IMAGING BOXED WASTE ASSAY SYSTEM

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INTRODUCTION

In recent years Pajarito Scientific Corporation (PSC) has been developing nondestructive assay (NDA) technologies that employ neutron imaging to achieve improved measurement performance[1,2,3]. Applied to standard 200 liter (55 gal.) waste drums this technology results in 300% improvements in average assay accuracy. PSC's pulsed active neutron imaging methodology is both rapid and robust. It has been used successfully in 5 minute assays of low level transuranic (TRU) wastes (10 nci/g). The imaging methodology is readily applied to assay systems of all sizes and to both standard passive neutron as well as PSC's pulsed active neutron measurements.

The same basic neutron imaging methodology has been used to solve problems ranging from the quantitative measurement in situ of plutonium holdup in glove boxes[4,5] and process duct work to the low level TRU assay of 1.5 x 1.5 x 2.5 m (5x5x8 ft.) boxes containing 7000 kg (15,000 lb) of miscellaneous waste contaminated at the 10 nci/g level[6]. At the Nuclear Fuel Services (NFS) facility in Erwin, TN this neutron imaging technology was used to find plutonium contaminated hot spots during the decontamination of large glove boxes and in a position sensitive plutonium holdup monitor in an on-line criticality safety system[5].

PSC's Imaging Passive and Active Neutron (**IPAN**) NDA technology is readily incorporated into systems employing high resolution gamma ray spectroscopy—or more generally, Gamma ray Energy Analysis (**GEA**). We have designed and produced combined IPAN and GEA systems in a variety of sizes and shapes. A "Five Station NDA System" utilizing IPAN and GEA in an integrated fashion has been in operation at the NFS Erwin facility since July 1990[5].

PSC has also just completed calibration and acceptance testing of a combined IPAN and GEA assay system for a customer in Belgium. The system is scheduled for installation at the customer's site in November 1993. This system features "automatic" (computer controlled conveyor/drum transport unit) combined IPAN and GEA assay of batches of drums—as many as 25 per batch. The automated conveyor and IPAN/GEA system can be used with a variety of waste packages: 400 l, 200 l, 150 l, 100 l, 28 l. Computer controlled assay system configuration allows each size waste package to be assayed in an optimized geometry. The nominal assay sensitivity specification for this system is 5 nci/g for TRU contaminated wastes having a wide range of TRU isotopic compositions.

The primary subject of this paper is PSC's current work on a large waste box assay system (combined IPAN and GEA) scheduled for installation in early 1995 at the USDOE's new WRAP facility at the Westinghouse Hanford site. The specifications for this system include quantitative TRU assay at the 10 nci/g level of waste boxes that may be as large as 5x5x8 ft. and may contain as much as 15,000 lbs. of miscellaneous TRU contaminated waste. In addition, fission and activation product gamma emitters are to be quantified at the 100 pci/g level. Combining and achieving these requirements in a single, integrated assay system having a limited footprint presents a considerable design challenge.

OVERALL SYSTEM DESIGN AND ASSAY STRATEGY

Figure 1 shows a schematic drawing of the WRAP Boxed Waste Assay System (BWAS) concept. Boxes are loaded from one end onto a computer controlled turntable. Boxes are transported into the assay system proper via a computer controlled, chain driven conveyor unit. The box first encounters the IPAN portion of the measurement system. The large protruding object on the right side of the IPAN section is the pulsed neutron generator external Moderating Assembly (MA). A PSC produced MA165C/Zetatron neutron generator is located at the center of the MA. Short time bursts (10 microsec) of original 14 MeV neutrons are produced in the Zetatron and exit the internal surface of the MA as 1 millisec duration, "plane wave" interrogation pulses of mixed epithermal/thermal energy neutrons.

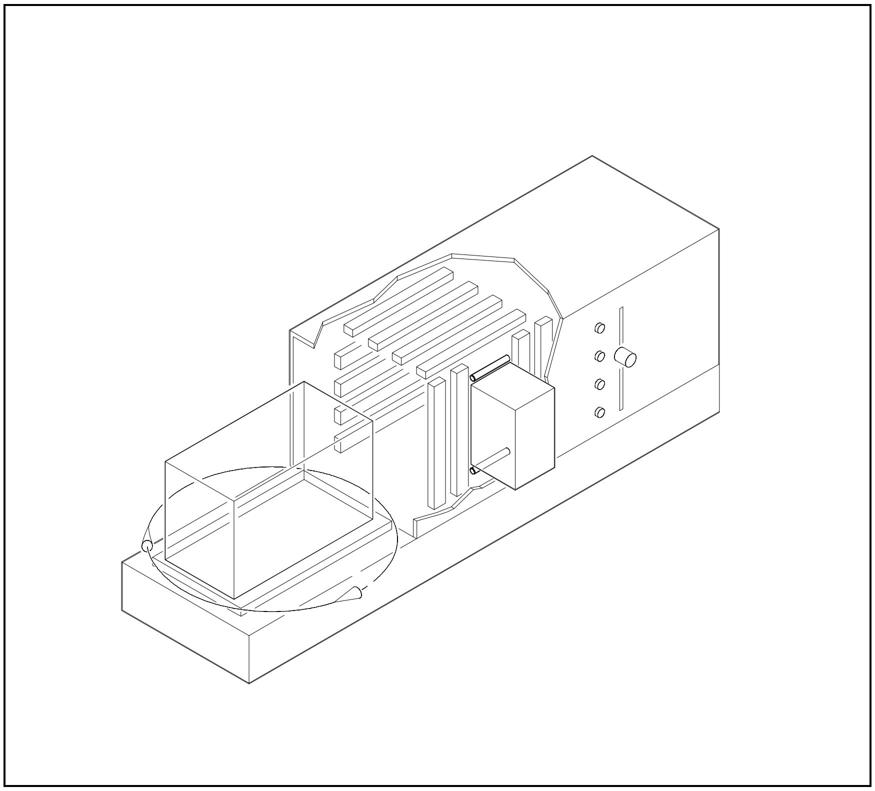

Figure 1: *Combined IPAN/GEA Crate System*

The MA is centered on the "quasi-4 pi" imaging neutron detection system that is used for both passive and pulsed active measurements. The neutron detection system is composed of 142 individual 183 cm long x 5 cm OD x 2 bar (72" long x 2" OD x 2 atm) ^{3}He proportional counters positioned on both side walls and top, bottom of the BWAS.

Three dimensional neutron imaging is achieved by (a) monitoring individual detector elements in separate counting electronics and (b) by making measurements at various box positions within the BWAS. This procedure is used for both passive and active neutron measurements. Several thermal and epithermal neutron flux monitors are located on the side wall opposite the MA and on top, bottom surfaces. These are used during the pulsed active measurement to determine proper matrix corrections in an imaging format.

The next measurement station consists of 16 collimated NaI(Tl) gamma ray detectors—each detector is 12.7 cm OD x 5 cm thick (i.e., 5 in. x 2 in.). Four NAI(Tl) detectors are located symmetrically on each side wall, top and bottom of the BWAS. These are all centered in the same plane perpendicular to the box axis. Imaging gamma measurements are accomplished by recording individual spectra from each NaI(Tl) and for several positions of the box as it is transported through the BWAS. ^{60}Co and ^{137}Cs gamma transmission sources are located in the top and one side—also in the plane of the NaI(Tl) detectors. These are utilized to provide a comprehensive gamma transmission correction.

The final measurement station is a 40% HPGe detector mounted on one side wall in a computer controlled up/down scanner. The purpose of the HPGe is to obtain definitive high resolution spectra of all significant hot spots (gamma) identified in the coarser resolution NaI(Tl) imaging measurements. **Note that the 16 unit NaI(Tl) system has a collective gamma ray detection efficiency that is 80 times that of a single 40% HPGe detector.**

System specifications require all three (passive/active neutron, passive gamma) measurements to be made on each waste box. In practice it is anticipated that only the pulsed active measurement will provide quantitative TRU assay at the 10 nci/g level. However, many boxes scheduled to be processed at WRAP are thought to contain large amounts of TRU isotopes as well as significant amounts of fission and activation products. All three measurement modalities will be utilized for most boxes.

The imaging assay algorithm produces a formal assay value for each volume element of the box . The combined measurement algorithm allows for each modality to be used in individual volume elements of the box according to (a) observed signal levels and (b) "signal quality" which is loosely defined to be good if the appropriate matrix correction factor is small and poor if it is large.

TURNTABLE AND CONVEYOR SYSTEM

The "organizing core" of this system is a computer controlled, chain driven box conveyor unit that runs the entire internal length of the assay system. The IPAN and GEA measuring instrumentation are literally built around the conveyor. The conveyor unit mates with a heavy duty, external turntable at one end. The turntable assembly is 3.05 m (10 ft) in diameter and the conveyor is 6.55 m (21.5 ft.) long. Both conveyor and turntable were manufactured by Pentek Corporation of Indianapolis, IN to specifications provided by PSC. A convenient (x,y,z) coordinate system is defined using the translation axis of the conveyor as the x axis. The coordinate center (0,0,0) is conveniently taken to be the center of the transport pallet top surface when it is centered in the neutron detector section. The positive z direction is the height within the box. y=0 is the plane midway between MA and the opposite side.

The turntable functions also as the box loading platform—WRAP operations call for fork lift loading of all boxes. Besides the box size and weight requirements (5x5x8 ft., 15,000 lbs.) the system is designed to operate under computer control with linear positioning accuracy of better than +/- 0.3 cm. An ultrasonic position measuring device is used in feedback mode to assure proper positioning for all scanning measurements. The complete measurement cycle requires a box to traverse the length of the conveyor, return to the turntable for a 180 degree rotation, followed by another complete conveyor length traverse. Complete measurements of all types are made during conveyor traverses for both the original and 180 degree rotated configurations.

GEA MEASUREMENT SYSTEM

Figure 2 shows a to-scale cross sectional view of the 16 NAI(Tl) detectors housed in their shield/collimating assemblies. The collimation is designed so that each set of four same side individual NaI(Tl) detectors view substantially non-intersecting cone shaped segments of the largest boxes to be assayed. The combined scans of all 16 detectors cover all volume elements of the box.

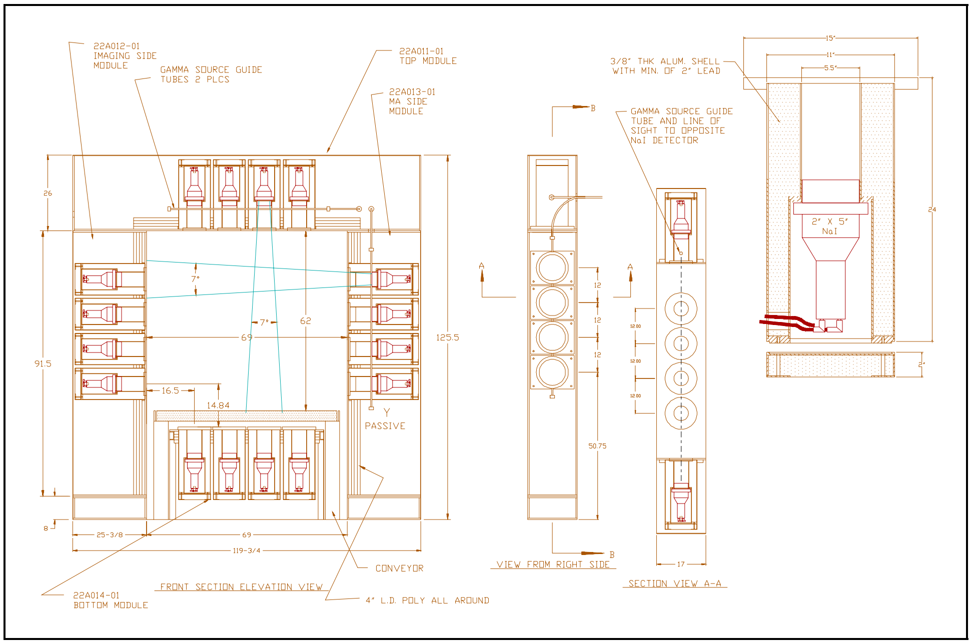

Figure 2

The individual NaI(Tl) detector collimation also makes possible a complete gamma transmission of each x, z slice of the box. The "dual energy" (^{137}Cs and ^{60}Co) gamma transmission measurement, using a simplified model of waste constituents, allows an accurate gamma transmission correction to be made for all box locations and for gamma energies of practical interest.

Figure 3 shows a scaled drawing of the HPGe scanning assembly, indicating the extent of box height coverage. We note that the HPGe can be "aimed" in an optimal sense at any significant gamma source in the box—under complete computer/automated control. That is, through the combined effect of 0 or 180 degree box rotation to "optimize" y , use of conveyor transport of the box to the proper x coordinate and use of the up/down scanner to go to the indicated z position—the HPGe may be positioned at the "optimal location" in which to acquire a high resolution spectra from any given portion of the box. The "3-D" gamma spectral imaging analysis provided by the NaI(Tl) system determines the (x,y,z) box location of whatever hot spots are subjected to HPGe analysis.

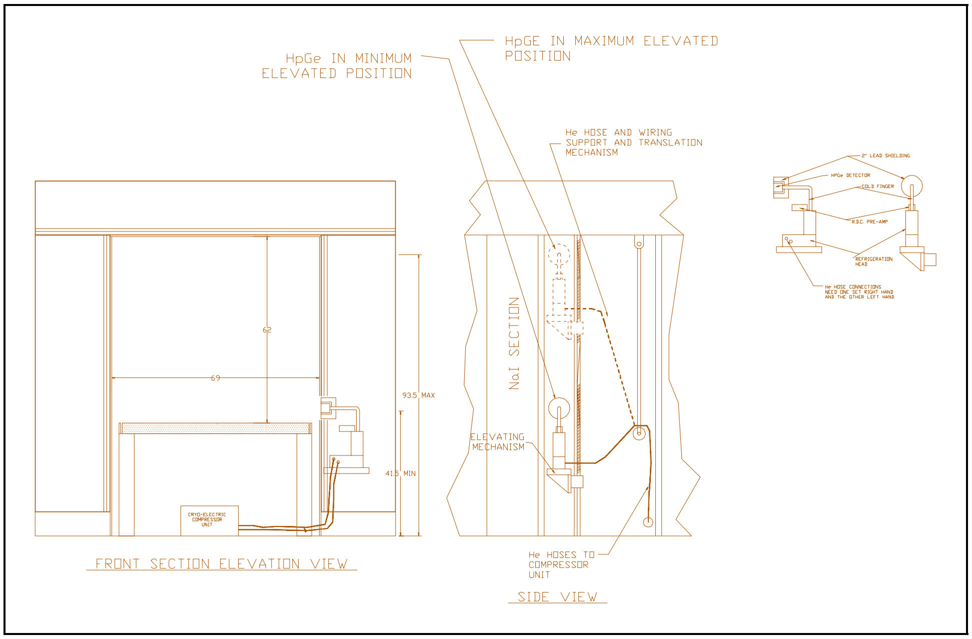

Figure 3

PASSIVE AND ACTIVE NEUTRON DETECTION SYSTEM

Figure 4 shows a cross sectional view at the center of the neutron detection section. A double row of ^{3}He counters is utilized to provide enhanced performance. Nominal 4 pi detection efficiency is 15% for a fission neutron source. All the 142 detectors are used for both passive and active measurements. The system imaging electronics, including PMCCM neutron multiplicity sorter[7], will be described in an upcoming publication[6]. A total of 96 separate neutron counting channels are included—some of which are used to monitor thermal and epithermal flux monitors. It should be noted that separate images are determined for passive and active measurements.

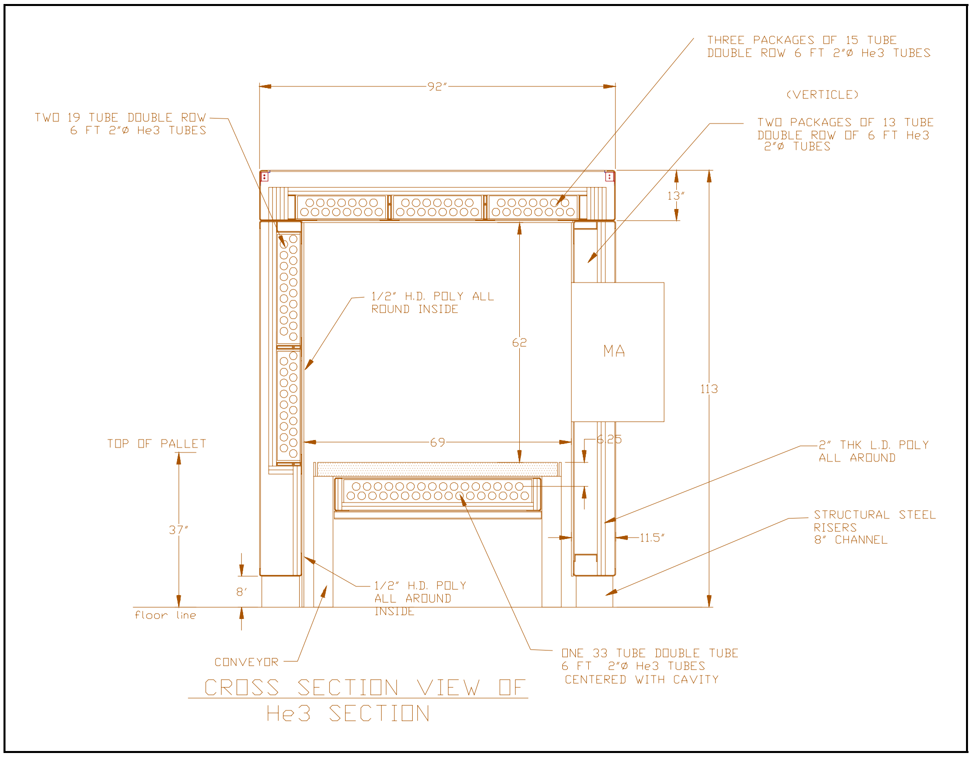

Figure 4

BWAS PROTOTYPE ASSEMBLY AND MEASUREMENTS

Because of the complexity of the system and the need to perform a large number of sophisticated component tests well before the final assembly would be ready and available—PSC built a "nearly full scale" BWAS prototype assembly. This assembly has dimensions of 1.6x1.6x3.0 m (64x64x144 in.). It is thus suitable for a large variety of component testing—including realistic waste box measurements. The prototype is outfitted with manual rollers and easily accommodates the so-called "WIPP Standard" or SWB and B-25 type waste boxes that have dimensions of 4x4x7 ft or less. The BWAS prototype has been designed to approximate BWAS neutronic conditions, including provision for an external MA pulsed interrogation source.

Figures 5a,b and 6 show examples of pulsed active neutron measurements made recently in this prototype. Approximately 1/2 of the final BWAS neutron detectors—in final modular form (see Figure 4)—were used for these measurements. In the configuration utilized, the 4 pi detection efficiency was approximately 10%. Figure 5a shows the systematic "singles" active assay response for small fissile sources placed in a B25 box filled with about 800 kg (1760 lbs.) of mixed scrap iron/steel, concrete rubble and cellulose.

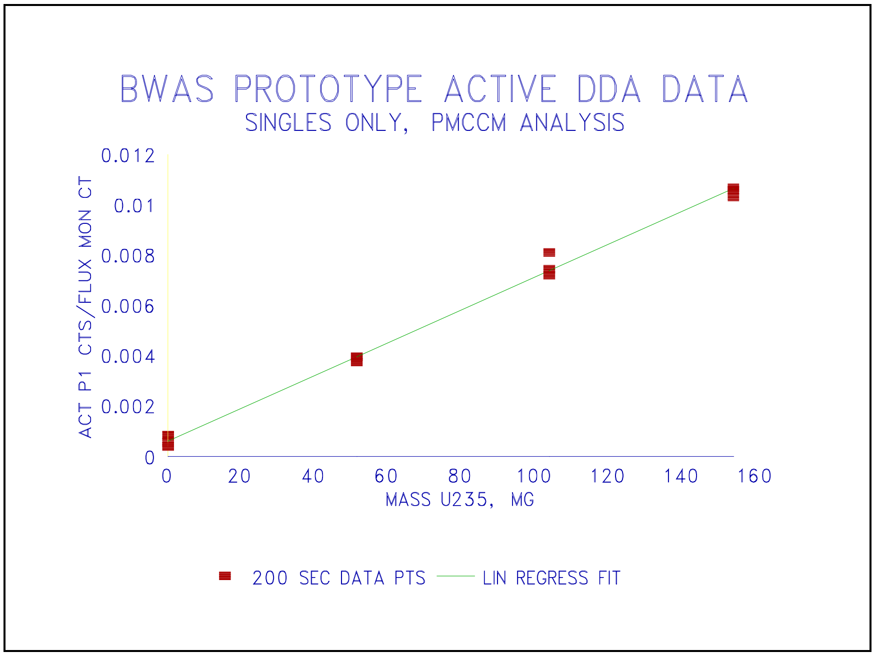

Figure 5a

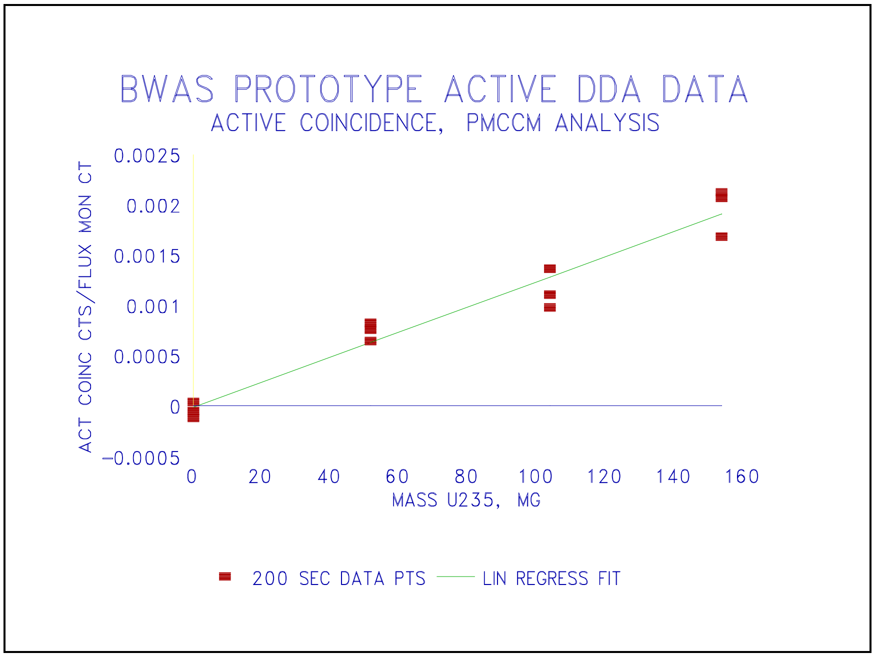

Figure 5b

As can be seen a linear response is obtained as a function of ^{235}U fissile mass. Note that the response with no fissile mass present is not zero. This "Zero Mass" response is also called the "Active Background" and is a well known phenomenon in standard differential dieaway measurement systems of all sizes. It is also the factor that determines detection limits in this measurement. As can be seen, the Zero Mass is approximately equal to the net response obtained for a 20 mg ^{235}U source. Unfortunately, the magnitude of the Zero Mass is matrix dependent and can amount to as much as 100 mg of equivalent fissile mass signal in many common matrices encountered in waste box assays. Net active singles assays must always subtract this background—and estimating it accurately for poorly characterized waste packages is difficult.

Figure 5b shows the corresponding "active coincidence" pulsed active assay response for the same measurement data shown in Figure 5a. In fact, both singles and coincidence portions of this data were acquired simultaneously using a PSC PMCCM neutron multiplicity analysis module. The same slope linear response is obtained with the active coincidence data. However, as can be seen, there is no Zero Mass effect.

That is, the active background is zero for the coincidence measurement. This has very significant implications for the lower limit of detection (LLD). In PSC's new Belgium IPAN system the measured LLD is reduced almost an order of magnitude by use of active coincidence as compared to the standard singles active measurement. We expect, in the fully implemented WRAP BWAS unit with its 15% detection system, that the improvement factor will be even greater.

Another significant improvement in assay technology that PSC's use of the PMCCM active neutron multiplicity sorter has made possible is illustrated in Figure 6. This shows experimental active assay PMCCM data obtained with a small (approximately 15 mg) ^{239}Pu source. The expected neutron multiplicity distribution for (^{239}Pu + n) fission[8] (i.e., number of active fission events in which 1,2,3,4... neutrons are detected) is a strong function of the actual system 4 pi neutron detection efficiency. We show here the observed ratio of measured-to-calculated multiplicities for 1's,2's and 3's. The "assumed efficiency" for which these ratios are unity is the true detector efficiency. Note that the methodology used does not assure the same "apparent efficiency" for the different multiplicities. As can be seen, however, there is excellent agreement among the three multiplicities—all indicating an apparent detection efficiency of 10.1 +/- 0.1 %.

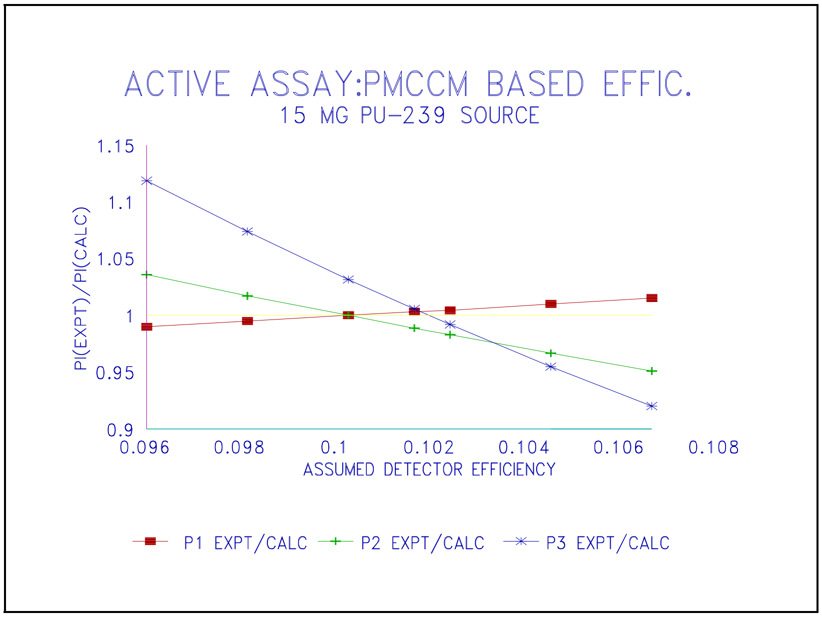

Figure 6

The significance of Figure 6 is considerable. First—a good statistics multiplicity distribution can be obtained for even quite small fissile masses—15 mg was the source used for the Figure 6 data. It also implies that one can deduce "in situ" average detector efficiencies for almost any waste package—which can be used to improve the accuracy of both active and passive assays. We note additionally that the same type of PMCCM multiplicity data is obtained for the passive portion of the IPAN measurements. (In that case, the ^{240}Pu spontaneous fission multiplicities[8] are used for analysis.) Thus, separate passive and active assay efficiencies are determinable.

CONCLUSION AND FUTURE SCHEDULE

We will complete assembly of the full BWAS system by about the end of December 1993. The conveyor/turntable and NaI(Tl) subsystems are already (September 1993) completed, as is about 50% of the neutron detection subsystem, including the MA portion. Calibrations and a large portion of acceptance testing will proceed at the PSC Los Alamos facilities in the first quarter of calendar 1994. We are now scheduled to move the BWAS system to LANL (TA-55 site) for additional testing in the remainder of calendar 1994. In early 1995 the system will be installed at WRAP.

Although the full BWAS system is not yet completed—it is already clear that the new imaging, neutron multiplicity and combined IPAN/GEA assay technology PSC has incorporated has lead to dramatic improvements in the state of the art.

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