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Review of Equipment Used in Russian Practice for Accounting Measurements of Nuclear Materials*

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ABSTRACT

The objective of this work was to analyze instrumentation and methodologies used at Russian nuclear facilities for measurement of item nuclear materials, materials in bulk form, and waste streams; specify possibilities for the application of accounting measurements; and develop recommendations for improvement.

The major steps and results:

- Representative conversion, enrichment (gas centrifuge), fuel fabrication, spent fuel reprocessing, and chemical-metallurgical production facilities in Russia were selected;
- Full lists of nuclear materials were prepared;
- Information about measurement methods and instrumentation for each type of nuclear material were gathered; and
- Recommendations on methodological and instrumentation support of accounting measurements for all types of materials were formulated.

The analysis showed that the existing measurement methods and instrumentation serve mostly to support the technological process control and nuclear and radiation safety control. Requirements for these applications are lower than requirements for MC&A applications. To improve the state of MC&A at Russian nuclear facilities, significant changes in instrumentation support will be required, specifically in weighing equipment, volume measurements, and destructive and non-destructive analysis equipment, along with certified reference materials.

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The three major issues to be addressed are:

- development and certification of new measurement methods,
- certification of measurement equipment, and
- training of MC&A personnel.

INTRODUCTION

The review work presented in this paper is a result of a cooperative effort between Brookhaven National Laboratory (BNL), operated by Brookhaven Science Associates under contract to the US Department of Energy, and the All-Russian Research Institute of Automatics (VNIIA), subordinate institute of the Atomic Energy Ministry of the Russian Federation, within the collaborative US-Russia Material Protection, Control, and Accounting (MPC&A) Program.

The main objectives of this work were to analyze equipment and methods used at Russian facilities for measurement of item nuclear materials, materials in bulk form, and waste streams; specify possibilities for the application for accounting measurements; and develop recommendations for their improvement[•].

BACKGROUND

Measurements of nuclear material characteristics – a key element of successful MC&A systems – were until recently not generally done at Russian nuclear facilities. Presently, there is work underway on improvement of the Russian State MC&A that includes improvement of measurement equipment and methodological support. Valuable financial sources of this work are international collaborative programs, particularly the US-Russia MPC&A Program. Within this Program, work on implementation of modern methods and equipment is conducted through contracts between Russian facilities or Research Institutes and the US national laboratories. To increase the effectiveness of this work, three needs were identified: a) a review of the status of measurement methods and equipment support at Russian nuclear facilities, b) determination of possibilities of their application for accounting measurements, and c) development of recommendations for their improvement.

MAJOR STEPS

The major steps and results of the work are listed below:

- Representative facility types covering the majority of nuclear materials were selected. These included conversion, enrichment (gas centrifuge), fuel fabrication, spent fuel reprocessing, and chemical-metallurgical production facilities.
- For each of the chosen types of nuclear facilities full lists of nuclear materials were prepared by contacting the facilities.
- Information about measurement methods and instrumentation for each type of nuclear material in item, bulk, and waste stream forms were gathered at several large nuclear facilities, including Ural Electro-Chemical Combine (Novouralsk), Siberian Chemical Combine (Seversk), Mining and Chemical Combine (Zheleznogorsk), Production Association “Mayak” (Ozersk),

[•] No consideration of the costs associated with the recommended improvements to measurement methods and equipment has been made in this work and no prioritization of the recommendations was suggested or implied.

Novosibirsk Combine of Chemical Concentrates (Novosibirsk), and Elektrostal Machine-Building Plant (Elektrostal).

- The measurement methods and instrumentation applicable for accounting purposes were analyzed. Recommendations on methodological and instrumentation support of accounting measurements for all types of material were developed.

DATA ON MATERIALS, METHODS AND EQUIPMENT

Information provided by the Russian nuclear facilities contained lists of materials subject to accounting measurements along with the corresponding measurement methods and equipment. Each method and equipment description included information on the purpose of measurement. As a rule, that purpose was either process control, or nuclear or radiation control. In addition, most of the method/equipment data entries contained information on measurement accuracy for each particular material as well as the accuracy required for accountancy measurement (according to the facility's MC&A specialists).

The list of nuclear materials, methods and equipment used at Russian facilities is shown in Table 1[•]. For more detailed technical information on DA and NDA equipment and methods used in US and Russia the reader is referred to the MC&A Instrumentation Catalog recently compiled and published within the US-Russia Cooperative MPC&A Program [1].

ANALYSIS OF THE STATUS OF METHODS AND EQUIPMENT

Analysis of the status of methods and equipment currently used at Russian nuclear facilities showed the following:

- Measurement methods and instrumentation are used mostly for the purposes of control of
  - Production process
  - Criticality safety
  - Radiation safety
- Methods and instrumentation used at Russian facilities are adequate for the purposes listed above
- A large fraction of the existing measurement equipment at Russian nuclear facilities has reached the end of its useful life
- Significant number of methods and equipment used at the nuclear facilities do not meet requirements for accountancy measurements.

RECOMMENDATIONS FOR IMPROVEMENT OF MEASUREMENT METHODS AND EQUIPMENT

The major recommendations for improvement of measurement methods and equipment applicable for accounting measurements of nuclear materials in item and bulk forms, and wastes are presented in Table 2. Note that much of the recommended equipment has in fact been supplied to Russian nuclear facilities. Routine implementation depends partly on the resolution of certification issues.

[•] *Methods and equipment that were not tested and are not involved in the production process are not presented in the table. Currently nuclear facilities are being equipped by advanced measurement equipment within the US-Russia Cooperative MPC&A Program*

RECOMMENDATIONS FOR MEASURING NUCLEAR MATERIALS IN VARIOUS FORMS

Nuclear materials in item form including waste in containers

Confirmation measurements require NDA methods and equipment. Those include gamma spectrometers (determination of isotopic composition), neutron coincidence and multiplicity counters (determination of effective mass of isotopes), and calorimeters (determination of mass of plutonium). These pieces of equipment can be integrated into multi-functional systems.

NDA methods of analysis of nuclear materials in item form require, as a rule, reference materials for each type of measured item containing nuclear material.

Nuclear materials in bulk form including liquid waste

Improvement of nuclear materials analysis methods requires the following:

- Metrological support
  - Develop more accurate procedures of sampling for electrochemical, spectrochemical, spectrophotometric, and radiochemical measurements;
  - Enhance the methods' selectivity;
  - Account for the effects of polymer and colloid forms of elements;
  - Perform metrology certification of measurement methods.
- Implement destructive analysis methods with equipment that is not currently used in Russian practice (for example, K-edge hybrid densitometer for accounting and confirmation measurements in solutions should be considered).
- Develop and certify NDA methods and equipment for bulk materials employing sampling.

General recommendations for all materials

To implement the most promising measurement methods and equipment for analysis of nuclear materials in MPC&A applications the following activities are required:

1) Development and certification of new methods;
2) Certification of equipment;
3) Training and certification of MC&A personnel using new methods and equipment.

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REFERENCES

1. MC&A Instrumentation Catalog, Brookhaven National Laboratory (BNL, USA) and All-Russian Institute of Automatics (VNIIA, Russia), Editors: L. Neymotin and V. Sviridova, BNL-65619-99/01-REV, G35054, Second Edition (Expanded), July 1999

Table 1. List of Nuclear Materials, Measurement Methods and Equipment

No.	Nuclear Material	Form: gas, solution, powder, pellet, etc.; (Type: item, bulk, waste)	Measured Properties	Measurement Equipment/Method
1.	Alkaline – aluminum solution containing U and Pu after dissolving rod shells; Alkaline decantate	Solution; (Bulk)	Total volume; Concentration of Pu; Concentration of U	Level gauges; Alpha rate meter; Spectrophotometer
2.	Ash	Ash in cans; (Waste)	Total mass	Scales
3.	Discarded UO_2 pellets (natural/enriched uranium)	Pellets in cans; (Bulk, Item)	Total mass	Scales
4.	Fuel assemblies (natural, enriched uranium)	Transport container; (Item)	Measurements are not done	
5.	Fuel rods (natural, enriched uranium)	Plant transporting container; (Item)	Total mass	Scales
6.	High Activity Waste prepared for burying	Solution; (Waste)	Total mass; Concentration of U	Scales; Spectrophotometer
7.	Liquid uranium oxides after reprocessing (fuel fabrication)	Liquid in barrels or cans; (Bulk, Item)	Total mass; Concentration of U	Scales; Ferrous phosphate method
8.	Liquid waste	Liquid in cans or containers; (Waste)	Total mass	Scales
9.	Liquid waste for burying (technological solutions, oils, organic)	Liquid waste in tanks or barrels; (Waste)	Total mass; Concentration of Pu; Concentration of U;	Scales; Alpha rate meter; Spectrophotometer
10.	Low concentrated solutions	Solution; (Bulk)	Total volume; Concentration of Pu; Concentration of U	Level gauges; Alpha rate meter; Spectrophotometer
11.	Medium Activity Waste prepared for burying	Solution; (Waste)	Total mass; Concentration of Pu; Concentration of U	Scales; Alpha rate meter; Spectrophotometer
12.	Metal scrap: ingots, parts, intermediate products	Metal in containers	Total mass	Scales
13.	Metallic plutonium ingots, metallic plutonium intermediate products	Metal in container; (Item)	Total mass	Scales
14.	Plutonium and neptunium (concentrated nitric acid solutions)	Solution; (Bulk)	Total volume; Concentration of Pu; Concentration of Np	Level gauges; Neutron rate meter; Neutron rate meter
15.	Plutonium Dioxide, PuO_2	Powder in hermetic cylinders placed into sealed containers; (Bulk, Item)	Total mass; Content of impurities; Mass of Pu	Scales; Chemical method; Calculation

16.	Plutonium oxides after burning waste	Powder in container (Bulk, Item)	Total mass; Content of impurities	Scales; Chemical method
17.	Scrap: metallic equipment, gloves, filters, ceramic scrap, residues, wiping material, etc.	Solid waste in containers; (Waste)	Total mass	Scales
18.	Solid waste	Solid waste in containers; (Item)	Total mass Pu mass	Scales; Total thermal neutron counting
19.	Spent fuel assemblies	Irradiated assemblies (Item)	Measurements are not carried out	
20.	U_3O_8	Powder in containers, Powder; (Bulk, Item)	Total mass	Scales
21.	UO_2 pellets (natural/ /depleted/enriched uranium)	Boxes in transport containers, trays; (Bulk, Item)	Total mass; Concentration of U; Isotopic content of U	Scales; Gravimetry; Mass spectrometry
22.	UO_2 powder (natural/ depleted/enriched uranium)	Powder in containers; (Bulk, Item)	Total mass; Concentration of U; U enrichment; Isotopic content of U	Scales; Gravimetry; Gamma spectrometry ; Mass spectrometry
23.	Uranium and plutonium nitric acid solution after the dissolution of fuel rods and alkaline pulp	Solution; (Bulk)	Total volume; Concentration of Pu; Concentration of U	Level gauge; Spectrophotometer; Complexonometric method
24.	Uranium Hexafluoride residues, UF_6 (natural/ depleted/enriched uranium)	Gas in containers; (Item)	Total mass	Scales
28.	Uranium Hexafluoride, UF_6 (natural, depleted, enriched uranium)	Gas in containers; (Bulk, Item)	Total mass; Concentration of U; Concentration of Impurities; Isotope composition of U	Scales Spectrophotometer; Mass spectrometer
25.	Uranium Hexafluoride, UF_6 (natural/depleted/enriched uranium)	Gas in process; (Bulk)	Mass portion of U-235	Gamma spectrometer
26.	Uranyl nitrate solution after destruction of hydrozine	Solution; (Bulk)	Total volume; Concentration of Pu; Concentration of U;	Level gauge; Spectrophotometer; Complexonometric method

Table 2. Current Measurement Methods and Equipment and Recommendations for Improvement

Form of NM	Measured Property	Measurement Method/Equipment	Recommendations for Improvement
Items	Total mass	Scales (much of weighing equipment does not meet accuracy requirements)	Replace obsolete equipment by more precise equipment with automatic calibration and interface with computerized MC&A systems. Use bar code equipment linked with the weighing instruments
	Isotopic content	As a rule, measurements are not done	Use gamma-spectrometers and gamma-scanners
	Effective isotope mass	As a rule, measurements are not done	Implement passive and active neutron coincidence counters and calorimeters for plutonium
Bulk	Total mass of sample	Analytical scales	Replace obsolete equipment by more precise equipment with automatic calibration and interface with computerized MC&A systems.
	Liquid volume	Level gauges (do not meet accuracy requirements)	Use modern tank volume measurement equipment
	Element concentration	Uranium: gravimetry, Spectrophotometry, Complexonometric method, ferrous phosphate method; Plutonium: alpha rate meter, neutron rate meter, total thermal neutron counter	Implement the most accurate methods of Analytical Chemistry including coulometric titration, injection spectrophotometry and titrametric methods with the instrumental indication of the end point of titration. Consider K-edge densitometer, hybrid K-edge densitometer, X-Ray Fluorometer for measurements in solutions
	Isotopic content	Gamma-spectrometry	Implement gamma spectrometers for confirmation measurements
		Mass spectrometry	Resume production of domestic mass spectrometers
Wastes	Total mass	Scales (much of weighing equipment does not meet accuracy requirements)	Replace obsolete equipment by more precise equipment with automatic calibration and interface with computerized MC&A systems. Use bar code equipment linked with the weighing instruments
	Isotopic content	Measurements are not done	Use gamma-spectrometers and gamma-scanners
	Effective isotope mass	Gamma and neutron rate meters (do not meet accuracy requirements)	Use passive and active neutron coincidence counters