VALIDATION AND PERFORMANCE TEST OF THE PLUTONIUM INVENTORY MEASUREMENT SYSTEM (PIMS) AT THE ROKKASHO REPROCESSING PLANT (RRP)

Dan Parvin

British Nuclear Group, Project Services Limited, UK

ABSTRACT

At the Rokkasho Reprocessing Plant (RRP), MOX powder is converted from Plutonium-Uranyl nitrate solution by microwave heating. In this process, a large quantity of bulk plutonium material is transported within the plant. LASCAR (Large Scale Reprocessing Plant Safeguards) recommended the need for safeguards measures to detect on a continuous basis both the normal movement and possible diversion of material. As a result JNFL installed the Plutonium Inventory Measurement System (PIMS) developed by BIL Solutions – now the Services and Instrumentation division (S&I) of British Nuclear Group, Project Services (BNGPS) at RRP.

The Plutonium Inventory Measurement System (PIMS) employs novel electronics designed to permit unattended use by Safeguards Inspectors. The design and functionality of this system has been developed in close collaboration with both the operator (JNFL) and IAEA Safeguards Inspectors to provide a system that meets the operator's requirements for non-intrusion into plant operations, and also the IAEA's requirements for validation and authentication of declared plant operations.

As part of the system validation, active tests were performed in October 2006 in order to confirm the accuracy and performance of the PIMS system.

INTRODUCTION

The PIMS system developed by BNGPS is an installed, non-intrusive measurement system capable of determining the quantity and distribution of plutonium process materials throughout an operating plant. This information is used for material accountancy purposes and provides operators with a near real time indication of the distribution of plutonium in the plant, allowing early identification of plant abnormalities, such as blockage occurrence, spillages etc. The system operates 24 hours a day and does not interfere in any way with the continuous nature of the plant process.

Verification of the PIMS was performed in two stages. Firstly, an inactive calibration campaign in 2003 used an intense neutron source moved throughout the process line to simulate neutron emitting material.

The sensitivity of each detector to this "point" source in each of the calibration positions was accurately measured and the data used to build a calibration matrix, defining the response of each detector to material within each process area to be monitored. This calibration matrix is used to interpret the count rate data from the detectors and to estimate the plutonium mass in each area.

Secondly, an active campaign compared actual known masses of material with the results obtained from PIMS measurements. In this test U-Pu nitrate solution was first introduced into the MOX conversion area in October 2006. Validation tests using MOX powder were performed in order to check the accuracy of the system and derive any further optimization parameters. The testing was conducted by JNFL in co-operation with BNGPS and IAEA inspectors.

Details are provided of the PIMS system, electronics platform, overview of the safeguards validation and authentication measures, and a summary of the results of the active tests.

PLUTONIUM INVENTORY MEASUREMENT SYSTEM (PIMS)

The PIMS is a distributed total neutron counting system jointly used by JNFL and the IAEA to meet a number of requirements. The sharing of such instrumentation and data reduces the costs associated with such safeguards equipment to both the operator and the safeguards authorities.

The system uses total neutron counting techniques to determine the overall count rate at each neutron detector and mathematically deconvolutes the responses from each detector to determine the number of neutrons emitted from each plant item (vessels, gloveboxes, etc.) using a knowledge of the response of each detector to each plant area determined during commissioning.

This calculated neutron emission is then converted into an equivalent mass of plutonium using known or declared material characteristics (plutonium and uranium isotopic composition, chemical compositions, etc.). This enables a determination of the distribution of material throughout the plant to be made.

The ability to monitor all process areas for Pu conversion and finishing at RRP simultaneously and the rapid update time of the system (approximately 60 seconds) permits near real-time tracking of process material to be performed.

The specific requirements for the PIMS at RRP are:

- to provide a monitoring system that enables continuous tracking of process material as it moves through the plant in order to provide assurance that the plant is being operated as expected. The near real-time nature of the PIMS permits the safeguards authorities to monitor plant activities and maintain continuity of knowledge over process material being fed into the plant. This tracking and monitoring also provides the operator with reassurance that the plant is functioning correctly and material blockages are not occurring.
- a plutonium inventory monitoring system that provides a 'snap-shot' view of the inventory within the plant and the distribution of that material. The system is used both for the operator to declare such inventories (in conjunction with book accountancy and other methods) and by the inspector to verify that the operator declared data is correct
- a means of confirming that the plant has been effectively cleaned out of all process material prior to performing the annual Physical Inventory Verification (PIV) measurements

In the case of RRP, 142 commercially available ^{3}He neutron detectors are employed around the main processing gloveboxes and in any adjacent areas that may contain significant quantities of plutonium. The electronics platform used has been developed specifically for high speed distributed systems to provide optimum performance, high reliability and minimum cost.

Figure 1 shows an overview of the PIMS electronics system, detailing the individual components and how they are linked together. This is a new electronics platform with an integrated Safeguards capability incorporated into the design Ref. [1, 2].

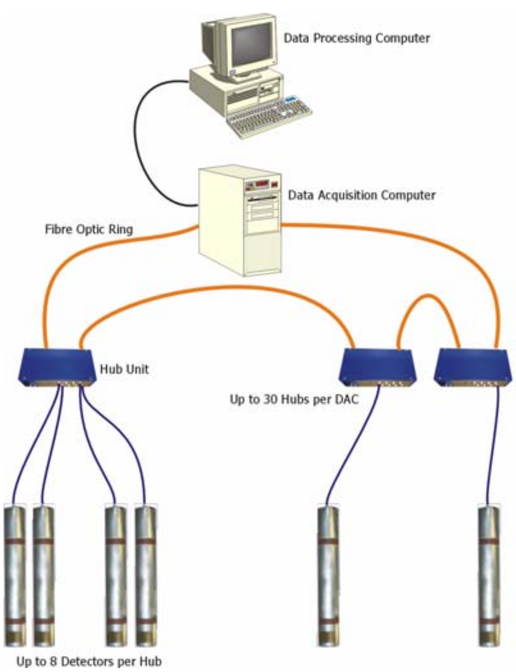

Figure 1: Typical PIMS electronics platform

Figure 2: Head amplifier design showing the cable connection to the HUB unit

Figure 3: HUB unit design

Each of the 142 neutron detectors at RRP is fitted with its own directly mounted slim-line head amplifier and the coupled detector and amplifier are mounted within a cylindrical polyethylene moderating module. This close coupling ensures minimal noise pickup between the detection and amplification stages when operated in industrial environments. These amplifiers (shown in Figure 2) are simple low cost units with no serviceable components and as such are designed to be disposable in case of failure.

The detector/amplifier combinations are connected to a hub unit where processing of the amplified signal is performed. Typically each channel comprises one detector and amplifier although the system is sufficiently flexible to permit multiple detectors to be connected in parallel into a single amplifier unit.

Each hub unit (shown in Figure 3) provides all high and low voltage power supplies for a maximum of 8 amplifiers and detectors thereby reducing the complexity of the amplifier design. The hub also provides all signal processing (pulse shaping and noise discrimination) for the signals from the neutron detectors and assigns a digital address to the pulse that identifies the hub/neutron detector combination where the pulse originated.

This digital address data is then sent via a high speed fibre optic link to a dedicated Data Acquisition Computer (DAC) where the address data is retrieved by a timestamper unit and appended with “time of arrival” data. The high speed of data processing and transmission along the fibre optic link ensures that the time of arrival of the pulse at the timestamper is effectively the same as the time of neutron detection. In this manner, the detector that generated the pulse (i.e. detected the neutron) and the time of arrival of this data at the timestamper are recorded and used to determine the neutron counting rates for each neutron detector.

The count rate information generated at the DAC is then transmitted over a local instrument network to a Data Processing Computer (DPC) where the count rate is analysed to calculate the plutonium and uranium mass distribution throughout the plant. The mass distribution and uncertainty information may then be sent over a plant network to the plant control computers (not shown on Figure 1).

This system offers a number of benefits over conventional hardware based systems:

Scalability – the system permits the use of a single detector to up to 8 detectors per hub and up to 30 hubs per data acquisition computer (DAC), giving a maximum number of up to 240 detectors per DAC. Expansion beyond this point is possible using additional networked DACs.

Flexibility – as all data processing and analysis is performed within the application software the system can be configured to perform total, coincidence or multiplicity analyses without the need for alternative or additional hardware. This also minimises the need to maintain spares holdings since all neutron counting systems (whether total, coincident or multiplicity based) may use the same basic modules. Furthermore, as all data may be logged it is possible to process such stored data retrospectively should this prove necessary.

Costs – since the installation of multiple cables (high voltage, low voltage and signal) linking individual detectors back to the central counting computer is replaced by a single fibre optic loop, installation costs and disruption to plant are significantly reduced. Additionally, training of maintenance personnel is potentially reduced due to the use of common components across many neutron counting systems.

Reliability – as the amplifiers are mounted directly onto the neutron detectors there is reduced susceptibility to noise and other interference before or during the amplification stage. Also, since data is transmitted around the facility digitally using fibre optics (up to 1km in length) there is no potential for electromagnetic noise of industrial environments to be introduced following amplification.

Tamper Resistance – as the low cost amplifiers are potted in an electrically insulating resin that prevents access to internal circuitry, hubs are provided within sealable enclosures and fibre optics are monitored for continuity, improvements to the tamper resistance of the system are possible thereby enhancing its application within regulatory environments.

SAFEGUARDS ARRANGEMENTS FOR RRP PIMS

The PIMS monitoring system has been designed with the flexibility to incorporate features that permit enhanced Safeguards to be installed in the system. Many of these features have been designed or developed in close cooperation with personnel from the International Atomic Energy Agency.

The design of the detector/amplifier module has been developed to ensure that access to the detector or amplifier is restricted. A special end-cap (shown in Figure 4) has been designed that inhibits access to any cable connections and permits the use of standard IAEA Safeguards seals.

Figure 4: Design of Safeguards end-cap: (Left) fully dismantled (Right) full Safeguards cap and cable housing assembled onto module

In order to permit Safeguards authorities to monitor the data from the system over the fibre optic network is has been necessary to develop a modified electronics topology. Figure 5 shows the RRP system block diagram.

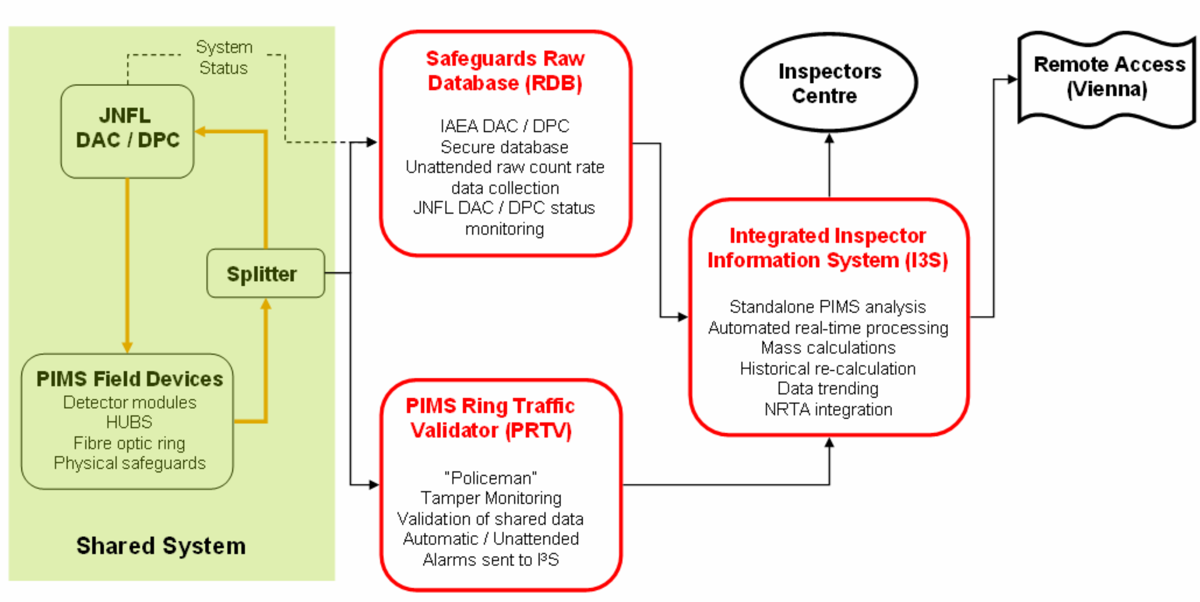

Figure 5: Safeguards arrangement for RRP PIMS

Identical DAC and DPC computers are employed by the safeguards authorities to provide independent processing of the counting data. Unlike the JNFL system, however, the inspector's DPC will operate in unattended mode. Here, the counting data will be transmitted to the Safeguards Raw Database (RDB).

Additionally, a parallel link between the Operator and Inspector systems ensures that the safeguards system is informed of the status of the operator's PIMS. This includes, for example, remote switching of the Safeguards PIMS into Interim Inventory Mode when manually selected at the operator's system, and synchronisation signals to ensure that both systems remain "in-step".

The count rate data is retrieved from the Safeguards RDB into the PIMS subsystem of the Integrated Inspector Information System (I3S). This system validates the digital signature on the data and then performs the same mass calculations as the operators DPC, storing the mass and uncertainty results in a dedicated IAEA database and permitting inspector access to the data from the Inspector's Centre. The I3S also permits the Inspector to retrieve the mass data from the database and make comparisons between the measured and predicted data. Facilities such as data trending, comparison of masses against action levels, etc. may be performed on this system.

All facilities are remotely accessible via a web interface over a secure IAEA network infrastructure.

Because of the shared nature of the detection equipment the PIMS Ring Traffic Validator (PRTV) system is required to provide validation of all PIMS raw data for the RDB and I3S systems. This system was designed specifically for the IAEA to meet their specified validation requirements and provides continuous, fully automatic and unattended operation. The PRTV monitors all data before and after the detection equipment for signs of unauthorized tampering, either on the fibre optic ring or the data collection equipment. In the event of an alarm, the result is sent directly to the central Safeguards system.

RRP PIMS VALIDATION

In 2005, JNFL proposed a series of active validation measurements to be performed as part of the active testing phase of the RRP. Discussions between the safeguards authorities and BNGPS resulted in confirmation of a set of test measurements (detailed below). The testing was performed in October 2006, inspected by the IAEA with personnel from BNGPS in attendance. A comparison of declared mass values with PIMS measured data was performed. A sample of measurement results are presented in Figures 6 and 7. The process monitoring capability of PIMS was also assessed, examples of which are presented in Figures 8 and 9.

Overview of validation measurements:

<u>De-nitration Operations</u>
25 batches of nitrate solution were processed through the de-nitration process, and PIMS measurements performed at defined intervals.

<u>Temporary Canister Operations</u>
After the de-nitration process MOX powder was introduced into the calcination, reduction and milling gloveboxes resulting in the production of 4 temporary canisters of MOX.

<u>Blender Operations</u>
During the validation phase a series of controlled material transfers into and out of the blender area were performed. In each case the mass of MOX input from the temporary canisters and removed from the blender area into powder filling cans was measured along with chemical analysis to determine the output MOX mass. Using this input/output data the Pu inventory within the blender was calculated and compared with the PIMS measurement results.

<u>Process Monitoring</u>
During the validation the continuous trend graphs displayed by the PIMS system were analyzed to assess the process monitoring capability of PIMS.

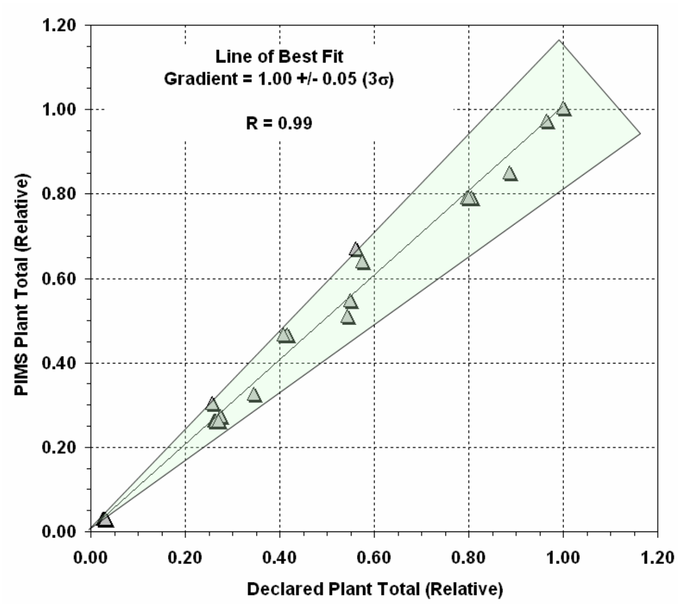

Figure 6:

The target performance for the PIMS plant total inventory is to measure the expected or declared inventory to within an accuracy of +/-6% (1σ) during normal plant operations. The figure opposite compares the JNFL declared plant total inventory against the PIMS measured inventory after optimization. The shaded region represents the target PIMS performance of +/- 6% (1σ).

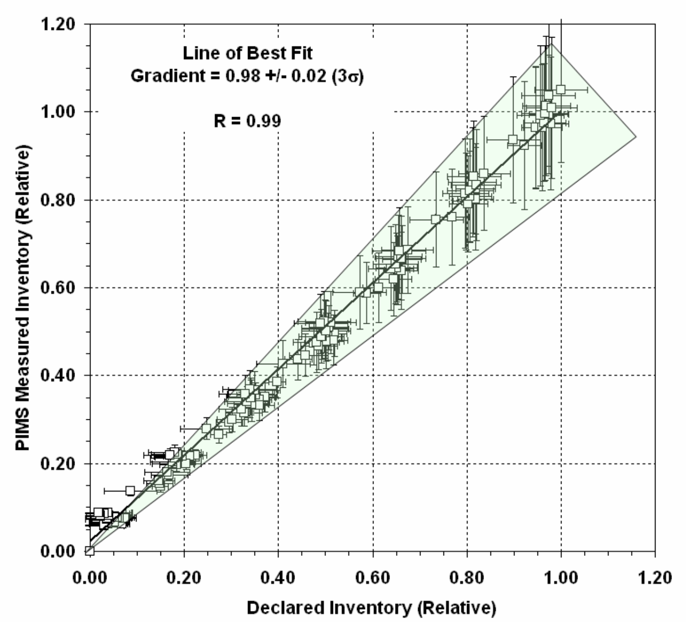

Figure 7:

The target performance for the PIMS blender inventory is to measure the expected or declared inventory to within an accuracy of +/-6% (1σ) during normal plant operations. The figure opposite compares the JNFL declared blender inventory against the PIMS measured inventory after optimization. The shaded region represents the target PIMS performance of +/- 6% (1σ).

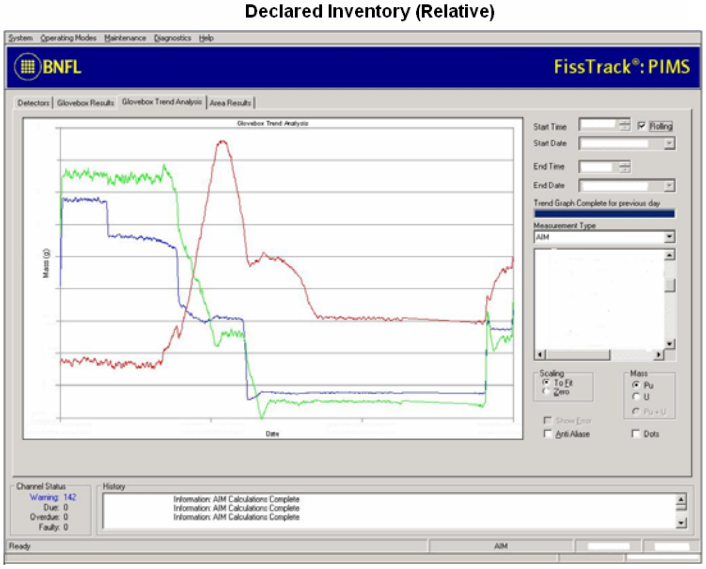

Figure 8:

Example of PIMS real-time process monitoring. Each coloured line represents an individual process area with a glovebox. The transfer of material between process areas is clearly visible.

British Nuclear Group
Intelligent nuclear clean-up

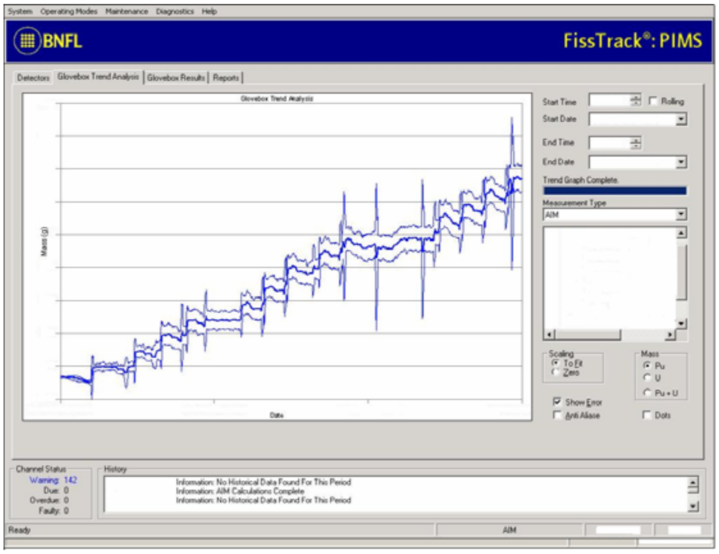

Figure 9:

Example of PIMS real-time plant total monitoring. The steady increase in material mass within the plant is shown along with the associated combined uncertainty. The 'spikes' in the uncertainty profile is characteristic of material movements between calibrated areas.

SUMMARY

Due to its continuous real-time monitoring capabilities, the PIMS provides both the plant operator and the Safeguards authorities with sufficient data to accurately monitor both the plutonium inventory within a working process and the flow of such material throughout the plant process.

The PIMS at Rokkasho has been designed specifically to allow its use by both the operator and the Safeguards inspector. This design process has involved consultation and collaboration with the operators and Safeguards inspectors to ensure that their different requirements were identified early in the design phase of the PIMS. This has resulted in a non-intrusive system that is able to permit the operator to run his plant without interruption while still providing all of the data and authentication measures required by the Safeguards authorities.

The PIMS validation performed in 2006 demonstrated the PIMS functionality and good correlation was observed between declared and measured values during the active tests. The results provide confidence that PIMS can perform measurements satisfying both the plant operators and Safeguards authorities for all plutonium (MOX) plants.

The following highlight the benefits of PIMS for future Safeguards and Pu plant systems:

- A proven technique with extensive experience from a number of operational plutonium facilities
- Total neutron counting allows automated, continuous real time inventory of an operating plant
- In Situ system and therefore no disruption to plant operations
- Shared system designed for Safeguards and plant operations
- Continuity of historical data for investigation of previous plant events
- Re-analysis of historical raw data to maximise inventory accuracy

- Trending of raw and inventory data to aid identification and better understanding of previous plant events
- Proven integration with IAEA Safeguards systems (NRTA, I3S)
- Shared detection system to minimise procurement costs
- Unattended with remote access to minimise operational costs
- Patented neutron time stamping solution – with capability for totals, coincidence and multiplicity data analysis.
- Automated unattended real time tamper detection system (PRTV)
- Common spares
- Past investment = minimal future development costs
- Existing & Proven technology = no development risks

REFERENCES

[1] Neutron Electronics Patent - International Publication Number WO 00/67044

[2] PIMS Patent, Japanese Pub. Number 2002-341045, UK Publication Number GB 2374976A

ACKNOWLEDGEMENTS

BNGPS would like to acknowledgement the collaboration and support of both the IAEA and JNFL