OPERATING THE WAND AND HERCULES PROTOTYPE SYSTEMS

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ABSTRACT

Two prototype systems for low-density Green is Clean (GIC) waste at Los Alamos National Laboratory (LANL) have been in operation for three years at the Solid Waste Operation's (SWOs) non-destructive assay (NDA) building. The Waste Assay for Nonradioactive Disposal (WAND) and the High Efficiency Radiation Counters for Ultimate Low Emission Sensitivity (HERCULES) are used to verify the waste generator's acceptable knowledge (AK) that low-density waste is nonradioactive.

GIC waste includes all non-regulated waste generated in radiological controlled areas (RCAs) that has been actively segregated as "clean" (i.e., nonradioactive) through the use of waste generator AK. GIC waste that is verified clean can be disposed of at the Los Alamos County Landfill. It is estimated that 50-90% of the low-density room trash from RCAs at LANL might be free of contamination. To date, with pilot programs at five facilities at LANL, 3000 cubic feet of GIC waste has been verified clean by these two prototype systems.

Both the WAND and HERCULES systems are highly sensitive measurement systems optimized to detect very small quantities of common LANL radionuclides. Both of the systems use a set of phoswich scintillation detectors in close proximity to the waste, which have the capability of detecting plutonium-239 concentrations below 3 pCi per gram of low density waste. Both systems detect low-energy x-rays and a broad range of gamma rays (10-2000 keV), while the WAND system also detects high energy beta particles (>100 keV).

The WAND system consists of a bank of six shielded detectors which screen low density shredded waste or stacked sheets of paper moving under the detectors in a twelve inch swath on a conveyor belt. The WAND system was developed and tested at the Los Alamos Plutonium Facility in conjunction with instrument system designers from the Los Alamos Safeguards Science and Technology group.

The HERCULES system consists of a bank of three shielded detectors, which screen low-density waste in two cubic foot cardboard boxes or in bags sitting on a turntable. Waste that does not pass the verification process can be examined within the facility to determine the type and quantity of the contamination and its origin within a waste container. The paper discusses lessons learned that have helped generators improve their AK segregation.

BACKGROUND

The cost of low-level waste disposal at LANL has been steadily increasing over the past ten years. Recent estimates have been from \$550 to \$4000 per cubic meter,(1,2) depending on the type of waste. Low density, low-level, non-hazardous waste is on the less expensive end, but still considerably more expensive to dispose of than non-radioactive waste, which can be sent to the county landfill at a few dollars per cubic meter. The WAND and HERCULES systems both deal with low density waste from radiation areas at LANL that is declared clean by generator acceptable knowledge. After verification in the WAND and/or HERCULES, the waste can be sent to the county landfill for disposal.

Detectors

Both the WAND and HERCULES systems are highly sensitive measurement systems optimized to detect very small quantities of common LANL radionuclides (e.g., Pu-239, Am-241, U-235, and U-238). Both of the systems use a set of phoswich scintillation detectors in close proximity to the waste, which have the capability of detecting activities below 3 pCi (0.1 Bq) per gram in low density waste.

Phoswich detectors consist of two crystals, a thin thallium-activated sodium iodide (NaI) crystal (3 mm thick), which is optically coupled to a thick thallium-activated cesium iodide (CsI) crystal (50.8 mm thick).(3,4) The circular detectors are 5 inches (12.7 cm) in diameter inside an oxygen free high conductivity (OFHC) copper housing with an aluminzed mylar entrance window. The sodium iodide crystal detects low energy x-rays and gamma rays, and the cesium iodide crystal detects higher energy gamma ray signals. Because of their differing decay constants (0.23 μs vs. 1.0 μs), the pulses of the two crystals can be discriminated through pulse shape analysis. This allows the electronics to use coincidence/ anticoincidence gating of preamplifier pulses to reject background radiation signals that create pulses in both crystals. The discrimination and rejection of background signals reduces background count rates in the NaI crystal by approximately a factor of three in the x-ray region of interest (ROI) and a factor of ten in the 59.5 keV gamma ray ROI. The NaI crystal is thick enough to absorb nearly all low-energy x-rays and gamma rays, but thin enough to allow most of the higher energy gamma rays to travel into the CsI crystal. The energy calibration allows the NaI crystal to detect photons ranging from 10 to 800 keV and the CsI crystal to detect photons ranging from 100 to roughly 2000 keV. The NaI crystal is also capable of detecting beta particles with energies greater than 75 keV. The combination of the two crystals allow for the sensitive detection of a wide variety of radionuclides.

WAND System

The WAND system was developed at the Los Alamos Plutonium Facility as a pollution prevention effort beginning in 1993, based on work originally conducted in the 1970's by LANL researchers in what is now the Safeguards Science and Technology Group. The WAND was specifically designed to assay low-density cellulosic materials, which pass 2 inches (5.1 cm) under a bank of six phoswich detectors in a staggered array designed to allow maximum coverage of the passing waste and to provide the lowest minimum detectable activity (MDA) for the radionuclides of interest. The detector array is housed inside a lead shielded box that is lined with 1/32 inch (0.8 mm) sheets of cadmium and copper on the inner wall to reduce the backscattering of lead x-rays. The waste moves on a conveyor belt at a low rate of speed in an approximately 1 inch high by 12 inch (2.5 cm by 30.5 cm) wide stream, with an effective density of around 0.2 g/cm^3. The waste that is verified clean falls into a plastic bag at the end of the conveyor. It is then closed up and put into a dumpster outside the building, which is destined for the county landfill. Paper that does not pass verification is treated as radioactive waste and the system is decontaminated prior to re-use. Figure 1 is a picture of the WAND system.

Fig. 1. The WAND System. Detectors are housed to the left of the conveyor belt.

HERCULES System

The HERCULES system was designed to maximize detection sensitivity for the same radionuclides as the WAND system (e.g., Am-241, Pu239, U-235, U-238). HERCULES assays a variety of low-density waste including paper, plastics, wood, and cloth. This system consists of a bank of three shielded detectors that screen the waste in 2 ft^3 (0.06 m^3) cardboard boxes or in bags placed in a plastic 30-gallon (114 liter) drum on a turntable. The detector array is located 1.5 inches (3.8 cm) adjacent to the rotating drum with the detectors evenly spaced in the vertical plane. Both the detector array and the assay chamber are shielded with lead and lined with 1/32 inch (0.8 mm) copper and cadmium sheets. Waste that passes the verification step is put into a dumpster outside the building, which is destined for the county landfill. Waste that does not pass the verification process is handled as radioactive waste. This waste can be examined within the facility to determine the type and quantity of the contamination and its origin within a waste container. Corrective actions are undertaken with the waste generator to upgrade their AK. Figure 2 is a picture of the HERCULES system.

Fig. 2. The HERCULES System. Detectors are housed on the near side of the chamber, waste is placed on the far side.

OPERATING EXPERIENCE

Detector Performance

The phoswich detectors and their associated electronics are stable systems. The detectors are put through quality assurance (QA) and background checks each time they are used and they are calibrated once a year. QA check failures are rare and can usually be attributed to significant changes in the radiation environment. Since the detectors are well shielded, the standard background radiation has little effect on the system performance. Large radiation sources (mCi) in the vicinity of the detectors will affect the systems. Recently, a waste box with a large amount of Co60 in an adjoining room caused the detectors to fail their QA check. Another instance where the QA check failed was when high curie content sources were added to the source cabinet in the operating room. Additional shielding was placed around the source cabinet to eliminate this problem. Another factor that is important to detector performance is maintaining a stable temperature in the operating room. The detector energy calibration drifts with changing temperature and the detector efficiency suffers as the temperature goes up. Therefore, temperature fluctuations cause the QA check to fail and the system is unusable until it is adjusted for the temperature or the temperature is adjusted for the system. Changes in the air conditioning system in the building have highlighted this factor in detector performance.

Software

Since their initial design, the WAND and HERCULES systems have been run using an S100 board (MCA) from Canberra Industries. The original software for the system was written in C++™, and run with Windows 3.1™ on IBM 486 computers. Upgrading the computers to Pentium IIIs™ and installing Windows 98™ caused us to re-evaluate the existing software. After examining the options, it was determined that further automation and upgrading of the operator interface would be the best software route for WAND and HERCULES. The software was re-written this year to utilize Canberra's Genie-2000@ data acquisition software with a National Instrument's LabVIEW™ front end. The S100 board and all other hardware was retained.

This transition to LabVIEW allowed for a much more seamless interaction between the operator and the assay systems. Levels of authority were included in the rewrite so that the system engineer is the only one allowed to make significant changes in the assay parameters. Signals such as "radiation detected" are sent to the operator and require an acknowledgement. The "radiation detected" signal is also audible to alert an operator who may not be standing right next to the computer screen.

A copy of the WAND system screen that is displayed during an assay of a known plutonium 239 source on shredded paper is shown below as Figure 3. Several features of this screen need to be highlighted. Recall that the WAND system has six phoswich detectors. Each detector has four regions of interest (ROIs) set up for the assay. The upper left portion of the screen indicates the limit of counts allowed in a particular ROI and detector. Once a count limit in an ROI is exceeded, the conveyor backs up and recounts that portion of the waste. Exceeding the limit in both assays indicates that this is a true radiation "hit." The assay stops and the "radiation detected" signal is activated. The ROIs for this assay include the x-ray region, the americium 241 peak at 59.5 keV, the beta region, and the cesium 137 peak at 661.7 keV.

The system is set up to perform continuous 10-second assay cycles. In the assay shown in Fig. 3, during the first two 10-second cycles, the waste had not yet moved into the assay area. The third 10-second cycle indicated both detectors #1 and #2 saw elevated counts in the x-ray region of interest. The fourth cycle confirmed that there were elevated counts in ROI #1 for detector #1 and alerted the operator that radiation had been detected.

The bottom left portion of Fig. 3 shows the overall spectrum for both the CsI crystal (on the left, and the NaI crystal (on the right) for all six detectors. Each crystal is allotted 1024 channels for its spectrum acquisition. Each portion of the spectrum can be expanded to show the operator more detail. An expanded spectrum for the NaI crystal of Detector #1 is shown in Fig. 4 showing elevated counts on the first pass for all detectors and ROIs. Note that even though no actual peaks are visible in this sample, the fact that the counts are elevated in the ROIs indicates that radiation above the background is present and trips the radiation detected alert.

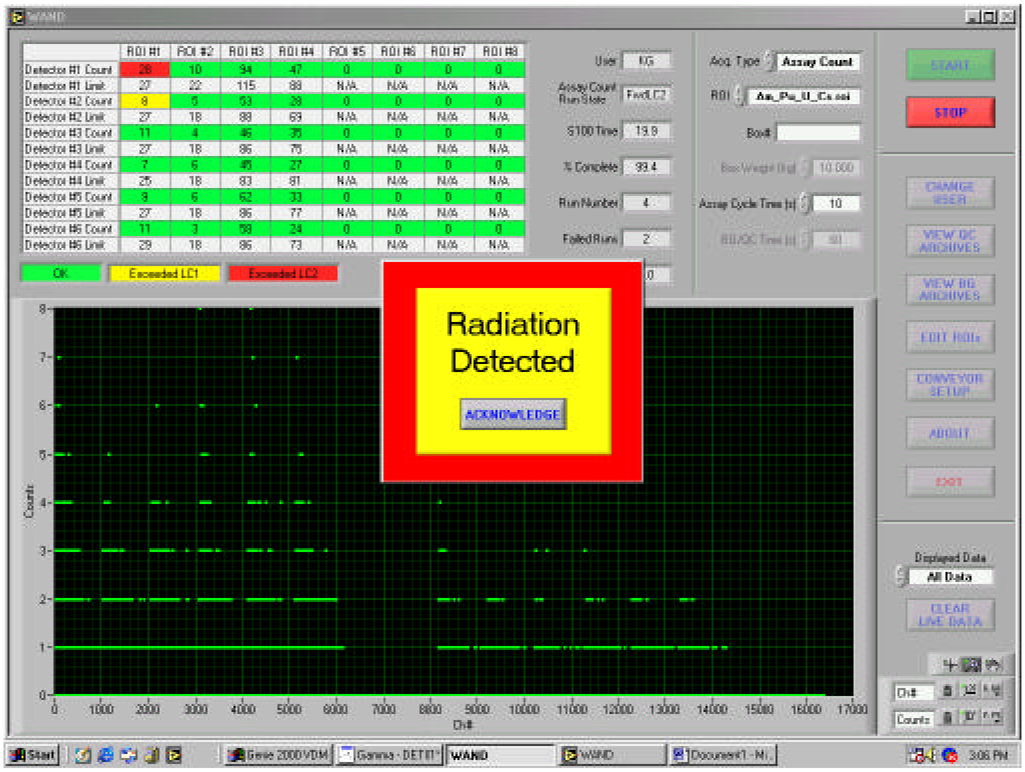

Fig. 3. The WAND system assay of known plutonium source with "radiation detected" alert.

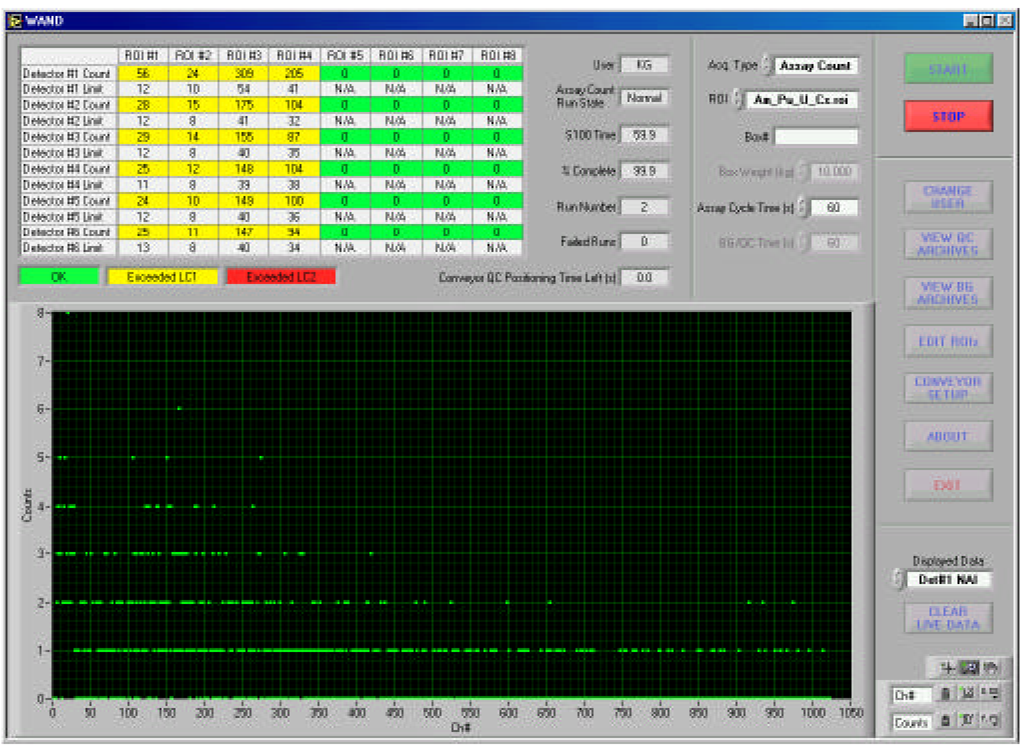

Fig. 4. Detail of NaI spectrum from Detector #1 on a WAND system assay of a known plutonium source with an artificially long count.

By way of comparison, Fig. 5 shows the detail of a cobalt 57 QC spectrum for the NaI crystal of Detector #1. In this case, the peaks at 14.4 keV and 122 keV are clearly visible. The 122 keV peak also appears in the CsI spectrum.

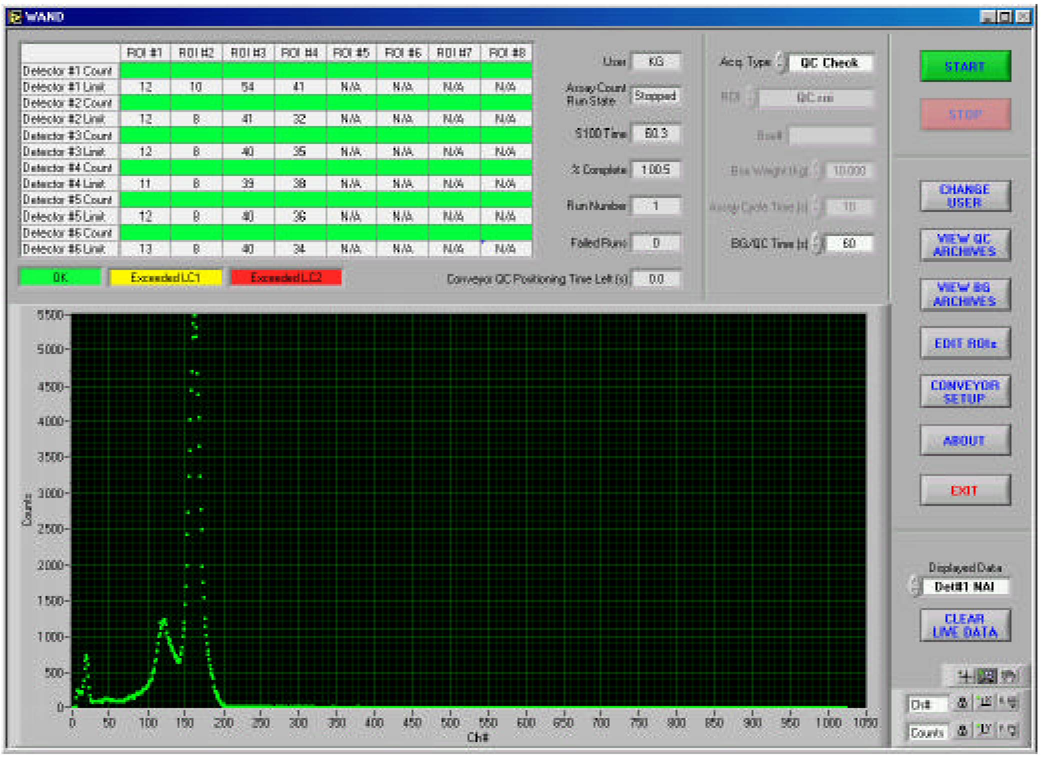

Fig. 5. Detail of NaI spectrum from Detector #1 on a WAND system assay of a cobalt 57 QC source.

When a QC count is done, the operator is able to observe the accumulation of counts in the ROIs real-time to determine, if necessary, where the QC count might fail. A copy of this screen for Detector #1 is shown below as Fig. 6. The operator is told whether the QC check passed or failed. This is in contrast to the previous method of checking the QC counts in each ROI against a paper copy of the QC limits.

Additional features of the software include computer controlled operation of the conveyor belt, a visual setup screen for the ROIs, and QC and background check archives and graphs. The HERCULES system software is very similar to the WAND system software, with the change from six detectors to three and from a conveyor belt to a turntable.

Type and Volume of Low-Density Waste Processed

The waste sent to SWO for verification of acceptable knowledge generally is delivered in 2-4 ft^3 (0.05 – 0.10 m^3) boxes or bags weighing from 10-35 pounds (4.5-15.9 kg). When contamination is detected in a container, the entire container is rejected and treated as radioactive waste.

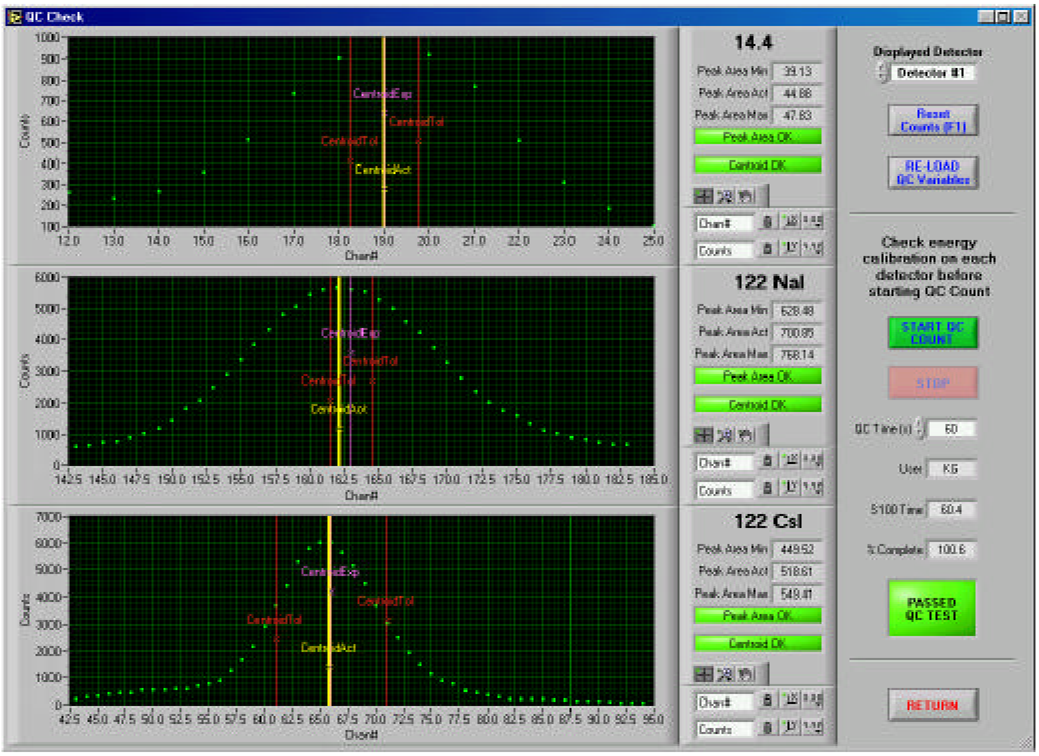

Fig. 6. The QC count screen for the WAND system showing detail of ROIs for Detector #1.

Waste destined for WAND is screened at the generator site prior to shipment to SWO. This screening is done in a radiation area with the Multiple Axis Dual Assay Measurement (MADAM) system. This screening effort is not in itself adequate for verifying the waste as clean because there is some radioactivity present in the generator's background, and because the MADAM system is not as sensitive as the WAND and HERCULES systems to the radionuclides of interest for common LANL waste streams. At SWO, the waste is again pre-screened by the HERCULES system, in a very low background area. Then, it is shredded using an industrial cross-cut paper shredder, and placed on the WAND conveyor belt for final verification.

The WAND system has processed mainly shredded paper (including cardboard) waste at SWO. Other items that have been processed at SWO include shredded fabric, plastic, and sheets of paper. The WAND process has handled 467 ft^3 (13.2 m^3) of waste at SWO, with 8 ft^3 (0.2 m^3) not passing the verification. Since the process volume for WAND is low and the generator's AK is generally excellent, containers that do not pass verification are thoroughly examined to identify the source of failure. Three of the containers that failed verification were identified in the pre-screening performed by the HERCULES system. All of the containers were contaminated with very low levels of transuranics. One container had a single contaminated piece of paper. Two containers have not yet been opened to determine the source of the contamination. The fourth container was one of the earliest items processed in the WAND at SWO, prior to the installation of the HERCULES system, and so did not go through the pre-screening process.

The HERCULES system has processed all manner of low-density waste, such as paper (including cardboard), plastic, fabric, styrofoam, carpet, wood, and aluminum metal chips. Since the HERCULES is still a prototype system, many of the items were processed on an experimental basis. The HERCULES system has processed 3815 ft^3 (108.1 m^3) of waste. 665 ft^3 (18.8 m^3) of this waste failed the verification count and six loads (184 containers) of waste were rejected in their entirety because of a high reject rate in the load (these are not included in the processing volumes above). Additional reasons for the substantially greater overall reject rates in HERCULES vs. those seen in WAND are discussed below.

Generator Education

Personnel from the Environmental Stewardship Office (ESO) work with waste generators and their site waste management coordinator (WMC) to write a site specific Green is Clean assessment and prepare acceptable knowledge documentation. The ESO personnel also provide initial training to waste generators on acceptable Green is Clean waste. Special waste containers identified as GIC containers are provided to the waste generator site and distributed to rooms or areas participating in the GIC program. Waste is not accepted for either WAND or HERCULES until this entire process is complete.

In addition to the initial training, feedback is provided to the generators through their WMC whenever high reject rates are encountered in WAND or HERCULES, or when unacceptable items such as metal, polyvinyl chloride (PVC), or large quantities of glass are included in their waste for verification. For generators experiencing high reject rates, the ESO personnel provide additional assessments and further training as needed. Part of the WMC and generator learning process is this steady stream of feedback from SWO identifying containers that have been rejected and the reason for the rejection. Each container has a GIC identification number and has the originating building and room number written on it. This system of identification allows easy traceability of the origin of both accepted and rejected waste. Buildings or rooms with consistently high reject rates are excluded from participation in the GIC program.

A general problem comes up when a waste generator site hires a new WMC who has not previously participated in the GIC program. The new WMC has to be trained by ESO personnel and go through a learning process with the generator site specific waste streams. This sometimes results in waste being sent to SWO by the WMC as GIC waste when it really should be handled as radioactive waste. High reject rates result, and ESO personnel work closely with the new WMC and the waste generators to bring the site specific GIC program back into line.

HERCULES Verification Failures

Since the instruments are housed at SWO, it was natural to use waste from the radioactive waste storage and disposal areas at SWO as test waste for the WAND and HERCULES systems. Waste from this site accounts for the greatest portion of the rejected HERCULES waste noted above, since the greatest volume of waste came from this site and the most experimentation was done with this waste. A comprehensive evaluation of the reasons for the verification failures has been done and only a small percentage of SWO waste boxes submitted for verification now fail. The reasons for failure included:

- More complete generator education required. The site has a large percentage of contractors performing construction and equipment installation activities. These contractors are generally on site for only a short period of time and even with training, are not as attuned to the GIC requirements as permanent employees.

- Waste, which has been picked up from out of doors frequently fails verification. As will be discussed below, residual soil from the area has natural radioactivity that causes the verification to fail.

- Some buildings that have had contamination on the floor in the past may have residual contamination that is transferred to waste items.

- Protective clothing used in handling radioactive waste cannot be thrown into the Green is Clean trash, even though radiological field screening indicates no contamination is present.

Physical Limitations - WAND

Although the WAND was originally designed specifically to handle stacks of paper up to 27 sheets thick, shredding the paper just prior to placing it on the conveyor belt has been the most common method of processing the waste. There are two reasons for this. One is that some of the paper is frequently somewhat crumpled and will not fit under the 2 inch gap between the conveyor belt and detector box. The second is that unclassified controlled nuclear information (UCNI) is sometimes included in the waste and it is a best management practice to shred it prior to disposal at the county landfill.

The WAND system was originally fitted with a hopper and screw auger to transport shredded paper waste from the shredder to the conveyor belt. The screw auger frequently jammed and the shredded paper did not spread evenly on the conveyor belt. Furthermore, it was quite troublesome to feed shredded paper in the hopper so that it fell onto the auger screw. Therefore, the hopper and auger were abandoned in favor of manual transport and placement of the shredded paper on the conveyor belt. Shredding paper in the operating room does generate paper dust, but this is controlled to a large extent by the use of a plastic screen over the shredder outlet and collection bin. The operator wears gloves and a dust mask when transferring the shredded paper from the collection bin to the conveyor belt, and has the option of wearing a half-face respirator if desired. The processing time for a box of WAND waste ranges from 15-45 minutes, depending on the amount and condition of the incoming waste. This includes all necessary documentation and handling.

Physical Limitations - HERCULES

The main physical limitation of the HERCULES system is the type of material that is assayed in the system. The density of the waste has a significant effect on the ability of the system to detect low-energy photons. For example, a box of stacked paper sheets can be configured to eliminate the transmission of low-energy x-rays from the center of the waste box. In such a case a point source of contamination in the right position would not be detected by the system. Putting a limit of 35 pounds (16 kg) on the weight of the box and assuring that the waste is fairly evenly distributed within the box assures that low energy photons have a high probability of reaching the detectors.

Another density issue is the waste composition. Metal in general is too dense to be effectively assayed by the system because it is highly attenuating for x-rays and gamma rays. An exception to this occurred when we screened aluminum chips for the presence of uranium isotopes. The gamma-rays associated with these isotopes are energetic enough to penetrate the aluminum matrix. PVC, although in the general class of plastics, is also too dense to allow low-energy x-rays (12 – 20 keV) to penetrate easily.

Glass is not only too dense for the transmission of low-energy photons, but it usually contains some naturally occurring K-40 that interferes with the assay. Small amounts of glass in a waste container do not adversely affect the assay results, but anything greater than about 10% of the volume is not acceptable. Residual soil is another problem material in the waste. The natural radioactivity in soil at Los Alamos is high enough that waste items which have been outside, such as silt fencing, contain enough radioactivity to fail the verification assay, even though they have no DOE added radioactivity.

A clean box filled with 8 kg (17.6 lbs) of low-density waste is placed in the detection chamber when background counts are performed in HERCULES. However, the actual background rates in the HERCULES chamber have been determined to vary directly with the total mass of low density material placed in front of the detectors. Because of this, heavier than normal boxes [i.e., > 10 kg (22 lbs)] commonly fail the verification measurement in spite of the fact that they contain no additional radioactivity. Therefore, a second clean, heavier waste box [~ 12 kg (26.5 lbs)] is used to determine the background rates expected for heavy waste boxes. We are also re-programming the HERCULES system so that a correction algorithm will be used to modify the expected background rates, and subsequently the critical levels of rejection, as a function of the mass of the waste box.

CONCLUSION

The operating experience with these two prototype systems has shown that WAND and HERCULES are effective verification tools for low-density Green is Clean waste at Los Alamos National Laboratory. Some adjustments in the original concepts of the systems and in the waste acceptance criteria have been made to make them more successful in verifying the waste. The most important elements contributing to the success of the Green is Clean program remain the generator education aspects and the extent of the generator acceptable knowledge of the waste.

Future work for the WAND and HERCULES includes expanding the generator base to include other facilities at LANL that process radioactive materials and updating the programming for the systems. The GIC program is also being expanded to include the capability for verification of small high-density items (e.g., tools) from facilities with alpha emitting radionuclides such as plutonium. Two long-range alpha detectors are being prepared to handle this waste stream.

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