Electronics Upgrades to the Green is Clean Phoswich Detector Systems and Programmatic Implementation at LANL – Phase II Completion – 18403

Randy Lucero *, David Sager *, Roland Bustos **, Wynn Christensen **, Lucas Gallegos **, Kathleen Gruetzmacher **, Wolfgang Hennig ***
* Pajarito Scientific Corporation
** Los Alamos National Laboratory
*** XIA LLC

ABSTRACT

Los Alamos National Laboratory (LANL) radiological facilities produce low-density room trash that, in many cases, is not contaminated with radioactivity. It has been estimated that 50 to 90% of low-density room trash is free of radioactive contamination and eligible for inclusion in LANL's Green is Clean (GIC) program. The GIC program is a verification program for non-regulated waste from radiation controlled areas that has been actively segregated as nonradioactive through the use of the waste generator's acceptable knowledge.

The GIC program has employed two large area Phoswich gamma ray detector systems (HERCULES and ZEUS) to verify that GIC candidate low-density waste contains no radioactivity above background. The large area (127 cm^2) Phoswich detectors consist of a thin NaI front crystal (3 mm thick) that is optically coupled to a thick CsI back crystal (50 mm thick). The scintillation properties of the two crystals are different enough to allow the system's electronic components to identify the origin of any pulse. The original systems utilize Nuclear Instrumentation Module (NIM) electronics to process the detector signals. The electronics currently in use by the systems are out of date and some components are no longer manufactured.

In 2015, phase I upgrades to the GIC detector systems were completed. Phase I objectives included identifying more modern commercially available electronics that could replace the NIM electronics. A pulse shape discriminator (PSD) module, the Digital Gamma Finder (DGF) Pixie-4 made by XIA LLC, that fits in a compact National Instruments™ PXI chassis was identified to replace the majority of the original NIM bin electronics – a single Pixie-4 module replaces four NIM amplifiers and four NIM pulse shape analyzers (PSAs). Another phase I objective was to show that that new PSD could separate out the NaI and CsI detector signals in a manner equivalent to or better than the NIM electronics. Proof of concept was achieved in 2015 when a prototype upgrade system on ZEUS was built and tested and gating parameter settings were determined that successfully separated the NaI and CsI signals.

Phase II required establishing a LabVIEW software interface with Pixie-4 electronics in lieu of the manufacturer provided Pixie-4 software called the Pixie Viewer. In addition, phase II included 1) final optimization of the gating parameters on the prototype Pixie-4 ZEUS system, 2) finalizing Requirements, Design and Test Plan documents, 3) LabVIEW software interface quality assurance (QA) testing, 4) setting up the HERCULES system with the Pixie-4 upgrade electronics, 5) check source and background calibration of both systems, 6) absolute efficiency determination on both systems and 7) procedure revisions and implementation of both systems into routine operations.

In 2017 phase II was completed including the preparation of detailed Requirements, Design and Test Plan documents. The LabVIEW interface software that communicates and controls the Pixie-4 has been completed, merged with the preexisting LabVIEW operations software and fully tested. Gating parameter optimization, configuration of HERCULES with the Pixie-4 electronics, check source and background calibrations and absolute efficiency determinations have all been performed – quantitative results are presented in the full paper.

For performance validation, comparison measurements of actual GIC bags on both the HERCULES system using the old NIM Bin electronics and the ZEUS system using the upgraded Pixie-4 electronics have been done and evaluated. Finally, procedure revisions and implementation of both systems into routine operations is currently in process and planned to be complete by the end of calendar year 2017.

INTRODUCTION

The Los Alamos National Laboratory (LANL) Green Is Clean (GIC) program is designed to reduce the amount of non-radioactive waste that is sent to low-level radioactive waste disposal facilities. Up until 1994, when the concept of "Green Is Clean" was introduced at LANL, waste generated in a LANL radiological control area (RCA) was considered to be at least "suspect" radioactive waste. Many LANL radiological facilities produce low-density room trash that, in many cases, is in fact not contaminated with radioactivity. This low-density trash consists of items such as plastic, paper, gloves, protective clothing, tape, and cardboard. It has been estimated that 50 to 90% of low-density room trash is free of radioactive contamination and eligible for inclusion in LANL's GIC program. The GIC program is a verification program for non-regulated waste from RCAs that has been actively segregated as nonradioactive through the use of the waste generator's acceptable knowledge (AK) [1].

The GIC program has most recently employed two large area Phoswich gamma ray detector systems (HERCULES and ZEUS) to assay and verify that GIC candidate waste meets free release disposal requirements [2], [3]. Figure 1 shows the HERCULES and ZEUS systems. These systems utilize large area (12,668 mm2) Phoswich detectors that consist of a thin NaI front crystal (3 mm thick) that is optically coupled to a thick CsI back crystal (50 mm thick). The scintillation properties of the two crystals are different enough to allow the system's electronic components to identify the origin of any pulse. Figure 2 shows the Phoswich detectors inside the cavity of the ZEUS system. The GIC systems accommodate bagged and boxed GIC waste packaged to fit inside the waste chamber.

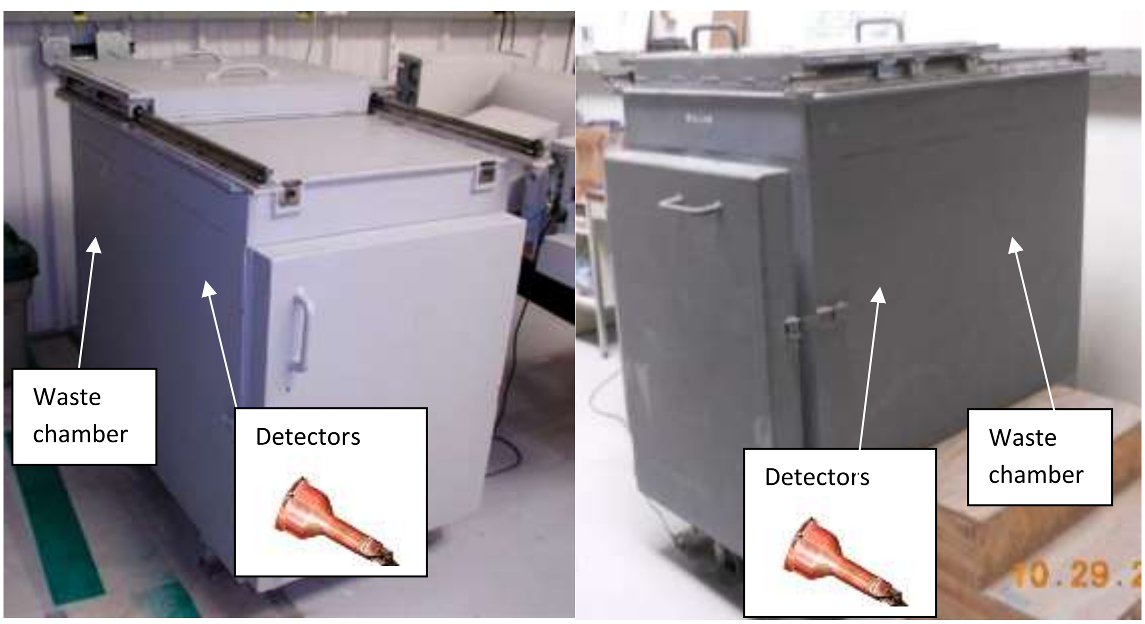

Fig. 1. The HERCULES (left) and ZEUS (right) Systems.

Fig. 2. Phoswich Detectors in the ZEUS System.

The counting electronics originally used to operate the systems are based on the Nuclear Instrumentation Module (NIM) standard. While NIM modules are still commercially manufactured and supported, the NIM chassis required for the numerous NIM modules needed to operate the systems are bulky and heavy, and it is possible that the NIM standard will eventually become obsolete. In Phase I [4] of the project, it was determined by the LANL EPC-WMS team that an upgrade to modern commercially available digital electronics was required. Phase II of the project continues where Phase I ended and takes the project to completion.

PHASE I SUMMARY

The original GIC verification systems employed a NIM Bin configuration where each detector is equipped with a Canberra Model 2005 preamplifier and two NIM modules: an ORTEC® Model 572 amplifier and an ORTEC® Model 552 pulse shape analyzer (PSA). These electronic modules provide the buffering, amplification, and PSA needed for the proper presentation of signals to the custom LANL designed Phosmix router module. The Phosmux module separates the sodium iodide and cesium iodide signals by their rise times and transfers this information into the computer-mounted multichannel analyzer, a Canberra Model S-100 system. The selection of the S-100 board dictated the requirements for the analog-to-digital (ADC) module, which had to be compatible with the S-100. A Canberra Model 8706 NIM module was used. In order to use a single ADC module for multiple dual-crystal detectors while preserving the individual signals from each of the detectors, a custom multiplexer module to handle the data was designed and developed by LANL – the Phosmux multiplexer. Figure 3 shows the HERCULES system NIM counting electronics.

Fig. 3. The HERCULES NIM Bin Electronics.

The computers that house the S-100 and operate the systems are over 15 years old, run the Windows98 operating system and are in obvious need of replacement. Also, LANL no longer has the ready capability to manufacture new or replacement Phosmux multiplexers. These additional factors confirmed the need to upgrade the system electronics and a prototype to be built using the commercially available XIA Pixie-4 Digital Gamma Finder (DGF). The prototype was established on the ZEUS system since it is not operational with the NIM electronics [4].

The Pixie-4 DGF made by XIA LLC is a 4-channel all-digital waveform acquisition and spectrometer card based on the Compact PCI/PXI standard for fast data readout to the host. The DGF family of digital pulse processors features unique capabilities for measuring both the amplitude and shape of pulses in nuclear spectroscopy applications. The DFG combines spectroscopy with waveform capture and on-line pulse shape analysis. Waveforms, timestamps, and the results of the pulse shape analysis can be read out by the host system for further off-line processing [5], [6].

The Pixie-4 module is housed in a 6-slot National Instruments™ PXI chassis and replaces the NIM Bin amplifiers, PSAs, ADCs and the custom Phosmux module. For the ZEUS prototype, the XIA PXI Power Distribution Module (PDM) provides the low voltage to the detector preamplifiers and the ISEG EHQ-102 PXI HV module provides the high voltage to the detectors. Both modules fit in the 6-slot National Instruments™ PXI chassis. Figure 4 shows a Pixie-4 module and PXI chassis.

Fig. 4. Pixie-4 and PXI Electronics Configuration.

Modern desktop PCs running 64-bit Windows 7 Enterprise have been set up for the operation of each GIC system. Running on each data acquisition computer (DAC) is the XIA Pixie Viewer software –the manufacturer's graphical user interface to set up and run the Pixie-4 modules.

The digital signal processor (DSP) controls the operation of the Pixie-4, reads raw data from the Real Time Processing Units (RTPU), reconstructs true pulse heights, applies time stamps, prepares data for output to the host computer, and increments spectra in the on-board memory.

In order to discriminate the NaI and CsI signals of the Phoswich detectors, the Pixie-4 DSP had to be customized for the LANL GIC system upgrade project. The custom code analyzes NaI/CsI Phoswich waveforms and allows setting of an upper and lower rise time (RT) threshold and/or pulse shape ratio P/E [4] to categorize pulses as NaI (fast) or CsI (slow) which are then binned into separate MCA spectra.

At the end of Phase I the customization of the Pixie-4 DSP code and Pixie-4 Viewer were complete and established adequate to perform comparable NaI and CsI signal discrimination to that of the NIM Bin electronics. One complete Prototype PXI Pixie-4 upgrade electronics system was configured on ZEUS. Custom features to the Pixie viewer were added and preliminary optimization of the RT vs P/E threshold was performed [4].

Since ZEUS is not functioning with the NIM Bin electronics, the PXI Pixie-4 electronics were connected to the HERCULES detectors for initial direct comparisons of the same detectors on the two different electronics configurations. Absolute efficiency and resolution was compared between the NIM configuration and Pixie-4 configuration. The FWHM for the three HERCULES detectors for the NaI Co-57 14.4 keV and 122 keV regions were within 6% and 2% on average, respectively. The FWHM for the NaI Am-241 X-ray and 59.5 keV regions were within 14% and 2%, respectively. The FWHM for the CsI Co-57 122 keV and Cs-137 662 keV regions were within 15% and 6 %, respectively.

The efficiency for the three HERCULES detectors for the NaI Co-57 14.4 keV and 122 keV regions were within 9% and 1% on average, respectively. The efficiency for the NaI Am-241 X-ray and 59.5 keV regions were within 14% and 2%, respectively. The efficiency for the CsI Co-57 122 keV and Cs-137 662 keV regions were within 15% and 16 %, respectively. The NaI Pixie-4 efficiencies were all higher (better) than the NaI NIM efficiencies, but the CsI Pixie-4 efficiencies were lower. The most important regions for GIC verification are the NaI low energy regions and based on the Phase I preliminary work "Proof of Concept" was established.

Finally in Phase I, since the original GIC operations software (written by a commercial vendor, VI Controls Systems, Ltd.) was programmed in the LabVIEW™ platform, the development of a custom LabVIEW™ front end software to communicate with and operate the Pixie-4 electronics was initiated.

PIXIE-4 GATE THRESHOLD PARAMETER FINALIZATION

The RT vs P/E threshold was mostly optimized in Phase I of the project. But after further evaluation it was determined that the "coincidence" or "in-between" events were capturing some of the CsI peak events. While it was also capturing true coincidence events, the contribution to the Compton continuum was negligible. Therefore, it was decided to combine the coincidence event signal with the previously determined CsI slow event signal and have a single threshold separating all events. Figure 5 shows the final gate setting where the P/E threshold parameter is set at 1.465. Once proof of concept of the prototype system was established, all the necessary electronics to upgrade the HERCULES system were procured, installed, and set up so each system had a separate set of electronics.

After final gate parameter optimization, NaI energy calibration was performed on both the ZEUS and HERCULES systems using Co-57 check sources setting the calibration at 0.75 keV/channel.

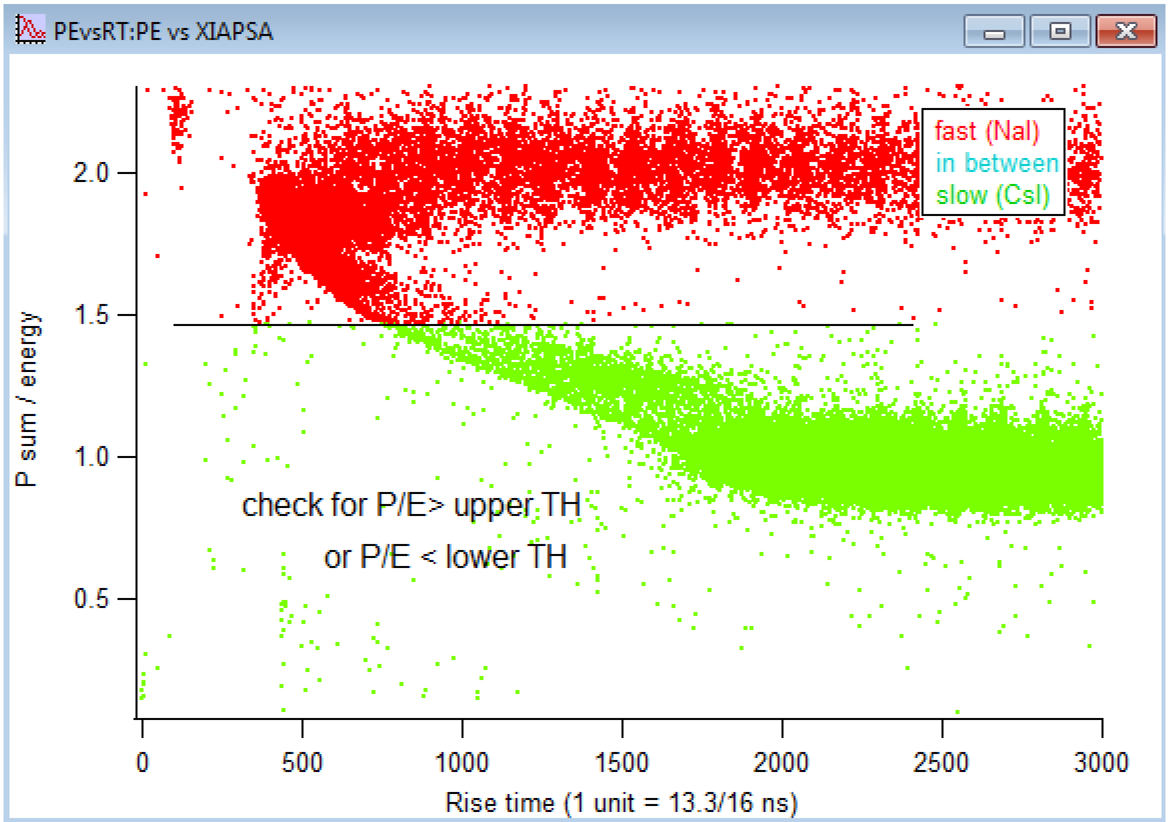

Fig. 5. Final RT versus P/E Threshold Setting.

Figure 6 shows the final configuration of the ZEUS Pixie-4 electronics (with the Pixie-4, low voltage and high voltage modules connected to the system) and the operations computer.

Fig. 6. Final ZEUS Pixie-4 and Computer Configuration.

EFFICIENCY MEASUREMENTS

A key component of system sensitivity (detection limit) is detector efficiency – sensitivity is directly proportional to efficiency. The more efficient the detector system the better the sensitivity will be (i.e., the lower the detection limit). Thus, absolute efficiency measurements were performed on both ZEUS and HERCULES with the Pixie-4 electronics configuration. Also, for comparison purposes, absolute efficiency data was also taken on HERCULES with the Pixie-4 electronics and the NIM electronics configurations with the reference source in the exact same location.

Absolute Efficiency

Baseline absolute efficiency measurements for the NaI detector were performed on both systems using a 37 KBq (1 µCi) Am-241 source place at the center of the system chamber across from the detector. Table I shows the absolute efficiency for the Am-241 X-ray and 59.5 keV energy regions for ZEUS and HERCULES. Equation 1 is used for the calculation:

$$\mathrm{E_{abs}} = \frac{C_s - C_b}{A_s \times I \times t} \qquad \text{(Eq. 1)}$$

where,

E_{abs}	=	Source ROI counts per gamma emission
C_s	=	ROI integral counts from the source
C_b	=	Expected background counts in the ROI (background rate × live time ─ obtained from background standard file)
A_s	=	Activity of the source (in Bq)
I	=	Intensity, or emission probability, per decay of the radiation of interest
t	=	Live time (in seconds).

TABLE I. HERCULES and ZEUS Absolute Efficiencies

	ZEUS	HERCULES
59.5	**Eabs**	**Eabs**
Det. 1	0.0022	0.0025
Det. 2	0.0030	0.0028
Det. 3	0.0029	0.0025
Det. 4	0.0021	
X-Rays	**Eabs**	**Eabs**
Det. 1	0.0011	0.0011
Det. 2	0.0015	0.0011
Det. 3	0.0015	0.0011
Det. 4	0.0011	

HERCULES Pixie-4 and NIM Efficiency Comparisons

For direct comparison of the gross detector efficiencies using the Pixie-4 electronics and the NIM electronics, efficiency measurements were taken on the HERCULES system using the same Am-241 (approximately 37 KBq or 1 µCi) and Cs-137 (approximately 370 KBq or 10 µCi) sources positioned exactly at the same location for both the Pixie-4 and NIM configurations. The source measurements were performed with the Am-241 and Cs-137 sources taped together in the center of the back wall across from the detectors with the Am-241 source in front of the Cs-137 source. Pixie-4 and NIM efficiencies for the Am-241/Pu-239 combined X-ray and Am-241 59.5 keV energy regions and the Cs-137 662 keV energy region were compared – the ratio of Pixie-4 and NIM raw region counts (%R = Pixie-4 region counts/NIM region counts) was calculated and is equal to the gross efficiency ratio. Three measurements were taken and averaged to compare the efficiency ratio for each detector. Table II shows the efficiency ratio %R.

TABLE II. HERCULES Pixie-4 versus NIM Am-241 and Cs-137 Efficiency Comparison

	Pixie-4	**NIM**	
Det. 1			
ROI	**ROI total counts**	**ROI total counts**	**AVG %R**
X-ray	28916	27240	1.06
59.5	35375	32760	1.08
661.6	19334	26797	0.72
Det. 2			
ROI	**ROI total counts**	**ROI total counts**	**AVG %R**
X-ray	32429	25654	1.26
59.5	42065	37961	1.11
661.6	24549	31612	0.78
Det. 3			
ROI	**ROI total counts**	**ROI total counts**	**AVG %R**
X-ray	30344	31158	0.97
59.5	36240	34436	1.05
661.6	24829	28146	0.88

The Am-241 X-ray and 59.5 keV regions are captured by the NaI detector while the Cs-137 662 keV region is captured by the CsI detector. The Pixie-4 NaI regions exhibited better efficiency than the NIM NaI regions for all detectors (30% for detector 2) except detector 3, which was just 3% less than the NIM NaI region. These are the most sensitive regions for GIC verification [2], [3]. The Pixie-4 CsI 662 keV region, however, had an efficiency that was lower the NIM CsI 662 keV region for all detectors on average by 20%. Since the low energy NaI sensitivity is the basis for meeting release criteria this does not affect the effectiveness of the system.

BACKGROUND MEASUREMENTS

Another key component of system sensitivity (detection limit) is detector background – sensitivity is proportional to the square root of the background. The lower the background the better the system sensitivity will be (i.e., the lower the detection limit).

The extremely well shielded system chamber reduces background significantly (compared to an “open” measurement), but some background always remains. Thus, background measurements were performed first to compare the Pixie-4 configuration and the NIM configuration background on HERCULES. Then, because Compton background is affected by material being in the assay chamber, background was measured in both HERCULES and ZEUS with material in the cavity. The mass of material in the cavity was systematically increased for 0 to the upper range of the assay systems.

HERCULES Pixie-4 and NIM Background Comparisons

Long 50,000 second background measurements were acquired on the HERC system with both the Pixie-4 and NIM configurations. The measurements were done with only the plastic barrel that holds waste bags in the chamber. These are considered baseline standard background measurements during operations. The count rates for four energy regions were calculated: Am-241/Pu-239 X-Ray, Am-241 59.5 keV, U238 (Th234) 92.6 keV, and Cs-137 662 keV. Table III shows the %R (%R = Pixie-4 background count rate/NIM background count rate) for all three detectors.

Table III. HERCULES Pixie-4 versus NIM Background Count Rate Comparison

	%R				
ROI	**Det. 1**	**Det. 2**	**Det. 3**	**AVG**	**STDEV**
X-ray	0.51	0.55	0.67	0.58	0.08
59.5	0.98	0.96	1.02	0.99	0.03
92.6	0.99	0.98	1.03	1.00	0.03
661.7	0.52	0.67	0.73	0.64	0.10

The data shows that the background count rates for the 59.5 keV and 92.6 keV energy regions are effectively equal between the Pixie-4 and NIM configurations (on average within 1%). The data also shows that the Pixie-4 background count rates for both the X-ray and 661.7 keV energy regions are approximately 40% less than the NIM background count rates. The reduced background improves the sensitivity of the system for those regions. Further, for the 662 keV region this lower Pixie-4 background contributes to the lower source efficiency observed in the efficiency comparisons. Note that the 662keV background rate is 6 times larger than X-ray background rate (1.2 counts per second versus 0.2 counts per second) for the Pixie-4. So the contribution of the background to the gross source counts is more significant for the 662 keV region than the X-ray region. Then, with the decrease in background in the 662 keV by 40%, the sensitivity improves by approximately 30%, which more than offsets the absolute efficiency decrease of approximately 20%. With the X-ray region efficiency being approximately the same for the Pixie-4 and NIM configuration, but with the background being 40% lower for the Pixie-4, there will be a sensitivity improvement of approximately 30% for that region.

Background as Function of Bag Weight

It was established in the initial development and setup of the GIC systems that that background was affected by material (in addition to the empty barrel) in the chamber. This is due to increased Compton scattering in the chamber when material is introduced. This affects some energy regions more than others. Thus, a calibration is required for the Pixie-4 configuration to adjust for the increase in background when material is introduced. For this purpose, the EPC-WMS team built surrogate (clean) GIC waste bags ranging from 2 kg up to 8 kg to establish the functional behavior of the background with increased bag weight. The bags were built using paper, plastic and rubber gloves.

Figures 7 and 8 show the bag mass versus background count rate for ZEUS for each detector for the energy regions Am-241 59.5 keV and U238 (Th234) 92.6 keV, respectively. The Am-241/Pu-239 X-ray and Cs-137 662 keV regions showed no effect from increased bag weight so the plots are not shown. A linear function sufficiently characterizes the data. Figures 9 and 10 show the bag mass versus background count rate for HERCULES for each detector for the energy regions Am-241 59.5 keV and U-238 (Th234) 92.6 keV, respectively. The X-ray region shows no increase in background with an in increase in bag weight likely because these very low energy gamma rays are absorbed before scattering. Also, the 662 keV region shows no increase in background with an in increase in bag weight likely because these higher energy gamma rays are penetrating enough that minimal scattering from the added material occurs.

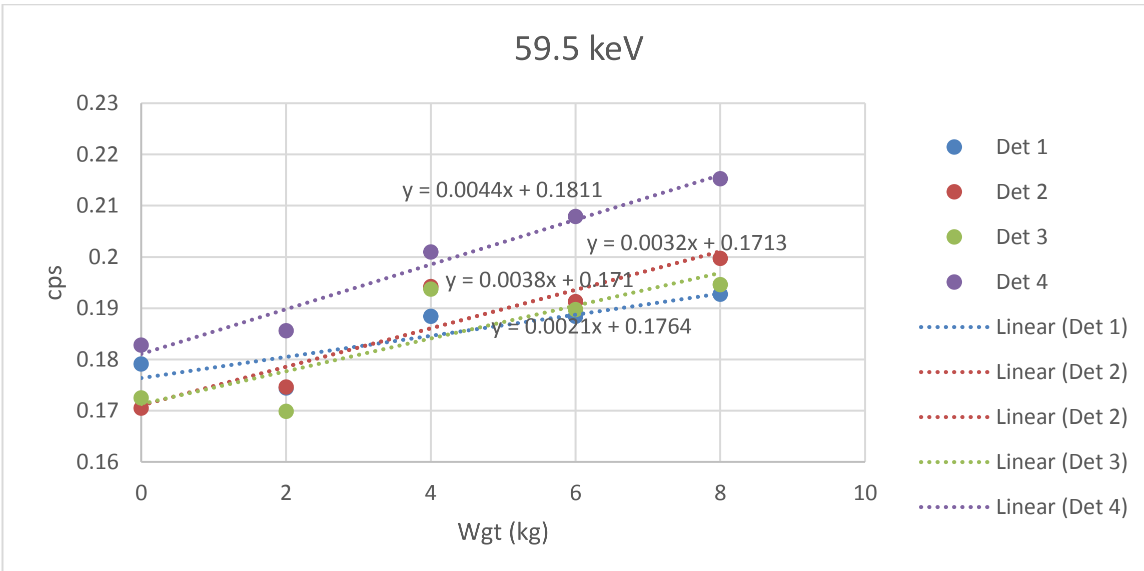

Fig. 7. ZEUS 59.5 keV Background as a Function of Mass.

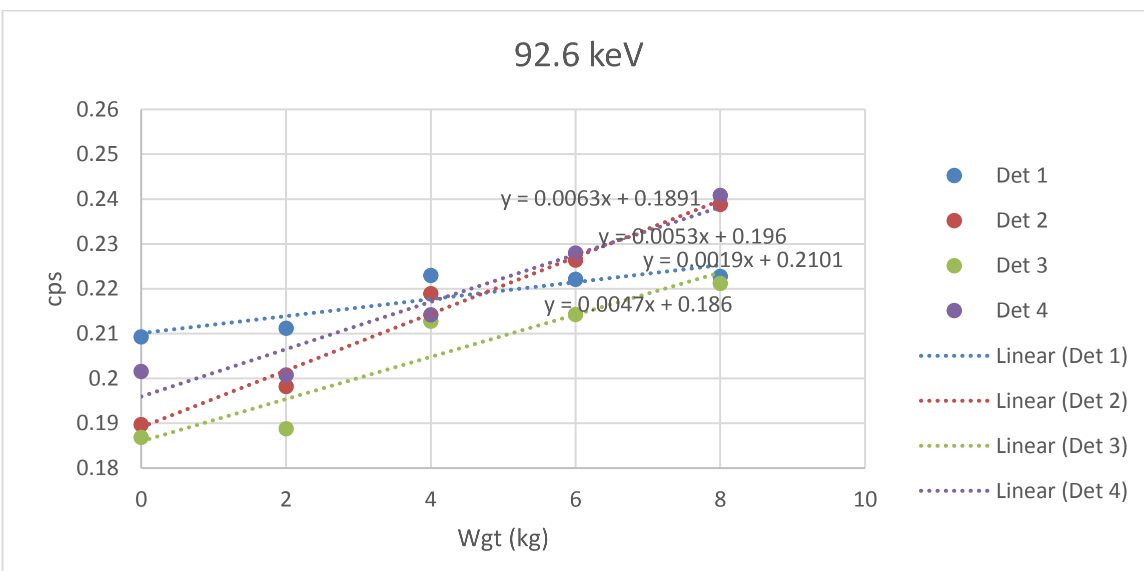

Fig. 8. ZEUS 92.6 keV Background as a Function of Mass.

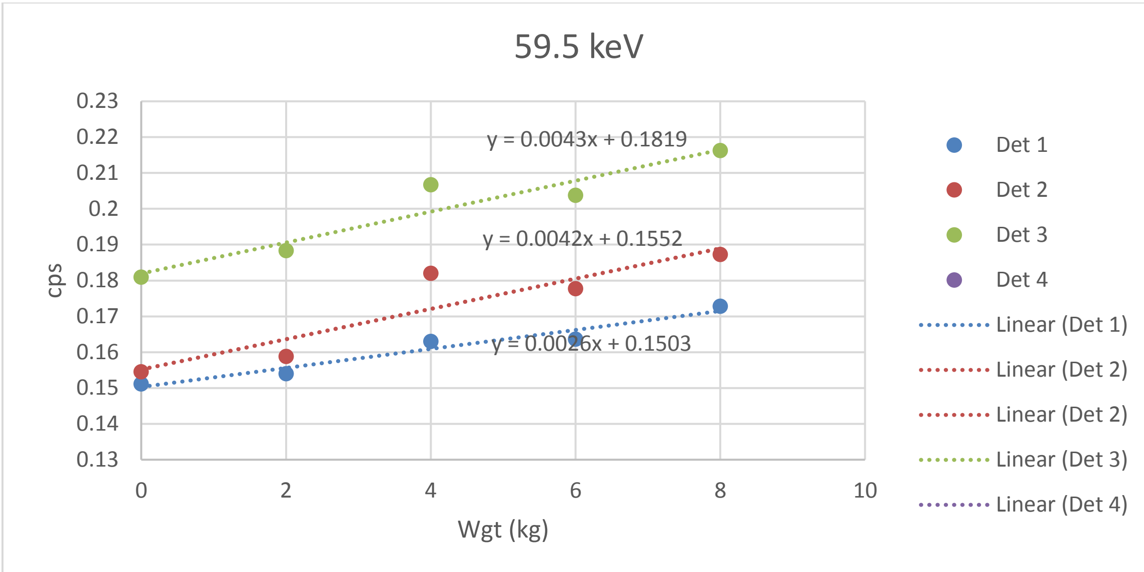

Fig. 9. HERCULES 59.5 keV Background as a Function of Mass.

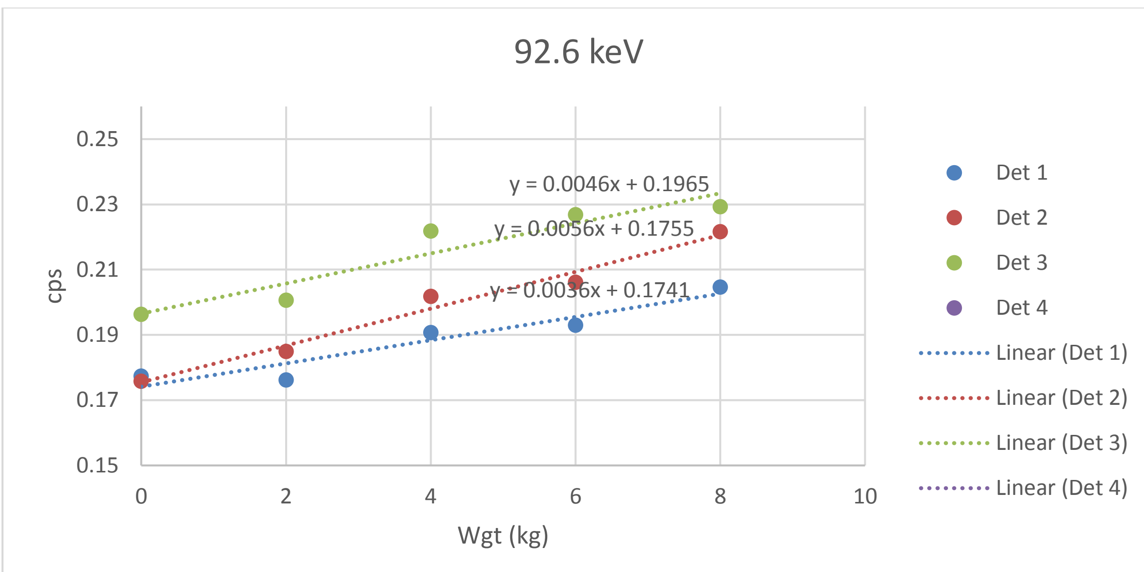

Fig. 10. HERCULES 92.6 keV Background as a Function of Mass.

GIC LabVIEW™ PRODUCTION OPERATIONS SOFTWARE

A key challenge with the transition to the Pixie-4 configuration is dealing with the different spectrum outputs from the different MCA softwares. The original Canberra Genie2K MCA software communicated with the S100 card and histogrammed the signal from all detectors into a single 16K spectrum. The first 8,192 channels were assigned to all the CsI events and the second 8,192 channels were assigned to all the NaI events. The original LabVIEW™ software communicates with Genie2K while it runs in the background. With the Pixie-4 configuration, each detector has a 32K spectrum with the NaI events being assigned the first 8,192 channels and the CsI events being assigned the second 8,192 channels. A single Pixie-4 module can accommodate up to four Phoswich detectors.

Four detectors is the current maximum for the ZEUS system, but more detectors could be accommodated with the introduction of additional Pixie-4 modules.

Thus, a new translation of the incoming Pixie-4 spectra was developed and completed in Phase II of the project. This has been achieved with a supplemental LabVIEW™ user interface called the "GIC Main Boot VI". This replaces the Genie2K MCA software and communicates directly with the Pixie-4 module primarily through a LabVIEW™ compatible ".dll" control file and a pre-optimized parameter settings file. Pixie-4 gains and offsets can be adjusted through the "GIC Main Boot VI". Figure 11 shows the window (named "GIC Boot Window") of the "GIC Main Boot VI" in its final state. In the graphic, a zoomed in portion of the NaI spectrum is displayed in the top portion of the window with the x-axis indicating bin (or channel) number. The middle portion of the window shows the full 32K spectrum for each detector and the section of the spectrum displayed in the top portion. The bottom portion of the window includes data acquisition, spectrum view, and gain and offset adjustment controls. Also, graphical zoom, acquisition start/stop/pause, peak find, peak area, and diagnostics features were added to the window. Finally, in phase II, integration of the main boot interface with the rest of the original LabVIEW™ operations user interface and algorithms was achieved. This included minor changes to the original LabVIEW™ software to accommodate the digital gain and offset adjustments for the Pixie-4 and to automate some of the calibration data entry, file save, and backup operations manually performed with the original version. Figure 12 shows the QC check window in the original LabVIEW™ software that allows digital gain and offset adjustment.

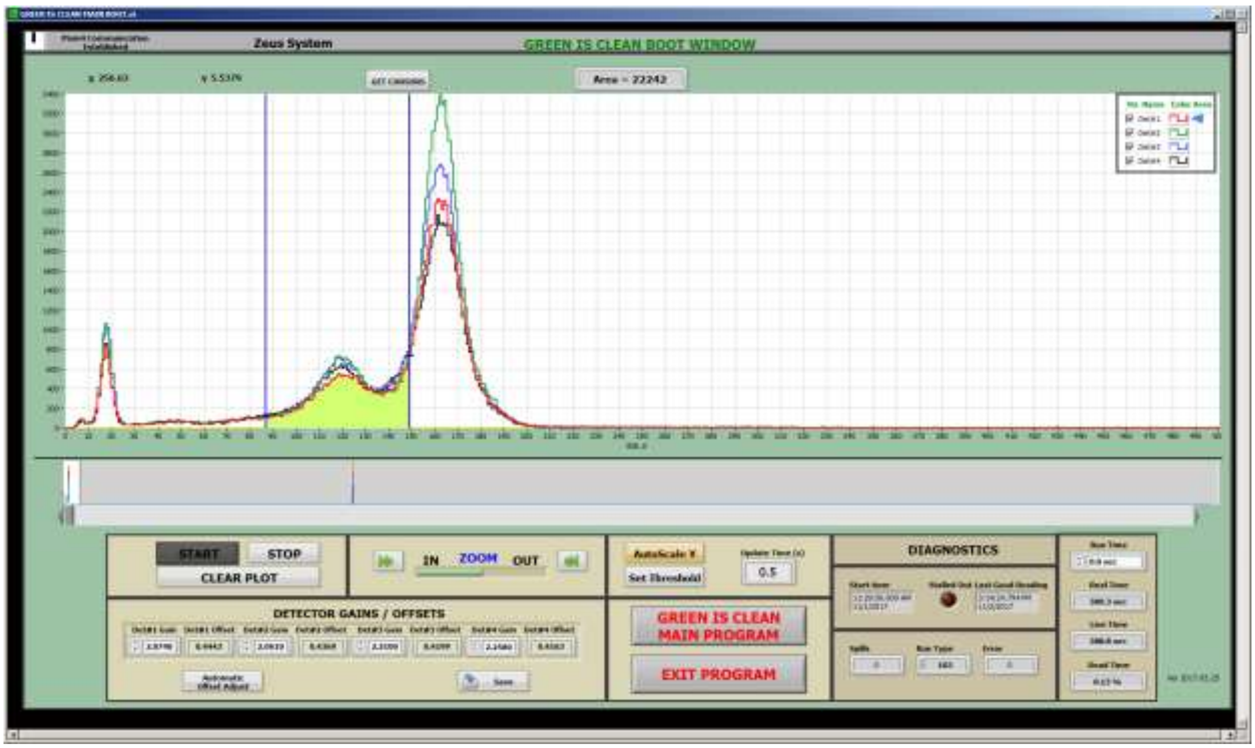

Fig.11. The GIC Main Boot VI.

In compliance with LANL software development QA program, several QA documents were prepared throughout the evolution of the software. First, a requirements document was prepared that guided the programmer on what to implement in the programming. Second, as the software was being programmed, a design document was prepared detailing the program structure of the software. Finally, when the software was complete, a formal verification and validation (V&V) exercise was performed and documented following a V&V plan.

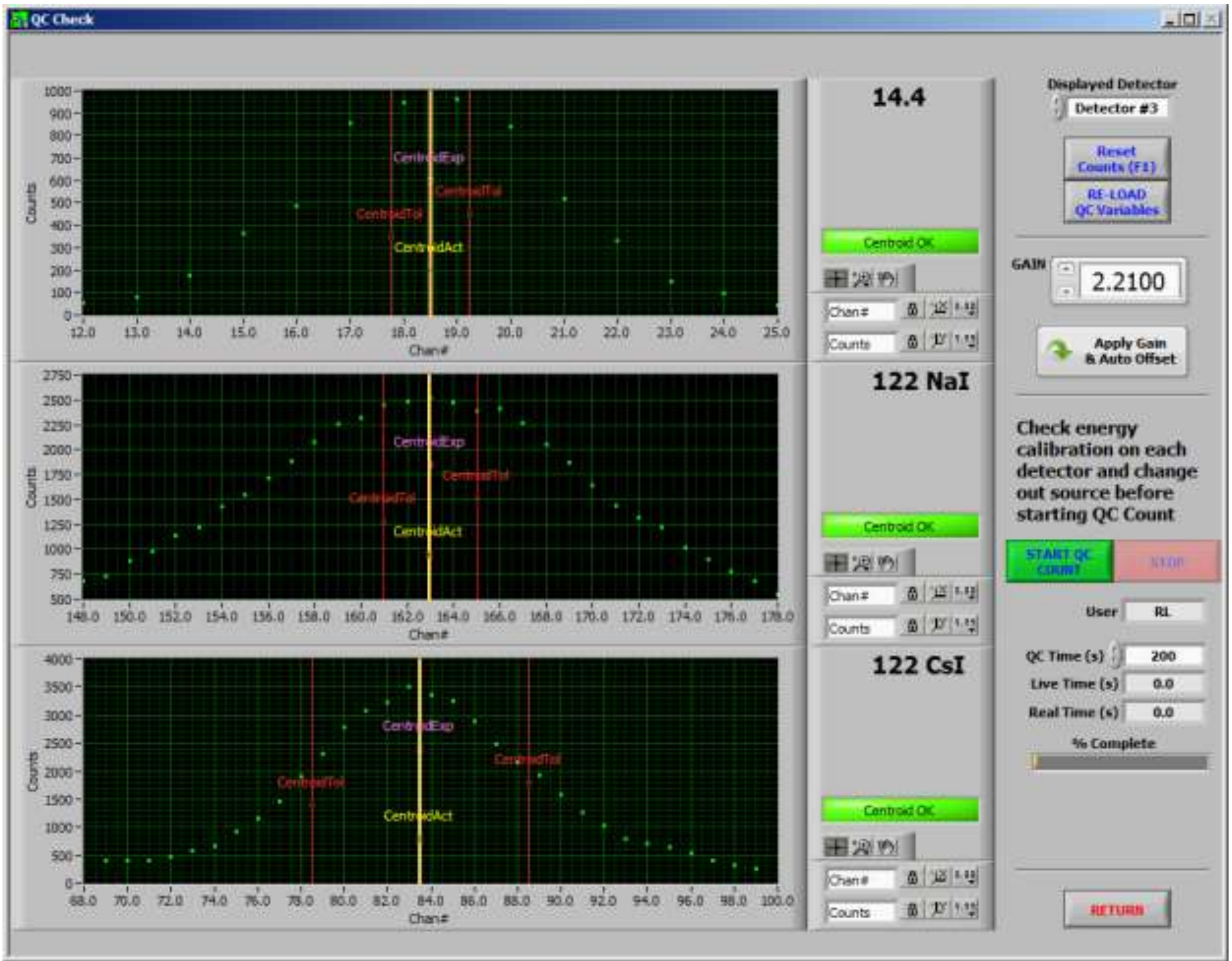

Fig.12. QC Check Window.

PROGRAMMATIC IMPLEMENTATION

With the new GIC LabVIEW™ software complete, both GIC systems upgraded to the new electronics and basic energy, efficiency, and background calibrations complete, programmatic implementation of the upgraded systems could be performed. Two formal procedures guide and control GIC production operations: a calibration procedure and an operations procedure. The calibration is performed annually and covers checking the detector gating, energy calibrating, and efficiency. The operations procedure covers daily production operations counting GIC bags. This includes performing background standards and checks, QC standards and checks, and making daily gain adjustments as necessary. Both these procedures were revised to be applicable to the new Pixie-4 upgrade configuration and have been implemented into the GIC program.

CONCLUSION

The GIC Phoswich detector systems, HERCULES and ZEUS, were developed in the late 1990s and have been a vital part of the GIC program at LANL over the past twenty years.
The HERCULES system is still operating using the original developed NIM Bin electronics configuration. Due to the GIC systems' age, potential obsolescence of the NIM and Phosmux modules, and the availability of modern comparable digital electronics, the EPC-WMS group moved to upgrade the GIC system electronics.

The XIA LLC Pixie-4 DSP was selected – along with the low voltage XIA PXI PDM and the ISEG EHQ-102 PXI HV high voltage module – to build a prototype on the ZEUS system in Phase I of the project where proof of concept was established. Phase II completed the upgrade project where gate parameter optimization to separate the NaI and CsI rsponses of the Phoswich detectors was finalized and the HERCULES system was also upgraded to the new electronics. On both systems efficiency measurements were performed to establish the baseline absolute efficiency. Also, efficiency comparisons between the Pixie-4 and NIM configurations on the HERCULES system using Am-241 and Cs-137 were performed. For the Pixie-4 configuration the efficiencies for the low energy NaI detector X-ray and 59.5 keV regions were better than the NIM configuration efficiencies for all detectors except one that was only 3% lower, however, the efficiency for the 662 keV region was on average approximately 20% lower for the Pixie-4 configuration. Empty drum measurements were also performed comparing the Pixie-4 configuration background to the NIM configuration background. The 59.5 keV and 96.2 keV region backgrounds were effectively equivalent between the two configurations, but the X-ray and the 662 keV regions were both approximately 40% lower for the Pixie-4 configuration. For the 662 keV region this compensated for (and explained) the 20% efficiency drop resulting in an overall improvement in system sensitivity. Further, background measurements with added material in the assay chamber were performed with the added weight systematically increasing from 0 kg to 8 kg in increments of 2 kg. This data was plotted for the X-ray, 59.5 keV, 92.6 keV, and 662 keV regions. The X-ray and 662 keV regions showed no affect from the added weight, but the 59.5 keV and 92.6 keV regions showed the background increasing with increased added weight – a linear function was fit to the data to represent the behavior. Implementing the new Pixie-4 electronics required that new front end LabVIEW™ software be developed that communicated with and controlled the Pixie-4 electronics and integrated with the original LabVIEW™ operations software. This software called the “GIC Main Boot VI” was completed, documented, and formally tested in Phase II and included gain adjustment controls, graphical tools, and diagnostic tools. Finally, with the instruments upgraded, the new system design was implemented into the GIC program by producing calibration and operations procedures for the new Pixie-4 configuration. The instruments are currently assaying waste bags in routine operations.

REFERENCES

1. Arnone, G.J., et al., “Status of the WAND (Waste Assay for Nonradioactive Disposal) Project as of July 1997” LA-13432-SR, LANL Status Report, March 1998.

2. Myers, S.C., et al., “LANL Operating Experience Using the WAND and HERCULES Prototype Systems” LA-UR-00-4552, Spectrum 2000 Conference, Chattanooga, TN, USA, September 24-28, 2000.

3. Myers, S.C., et al., “Qualifying the ZEUS System for Verification of GIC Room Trash from Radiologically Controlled Areas” LA-UR-04-1225, 2004 Waste Management Symposia, Tucson, AZ, USA, February 29-March 4 ,2004.

4. “Status of Electronics Upgrades to the LANL Green is Clean Phoswich Detector Systems – 16419”, Waste Management Symposia 2016 Conference, Phoenix, Arizona, USA, March 6-10, 2016.

5. W. Hennig, et al., “The DGF Pixie-4 spectrometer - compact digital readout electronics for HPGe clover detectors”, 6th Topical Meeting on Industrial Radiation and Radioisotope Measurement Applications, Hamilton, Ontario, Canada, June 20-24, 2005.

6. W. Hennig, et al., “Single Channel Beta-Gamma Coincidence Detection of Radioactive Xenon Using Digital Pulse Shape Analysis of Phoswich Detector Signals.” IEEE Transactions on Nuclear Science, Vol. 53, No. 2, April 2006.