Implementation of Tank Volume Measurement Equipment
At the Mayak Production Association

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1. ABSTRACT

One goal of the United States Russia Cooperative program to improve nuclear material protection, control, and accounting (MPC&A) in Russian facilities is to computerize material accounting techniques for bulk materials. Such materials include liquid solutions at radiochemical plants: dissolver, intermediate product, and waste. Material accounting techniques for tank volume measurements (TVM) are needed to determine the nuclear material content of these solutions (chemical and isotopic analysis are also required). The content is required to close the material balance in a radiochemical plant. Computerization of these techniques can provide unattended measurements of material flows, improved precision and accuracy, reduced operator effort, and lower radiation exposure of operators—with equipment that is predominantly remote from high radiation areas. This paper describes the technical activities that contributed to the successful integration of the TVM system, developed by Brookhaven National Laboratory (BNL), into the Mayak Production Association radiochemical plant conducted under the US/Russian cooperative MPC&A Program. U.S. assistance with installation and adjustment of the instrumentation was completed in May 1997. After that, Mayak experts on measurement and metrology continued mastering and testing the equipment.

2. INTRODUCTION

2.1. Mayak Production Association

Production enterprise "Mayak" is situated in the city of Ozersk in the Chelyabinsk Region, 140 km to the south of Ekaterinburg in the eastern foothills of the Ural Mountains. One of the largest sites of the Ministry of Atomic Industry in Russia, it was established in 1946 and started operation in 1948. Since then
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the operation has been expanded and upgraded, and its functions and priorities changed. In 1976, the RT-1 radiochemical plant with design throughput of 400 MT/year was put into operation for processing of irradiated nuclear fuel. RT-1 process technologies include chop-leach dissolution and mixer-settler Purex process. The plant involves the following three head end production lines.

(a) VVER-440 reactor fuel
(b) BN-350 and BN-600 fast reactor fuel
(c) Returned fuel from icebreakers, submarines, and research reactors

Implementation of tank volume technology at the RT-1 plant, under the cooperative program for Enhancement of Material Protection, Control, and Accounting (MPC&A), is one of the twelve original tasks agreed to in May 1996. Cooperative work was started in February 1996 with an initial site visit by six U. S. National Laboratories. The participating laboratories in the MPC&A program are Sandia-Team Leader, Brookhaven, Oak Ridge, Lawrence Livermore, Los Alamos, and Pacific Northwest.

2.2. Back fitting of equipment

From the start, it was understood that an exchange of detailed information between the technological specialists in the radiochemical plant and the equipment developer would be required for expeditious and successful back fitting of equipment into an operating facility. The exchange of information would include both a working knowledge of the tank structure, its location, and its current instrumentation and operating procedures, as well as, hands-on familiarity by the plant operating staff with the measurement equipment and software. This was accomplished in two steps.

The first step involved visits to the Mayak radiochemical plant by BNL staff at which time tank-specific installation requirements for the bubbler-probe TVM system were determined. The requirements included specifications for the instrument air, pneumatic and electrical power lines to the measurement module, and communication lines to the location of the computer. Mayak staff provided a description of the current means for tank volume measurement being used, pump fill and drain rates, the introduction of air
pressurized to three atmospheres for sparging and mixing of the tank contents, and description of the operating pressure conditions in the tank.

2.3. High frequency level probe: Inductance

High frequency inductive level probes of UVM, UVV, URES and other types are widely used at RT-1 to measure the volume of conductive solutions. The sensor is a coaxial cable a portion of which is the level probe (rod in perforated tube) closed at the end. The measurement involves primary and secondary electrical oscillation generators whose wavelengths are continuously compared. The mismatch of wavelengths of the oscillations results in an inductive resistance due to the offset in the current and voltage phase in the standing wave in the level probe. When the secondary device's generator senses its wavelength exceeds that of the primary by a factor of four, it initiates the frequency tuning circuit.

The value of the inductive resistance is proportional to the level of conducting solution, a moving point on the circuit along the height of the sensor. The difference in the frequency output between the primary and secondary generators is measured which varies from zero (empty tank) up to one MHz (full tank). After conditioning the signals, the frequency output signal ranges from zero to 10 MHz and the analog output signal range from 0 to 5 mA. Measurement uncertainty is on the order of 0.5% for the frequency and 1.0% for the analog outputs. Theoretically, it is possible to reduce the frequency output error to the range of 0.05 - 0.1%. Drawbacks to the UVM device are:

(a) it does not measure level of solutions with electrical conductivity below 10 S/cm
(b) organic or other particles clinging to the probe act as a wick or insulator resulting in biased or unstable readings

2.4. Pre-installation Workshop

The second step in the exchange of information was the weeklong work session held at Brookhaven in December 1996 involving hands-on familiarization with the TVM. At the meeting, the principal
investigator from Mayak was instructed on the theory and operation of the bubbler-probe tank volume measurement system. A review of the modular hardware design of the TVM was conducted with an explanation of the computer display screens, as well as a demonstration of how the various screens could be utilized to provide functional information during the measurement cycle. Operational demonstrations of the system were conducted including changes in the air mass-flow controller rates while noting the appropriate computer screen display. Further demonstrations included the effects of mass additions to the tank and compensation for temperature effects on pressure measurements for density, height, and volume determinations. A computer-based exercise was conducted to illustrate data analysis methods using a spreadsheet program.

Detailed discussions were conducted on the installation requirements for the TVM based on component configuration design wherein the air flow controllers are located in a separate cabinet near the tank, and the measurement module is located in a separate cabinet mounted on the wall. Mayak staff was given schematic drawings showing the tank and technological features such as the installed probes, and proposed location of the measurement and tank modules, and the computer.

3. SYSTEM DESCRIPTION

3.1. Bubbler probe tank volume measurement technique: Pressure

Computerized tank volume measurement equipment was developed by Brookhaven National Laboratory (BNL) and first used under operating conditions in the Tokai Reprocessing Plant (TRP) in Japan in 1979. The pressure gage in the TRP bubbler-probe system was the Ruska Electromanometer (Ref. 1, 2). Since then, the Brookhaven TVM has undergone two upgrades. Version II is a portable system that was designed for use by domestic and international inspectors (Ref. 3, 4). Pressure measurements in this system are made using the Paroscientific Digiquartz pressure transmitter.
The upgraded Version III of the bubbler-probe TVM system was installed in the Mayak PA radiochemical plant in May 1997. It also uses the Paroscientific Digital Pressure Transmitter, but is different from the previous version in two ways. One is the use of the computer to control the air mass flow meters (in lieu of rotameters), and the other is an update of software using Labview with Russian language screen displays and help units. Labview software sets and monitors the operation of the airflow controllers and the pneumatic scanner, and collects measurement data from the pressure gage and temperature sensor. A layout of the installation of the TVM system in a plutonium product tank is shown in Fig. 1. The annular tank, given in Fig. 2, has a capacity of 340 liters, and is 2 meters high with an inside diameter of one meter and an annulus of 63 mm.

3.2. Labview data acquisition

The data acquisition software has two main screens for displaying routine measurement data used by the technological workers. The first screen is the measurement page, shown in Fig. 3. It is comprised of the following five types of data.

(a) PC system data consisting of the date, time, and tank ID.
(b) The measured data are density and level probes pressure readings and the tank temperature.
(c) Calibration data consisting of the probe separation and calibration curve coefficients.
(d) Calculated data are the density, height, volume, and mass of the solution.
(e) Transfer data containing the sample identification and the worker’s name. When completed, the measurement data page become the transfer record for the batch of solution. The transfer data can be printed at the time of the measurement, and is saved to a separate file.

Figure 4, the second main screen, is a screen containing a plot of the pressure readings and the values of the latest measurement cycle. Using a pneumatic scanner and a single pressure gage, differential pressure readings of the density and level probes relative to the vapor head are obtained. A table containing the
average of 100 readings for four pressures, standard deviation of the readings, and the airflow rates is displayed on the screen. The screen also contains function keys that branch to other data display screens. Additional displays include equipment-setup and calibration data screens, and measurement control screens.

An example of a measurement control screen is the plot of the bubble waveforms shown in Fig. 5. Abnormalities in the bubble waveform pattern are an indication of possible airflow problems, for example, a probe that has started to plug. In addition, there are five Labview program user screens for advanced setup and program diagnostics. Bubble waveform pattern data are saved to a separate file.

The Labview software involves data acquisition and equipment control programs. The data acquisition routine consists of a two-minute cycle during which pressure and temperature instrument readings and measurement control data are collected, processed, and saved in data files. The data are saved in ASCII format compatible with spreadsheet input protocols.

4. TESTING OF TVM UNDER PRODUCTION CONDITIONS

The start of the testing and evaluation of the TVM system coincided with the start of the next routine reprocessing program of VVER fuel causing some difficulties in the work. However, one tank calibration run and a temperature effects test were completed prior to the start of the campaign. During routine tank operation, measurement data was continuously collected and development of familiarity with the Labview and TVM software continued. Analysis of the data included studies of the effects of mixing of solutions and the effect of airflow changes in bubbler probes. RT-1 plant specialists without outside assistance conducted these activities.

4.1. Tank calibration

Preliminarily, the tank was washed with water and completely emptied. Tap water with nitric acid addition (at 30g/liter concentration) was used for calibration. The calibration solution, with density of 1.0147 gram/cc, was added to the tank using 2-liter and 10-liter volumetric provers. The total volume of solution put in the tank was 340 liters. During the calibration process, TVM system readings and UVM
level meter readings were registered. Throughout the calibration process, the solution temperature was within 25±0.5 °C.

The calibration results are shown in Fig. 6. Using these data, the height of the liquid was calculated and calibration equations were derived. Density and level probe residuals for each measurement did not exceed ± 0.5 liter. This means that they are within the required precision (95% confidence level) for the volume calibration method. The vertical height between the density and level probes (probe separation) was calculated and compared with the measured manufactured distance of 200 mm. At this time, the results are not in complete agreement, requiring additional data and analysis.

The calibration equation for the UVM meter is linear in the range from 200 mm to 1200 mm linear with residuals not exceeding ± 0.5 liter. However, as seen in Fig. 6 in the region above 1200 mm (> 266 liters) it is not. It was fitted with a third degree polynomial with residuals not exceeding ± 6 liters. Additional calibration points are needed in this region to better define the response function and reduce the measurement error. The departure from linearity is most probably caused by an accumulation of organic and other particles that effect the conductivity of the probe. A similar condition was observed near the bottom of the tank. Unfortunately, both of these ranges are regions of routine tank transfer operations.

4.2. Effect of temperature on measurements

Following the calibration run, the tank content was heated to 56 °C and isolated from operations while it cooled over night. Figure 7 shows the changes in the pressure readings and the calculated height of the two probes during the cooling of the tank from 56 °C to 29 °C. Because of the small annulus, the level probe could not be placed near the bottom of the tank, but is located above the sparge ring. The result is that the pressure readings do not show the characteristic increase in pressure during cooling. The main temperature affect is the volume of liquid below the probe, and hence, each probe has its own temperature response.
Calibration and temperature affect exercises were run not only to observe the effects of temperature on the pressure readings, but also to demonstrate how the changes are accommodated in the data acquisition software.

4.3. **Conditions of TVM operation**

Analysis of the data showed that conditions of TVM operation were more demanding than was thought before. In particular, comparison of pressure readings in the cell and pressure readings in the vapor head probe indicate that there are; (1) significant variations and rapid rate of change in the vacuum in the tank, as shown in Fig. 9; and (2) abnormal situations that take place when the pressure approaches 600 mbar as shown in Fig. 10. Mostly, the vacuum and pressure variations did not influence the main measurement results, but in rare cases, there were some outliers as plotted in the period between 5:17 and 6:06 p.m. (Fig. 9). All of the outlier values are associated with standard deviations in the averaged pressure measurements that were more than two orders of magnitude larger than for other measurements. Anomalous results could be eliminated using computer codes before providing the results to technical personnel. In addition, the software could be used to ensure safe operation of TVM by automatically closing the Sierra flow meter valves when pressure in the tank exceeds a specified level. Both of these suggestions will require upgrades to the TVM program.

4.4. **Routine technological process and TVM**

Routine technological operations are shown in Fig. 10. Here we can see zones where pressure readings of the density and level probes change rapidly during plutonium nitrate solution filling and emptying, and plateau zones where the volume is not changing. In general, the TVM is an adequate indicator of the technological process except in cases of fast volume changes during solution input and output. In these cases, the TVM instrument readings are delayed in comparison to the UVM level meter that is almost inertia-free. To expand the TVM system from only accounting functions to technological process
control functions, it will be necessary to add a dynamic measurement cycle of about 30 seconds during solution input and output. Accuracy is already reduced during periods of rapid change. However, the most important requirement for routine use of the TVM is the installation of a communication line between the TVM computer and plant (technological) computer. This will require some additional joint efforts of BNL and MAYAK experts.

5. CONCLUSION

In this paper, there is a description of the installation, testing, and evaluation of non-stop operation of the TVM system for a process tank with plutonium solution during routine plant reprocessing operation. Analysis of the test results showed that conditions of TVM operation were more demanding than previously thought. However, in spite of these conditions, the TVM system showed good operating characteristics such as high reliability, accurate faultless operations of all the system elements, exceptional computer control of the scanner and of the air flow meters. The conclusions made were only possible through the training, calibration effort, and close cooperation between BNL and Mayak specialists.

This is the first equipment at the RT-1 plant utilizing a local computerized control system. It has changed the routine measurement process to a new qualitative level. Implementation of such new techniques will not only increase significantly the accuracy of measurements and reliability of tank measurement control and accounting, but will also open for MAYAK personnel new perspectives and new ways to improve in other measurement areas. Integration of the TVM system for routine measurements will require software modification and additional equipment.

The possibilities are apparent of extending the use of similar TVM systems to other control areas, for example, to measure uranium concentration (by density) in the production-line mixer-settler of the Purex process.
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Process signals
High frequency level probe
Tank temperature

* Windows 95
* Labview
* TVM Program
* MSOffice

Air Supply

Process Tank

Fig. 1 Schematic of Mayak Bubbler Probe TVM
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