Implementation of Continuous Inventory Technologies at the All-Russian Scientific Research Institute of Experimental Physics[1]

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Abstract
As part of US/Russian Material Protection, Control and Accounting (MPC&A) Program, technologies that can maintain continuous inventory of stored nuclear material are being implemented in a test facility at the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) at the Russian Federal Nuclear Center at Sarov, Russia. These technologies were developed at the Oak Ridge Y-12 Plant[3] to reduce the frequency of physical inventories, reduce the cost of inventories and reduce worker exposure. The technologies that are being implemented in Russia include SmartShelf™, capacitance weight sensors, and gamma ray sensors. This paper will provide a description of the technologies, problems encountered in adapting the technology to the Russian facility, and results to date.

INTRODUCTION

Among the goals of the US/Russian MPC&A Program is to provide, for evaluation at Russian nuclear facilities, equipment for monitoring nuclear materials. To that end, three technologies, the SmartShelf™ inventory system, capacitance weight sensors, and silicon PIN diode radiation sensors (RADSiP™), developed at the Oak Ridge Y-12 Plant have been installed at the Russian Federal Nuclear Center at Sarov, Russia. Hardware (and accompanying software) sufficient to track the weight, radiation level, and physical location of up to 20 containers in nearly real time has been fielded on a test bed and has been operating during 1998.

The technologies fielded at Sarov were originally developed at Oak Ridge for the purpose of reducing the cost associated with planned and emergency inventories and to reduce the level of exposure of workers to radioactive material. They achieve these goals by implementing a monitoring system through which a set of attributes of the materials under surveillance is compared continually with a corresponding set of alarm limits. If any attribute value falls outside of its alarm limits, then the system raises an alarm to alert operations personnel of the excursion. Low radiation level and low weight are examples of alarms resulting from unauthorized removal of items from storage. In addition, SmartShelf™ can generate an alarm if the system's protocol for removal of an item from or placement of an item into storage is violated. In this manner, the systems decrease the need for frequent inventories because all items in their charge are under constant surveillance and worker exposure is reduced by the reduction in the frequency of manual inventories.

Capacitance weight sensors consist of two stainless steel plates, separated by springs, whose spacing is indicative of the compressive force generated by the weight of the container placed on the upper plate. The upper plate is used as one (moveable) plate of a parallel plate capacitor that is used by an electronic circuit to generate a pulse whose width is a function of the capacitance of the system. Since capacitance increases approximately inversely proportionally to spacing of the plates, pulse width and applied weight can be correlated with a calibration function.

The RADSiP™ is a reversed biased silicon PIN photodiode diode connected to a charge-sensitive amplifier and a thresholding circuit, and is used to measure gross gamma and x radiation above 60 keV. Since neither the diode nor the electronics is cooled, and radioactive nuclear material has significant emission above this energy, this lower level was chosen to improve the signal-to-noise characteristics of the detector. The detector is sensitive primarily to photons under 100 keV (via direct conversion to electron-hole pairs) and to photoelectrons under 200 keV created in the diode's case. The output is monitored as counts per seconds averaged over a moving 40-second interval. RADSiP™s and the weight sensors send their data to a sensor concentrator unit which is in turn interrogated by a remote PC.

The SmartShelf™ system is an automatic inventory system based on Dallas Semiconductor touch memories. Each container to be tracked is fitted with a touch memory and is tracked by direct connection to a computer-monitored network. The removal (disconnection) of a container is noticed by a computer within a few seconds and a sequence is started during which the person removing the container must identify himself by presenting an operator identification touch memory to the now empty connector. If the operator fails to identify himself, then a theft is recorded and an alarm is posted. If the operator makes a proper identification, then the removal is credited to the operator. Placing a container into storage is accomplished by reversing the order of operations. Since the computer monitors all network activity, a record of all transactions, both proper and improper, is available within minutes to operations personnel. In addition, the computer can produce an accounting of all items in storage.

ADAPTATIONS FOR USE IN RUSSIA

The containers in use in Russia are significantly different than those for which the weight sensors and RADSiP™s were originally developed. Original designs called for containers up to 15 cm in diameter and a dose rate of at least 0.5 mrem/hr at the surface. The weight sensors were designed so that a RADSiP™ could be placed between the plates and under a hole in the upper plate. This placement gives the RADSiP™ an unshielded view of the container sufficiently large to generate about 1 count/second. However, the Russian containers measure 25 cm across and produce a dose rate of no more than 0.4 mrem/hr at the surface. Thus it was necessary to retrofit the original designs to accommodate the Russian containers.

Adapter plates to fit the larger containers, as shown in Figure 1, were fabricated in the U. S. to Russian specifications and shipped with the weight sensors. These plates are solid steel and fit over the upper plate of the weight sensor. Because the Russian containers already had low dose rates, the additional shielding of the adapter plate necessitated the placement of the RADSiP™ on the sides of the containers as shown in Figure 2.

Fig. 1. Russian container on weight sensor with adapter plate

Fig. 2. Russian container with RADSiP™ and SmartShelf™ hardware attached

The two lowest plates in Figure 1 form the weight sensor as it was originally designed. The electronic circuit for sensing the distance between the top and bottom plates is mounted between the plates. Although it is not visible in the photograph, a fixed parallel plate capacitor is also on the circuit board to compensate for changes in capacitance due to changes in the dielectric constant of air as a function of temperature, humidity, and barometric pressure. The adapter plate is the thick uppermost plate in direct contact with container.

Figure 2 shows the placement of the RADSiP" and SmartShelf™ connection. The RADSiP" is the vertical rectangular box mounted in the triangle painted on the side of the container. Moving the RADSiP" from below the container, where it was shielded by the bottom of the container and the adapter plate, to the side improved the count rate. The SmartShelf™ connector is attached to the top of the container where the touch memory is mounted. The connector's flexible cord hangs down the front of the container and is connected through a small RJ-11 modular telephone coupler to a modified RJ-11 modular telephone jack box mounted on the wooden strip on the edge of the table. The 4-conductor modular telephone wire connecting the jack box to the rest of the network is seen at the bottom of the box. The thin wires attached to the bolts of the container at the left in Figure 1 and at the right in Figure 2 are tamper-indicating seals.

Although no modifications to the SmartShelf™ hardware were required because of the Russian containers, materiel to effect several methods of attachment of touch memories to containers was shipped. These included adhesive pads, a flexible rubber adhesive, stainless steel plates that capture the touch memories and can be welded, glued, strapped, screwed, or riveted to a container, and a special connector and touch memory package (TO-92 instead of F5 can) for those containers on which none of the previous methods would work.

OPERATING EXPERIENCE

INSTALLATION   Weight sensors and RADSiP™s were installed on 20 containers according to written instructions provided by the U.S. side. These devices communicate with a computer through the sensor concentrator unit containing two CPUs, an RS-232 serial communications interface, electronics for counting pulses from the RADSiP™s, and electronics for sensing the width of the pulses from the weight sensors. SmartShelf™ equipment was installed according to written instructions on 18 containers, 14 of which are seen in Figure 3 while the remaining 4 were in a portable rack that was also used for demonstration purposes.

Fig. 3. Test stand containing 20 containers monitored by weight and radiation sensors. SmartShelf™ also monitors fourteen containers.

Figure 3 shows the table holding the 20 nuclear material containers. Each is resting on a weight sensor and the 14 SmartShelf™ nodes are visible mounted on the edge of each shelf of the table. The sensor concentrator is seen bolted to the wall near the rear of the table. The box on the wall at the left of the photograph is a power distribution unit for the sensor concentrator. The monitoring computers were located approximately 35 meters from these containers.

Installation of all equipment proceeded smoothly. It was observed that the bare aluminum case of the RADSiP” caused the sensitive amplifiers inside to pick up RF noise from the weight sensor electronics when the RADSiP” was in electrical contact with its weight sensor. Because of this, the present design has been modified to include an insulating layer of heat shrinkable plastic tubing on the outside of the RADSiP”. Intermittent problems in the SmartShelf™ system were traced to a faulty connector fabricated on-site at Sarov and a faulty contact inside one of the node boxes shipped from the U.S.

RESULTS OF OPERATION TO DATE   The SmartShelf™ system has been operating essentially error-free since early April, 1998, at which time the faulty connections were repaired. The system is started each working day at 8:00 and switched off at 17:00. During the operating hours, items are removed from and inserted into the system so that operators may be trained and familiarity with the system may be obtained. In addition, wires, boxes, and contacts are wiggled in an effort to locate other faulty connections in the system. During the months of April and May, approximately 400 manipulations of containers have been performed with only 9 reported errors in April and 5 in May. The causes of all of these errors save one are known. No problems concerning the attachment of touch memories to containers have been found; one of the special connectors with the TO-92 touch memory on it was damaged during one of the manipulations.

Weight and radiation sensor data was obtained first with MS-DOS-based and later with Windows 95-based software. Weight data for 7 May 1998 obtained with the MS-DOS software are shown in Figure 4. At approximately 9:15, all 20 weight sensors posted increased weights that subsequently decreased throughout the remainder of the day toward the initial values. This indicates a common mode problem probably related to temperature. On this particular day, the temperature in the test room started at 14 °C, rose to 19 °C by 11:35, and then fell slowly to 15.5 °C by 15:00. Similar data was obtained on other days when the temperature was varied; no such excursions were observed when the temperature was held constant. It should be noted that the excursion represents only a 1% deviation from the initially reported weight, and that prior to the excursion, fluctuations were no more than 0.1%.

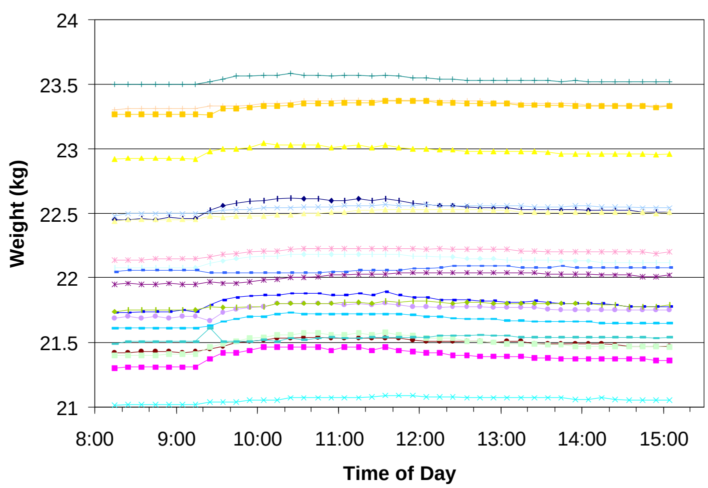

Fig. 4. Weight data for 7 May 1998.

Figure 5 shows the readings from a single RADSiP" acquired during 7 May 1998 and is typical of all twenty sensors. No correlation was observed between the 20 channels of data. Unlike the weight sensor data, radiation data appear unaffected by temperature. The error bars shown are statistical only and represent an uncertainty of approximately ±25%. Thus 50% change of signal

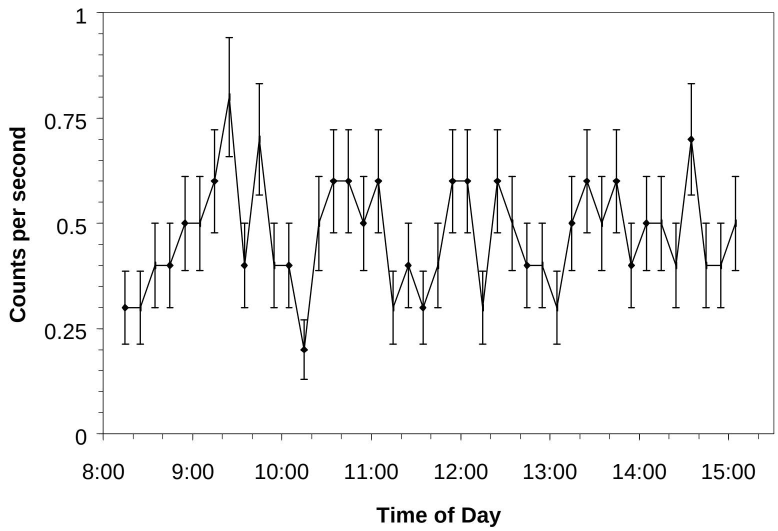

Fig. 5. Radiation data from a single RADSiP" for 7 May 1998.

level might be expected from random events 5% of the time and a 100% change can be expected at the level of 0.00634%. This implies that a reading of 0 should be expected 2 – 3 times per day and that a single low or high reading should not be interpreted as an alarm. Improvements in the sensitivity of the RADSiP™s are expected to improve this sensor's performance.

CONCLUSIONS

Initial operating experience with capacitance weight sensors and RADSiP™s has demonstrated that equipment designed for use in the U. S. often requires modification for offshore implementation. Differences in the design of containers were found to hinder radiation measurements and pointed out the need for more sensitive detectors. 20 such sensors have already been fabricated and are scheduled for shipment to Sarov in early August 1998. Only minor mechanical modifications to the weight sensors proved necessary, however, an apparent sensitivity of the electronics to temperature is indicated in the data. SmartShelf™ equipment functioned properly after faulty connections were corrected.

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[1] Work supported by the U. S. Department of Energy under contract DE-AC05-84OR21400.

[2] Managed and operated by Lockheed Martin Energy Research Corp. for the U. S. Department of Energy under contract DE-AC05-96OR22464.

[3] Managed and operated by Lockheed Martin Energy Systems, Inc., for the U. S. Department of Energy under contract DE-AC05-84OR21400.