44th INMM Annual Meeting
16.06.03

MODERNIZATION AND ENHANCEMENT OF NMAC AT THE MAYAK RT-1 PLANT

S. Guardini, P. Daures, P. Frigola, B. Hunt, G. Janssens-Maenhout,
P. Peerani, H. Ottmar, A. Poucet, JRC EC;
F. Gasperini, AIDCO EC;
B. Ryazanov, A. Bogorodskikh, IPPE, RF;
Yu. Glagolenko, A. Skobtsov, PA Mayak, RF;
J. Wark, BNFL, Risley, Warrington, Great Britain

ABSTRACT
The RT-1 plant at the PA Mayak complex of the Russian Federation is an operating nuclear reprocessing facility for civil spent fuel of VVER-440 and BN-600 nuclear reactors, submarines, ice breakers and research reactors.
Within the RF the RT-1 plant represents the future reprocessing facility for all the nuclear fuel from power reactors and power research reactors: as a consequence this site is of high importance concerning international nuclear safeguards.
Several Nuclear Material Accountancy and Control (NMAC) system devices and techniques at the RT-1 plant were installed many years ago and are in need of modernization.
Furthermore, the new Russian State System of Accountancy and Control (SSAC) imposes restructuring the accountancy and measurement approaches, and the implementation of the new system requires intensive personnel training, both in the use of instruments and in the application of NMAC procedures.
The European Commission (EC) decided to support an approach for the modernization and enhancement of systems at the RT-1 plant, with the main scope of improving the NMAC at the facility. The results of former projects to enhance accountancy methods and measurements by the DoE (US) and DTI (UK) will be taken into account.
The main objectives of the project are the implementation of the new system and the modernization of existing ones, coupled with intensive training in NMAC methodological activities for the staff. The project, when approved, will be carried out under the EC-TACIS program, by the Joint Research Centre, together with PA Mayak and the Institute for Physics and Power Engineering (IPPE), Obninsk.
Several other subcontractors will be called upon for various kinds of technical support within the RF and the EU.

This paper presents a summary of the project description and of the planned activities, which will be carried out under the project in a tight collaboration between the EU and the RF.

INTRODUCTION
The Mayak Complex in Ozersk is situated close to Chelyabinsk, a city near the North Western Ural Mountains. Production Association (PA) Mayak is one of the most important nuclear sites of the Russian Federation: almost all kinds of nuclear activities, with the exception of uranium enrichment and fuel assembly fabrication are covered by the nuclear facilities, including:

- Nuclear reactors decommissioning;
- Spent fuel reprocessing (RT-1 Plant);
- Chemical-metallurgical processing of uranium and plutonium;
- Production of radioactive sources, also for medical purposes;
- Waste conditioning, and
- Analytical laboratories.

The PA Mayak plant operates the nuclear reprocessing facility (RT-1) for spent civilian fuel of VVER-440 and BN-600, as well as for nuclear reactors from submarines, icebreakers and research reactors. All kinds of waste (liquid and solid) are stored on site: the various forms of liquid waste are first conditioned in the vitrification facilities before going to disposal.

The RT-1 plant was created from the basis of the radiochemical plant used for production of weapon grade plutonium dioxide and started in 1977 the reprocessing of spent assemblies on a larger scale. The installations are now in need of being upgraded.
The RT-1 plant has many facilities for spent fuel reprocessing, however this project will address only one line, which handles and treats spent fuel from VVER-440 (initial uranium enrichment from 3 to 4.4 %) and BN-600 (initial uranium enrichment from 15 to 26 %). The final products are uranium nitrate with uranium enrichment of between 2.2%-2.6% for RBMK fuel, plutonium dioxide powder from BN-600 spent fuel and plutonium dioxide powder from VVER-440 spent fuel. The capacity of these facilities is for the VVER up to 400 tons/yr whilst for the BN up to 20 tons/yr. The current throughput has fallen to 160 tons/yr for VVER and to 15tons/yr for the BN.

The European Commission, more specifically AIDCO within the framework of the TACIS (Technical Assistance to CIS Countries) programme supports the project for improving the Nuclear Material Accountancy and Control (NMAC) at the RT-1 facility of PA Mayak. A first EU-Russian common approach with description of the project can be found in the reference base document [1].
The current NMAC system devices and techniques having been installed several years ago need modernisation. Furthermore, the implementation of the new Russian NMAC elements requires intensive personnel training both in the use of the instruments and on the application of NMAC procedures.
The project will consist of an initial Design Study of the facilities to identify the main areas/locations for improving NMAC. This part of the project will take into consideration the results of the former cooperation [2] between BNFL and PA Mayak (funded by the UK DTI) that reviewed the NMAC arrangements at the RT-1 Plant: this resulted in a document with several recommendations and guide-lines for further work.
Following the results of the Design Study, modernisation and implementation of solution monitoring systems and of other nuclear material accountancy systems, identified in the study, will be implemented: systems such as solution mass/volume devices, gamma/X-ray densitometers, gamma-absorption meters and neutron control detectors will be installed for NMAC purposes. Training will form an integral and fundamental part for the successful implementation and future utilisation of the instruments and application of the software.

The project consists essentially of five main activity lines:

- The initial Design Study of the facilities to identify the main areas/locations for improving NMAC;
- Modernization and implementation of solution monitoring systems inclusive of application software for data acquisition and elaboration;
- Modernization and Implementation of other NMAC systems, such as K-edge densitometer, NDA equipment and techniques, computerized accountancy system;
- Elements of near-real time accountancy (NRTA) for RT-1 plant will be studied, designed and implemented, allowing information gathering with its immediate analysis, and
- Training of trainers, custodians and Nuclear Materials Accountancy officers.

NEEDS FOR MODERNIZATION

There are two main elements, which have led to the decision to modernize NMAC systems of the RT-1 facility:

- The first element concerns the NMAC systems which have been in service for a long time and need modernization;
- The second driving element is the entry in to force of the new Russian State System of Accountancy and Control (SSAC), which requires completely new safeguard approaches.

The RT-1 plant evolved from the radiochemical plant utilised for production of weapon grade plutonium dioxide and which commenced in 1977 with spent assembly reprocessing. New instruments and techniques, and computerised systems have to be implemented to assure the NMAC quality requested by the new Russian regulations at different stages of spent fuel reprocessing and production of plutonium dioxide and uranium final products. Tank volume measurement systems have been provided by Brookhaven National Laboratory (BNL) for volume monitoring on 3 inventory tanks [2], but further improvements are needed to the solution monitoring and M/V systems, in order to achieve the Inventory Difference level and the accuracy now required by the new Russian (SSAC).

The Russian Federation decided in the early nineties to establish and maintain a new SSAC within its territory, jurisdiction or control, containing elements of accountancy closer to Regional and International Safeguards. The SSAC falls under the responsibility of Minatom and integrates several important components, including the state system of accountancy, nuclear export-import control and physical protection. The system was established in accordance with the "Federal Law on Use of Atomic Energy", which defines the responsibilities of Russia under the Safeguards Agreement between the IAEA and Russia under the NPT. According to the NMAC Basic Rules decree (2001) (OPUK[4]), issued by Gozatomnadzor (GAN) of Russia, Physical Inventories must be made periodically and the acceptance criteria for the Inventory Difference (ID) of the different categories of materials are dictated, as detailed in Table 1.

Table 1: Statistical criteria for Inventory Difference in the RF.

Material	RF SSAC Rules
Category I: PuO_2 powder Pu compounds With $c_{Pu}>25g/l$	$\|ID\| \le 2\sigma_{ID}$ *(corresponding to a confidence level of 95%)* $\|ID\| \le 3$ *kg Pu* $\|ID\| \le 2\%$ *of through-put (corresponding for 1 ton Pu/yr to ~ 1.5 kgPu/month)*
Category IV: LEU compounds	$\|ID\| \le 2\sigma_{ID}$ *(corresponding to a confidence level of 95%)* $\|ID\| \le 70$ *kg U-235* $\|ID\| \le 2\%$ *of through-put (corresponding to 160 ton SFA/yr to ~5kgU-235/month)*

There are many processing facilities in RT-1: the spent fuel assemblies (SFAs) are cut, chopped and dissolved, the main solution is transferred to the input accountancy tanks, then 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 reprocessing follows a modified PUREX process with additional separation of Np, which differs from the process followed in European reprocessing plants.

The structure of the facilities comprises 10 technological areas:

- Storage for nuclear material received: spent fuel assemblies of VVER-440 and BN-600 reactors;
- Preparation of spent fuel assemblies for chopping: cutting off the tail end parts and preparing batches for dissolution;
- Assembly identification (neutron emission measurement from spent fuel assemblies before chopping);
- Operations line for assembly chopping and dissolving;
- Chemical processing line for extracting fission products solution, separation and refining nitrate solution of uranium and plutonium;
- Oxalate precipitation and conversion to plutonium dioxide powder;
- Evaporation of nitrate low enriched uranium solution (2.4-2.6%);
- Storage for plutonium dioxide product;
- Storage for uranyl nitrate paste product, and
- Vitrification and storage for high and medium level waste.

The measurement accuracy for the final product and the main part of solution transactions between divisions is good for Nuclear Materials Accountancy and Control goals, but many techniques and

instruments have to be improved to reach criteria prescribed for Inventory Difference (ID) by federal rules. The implementation of NMAC basic rules requires the essential reconstruction of plant NMAC system, definition of Materials Balance Areas (MBAs) and re-establishing of Key Measurement Points (KMPs), modernisation of measurement techniques and instruments, implementation of new ones, creation of NMAC computerised system. The implementation and incorporation of new MBA/KMP structures, the development of detail specifications for modernised and new measurement techniques and instruments together with a computerised system is a major task for this project.
The informatic architectural structure of data acquisition and evaluation and analysis as well as the final NMAC reporting must be redesigned, as a consequence of the modernization measures introduced and of the new regulations. Considering the complexity of the plant, with the type of material flow and unit operations performed, an appropriate accountancy plan needs to be developed. The plan needs to integrate the information obtained from various sources (instrumentation, records etc.,) and aim for reliable and automatic accountancy techniques utilising modern technology. Information gathering in the so called *near-real time* with immediate analysis will allow several elements of near real time accountancy (NRTA) to be achieved.
In order to attain NRTA the following basic elements are required:

- Improvement of bulk measurement methods;
- Computerisation of data acquisition both from the plant and the analytical laboratory;
- Computerisation of record keeping and reporting, data evaluation and verification, measurement sequences;
- Estimation of in process inventory hold-up in order to have up-to-date and frequent material balances, and
- Computerised system with a well-defined architecture for data acquisition and interpretation.

OBJECTIVES AND MAIN LINES OF THE PROJECT

The main objective of the project is the improvement of the RT-1 NMAC system, through the implementation of new or the modernization of existing systems, coupled with intensive training in NMAC methodological activities for the staff.
NMAC within the facility presents problems of measurement, data collection and analysis, error propagation and statistical evaluation of ID related to Nuclear Material (NM) in various forms (solid, liquids, pulp and bulk form), which are processed in the plant. Practically all operations with NM products including the NM movements are made remotely; all equipment is protected by biological shields and can be reached only after careful decontamination during planned maintenance.

Input

Material accountancy measurements at this stage of the technological cycle are based on counting SFAs, transportation cask and canister identification, as well as identification of specific positions within the canister. Assembly identification is not a routine operation as individual serial numbers of assemblies are not always easily readable: to improve the operation of identification it is planned to implement lighting installations with video cameras for underwater operation of SFAs control, canisters number and identification codes reading and for improving the items control in the storage pond.

In-Process

Some equipment sub-facilities cannot be cleaned before any Physical Inventory Taking (PIT) and the content of NM has to be measured/evaluated by Destructive and Non-Destructive Analyses (DA/NDA) and by solution Mass and Volume Measurement (M/V) techniques and devices. This problem concerns:

- NM hold-ups in filters from spent fuel and solutions reprocessing facilities;
- Presence of organic and water phases in extraction/re-extraction facilities at different stages of the solution reprocessing, and
- Hold-ups in filters from the plutonium dioxide conversion lines.

As for M/V technique: 20 tanks at KMPs are equipped with level probes, 10 of them are inventory tanks. 8 out of the 10 inventory tanks do not have a pressurised transfer system. Because of this pressurised transfer system, Russian designed high frequency inductive level probes are installed.
Under cooperation with BNL [3] bubbling probes were installed in the tanks without a pressurised transfer system in the Pu cycle. A first dip-tube system with 5 probes was installed in 2 tanks in parallel and successfully tested.
Within this project it is further planned to deliver, install and test bubble probe systems in 9 measurement key points and produce, install and test modified inductive level meters in 10 key measurement points.

NDA equipment for U/Pu concentration measurements with gamma-spectrometers have been installed at 40 key measurements points. In order to enhance their accuracy and reliability these gamma-spectrometers are to be upgraded. Neutron Control Detectors (NCD) for Pu concentration are installed in various locations for NMAC. Presently such NCD devices at 25 KMPs need to be computerised with auto diagnostics. NCDs are requested also for the NDA of hulls and hold-up (about 20 KMPs).
Portable NaI gamma-spectrometers are requested for the verification measurements of uranium enrichment in paste items during PIT/PIV and before shipment.
Development or improvement of gamma and neutron NDA techniques for NM content in solution, hulls, accumulation and hold-up are requested in various KMPs for NMAC. Characterisation and certification of these techniques is also requested.

The chemical analytical laboratory at the Mayak RT-1 plant site is continuously operating. The analytical laboratory on site treats all samples of all lines. NDA techniques as well as DA techniques are used [5]. For DA a dilution of the highly concentrated sample by a factor 10^{-4} is made in the hot cell and transferred for the analysis to the glove box. Sophisticated techniques for sample preparation are available on site. The number of samples analysed is limited by the maximum capacity of the instruments, which leads to a maximum of 4 samples/day for Coulometry and 3 samples/day for mass spectrometry. Examination of the accuracy of the instruments as indicated in [5] lead to the following conclusions:

- The accuracy of the analytical analysis on the main input solution is not sufficient for the new rules of NMAC. Mayak agreed that the control on the input accountancy tank must be improved and the JRC proposed to purchase a Gamma/X densitometer;
- The gamma spectrometer for U-235 samples of reprocessing area is also not very accurate but fast. In case the results are not sufficiently accurate, a back-up analysis can be performed with the mass spectrometer, and
- An alpha spectrometer for Pu content measurement in solutions is recommended.

Output
As for the output, NMAC procedures and measurements for BN and VVER PuO_2 powders were essentially improved as results of co-operation with US/DOE, that provided High Level Neutron Coincidence Counters (HLNCC) and High Resolution Gamma Spectrometers (HRGS).
NDA for the output storages within this project will be oriented at the NMAC measurements of uranyl nitrate paste, which is shipped to the Ulba plant in the Republic of Kazakhstan for RBMK pellets production.
The only problem in this KMP at present is connected with measurement of net and gross weight of the containers with U paste. The delivering and installation of a weighing scale for this measurement is also planned.

THE DETAILED STUDY
As stated above, the project will be guided by a preliminary detailed study of the plant flow sheets and of the needs for modernization. Scope of the study is to provide an overall detailed analysis of the PA Mayak complex activities, with particular focus devoted to the NMAC aspects. The study will be conducted mainly by the RF counterparts (PA Mayak and IPPE), but the project will as well make use of the BNFL experience and the existing Mayak-BNFL studies will be carefully taken into account.

The expected result of the study will identify all the areas relevant to NMAC within the RT-1 plant of PA Mayak complex, describing the material flows of input/output to Mayak and more specifically to RT-1 plant, the internal process operations and exchange between different MBAs, as well as the current types of accountancy systems and measurement capabilities and the computerised accountancy records applied in the plant to the BN-600 and VVER-440 SFAs reprocessing. The study will identify and detail the needs and requirements in the above mentioned areas. The study will broadly report on the following:

1. *Introduction*
   This will describe the scope of the work, the RF civil cycle, the present and future role of Mayak and RT-1 in the RF cycle, the need for improving the NMAC system in RT-1.
   This chapter will also present the sections of the facilities, which will be involved by the Project.
2. *Spent fuel Input*
   This chapter will give details of the systems employed for receiving, assaying and conditioning the spent fuel prior to its input in the reprocessing facilities.
   This section will also describe the fuel cutting systems and the filtering aspects.
3. *Radiochemical installations*
   A description of the solution, filtration, separation and purification installations and their role will be provided.
4. *MBAs and Key-measurement points: NMAC system architecture*
   This chapter first describes with a complete overall picture, the existing system of NMAC currently in force at the RT-1 plant.
   The subsystems and equipment will be identified in the flowchart of the reprocessing facility.
   Subsequent sections will propose the new RT-1 NMAC architecture and sub-systems, the path to form the Inventory Difference and the statistical error propagation scheme.
   This chapter will also forward recommendations for NRTA.
5. *Solution Monitoring complex*
   One of the main tasks of the project will be the study and the modernisation of the existing solution monitoring system.
   In order to achieve the goal of performing level measurements with a precision of 0.2%, the performances of level probes should be upgraded, with some probes being replaced with bubbling dip-tube probe technology.
   Design studies will be carried out, in order to define the solution monitoring systems to implement or how to improve the existing ones. Calibration procedures and methodology of tank calibrations on mock-up tanks are required. Comparison of the performances of bubbling (dip-tubes) system with respect to the inductive system is also required.
6. *Sampling schemes and analytical measurement system*
   This chapter will deal with the study of the sampling and analytical flows in and "around" the RT-1 facility, in order to ascertain the requirements and specifications of equipment for U-Pu concentration measurements.
7. *Output Products*
   The output products of the facility will be described (PuO_2, RBMK $UO_2(NO_3)_2$) together with the existing measurements in place and the need for further NDA requirements, such as neutron monitoring and gamma NDA verification of the $UO_2(NO_3)_2$ paste by portable gamma spectrometer.
8. *Waste conditioning and assay*
   A description of the waste treatment facilities, including the type, quantity of waste produced and the existing assay methods and suggestions for future needs will be included.
9. *NRTA*
   This chapter will describe the architecture (modelling, hardware, software) of the NRTA system which will be implemented at RT-1. Functional and detailed specifications for NRTA will be elaborated.
10. *Training Needs*
    The training of the operators will be an important and fundamental aspect of the project. Training in mass/volume methodology, scales calibration, DA/NDA instrumentation, K-edge

densitometry, error propagation modelling, inventory difference (ID) build-up physical inventory taking and verification, are planned to familiarize plant staff, custodians and auditors with the new technologies and the novel NMAC system.

11. *Conclusions and Drafting of Detailed Specifications of the Project*
This chapter will be fundamental towards the subsequent specifications of the project. It will identify the instruments required, the activities and testing to be carried out and the role of each player in detail.

CONCLUSIONS

The European Commission, within the framework of the TACIS Programme proposes to carry out a project with as main scope the improvement of the Nuclear Material Accountancy and Control (NMAC) at the RT-1 facility of PA Mayak.

Several NMAC system devices and techniques at RT-1 were installed several years ago and the current NMAC equipment needs to be modernized and extended. Furthermore the implementation of the new Russian SSAC requires intensive personnel training both on the use of the instruments and in the application of NMAC new procedures: objective of the Project is the improvement of the NMAC system, through the implementation of new or the modernisation of existing systems, coupled with intensive training and methodological activities.

The project will consist of an initial detailed study of the facilities to identify the main areas/locations for improving NMAC; following the results of the study, modernisation of and/or replacement of systems will take place. Elements of NRTA will be implemented. The project duration is estimated to be 4 years.

REFERENCES

[1] S. Guardini, B. Hunt, G. Janssens-Maenhout, P. Peerani, A. Poucet, P. Daures, B. Ryazanov, A. Bogorodskikh, A. Skobtsov, O. Darenskikh, V. Krakhmalnik, G. Leluk, Modernisation and enhancement of NMAC at the Mayak RT-1 Plant: Reference Base Document, Technical Note No. I.03.16, January 2003

[2] Y. M. Zatorski et al, “Preliminary Results of Cooperation between the Mayak Production Association and British Nuclear Fuels plc (BNFL) in Nuclear Materials Control and Accountancy”, Proceedings of the NMAC International Conference, Obninsk (RF), 1997

[3] O. Darenskikh, S.C. Suda et al., “Implementation of Tank Volume Measurement Equipment at the Mayak Production Association”, BNL-64250, IAEA-SM-351/9, 1997

[3] “Basic Rules for Nuclear Material Accounting and Control by the Russian Federation Committee for Supervision of Radiation and Nuclear Safety (RF GAN)”, OPUK HII-030-01, No. 7, 9 July 2001

[4] V.K Sazhnov, Ye.G. Dzekoun and G.A Lelyuk; “DA and NDA Measurements of Nuclear Materials at the Mayak Reprocessing Plant”, Proc. of the Tripartite Seminar on Nuclear Materials Measurements and Evaluation for Physical Inventory, Obninsk, October 2000