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NUCLEAR MATERIAL MONITORING FOR THE REPROCESSING PLANT RT-1 AT MAYAK

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ABSTRACT
To enhance and modernise the Nuclear Material Accountancy and Control (NMAC) at Mayak RT-1 reprocessing plant the concept of near real time accountancy (NRTA) is applied. A defence in depth concept is proposed with the superposition of the following barriers:

- (i) continuous survey of the functional status,
- (ii) the follow-up of the nuclear material (NM) flow and inventory,
- (iii) Near real time control of declared NM in processed solutions,
- (iv) Periodical Physical Inventory Takings and Verifications.

The combination of an operational network architecture, allowing automatic data acquisition and an efficient plant-specific data analysis and interpretation software enables to follow in near real-time the NM flow and inventory through the plant. The JRC data analysis and interpretation kernel DAI integrated with the commercial data historian Wizcon is proposed to establish the RT-1 specific NM monitoring software tool. The data analysis focuses firstly on a combination of the pressure signals (for level and density) and the temperature signal, determining the total volume. This is then combined with the volume concentration measurement performed by the hybrid K-edge to derive the total mass of nuclear material. Once the complete system is validated, it can be applied also to other Russian reprocessing plants at Seversk and Zheleznogorsk.

RELEVANCE OF NUCLEAR MATERIAL MONITORING IN REPROCESSING PLANTS
In the Russian Federation, according to the NMC&A Basic Rules decree (OPUK, 2003) [3] physical inventory verifications are performed periodically (monthly or annually depending on the category of the material) with a 95% confidence level. To upgrade this traditional NMAC extra safety and safeguards enhancement is aimed at in a TACIS project [4] by providing a process monitoring system, which could identify timely and locally eventual problems with the NM accountancy. This is in line with the IAEA Safeguards approach for a reprocessing plant to monitor the nuclear material inventory and flow timely and locally throughout the complete reprocessing line [1, 2].
Characterisation of the spent fuel solution in the input accountancy tank is the important starting element because no direct measurements of the U and Pu content, the U enrichment and the Pu vector are made on unloaded reactor fuel. Alternatively to Mass Spectrometry (MS) – Thermal Ionisation MS for measuring the isotopic composition and Isotope Dilution MS for the element concentration - it was opted to install the hybrid K-edge densitometer (HKED) measuring the U concentration and the U/Pu ratio, so that a high throughput of samples can be analysed. Moreover the HKED is a non-destructive technique, allowing recycling of the sample solution in the process.
In order to determine the total amount of NM content, the concentration has to be combined with the total volume of input or output accountancy tanks, determined with an uncertainty that is not penalising the accuracy of the concentration measurements. The determination of the volume

combines the results of a gravimetric tank calibration with the measured level of the solution in the tank, for which unattended volume measurement stations were selected for installation at key accountancy tanks.

BACKGROUND SITUATION AT THE MAYAK REPROCESSING PLANT RT-1

The Radiochemical Plant RT-1 at the Mayak site bears many processing facilities, with a throughput of up to 400 tons/yr VVER-440 and BN-600 spent fuel assemblies (SFA). The spent fuel solution (input solution) is transferred to the input accountancy tanks (IAT), filtered and reprocessed to separate fission products, from uranium and plutonium and finally to obtain the final separate products of uranium and plutonium solutions.

The facility under consideration follows a modified PUREX process with additional separation of Np, which differs from the process followed in European reprocessing plants. The site-specific processing procedures cover the mixing of U solutions from reprocessing of VVER-440 and BN-600 spent fuel type and the fabrication of on the one hand low enrichment paste from Uranyl nitrate solutions and on the other hand PuO_2 powders [5].

The structure of the facilities comprises 13 technological areas:

- i) storage for NM received (SFA of VVER-440 and BN-600 reactors);
- ii) assembly identification (passive neutron counting of SFA);
- iii) preparation of SFA batch (cutting off the end parts) for dissolution;
- iv) operations line for assembly chopping and dissolving;
- v) fission products extraction,
- vi) separation/refining nitrate solution of Pu;
- vii) separation/refining nitrate solution of high enriched U (HEU)
- viii) separation/refining nitrate solution of low enriched U (LEU)
- ix) Pu oxalate precipitation and calcination to PuO_2 powder;
- x) Mixing of LEU and HEU solutions; evaporation of LEU nitrate solutions (2.4-2.6%);
- xi) storage for PuO_2 product;
- xii) storage for Uranyl nitrate paste product;
- xiii) vitrification and storage for high and medium level waste.

Following the federal NMC&A Rules each division of the plant has to make a physical inventory each month and the NM account is balanced in all divisions of the plant. The results of measurements of NM content and mass in reprocessed and final products (input solution, U and Pu solutions, liquid wastes, PuO_2 powder and Uranyl nitrate paste) composes the basic information for NM accounting and Inventory Difference (ID) evaluation.

Many installation equipment units and sub-facilities for solution reprocessing may not be emptied or cleaned before the physical inventory for technological and operational reasons. Therefore different NDA techniques and instruments measuring the NM content and mass (level meters, neutron coincidence counters, etc.) are introduced to estimate the hold-up and NM accumulation in the installation. The current instrumentation needs to be enlarged and improved to suffice the evaluation criteria of ID and sigma-ID of the plant at full throughput under the federal rules. Instrumentation capability regarding the measurement accuracy for the final product and the main part of solution transactions between divisions will be upgraded.

An appropriate informatic architectural structure of data acquisition and evaluation and analysis as well as final NMAC reporting is being set-up. Information gathering in so called near-real time with immediate analysis allows a near real time accountancy (NRTA). The complete Solution Monitoring System is setup with level and density measurements, and allows to monitor the volume and mass transferred from one tank to the communicating one. This is in particular applied to the input accountancy tank and the connected ones. The concentrations in nuclear material (U and Pu) of the input accountancy tank solution are measured with the Hybrid K-edge densitometer, so that the total amount of nuclear material that is dissolved can be accurately and almost near real time registered.

MEASURING NUCLEAR MATERIAL FLOW

Mass/volume measurements

Most of the tanks of the RT-1 plant are equipped with the Russian type so-called high frequency inductive level probes, which measure the variation in level by means of an inductance, transformed to a high frequency signal. These level probes are closed and therefore indifferent to the pressurization mechanism (up to 65 bars) used at many tanks in Mayak to transfer solution. They are electronically upgraded and recalibrated in function of the solution's ion concentration to enhance their performance.

However, whenever technically possible, the level measurement is performed using three or more dip tubes. This system remains more accurate because of the high precision of the digital pressure transducers. The twenty tanks at key measurement points, of which ten are accountancy tanks, are equipped with bubble probes. An uncertainty lower than 0.1% (1S relative) is routinely achievable if correction factors are applied to compensate the systematic errors [6] and if humid clean air is supplied at a constant flow rate (typically from 5 to 30 Nl/h) through the bubbling dip tubes of same size. The normalisation of the data to a reference temperature is ensured by the use of a PT-100. JRC Ispra (IPSC) assists with their expertise in the design, installation and use of unattended volume measurement stations for calibration, monitoring and re-calibration of input solution tanks.

Concentration measurements

The Hybrid K-edge Densitometer (HKED) as routinely used in the Euratom on-site laboratories at La Hague and Sellafield measures directly the U volume concentration by K-edge densitometry and the U/Pu ratio by X-ray fluorescence on input samples made of clarified dissolved spent fuel with a typical U concentration around 150-250 g/L, and with a U/Pu ratio in the range of 90 to 130 depending on the burnup of the spent fuel. Accurate measurements are achieved when using sample vials with reproductive dimensions (sample path length) and a small variation on the type of input solution [7].

JRC Karlsruhe (ITU) assists with its expertise in the design, integration into the installation and operation of a dedicated HKED instrument. They provide also the sample changer designed for automated measurements. The very limited space available in the high-active laboratory at Mayak requires the HKED to be installed on top of a shielded hot cell. A specially tailored HKED installation, with a vertical sample changer, has been designed to account for the given boundary conditions.

NETWORK ARCHITECTURE FOR SECURE AUTOMATIC DATA ACQUISITION AND TRANSMISSION

Reprocessing facilities work with a superposition of different acquisition systems as like almost all process industries. The collected data in their original, primitive form labelled with time and date are stored in an archive. These primitive data are sometimes classified as proprietary information and need encryption for any data transfer. Authentication of transmitting and receiving units is an important issue in safeguards applications to avoid unauthorized interception, deletion or modification [8].

To ensure flexibility and extension to future instrumentation, the network architecture was inspired on the Open System Interconnection (OSI) network reference with Object linked embedded Process Control (OPC) standard.[1] The message is authenticated with the addition of a signature and is encrypted with an AES (Advanced Encryption Standard) key.[2]

COLLECTING AND ARCHIVING WITH A DATA HISTORIAN

Experience over many years at the La Hague Reprocessing Plant has proven that a relational database is inappropriate to retrieve and visualise time-series over a selected interval. Instead a real-time database allows to display the time series at any interval with high performance. In order to optimally analyse large amount of time-stamped data, the collected data are compressed by the data historian. For the Mayak application the Wizcon data historian was selected because it supports the standard OPC HDA (Historian Data Access in OLE for Process Control) and allows a connection with a wide variety of OPC servers and a data supply to OPC clients [9]. The compression methods (e.g. swinging door for signals with constant slope and death band for constant signals) have to be optimally parametrised in order to minimise the influence of the data compression on the final NM flow monitoring [10].

The reported data of the historian with their time and date allocation are converted into the required quantities (density and temperature, tank level, volume transfer, gamma/neutron signals) taking into account the standard units, the chemical relationships and the calibration curves. The results of these conversions are stored in the real-time database. An overview of the data architecture for the Mass/Volume instrumentation at the two different locations is given in Fig. 1.

NEAR-REAL TIME MONITORING WITH DATA ANALYSIS AND INTERPRETATION

Process monitoring includes a two-fold task: firstly, a continuous survey of the health status of the instrumentation and process conditions and, secondly, a comprehensive real-time interpretation of the dynamic process functions. These tasks constitute the first two barriers of the defence-in-depth concept. For a reprocessing plant the first part is typically associated with the safety monitoring of the plant, whereas the second part, requiring a thorough understanding of the plants normal functioning and potential diversion paths, brings high value to nuclear safeguards.

A particular aspect of the process control, namely the follow-up of cyclic processes, can be performed by using the DAI kernel developed by JRC for automatic Data Analysis and Interpretation of vast amounts acquired batch data. The specific features of the DAI kernel consist in the analysis by autocorrelation of the signals to check the completeness and by cross-correlation between different simultaneous signals to check the comprehensiveness [11]. The latter covers also the coherency of the process signals with the safeguards purposes. The monitoring tool DAI concept with a generic syntactic pattern recognition analysis kernel and plant-specific design parameters allows to apply the software to different plants. It was validated in a major European reprocessing plant, UP2 and UP3 at the site of La Hague as inspection tool, and it was also applied for solution monitoring at the TETRA facility of the Japanese inspectorate NMCC and for the NM flow monitoring at the Tokai Reprocessing plant by the IAEA.

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[1] In case the network is used by inspector and operator, a mutual shielding can be provided with a Network Address Translation (NAT), enabling a local-area network with a small firewall. NAT modifies the IP addresses, so that only the restricted users can access the info exchange.

[2] The message can be sent to the user using an extra signed header, generated with the encryption key on the original message. This can be achieved with the SOAP (Simple Object Access Protocol) Digital header signature.

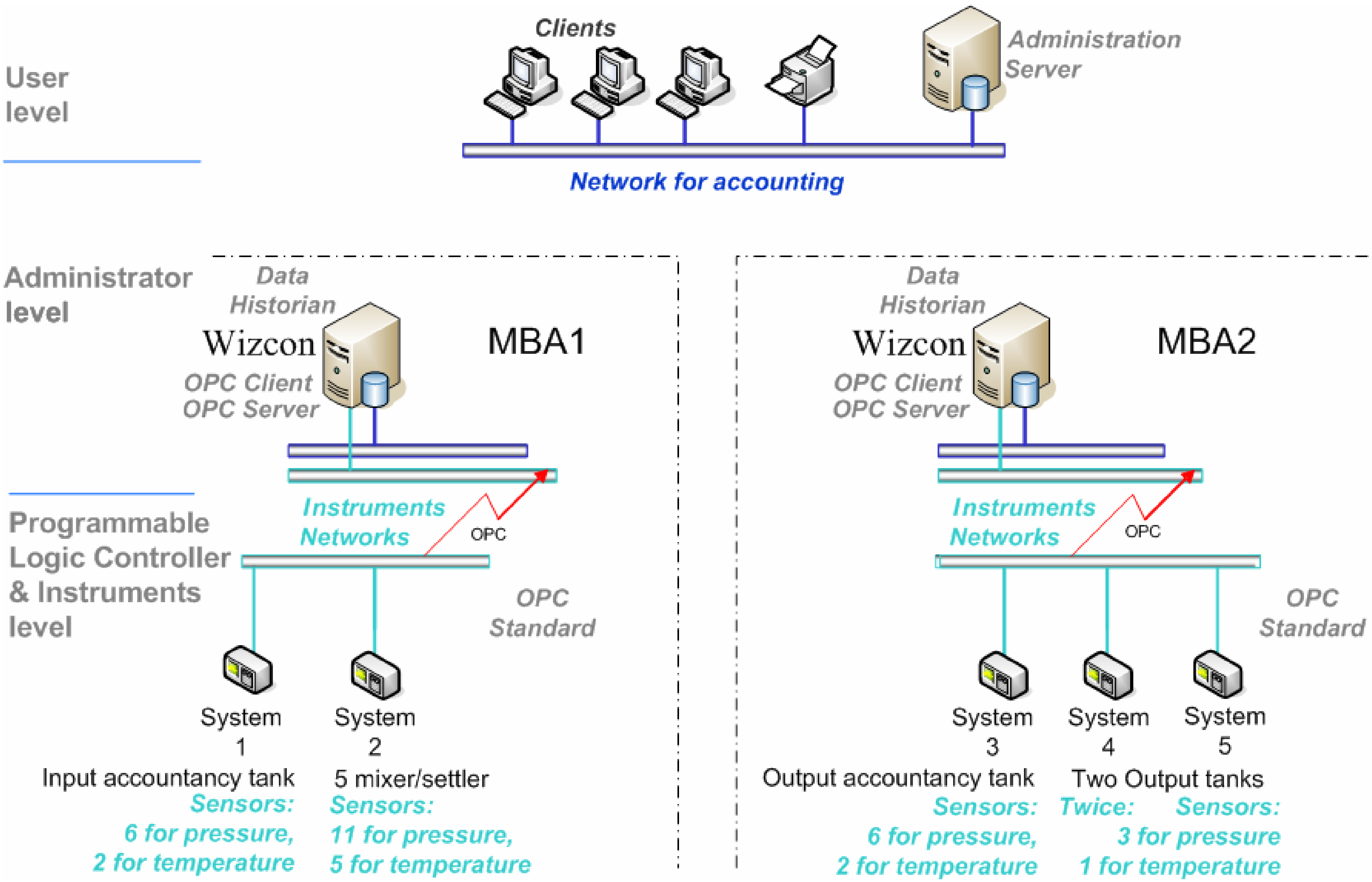

Fig. 1: Network architecture of the Mass/ Volume instrumentation for Mayak RT-1 Plant (included in the project)

CONCLUSIONS

Production Association (PA) Mayak will play a central role also in verifying, storing and processing of Pu. It is evident that PA Mayak is a strategic complex for nuclear material handling and hence safeguards. Process and solution monitoring allow Near Real Time Accountancy. Even though traditional nuclear material Accountancy and Control with periodical inventory difference verifications are required, the near real time accountancy helps directly in identifying timely and locally problems with nuclear material flows.
Solution and process monitoring is the key for a higher automation in process control with enhanced safety and safeguards because it automatically follows the process conditions and the nuclear material flow and inventory. It therefore contributes to the process quality and enhances the accountancy accuracy.

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