - The inspector data system should not be physically connected to any facility operational systems to prevent any threat of interference with plant operations.
  - Software should be capable of performing reviews and extensive pre-evaluations of data in an automated, real-time mode.

- The system should automatically call attention to possible data discrepancies, schedule changes, and completion of actions and should announce irregularities in the SOH.
- The system should allow for interactive reviews and “drill-down” capabilities to allow for final inspector reviews and investigation of possible discrepancies.
- Report-ready summaries and evaluations should be available at various stages of the verification process.
- Design specification for the software integration for the DC&E systems must be started very early and be an integral part of the safeguards approach. The I3S for RRP was started much too late, which required a change in OPD formatting and data transmission procedures. Both were costly changes.
- The handling of operator proprietary information must be addressed early and built into the design of the DC&E.

- Operator/state–inspector interface.
  - Financial and human resources need to be shared by the operator, state, and IAEA, with the operator carrying the largest burden.
  - The provision by the operator of a CFE to work with the IAEA safeguards team in Vienna was a significant contribution towards timely and clear communications between Vienna and Japan.
  - Responsibilities for equipment development, procurement, and installation should be shared by the operator, state, and IAEA. However, each party must ensure that the equipment meets its individual requirements and will provide independent results.
  - Inspector requirements can place a heavy burden on the operator in the areas of system and process design modifications, equipment installations, adjustments to testing and calibration procedures, and schedule disruptions. Early and continuous consultation between parties can reduce this burden.

Conclusions

Any discussion of lessons learned from RRP is also a culmination of lessons learned from all international safeguards applications at reprocessing facilities that came before. Many of the issues addressed at RPP have always been concerns. These include the need for increased independent verification measurements, more timely evaluations, deployment of evolving technologies, and, most importantly, starting the planning and negotiations for the safeguards approach as early as possible in the design and construction of new facilities.

The RPP effort was the largest and most complex safeguards application IAEA has faced. It encompassed the issues that have evolved with all applications over the years but also included a lot of new issues that will influence and offer lessons learned for future applications. Certainly the large throughput of a commercial scale facility challenged the ability of current safeguards and measurement technologies to meet IAEA detection goals. While this pushed the technology and development, the deployment also proved to be expensive. In the end, it might have been more practical and less expensive if the measuring and monitoring equipment had been owned and controlled by IAEA, reducing the cost of authentication. However, the reality of the physical constraints in a plant will always dictate that some systems must be jointly used by the various parties.

RPP is a lesson in itself, because it is not only the facility design that dictates the safeguards approach, but also the country of location; the geographical accessibility of the facility, from the Agency in Vienna or regional offices; and the participation, or sometimes lack of participation, by state authorities. In Japan there is a strong national influence and a strong national authority that actively influence all aspects of the design and application of the safeguards approach. Also, a facility which might be built in an area easily accessible from Vienna could possibly rely more heavily on inspector presence rather than extensive (and expensive) unattended verification systems. In the case of RPP, which is located in a remote area of Japan, a much heavier reliance on unattended systems was dictated.

But clearly the most relevant lesson learned from both RPP and all previous efforts by IAEA to deploy international safeguards is that the involvement and dialog between all interested parties must start from the earliest stages of the project. This is important not only for the design of the operator and inspector equipment and the development of the safeguards approach, but also for IAEA resource planning, both human and financial. This cooperation needs to continue during construction, commissioning, operations, and eventual decommissioning. The problem of maintaining CoK of the work and of experienced personnel throughout the safeguards implementation phase will always remain a challenge to IAEA. However, with the assistance of good program management skills and tools and the contribution from outside resources, the challenge can be met.

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Appendix A. Installed Safeguards Systems in the Rokkasho Reprocessing Plant

1. Integrated Spent Fuel Verification System (ISVS)

Purpose:

- To verify the unloading and receipt of spent fuel assemblies in an unattended mode for gross defects (100%).
- To verify that shipping casks are empty when leaving the unloading area, using surveillance.
- To maintain continuity of knowledge (CoK) of the inventory of spent fuel using aerial surveillance and radiation monitoring of passages.

Description: ISVS is based on surveillance cameras and nondestructive assay systems; it is an unattended system with joint use by IAEA and the state.

- Twelve aerial cameras, mounted on walls above the storage ponds, ensure the surveillance of the spent fuel storage.
- Six underwater cameras, mounted in the unloading bays, ensure that the casks are leaving empty and that the radiation detectors are not being shielded.
- Two redundant MiniGRAND based detector assemblies, mounted in the unloading canals, monitor the gamma and neutron signals emitted from the spent fuels as they move through the canals. Each of the MiniGRAND collects the signal from 2 detector assemblies, for a total of 8 neutron detectors and 8 gamma detectors.
- The combination and location of the neutron and gamma detectors provide a differentiation of whether the spent fuel is going in or out (neutron and gamma signals) and if it is a shipment of poison rods and channel boxes (gamma signals but no neutron).

2. Integrated Headend Verification System (IHVS)

Purpose:

- IHVS-Spent Fuel (IHVS-SF) maintains CoK of the spent fuel as it moves through the mechanical feeding cells to the shear cells and provides the spent fuel IDs.
- IHVS-Leached Hulls Drumming Cells (IHVS-LHDC) monitors the movement of the hulls drums after filling and during transfer to RHMS (see below) for measurement and then transfer to retained waste and provides the drum IDs. It can be used as backup for RHMS.

Description: Unattended systems; joint use by IAEA and state.

- IHVS-SF: 4 camera-radiation detector (CRD) systems, installed on the spent fuel mechanical cell lines, are inserted through the walls of the mechanical cells to monitor the passage of the spent fuel assemblies as they are brought into the feeding cell, transferred to the shearing cell with the tilting crane, and sheared. Each CRD contains a digital camera, a neutron detector, and an ionization chamber. In addition, each line has 1 in-cell radiation hardened camera which provide surveillance of the shearing machine, and 2 (unauthenticated) operator’s cameras which provide the possibility to read the ID of the spent fuel before shearing.
- IHVS-LHDC: 3 CRDs, based on the same principle as the ‘SF’, monitor the passage of the hulls drums from the filling station to the RHMS and then to retained waste, and record the drum IDs.

3. Rokkasho Hulls Measurement System (RHMS)

Purpose:

- To provide semi-quantitative assay of the nuclear material content in the leached hulls and end pieces of the spent fuel assemblies.

Description: Unattended system; joint use by operator, IAEA, and state.

- Installed in similar locations as the operator's system, RHMS uses 3 neutron counters on each hulls line, A and B, independent from the operator. While the operator uses an active measurement method, the RHMS detects the passive neutrons from the curium in the leached hulls and end pieces. It is assumed that the Cm/Pu/U ratios in the hulls are similar to that in the dissolver solution. These ratios are determined in the input accountancy sample by the on-site laboratory (OSL).

4. Vitrified Canister Assay System (VCAS)

Purpose:

- To provide semi-quantitative assay of the nuclear material content in the vitrified waste before being transferred to measured discards for termination of safeguards, and verifies that the NM has been effectively vitrified and practically irretrievable.
- To provide the ID of the canisters.

Description: Unattended system; joint use by IAEA and state.

- VCAS is an independent system equipped with fission chambers [two U235 and a U238 fission chambers]. These counters collect the neutrons emitted by the curium-244.
- The ratios Cm/Pu/U, as determined at OSL, lead to the respective amounts of Pu and U. The relative positions of the fission chambers provide confirmation that the canister is filled. The ratio of thermal/fast neutrons (respectively, U235 chamber/U238 chamber) provides verification that the canister does not contain aqueous solution and therefore must be vitrified.
- In addition, ionization chambers and surveillance cameras are installed on the route to and from the vitrification cell to confirm that canisters are not resubmitted for measurement.

5. Waste Crate Assay System A (WCAS-A)

Purpose:

- To provide semi-quantitative assay of the nuclear material content in the low active waste crates.
- To provide the ID of the waste crates.

Description: Unattended system; joint use by operator, IAEA, and state.

- The system is equipped with helium-3 detectors measuring the neutrons from the curium-244. The ratios of curium-244/plutonium/uranium are provided by the operator based on the building origin of the waste. The ratios were established during active commissioning.

- The detectors are distributed in different arrays (thermal, fast, shielded, and not shielded). This distribution allows for the estimation of the thermal effect of the matrix of the waste, and the measurement of wastes containing fission products.
- Two digital cameras provide the ID of the waste crate and ensure that it is not resubmitted for measurement.

6. Waste Crate Assay System B (WCAS-B)

Purpose:

- To provide semi-quantitative assay of the nuclear material content in the low active waste crates.

Description: Attended system; joint use by operator, IAEA, and state.

- The system is based on passive neutron coincidence counting and is designed to measure small quantities of separated plutonium in low active solid waste crates.
- After measuring several crates and before transferring them to retained waste, the operator provides the inspector with the list of items and the measurement results. The inspector verifies by random remeasurement of the declared items in attended mode.

7. High Resolution Gamma Spectrometry (HRGS)

Purpose:

- Provides semi-quantitative assay of the nuclear material content in the Low Active Waste Drums from the mixed oxide (MOX) conversion process, having no fission products.

Description: Attended system; joint use by IAEA and state.

- The system is based on the IAEA standard gamma spectrometry verification system (HRGS with portable Inspector Multichannel Analyzer). The software is enhanced to be able to provide an estimation of the quantity of plutonium. It includes—
    - a high resolution germanium detector, mounted on a trolley;
    - a portable IMCA; and
    - FRAM and ISOCS software, which has been adapted to accommodate the "Infinite Energy Method." This method provides a quantitative assay without depending on an operator isotopic declaration.
- Similar to WCAS-B, the verification is performed randomly and on a measurement campaign basis. The operator's declaration to be verified is based on the operator owned Waste Drum Assay System (WDAS), which uses neutron coincidence counting and gamma spectrometry.
- Measurement time is around 15 minutes and the expected detection limit is below 1 g of plutonium.

NOTE: The WDAS was originally planned for joint use by the inspectors. However, the cost of authenticating the system could not be justified.

8. Plutonium Inventory Measurement System (PIMS)

Purpose:

- To provide timely inventory measurements of plutonium in the glove boxes of the MOX conversion process lines at the time of the interim inventory verification (IIV). Does not include the Temporary Canister Storage.
- To provide continuous monitoring of the flow of MOX powder through the process lines to ensure that the operations are as declared.
- To provide verification of cleanout and/or process holdup of nuclear material in the glove boxes at PIV.

Description: Unattended system; joint use by operator, IAEA, and state.

- The system uses 142 helium-3 neutron detectors installed on the MOX process glove boxes. Up to 8 detectors/amplifier units are connected to a "hub unit." There are 30 hubs linked by a high speed fiber optic loop to the data acquisition computer (DAC) which timestamps the data. The DAC calculates the count rate information and transmits that data to a data processing computer (DPC) which calculates the plutonium and uranium distribution throughout the glove boxes. The total neutron signal of each detector is analyzed and, using the plutonium and uranium values and isotopic composition from the feed solutions, provides the total inventory in each glove box.
- Calibration and validation were carried out during active commissioning. Known amounts of plutonium were introduced into the process glove boxes and PIMS measurements were evaluated to adjust the calibration parameters.

9. Temporary Canister Verification System (TCVS)

Purpose:

- To provide inventory measurements of the plutonium in the MOX Temporary Canister Storage.
- To monitor the flow of MOX into and out of this area.

Description: Unattended system; joint use by IAEA and state.

- TCVS is a neutron coincidence based system for measuring the stored MOX powder. Three helium-3 detectors are installed on each side of the three storage pit locations (18 detectors per line).
- TCVS is designed to determine—
    - the number of MOX temporary containers that are present "left," "mid," and "right" and
    - the amount of plutonium mass by "known alpha" analysis in the 3 storage pits in each glove box of lines A and B. The isotopic composition is provided by the operator, and later verified by comparison to analyses of samples taken from the solution feed.

10. Improved Plutonium Canister Assay System (iPCAS)

Purpose:

- To provide quantitative verification of the MOX product in canisters, before they are placed in the MOX storage under dual containment and surveillance (C/S).
- To verify the ID of the MOX product canisters.

Description: Unattended system; joint use by IAEA and state.

- The iPCAS is based on neutron coincidence technique and gamma High Resolution gamma spectrometry.
- Two concentric arrays of helium-3 tubes, one undermoderated, the other overmoderated, provide correction for the moisture content. The quantity of nuclear material is determined using the operator isotopic composition (based on IDMS results).
- Three HPGe detectors, respectively positioned in front of each can of MOX, verify the isotopic composition of the operator. The detectors are electronically cooled and thus don't require liquid nitrogen.
- One digital camera provides the canister IDs.
- The detectors and ID camera are installed in a large shielded enclosure with access from the top for the canisters.

11. iPCAS Load Cells (IPLC)

Purpose:

- Verify the weight of the filled MOX Product Canisters, each containing three filled cans.

Description: Unattended system; joint use by IAEA and state.

- The IPLC is uses a precision load cell, which is installed in the iPCAS. It has an accuracy better than ±0.042%.As the empty MOX canisters move from storage to the canister filling glove box, the empty canisters are placed inside the iPCAS for tare weight measurement and ID check.
- After being loaded with 3 filled cans in the dedicated glove box, they are placed again in the iPCAS where the IPLC measures the gross weight and verifies again the ID while iPCAS carries out measurements for the plutonium and uranium content.

12. Directional Canister Passage Detectors (DCPD)

Purpose:

- To monitor the transfer of the MOX product canisters, after they have been verified with the iPCAS and IPLC and until they reach the MOX storage where they are put under dual C/S.

Description: Unattended system; joint use by IAEA and state.

- The DCPD is based on neutron counters installed along the path from the iPCAS to the MOX storage. The detectors in combination with eight cameras along two routes provide surveillance of the transfer carts in the corridors leading to each of the MOX storages.

13. MOX Storage C/S System (MSCS)

Purpose:

- To apply dual C/S on the MOX product storage area after verification by iPCAS and transfer under DCPD monitoring, in order to reduce or eliminate reverification at IIVs and the PIV.

Description: Unattended system; joint use by IAEA and state.

- Component 1: 2 area surveillance cameras looking over the storage pits.
- Component 2: A combination of—
  - o one DCPD type of neutron detector at the entrance hatch,
  - o one DCPD type of neutron detector at the unloading position of the transfer cart,
  - o one DCPD type of neutron detector at the personnel door,
  - o one metal seal on the back door, and
  - o one surveillance camera looking at the unloading position and providing the canister ID. In addition, an electromagnetic switch placed on the rail and/or hatch triggers this camera.

14. Uranium Bottle Verification System (UBVS)

Purpose:

- To verify the transfer of the UO_3 product before it is placed under C/S in the UO_3 product storage.

Description: Attended system; not joint use.

- The UBVS is based on standard IAEA portable uranium enrichment and weighing equipment. It comprises—
  - o CdZnTe detector connected to a standard IMCA with MGAU software (IMCC),
  - o rack (provided by the operator) for holding the bottle during measurement, and
  - o flat weighing scale.
- After weighing, the operator stores the UO_3 bottles in one of the storage bays. These bays are under USCS (below) surveillance. Periodically, and after a sufficient number of bottles have been produced and stored, an IAEA verification is scheduled. The inspector randomly selects the bottles to be verified and notifies the operator through the state inspector. The IAEA inspector then sets up the scale and the IMCC. The operator brings the UO_3 baskets to the measurement location, takes the lid off, and places the selected bottle inside the measurement rack, with the weighing scale underneath it. The inspector performs the weighing and enrichment measurements simultaneously and then verifies that the bottles are returned to the storage.

15. Uranium Storage Containment and Surveillance (USCS)

Purpose:

- To apply dual C/S on the uranium product storage, in order to reduce or eliminate the requirements for reverification of UO_3 bottles at the PIV.

Description: Unattended system; joint use by IAEA and state.

- Dual C/S comprises the following.
- Component 1: 4 surveillance cameras on the path of the bottle from the exit of the measurement room to the entrance of each storage bay.
- Component 2: A rail block and metal seal applied on the transfer machine rail of each storage bay. The seal is applied only when a storage bay is full or no longer in use.

16. Solution Measurement and Monitoring System—Type 1(SMMS-1)

Purpose:

- To measure and monitor the solution levels, volumes and densities in the most safeguards significant vessels in the main process.

Description: Unattended system; joint use by IAEA and state.

- SMMS-1 uses high accuracy, independent and authenticated pressure measurement devices in the 12 most important process vessels. A volume measurement uncertainty of ±0.05% was achieved during commissioning. The instruments are connected directly to the pneumatic dip tube measurement lines of the vessels.
- One additional pressure transmitter specifically measures the absolute pressure in the vapor space of the plutonium concentrator. Pneumatic bubbler transmitters evaluate the airflow in the pneumatic bubbling system on the two most critical vessels, the Input and Output Accountancy Tanks.
- The system includes very high accuracy differential pressure measurement devices manufactured by Ruska , Programmable Logic Controllers (PLCs) for instrument interface, and PCs for data collection, evaluation of state-of-health information, and data buffering and authenticated data transmission to the inspector's DC&E computer.

17. Solution Measurement and Monitoring System—Type 2(SMMS-2)

Purpose:

- To measure and monitor the levels, volumes and densities in vessels of less safeguards significance in the main process.

Description: Unattended system; joint use by IAEA, state, and operator.

- SMMS-2 uses mainly industrial pressure measurement devices in 80 process vessels. These can be pressure or temperature sensors, as well as neutron detectors mounted on the extractors in the main process. The signal is split from the operator pressure transducers, sent to the Inspectorate cabinets in each building and then to the inspector's DC&E computer.

18. Solution Monitoring Software (SMS)

Purpose:

- Process and analyze the data from SMMS-1 and SMM-2 instruments.

Description: SMS is a highly developed piece of software used routinely by the IAEA inspectors in the on-site inspector office, and includes configuration, preprocessing and evaluation functions. It automatically analyzes the data from the sensors (pressure, temperature, neutron detectors). It detects events in a series of data, compares the events with reference signatures, and raises alarms in case of differences (auto-correlation). It also calculates the volume transferred at the various flow points and correlates the information between sender and receiver vessels (cross-correlation). It provides the inspector with a high level graphical user interface, for configuration, parameterization, or evaluation.

19. Automatic Sampling Authentication System (ASAS)

Purpose:

- To authenticate the sampling jug and the taking and transfer of samples from the operator's process sampling benches to the joint use IAEA/state inspector's OSL.
- To authenticate that the sampling points continue to be connected to the declared sampling benches.

Description: Unattended system; joint use by IAEA and state. Operator owned and modified by IAEA/state.

- Sample jug. Consists of an inner pre-evacuated polyethylene vial in an outer cartridge used for transportation through a pneumatic transfer network (PTN).
- Inspector Jug Feeding Machine (IJFM). Loaded with sampling jugs which are sent to the sampling bench on command of the operator, based on a sampling schedule provided by the inspectorates.
- Sampling bench. A remotely installed and operated system which can sample up to 24 vessels. Each of the 24 sampling heads is fitted with a needle to pierce the septum of the evacuated sample vial and draw sample from the selected vessel. There are 23 sampling benches installed in 6 of the Rokkasho Reprocessing Plant buildings.
- PTN. A network of aluminum piping through which empty or full sampling jugs are transported at a speed of 20m/sec. The system is fitted with direction changers (2, 3, or 6 way) which provide for flexible routing of the sampling jugs.
- Jug Passage Detectors (JPDs). Used by the operator to monitor the correct routing of the jugs and for safety in case of jamming within PTN. The JPD is a photoelectric sensor that records the passage of the sample jug when the light beam is cut.
- Independent Jug Passage Detectors (IJPDs). Inspectorate owned and controlled JPDs installed at strategic locations on PTN to track the empty inspector sample jugs from IJFM to the sampling benches and the filled jugs back to OSL; record the flight time between IJFM, sampling bench, and OSL; and monitor sample jugs going to the operator's laboratory and those to OSL.