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Technical Equivalency Evaluation of Lynx Electronics and Apex-InVivo software for the LLNL Whole Body Scanning Bed System

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Executive Summary[1]

Lawrence Livermore National Laboratory (LLNL) Whole Body Counter (WBC) is replacing the following components for its scanning bed counting system:

- *NIM* electronics with modern *Lynx* electronics,
- The *Alpha Workstation* running *VMS* with a PC running *Windows*, and
- *Abacos-Plus* in-vivo counting software with the new *Apex-InVivo* software.

These new components provide a compact design, extend the lifecycle of the system as a whole, reduce maintenance and user time, an improve overall ease of use. The technical evaluations and results described in this document demonstrate that the total system, incorporating these new components, provides results that comply with Internal Dosimetry requirements.

[1] This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Introduction

The Lawrence Livermore National Laboratory (LLNL) whole body scanning system monitors and measures internally incorporated radionuclides that emit photons above approximately 100 keV. The LLNL whole body scanning system consists of four ~70% (relative efficiency) P-type high purity germanium (HPGe) detectors configured with electric cooling (E-cooled) units. The detectors and the electric coolers were manufactured by ORTEC (now AMETEK). The detectors are positioned in a stationary mount under the scanning bed (Figure 1).

Figure 1. Detector positions

Each of the four detectors is currently connected to a Lynx digital signal analyzer (Mirion-Canberra; Figure 2a). Through the end of 2018, the detectors were connected to NIM electronics (Canberra; Figure 2b).

The Lynx electronics combines the high-voltage power supply (HVPS), amplifier, analog to digital converter (ADC), and acquisition interface module (AIM) into one compact box. The compact design simplifies setup and maintenance, thereby reducing troubleshooting effort, and improving overall confidence in the system. The new electronics increase the life of the system as, in the coming year, Canberra will discontinue support for the old NIM technology, and the Lynx boxes will be supported for the foreseeable future.

The scanning bed system is presently under the control of the Apex-InVivo software package (Mirion-Canberra) running on a Windows 7 (Microsoft) computer (Dell). Previously, the system was under the control of Abacos-Plus software (Canberra) running on an Alpha Workstation under OpenVMS (Hewlett-Packard).

a) Lynx Electronics

a1) Front

a2) Back

b) NIM Electronics

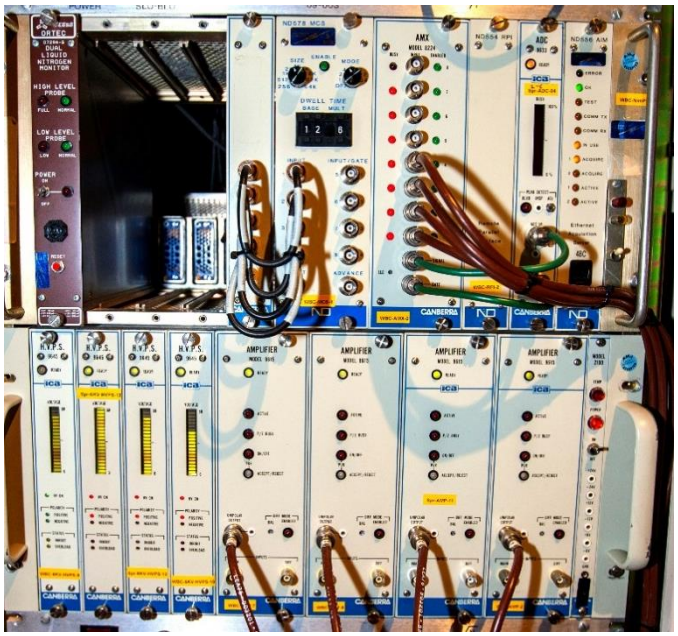

Figure 2. **Modern Lynx electronics and 1960's era NIM electronics**

The change in software and the operating system will extend the life of the system as Abacos-Plus is no longer supported by the manufacturer, and third-party support for the VMS system is becoming increasingly difficult with time.

The new in vivo software is easier to use, reducing tedium, technical errors, user time and effort. The customizable reporting facility improves the clarity of the reports for non-experts. It has the ability to accommodate distinct MDAs (and DLs) for all energy lines associated with a given isotope, and to associate the least of these MDAs with the nuclide. This feature simplifies user effort and reduces confusion caused by the outgoing system which periodically compared a given line's tentative activity with the DL of a different line preset by the user.

Prior to installing the new electronics, computer, and software, a transition plan was submitted to the Department of Energy Laboratory Accreditation Program (DOELAP) Senior Technical Manager for review and comment. Since the time that the transition plan was submitted, a number of unforeseen changes have transpired, affecting various aspects of the plan, which has been replaced with a new plan that better fits the transition of the Scanning Bed in retrospect; see Appendix A.

This document provides specific methods and results of LLNL's comparative evaluation of the scanning bed system with the incorporation of the new electronics, computer, operating system, and software.

Throughout the remainder of this document, the following terms will be used to refer to the systems:

- Old: refers to the accredited system with the NIM electronics, the Alpha Workstation, the VMS operating system, and the Abacos-Plus software
- New: refers to the equivalent system with the Lynx electronics, the PC with Windows, and Apex-InVivo software

Methods and Results

Calibration Efficiency

The Scanning Bed was calibrated using a solid matrix Bottle Manikin Absorption (BOMAB) Phantom containing ^{152}Eu mixed into LLNL muscle equivalent simulant material. Calibration of the bed under both the Old and New systems used the same BOMAB phantom. The National Institute of Standards and Technology (NIST) traceable reference activity used for these calibrations was 1.24×10^4 nCi as of February 2, 1987. The efficiencies for several ^{152}Eu photon energies are compared, ranging from approximately 122 keV to 1528 keV. Table 1 shows that the highest difference between the two systems is 6.32%, while the remainder of points differ by less than 3%. Figure 1 shows that at all but one data point, the efficiency is slightly higher with the New system.

Table 1: Efficiencies from the Calibration of the Scanning Bed under the Old and the New systems

	Computed Efficiency		Absolute	Percent
Energy (keV)	Old	New	Difference	Difference
121.8	0.0798	0.07768	-0.00212	-2.66%
244.7	0.0939	0.09983	0.00593	6.32%
344.3	0.0888	0.09048	0.00168	1.89%
411.1	0.0847	0.08521	0.00051	0.60%
444	0.0827	0.08303	0.00033	0.40%
778.9	0.0683	0.06911	0.00081	1.19%
867.4	0.0657	0.06667	0.00097	1.48%
964.1	0.0632	0.06427	0.00107	1.69%
1112.1	0.06	0.06107	0.00107	1.78%
1212.9	0.058	0.05913	0.00113	1.95%
1299.1	0.0565	0.0576	0.0011	1.95%
1408	0.0547	0.05589	0.00119	2.18%
1528.1	0.053	0.05418	0.00118	2.23%

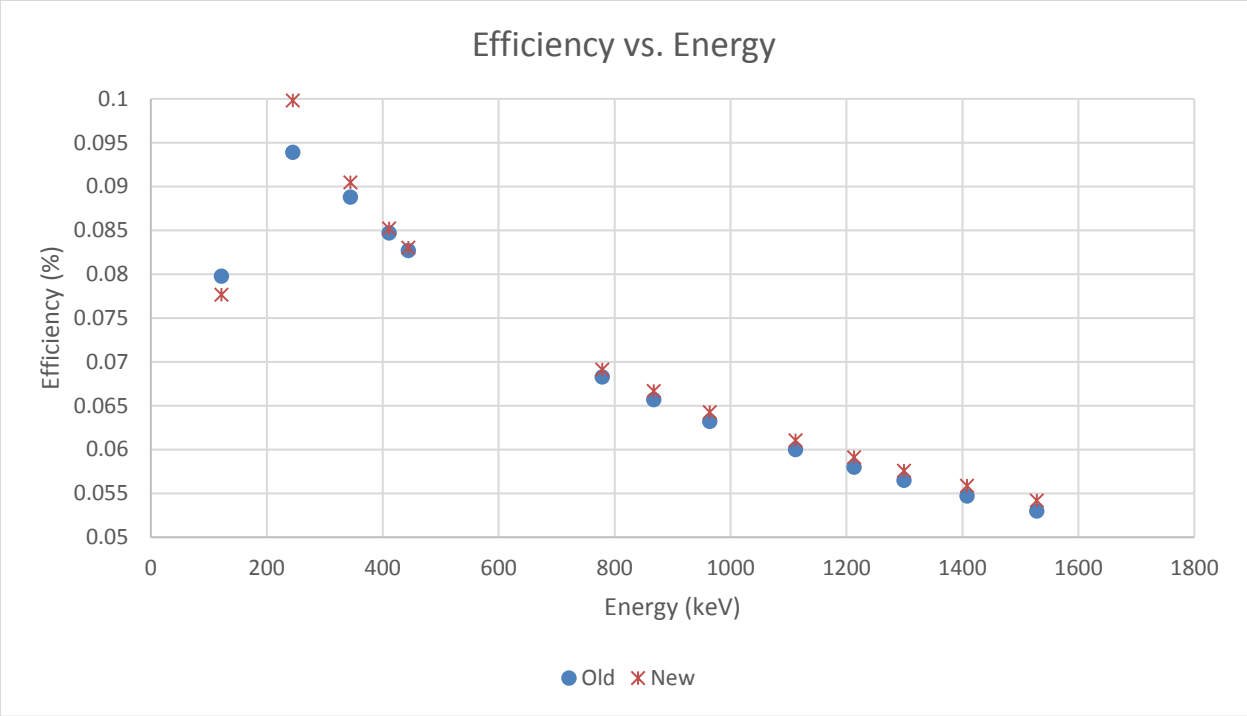

Figure 1: Efficiencies from the Calibration of the Scanning Bed under the Old and the New systems

Point Source Comparison

Point source data consists of decay corrected activities from the last twenty source checks conducted with the Old system and the first twenty source checks conducted on New system after calibration. Activities are found for the following nuclides and energy lines:

- Co-57: 122.06 keV
- Cs-137: 661.66 keV
- Co-60: 1173.24 keV, 1332.5

The Abacos-Plus data had been collected from daily source checks over the course of roughly eight weeks, and the Apex-InVivo data had been collected in two days in a process to establish the mean and deviation values for daily test criteria. This explained the greater variability in the Abacos-Plus data.

The Abacos-Plus data had been decay corrected to 14 September 2011, and the Apex-InVivo data had been corrected to 1 November 2016.

The attached Excel workbook, *Source Checks ANOVA.xlsx* presents the data in five spreadsheets. The first sheet, *Summary*, lists all the decay corrected activities for all four energy lines for both the Old and New systems, along with summary statistics. The mean values for the Abacos data are decay corrected to 1 November 2016, and the percent differences between the means are presented, all of which are below 2.5%. Note that decay correcting the mean yields the same result as taking the mean of decay corrected data.

The four subsequent spreadsheets each present data for one of the four energy lines (122, 661, 1173, and 1332 keV). The Abacos data are initially displayed, corrected to 14 September 2011, then all the individual values are corrected to 1 November 2016 in the next column, the third column has the Apex-InVivo data. Below these raw data are Summary Statistics, and to the right are the results of an Analysis

of Variance (ANOVA). In all four cases, the variance between checks is substantially greater than the variance between the Old system and the New system.

Summed Room Backgrounds

Summed Room Background data consist of background peaks from the last five environmental background checks conducted with the Old system and the first five environmental background checks conducted on the New system after calibration.

Background rates are known to vary annually, diurnally, and randomly. For this reason, there is no expectation that the background rates of the Old and New systems will be the same, but they are expected to be comparable.

The attached Excel workbook, *Environmental Backgrounds.xlsx*, has four spreadsheets. The first sheet, *Abacos 2018*, tabulates energy line (keV) and net peak area (counts) of all found peaks from the background counts on the Old system. These data are aligned so that each row has data with similar energy values (specifically, each individual energy is within 1.5 keV of the mean). The data are summarized to the right as follows: each cell in column Q has the mean of the energies in the given row, and each cell in column R has the sum of the net peak area of the given row. The second spreadsheet, *Apex 2019*, provides data from the New system similarly formatted.

The summary data in the first two sheets appear in the third sheet, *Summary*, dropping energies less than 90 keV. Again, the data are aligned so that each row contains energies within 1.5 keV of each other. Gaps in the data are filled with zeros. The Environmental Backgrounds measured with the Old system were collected in nine-hour counts, while the New system used twelve-hour counts. In the *Summary* sheet, the data from the New system is multiplied by ¾ to provide a level comparison. These same data appear in the fourth sheet, *Plot*, dropping energies above 1622 keV, and reformatted for graphing. The graph in the fourth sheet clearly shows that, within the range from 100 to 1600 keV, the background peaks are comparable.

Continuum Counts

Continuum count data are drawn from the 122, 661, 1173, and 1332 keV energy regions of the same Environmental Background spectra described in Summed Room Backgrounds above. For consistency, the continuum values each represent the sum of background counts in six channels. For each energy region, the continuum value was determined as follows:

- where the initial analysis had identified a peak, the counts in the three channels to the left and the three channels to the right of the identified ROI were summed,
- where the initial analysis had not identified a peak and the user identified an elevated region at the energy of interest, the count in the three channels to the left and the three channels to the right of the elevated region were summed,
- where Genie2000 had not identified a peak and the user did not identify an elevated region, the counts in the three channels to the left and the three channels to the right of the energy of interest were summed.

With the Continuum, as with the background peaks, background rates vary, and the two systems are expected to be comparable but not the same. The attached Excel workbook, *Continuum.xlsx*, has five spreadsheets. The first sheet, *Summary*, lists the continuum counts within the four energy regions and provides summary statistics and percent differences between the mean values for the two systems. The

remaining spreadsheets in *Continuum.xlsx* contain data and plots specific to the individual regions of interest. The percent differences for the four energy regions of interest are listed in Table 2.

Table 2: Percent Differences Between the Continuum Counts of the Old and New Systems

Energy of Interest (keV)	Percent Difference
122.06	29.1%
661.66	23.2%
1173.24	32.3%
1332.5	38.4%

The background continuums on the New system are greater than anticipated and are therefore expected to have an impact on the MDA values.

MDA Values

MDA was evaluated for select radionuclides where the MDA has been tracked for many years historically by LLNL. The MDA using the New and Old systems was evaluated for ^{134}Cs, ^{137}Cs, ^{60}Co, ^{131}I, ^{22}Na, ^{233}Pa, and ^{54}Mn. Forty-six personnel measurements were available for evaluation of the MDA using the New system (including 21 non-radiation worker test subjects, and 26 routine counts). Thirty-six personnel measurements are evaluated for the Old system: routine counts since the last calibration on 23 July 2018. All the personnel used for the evaluation were contaminate free for the evaluated radionuclides (i.e., no radionuclide peaks were identified for the radionuclides of interest).

Table 3 has selected average MDA values for the Old system (including person counts from July through December 2018) and the New system (including 20 non-radiation worker subjects and regular person counts from May 1 to June 14, 2019), along with absolute differences. It is readily apparent from these data that the MDA are higher on the New system than the Old system. In the worst case, the increase is ~0.5 nCi. In the remaining cases, the increase is < 0.2 nCi. This is not a prohibitive increase, and the Internal Dosimetry Program has accepted these values.

Table 3: MDA Values of the Old and New System with Absolute Difference

	Old System		New System		Absolute
Nulcide	MDA (nCi)	±1σ	MDA (nCi)	±1σ	Difference
Cs-134	0.657	0.0792	0.762	0.0565	0.104
Cs-137	0.805	0.107	0.959	0.0839	0.155
Co-60 (1173 keV)	0.858	0.0879	0.928	0.0798	0.0699
Co-60 (1332 keV)	0.786	0.105	0.828	0.0790	0.0417
I-131	0.935	0.0769	1.12	0.0822	0.185
Mn-54	0.612	0.0794	0.710	0.0838	0.0977
Na-22	0.595	0.0762	0.668	0.0984	0.0734
Pa-233	2.11	0.148	2.59	0.160	0.476

Appendix A

Amended DOELAP Technical Equivalency/Transition Plan for LLNL Whole Body Counter Equipment to APEX-INVIVO and new Digital Electronics for the Scanning Bed System

LLNL is transitioning its Scanning Bed system from our 30 plus year old VMS based Abacos-Plus software and NIM based electronics to PC based APEX-INVIVO analysis software and digital electronics (LYNX™). LLNL is required to demonstrate that these modifications will be technically equivalent and meet technical requirements. Documentation of this demonstration should be submitted to DOELAP prior to using the equipment for normal operations.

However, LLNL's use of APEX-INVIVO for the Scanning Bed whole body system required LLNL to transition to a new motor controller that interfaces with the worm gear motor on the scanning bed and APEX-INVIVO software. The physical replacement of the motor controller required replacement of the wiring to the worm gear motor and replacement of the communications link to the scanning bed control software. This new hardware was not compatible with the old software system. Therefore it was impossible to switch back and forth between the two systems, i.e., using the new system to collect technical equivalency data and using the old system to monitor workers.

The new system was installed and all component operations were verified. The system was calibrated and verified using a solid matrix Bottle Manikin Absorption (BOMAB) Phantom containing NIST traceable ^{152}Eu mixed into LLNL muscle equivalent simulant material. Calibration of the bed under both the Old and New systems used the same BOMAB phantom. An environmental 'room' background was established by existing methods used at LLNL. LLNL has continued to monitor workers while collecting technical equivalency data. Final technical equivalency documentation is currently being compiled . The initial calibration, verification, and background information will be included in the final technical equivalency documentation.

The following plan provides details of calibration, check source, environmental background, and MDA data collected on the Scanning Bed before and after the transition, and a comparison thereof, for technical equivalency evaluations and documentation.

Data Collection Prior to Transition:

- Point sources (Co-57, Co-60, and Cs-137) were measured as routine calibration checks; the last twenty results prior to the transition will be used in the evaluation.
- Efficiency ratios as a function of energy from the most recent calibration (July 2018) prior to the transition will be used.
- Environmental (room) Backgrounds were routinely measured; the last five results prior to the transition will be used. Parameters evaluated include:
    - Peaks appearing in the backgrounds;
    - Continuum counts in backgrounds.
- MDA values for isotopes of interest have been collected for each subject counted; all the MDA values for the second half of 2018 will be used.

Pre-use Evaluation (after replacement of software and electrical components):

- Calibrate new system with the same phantom used to calibrate the prior system.
- Perform environmental background counts.
- Perform QC (point source) measurements (minimum of 20 QC measurements).
- Re-establish QC criteria.

Final DOELAP Technical Evaluation and Documentation

- For final determination of measurement MDAs, perform at least 20 personnel measurements and use results where nuclides of interest were not detected. Perform comparison with old systems MDAs.
- Collect routine environmental background counts; compare background peaks and continuum after transition with background peaks and continuum prior to transition.
- Rewrite system descriptions for whole body scanning bed.
- Document comparison of calibration efficiencies of the scanning bed before and after the transition.
- Document changes in QC parameters and limits.
- Using in vivo measurement of background subjects, and subjects who test negative for isotopes of interest, document changes in MDAs.
- Document adequacy of the MDAs.
- Include sample output forms
- Submit documentation for DOE Field Office review, approval and submission to DOELAP STM.