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REMOTE NUCLEAR SCREENING SYSTEM FOR HOSTILE ENVIRONMENTS

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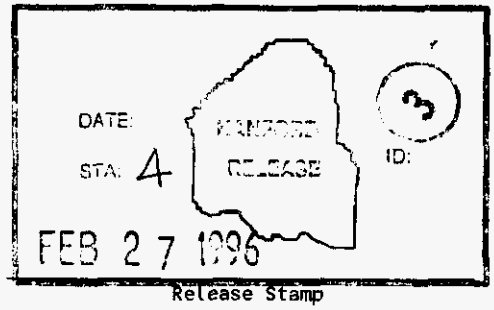
Abstract: A remote measurement system has been constructed for in situ gamma and beta isotopic characterization of highly radioactive nuclear material in hostile environments. A small, collimated, planar CdZnTe detector is used for gamma-ray spectroscopy. Spectral resolution of 2% full width at half maximum at 662 kiloelectronvolts has been obtained remotely using rise time compensation and limited pulse shape discrimination. Isotopic measurement of high-energy beta emitters was accomplished with a ruggedized, deeply depleted, surface barrier silicon dictator. The primary function of the remote nuclear screening system is to provide fast qualitative and quantitative isotopic assessment of high-level radioactive material.



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REMOTE NUCLEAR SCREENING SYSTEM FOR HOSTILE ENVIRONMENTS

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ABSTRACT

A remote measurement system has been constructed for in situ gamma and beta isotopic characterization of highly radioactive nuclear material in hostile environments. A small, collimated, planar CdZnTe detector is used for gamma-ray spectroscopy. Spectral resolution of 2% full width at half maximum at 662 kiloelectronvolts has been obtained remotely using rise time compensation and limited pulse shape discrimination. Isotopic measurement of high-energy beta emitters was accomplished with a ruggedized, deeply depleted, surface barrier silicon detector. The primary function of the remote nuclear screening system is to provide fast qualitative and quantitative isotopic assessment of high-level radioactive material.

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LIST OF TERMS

μCi/g	microcuries per gram
BAG	betas above gammas
FTIR	Fourier transform infrared
FWHM	full width at half maximum
GAC	gammas above cesium
Gy/hr	gray per hour
HLW	high-level waste
keV	kiloelectronvolt
LA-MS	laser ablation mass spectroscopy
LIBS	laser-induced breakdown spectroscopy
MCA	multichannel analyzer
MCNP	Monte Carlo neutron photon
MDA	minimum detectable activity
MDC	minimum detectable concentration
mR/hr	milliroentgens per hour
mW	milliwatt
PRC	pulse risetime compensation
PSA/T-SCA	pulse shape analyzer/timing-single-channel analyzer
PSD	pulse shape discrimination
R/hr	roentgens per hour
SCA	single-channel analyzer
SDS	silicon detector signal
TAC/SCA	time-to-amplitude converter/single-channel analyzer
TB	total betas
TBAG	total betas above gamma
TG	total gammas
TGAC	total gammas above ^{137}Cs
TRLIF	time-resolved laser-induced fluorescence
V	volts

1.0 INTRODUCTION

Laboratory analysis of highly radioactive, chemically complex materials is time consuming, hazardous, and extremely expensive. Analysis of high-level radioactive samples begins with sample preparation in shielded confinement chambers called hot cells. Analytical screening of samples within the hot cells can significantly reduce the problems associated with mixed waste characterization. A remote screening probe for in situ measurements provides:

- Immediate assessment of isotopic distribution within the sample
- The ability to focus analytical work on sample zones of interest
- Increased laboratory capacity by minimizing the number of analyses required per sample, and verifying re-runs
- Warnings of samples that could present a radiological hazard or a contamination control problem.

A multi-detector remote probe, shown in Figure 1, has been developed and deployed in a hot cell for screening purposes. This probe is an evolution of technology developed for in situ characterization of the high-level waste (HLW) tanks used to store high-level nuclear waste at the Hanford Site (Keele et al. 1995, and Addleman et al. 1991).

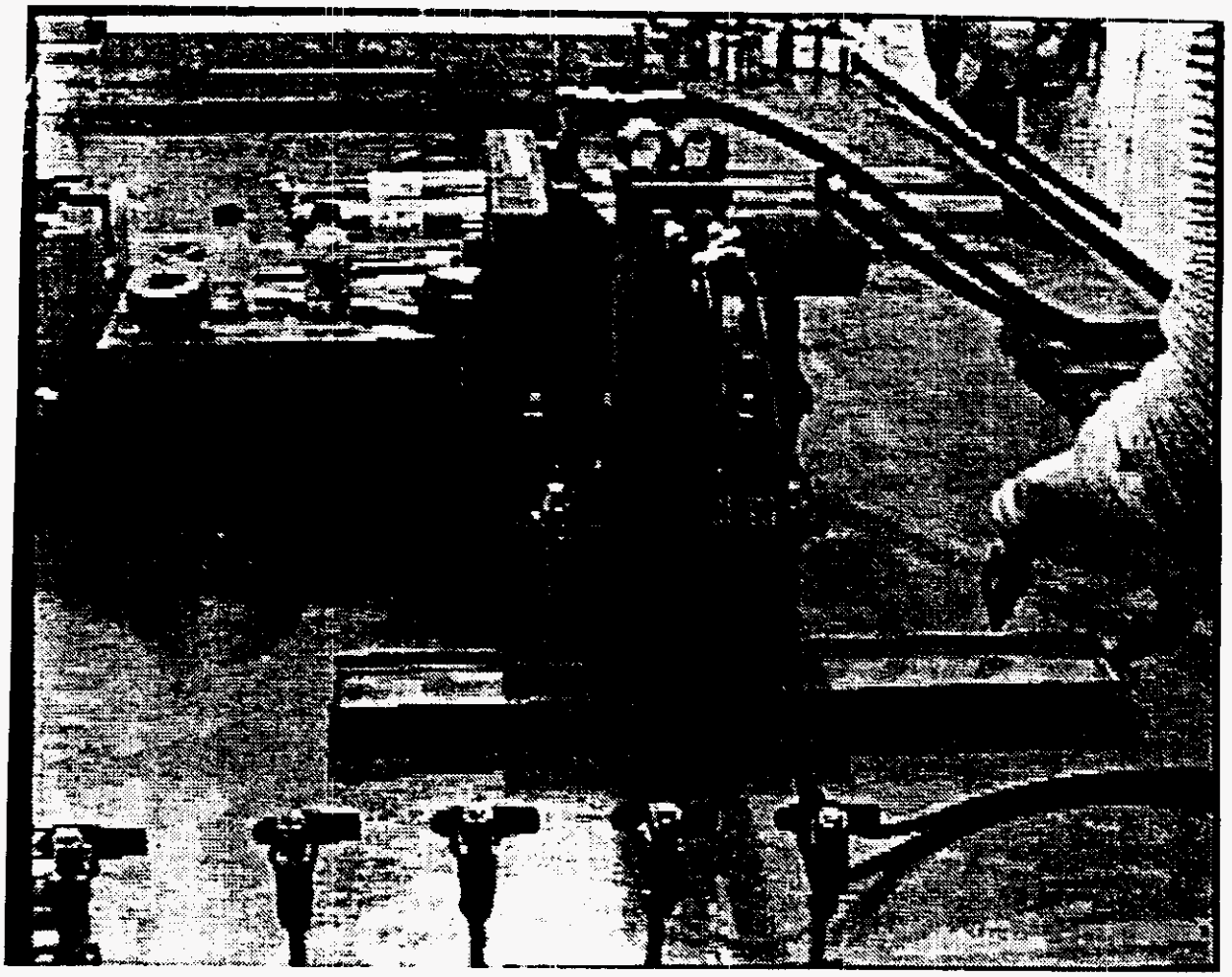
While the hot cell screening probe could be used for other analyses, its principal function is to determine semi-quantitative isotopic distributions within HLW tank sample. This determination was to be accomplished without significant modification to the hot cells or sample handling procedure.

The isotopes selected for measurement are: ^{137}Cs, ^{154}Eu, ^{152}Eu, ^{60}Co and $^{90}Sr/^{90}Y$. These isotopes were chosen because they constitute the majority of the activity in HLW tanks and are good indicators of material composition (Keele et al. 1995a, Addleman et al. 1991, Herting et al. 1992). For example, ^{154}Eu is typically found with the insoluble transuranics, while ^{137}Cs is usually found in the aqueous regions or soluble salt layers.

Measurement of uranium and transuranic radionuclides would also be valuable; unfortunately, all are weak- or low-energy gamma-ray emitters, and few are beta emitters. These properties preclude non-destructive assay of the actinide isotopes by beta or gamma-ray spectroscopy in the wet, dense, $^{90}Sr/^{90}Y$- and ^{137}Cs-rich HLW tank material. Without sample contact, alpha spectroscopic measurements of HLW tank material are not viable. The expected neutron emission rate is very low, and size limitations on the probe prohibit passive neutron measurements with a reasonable efficiency. Neutron count rate notwithstanding, the vast majority of neutron emissions in HLW tank material originates from the spontaneous

Figure 1 Nuclear Screening Probe in Hot Cell.

Nuclear screening probe shown as used. Probe mobility is provided with the hot cell manipulator arms shown gripping handling rings. The probe is connected to the nuclear instrumentation on the exterior of the hot cell with two (7 core) cables.



The sample tray is shown here in front of the probe, for clarity

fission of ^{244}Cm and alpha-n reactions from ^{241}Am, which are non-fissile isotopes with limited importance. For the above reasons, measurements of actinide elements with alpha or neutron detectors were not incorporated into the probe.

Moisture content is a key safety parameter for the HLW tanks, and consequently is a high-priority analysis. Hot cell ventilation creates a substantial air flow past the samples, resulting in significant evaporation. To minimize water loss from the sample, counting times must be limited.

2.0 ENVIRONMENT

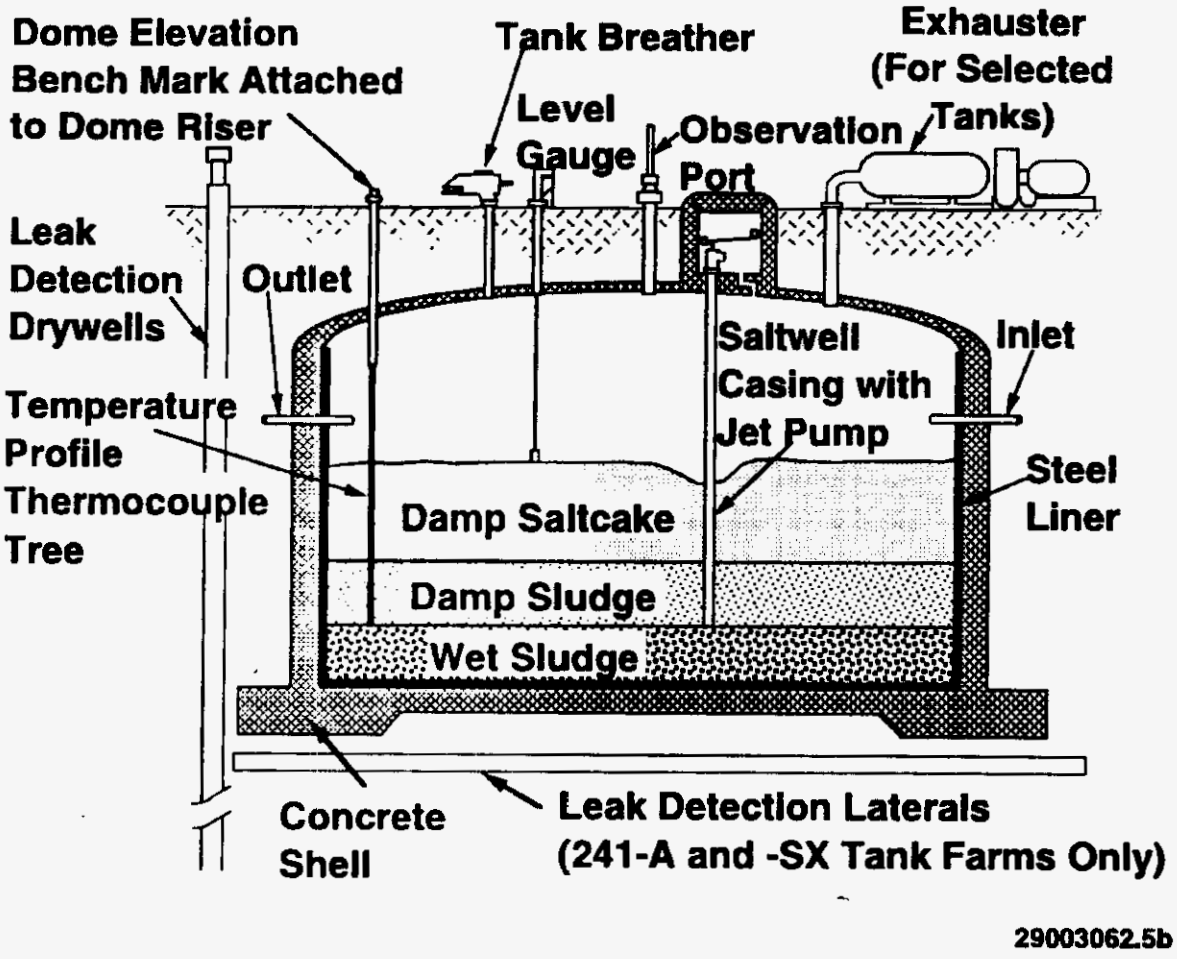
2.1 NUCLEAR WASTE MATERIAL

The materials in the HLW tanks originate from treated process wastes, primarily sodium salts of nitrate, nitrite, hydroxide, carbonate, aluminate and phosphate. Hydroxides of iron, manganese and other transition metals are also present. Additional process wastes and remediation additives include di-2-ethylhexylphosphoric acid (HDEHP), ethylenediaminetetraacetic acid (EDTA), hydroxy-EDTA (HEDTA), tributyl phosphate, methyl isobutyl ketone (hexone), normal paraffin hydrocarbons (similar to kerosene with C_{10} to C_{15} hydrocarbon chains), diatomaceous earth, ferrocyanide complexes, and decomposition products of all the above species.

These materials exist in three general forms: sludges, saltcakes, and liquids. Sludges, located in the bottoms of the tanks, consist of solids (hydrous metal oxides) precipitated from the neutralization of acid wastes before their transfer to the HLW tanks. A characteristic HLW tank, with typical distribution of material and equipment, is shown in Figure 2. Once transferred to the tanks, the wastes are maintained at highly alkaline conditions (pH 10-14). Saltcakes are made up of the various salts formed from the evaporation of water from these alkaline wastes. Saltcake crusts may reside on top of the liquids. Liquids may exist as supernate or interstitial liquid.

The radioactive components of the waste forms consist primarily of fission product radionuclides, such as ^{90}Sr and ^{137}Cs, and actinide elements, such as uranium, plutonium, and americium. The strontium and cesium isotopes are the primary heat and radiation sources within the HLW tanks, generating up to 7 gray per hour (Gy/hr) (1,100 roentgens per hour [R/hr]) dose rate on contact. Short-lived radionuclides are not important contributors to the radioactivity at this time, because no new fission products have been added since 1986 and most of the waste was generated in the 1950s and early 1960s.

Figure 2. High-Level Waste (HLW) Tank Used for Storage of Nuclear Waste on the Hanford Site.



Several sampling methods are used to support HLW tank characterization (Bell 1993). The HLW tank solid sampling methods are: supernate grab sampling, augering, and rotary- and push-mode coring. Supernatant sampling is used for liquids and light solids and slurries. Auger samples are taken by an auger screw; the samples consist of materials from the top 40 cm (16 in.) of the waste. Auger sampling is unsuited to very dry or slurry-type samples, and is only used for saltcake-type crust materials. An auger sample loses stratigraphic information because mixing may occur during the sampling process. The only methods that provide a continuous sample throughout a vertical cross section of the waste tank are the two coring methods, rotary and push mode. Both push- and rotary-mode core sampling provide sequential 2.5-cm (1-in.)-diameter by 48-cm (19-in.)-long samples (called "segments"). A push-mode sampler is a "thief" style coring device, and is most suited to softer sludges. A rotary-mode sampler drills through the hard saltcake materials present in some tanks.

A core segment is received in the laboratory encased in several layers of shielding and containment. In hot cells, the core is removed from its containment and the segment is subsampled for analytical purposes. A core segment is extruded by pushing it out of the sampler onto a moving tray. The core segment then lies on the tray with the stratigraphic order that it had in the sampler and presumably had in the tank. Depending on the cohesiveness of the core segment, it can retain its cylindrical shape or it can slump flat. The segment's colors range from off-white to brown (most common) to black. The segment is subsampled by determining differences in strata in the segment, or differences from adjacent core segments.

The HLW tanks contain nearly every element in the periodic table (as fission or neutron activation products) and a wide range of molecular and ionic species (inorganic and organic) from nuclear fuel processing. Laboratory analyses of HLW tank material include a wide variety of analytical techniques (Bell 1993). A short list of the principal analyses includes: inductively coupled plasma atomic emission spectroscopy (ICP) for most metals and a few non-metals; ion chromatography (IC) for non-metal anions; differential scanning calorimetry (DSC) for heat-producing or heat-absorbing qualities of the waste; volatile organics (VOA), semi-volatile organics (Semi VOA), and gamma energy analysis (GEA) for gamma-ray-emitting radionuclides; and total beta and alpha energy analysis (AEA). A wide variety of other chemical, physical and radiological analytical techniques are used to determine the properties and hazards of a specific sample.

A single HLW tank usually only has one or two complete core samples taken from it, because of the high cost of sampling and associated analyses. Hot cell sample screening reduces or eliminates many expensive, hazardous, time-consuming, and redundant laboratory analyses.

2.1.1 Hot Cells

Difficulties in applying technology to remote hot cell characterization are related to remote operation in harsh radioactive and caustic chemical environments. Instrument probes in a hot cell environment must be impervious to prolonged radiological exposure, corrosive vapors, and splashing from normal hot cell cleaning procedures. Radiation background is normally less than 0.1 milliroentgens per hour (mR/hr) outside the hot cell. Within the hot cell, radiation levels vary from 500 mR/hr to 10 R/hr, with the potential to exceed 100 R/hr when higher-radiation-level tank cores or other samples are being processed. Chemical contaminants of primary concern are condensed vapors, liquids, and solids ranging in pH from 8 to 14, and cleaning agents that include 6 molar nitric acid.

2.1.2 Current Analysis Methods

Core segments are prepared for analysis by compositing and homogenizing whole- or half-segment subsamples (or, much more rarely, quarter-segment subsamples). The subsamples are then removed from the hot cell and put through a digestion/dilution preparation prior to actual analysis. Gamma energy analysis and total beta samples are mounted on a flat dish for counting. ^{90}Sr samples are put through a separation process and then mounted on a dish and counted.

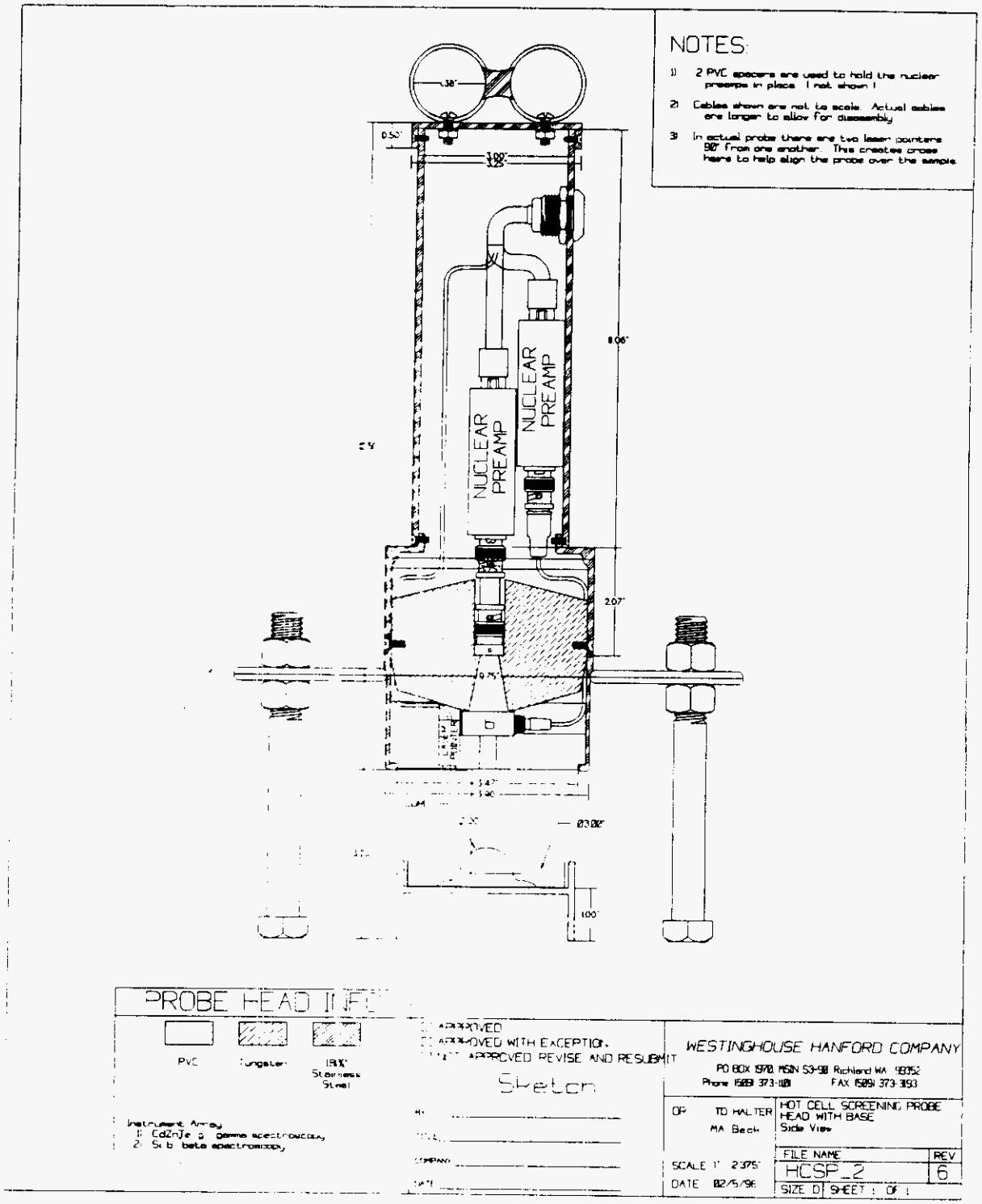
3.0 EXPERIMENTAL

3.1 MULTI-INSTRUMENT REMOTE PROBE

The harsh, confined environment in hot cells required a probe that is as rugged and compact as possible. Because the cabling required a controlled penetration of radiation zones, the number of cables and size of the connections where also reduced to a bare minimum. Several probes of different configurations have been constructed.

The weight and size of the probe had to be minimized to allow remote manipulators arms to provide mobility and positioning. The hot cell probe weighs only 10 kilograms (22 pounds) and is shown in Figure 3. Sample position determination is accomplished through the use of a pair of laser line generators mounted in the bottom of the probe. Mounted and aligned orthogonally, these 60-milliwatt (mW) diode laser line generators produce a red X on the sample. The center of the X is axially aligned with the probe, allowing unambiguous positioning of the sample, whatever the sample shape may be.

Figure 3. Remote Hot Cell Probe.



Preamplifiers for both detectors are mounted within the probe head, while all other signal processing equipment is located external to the hot cell. The preamplifiers used for both the gamma and beta systems are EuroRad PR6[1] models, chosen because of their performance, small size, and compact connections.

The type of cabling and connectors that will work in a hot cell environment are constrained by small openings in the hot cell, resistance to chemical attack, and radiological contamination concerns. Separate multiconductor marine video cables are used for the beta and gamma detectors. Each cable consists of 2 coaxial cables, 5 single conductors, and an overall metal foil shield. Environmentally sealing LEMO[2] quick couplers are used at both ends of the cabling that penetrate the hot cell wall. This allows removal of the probe head from the hot cell, and enables the instrumentation rack outside the hot cell to be disconnected and moved out of the way of other projects. Careful attention to grounding is required to prevent ground loops, cross talk, and ringing.

To prevent cross-contamination of the samples and allow positioning of the probe, stand-off distance from the sample is approximately 5 cm (2 in.). All collimators are designed and experimentally shown to be radially symmetric. Probe design provides insignificant beta interference on the gamma detector. Gamma interactions with the Si beta detector are unavoidable. It should be noted that the Si detector used is capable of alpha spectroscopy as well, but this capacity is not exercised for reasons discussed previously. Polyvinyl chloride is used as a lightweight, durable beta collimator on the bottom of the probe.

The radial response of the deeply depleted Si surface barrier detector with the collimator to $^{90}Sr/^{90}Y$ beta source at a typical sample stand-off (5 cm [2 in.]) is shown in Figure 5, along with the low spatial resolution gamma shielding plot . The beta detector was ruggedized and gold plated to function reliably once deployed. A 0.02-cm (0.008-in.)-thick aluminized Mylar window was placed below the beta detector to prevent ambient light interference and for physical protection from corrosive splatter.

The requirements on the gamma-ray collimator are the principal defining constraints for the probe's size, shape, and weight. Reduced collimation or shielding requirements result in smaller, lighter probes. A machinable, high-density tungsten alloy was chosen as the collimation material because it provides superior gamma attenuation per unit volume. Using Monte Carlo neutron photon (MCNP) modeling (Trumble 1992), two collimators were designed for measurement of the isotopic distribution within samples. High and low spatial resolution gamma-ray collimators, shown in Figure 4 and Figure 5, were constructed and tested. The high-resolution collimator had a spatial resolution of approximately $\pm$ 2.5 cm (1 in.) and the low-resolution collimator had a spatial resolution of approximately $\pm$ 4 cm (1.6 in.). The high-resolution collimator requires significantly longer counting times, and more measurements must be taken to profile a sample. The low-resolution collimator

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[1]Trademark of Eurorad, Strasbourg, France.

[2]Trademark of LEMO USA, Inc., Santa Rosa, California.

Figure 4. High-Resolution Collimator. Radial response of the CdZnTe detector to a ^{60}Co source at an atypical stand-off (9.5 cm [3.75 in.]).

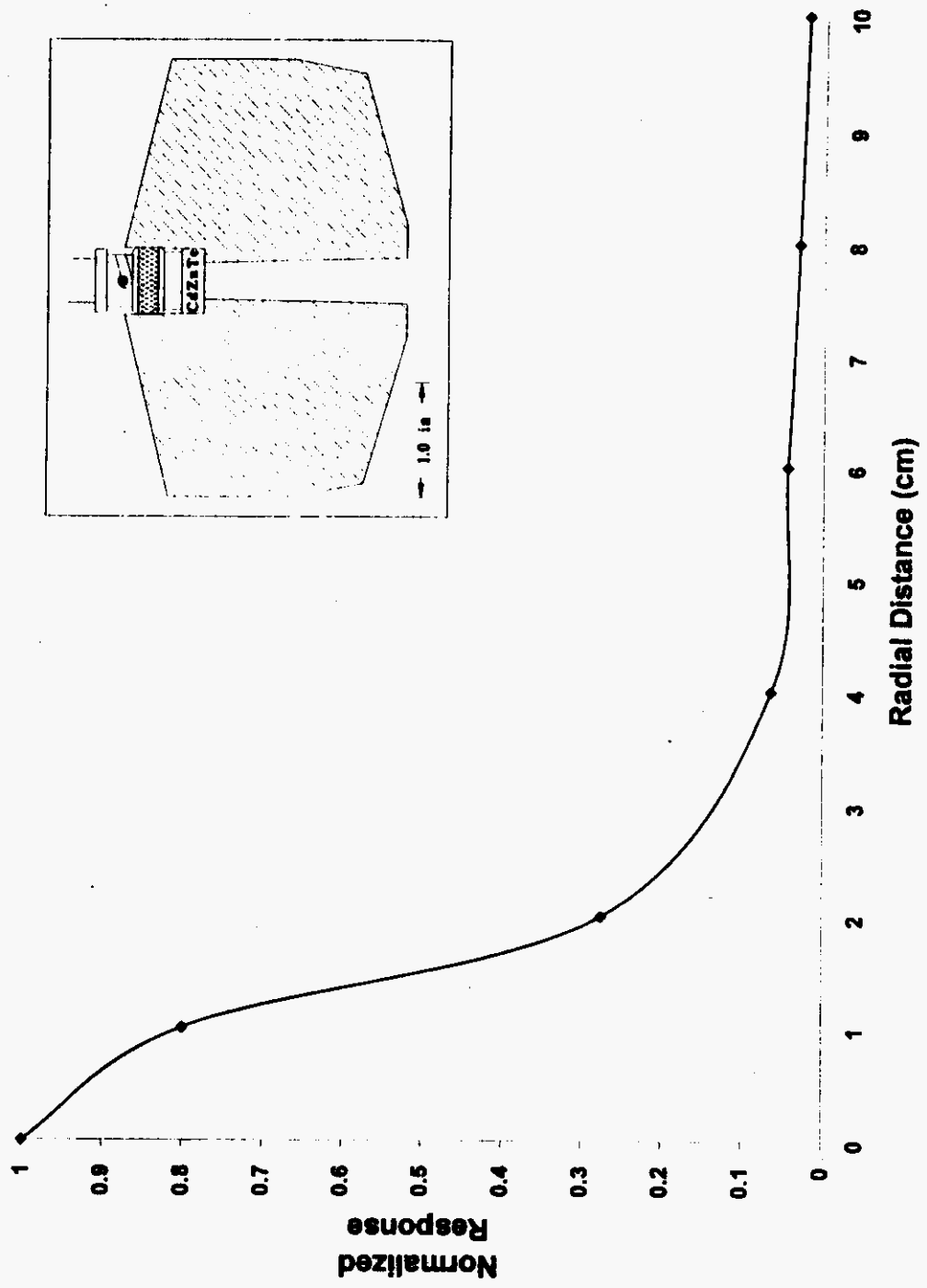
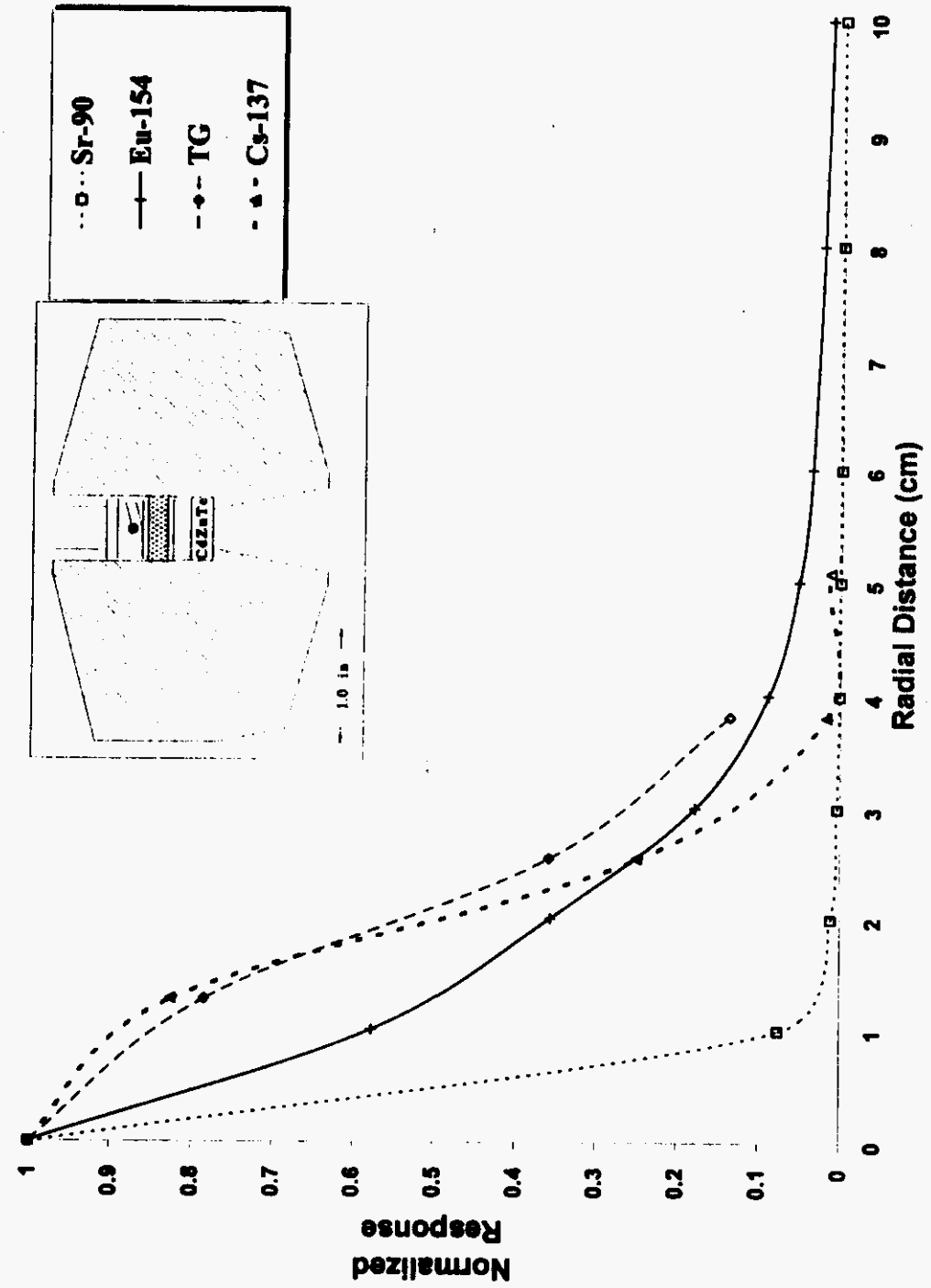


Figure 5. Low-Resolution Collimator. Radial response of the CdZnTe detector to a ^{154}Eu source at an atypical stand-off distance of (9.5 cm [3.75 in.]).



provides shorter data acquisition times but is less sensitive to spatial variations in the sample. The low-resolution collimator was selected for installation in the hot cells.

3.2 GAMMA SPECTROSCOPY

Gamma-ray energy spectroscopy provides some of the most useful information about mixed waste. Spectral data allow gamma-emitting radionuclide content and distribution to be determined. However, the application for in situ spectroscopic measurements of high radiation fields with a remote compact probe places unusual demands on the instrumentation.

Traditional high-resolution germanium gamma-ray detectors require cumbersome cooling mechanisms and are expensive. Room-temperature scintillation detectors yield low resolution spectra, limiting isotopic identification. CdTe and CdZnTe detectors, with electronic signal processing enhancements, were selected for this application. The specific advantages of these high-Z semiconductor detectors are:

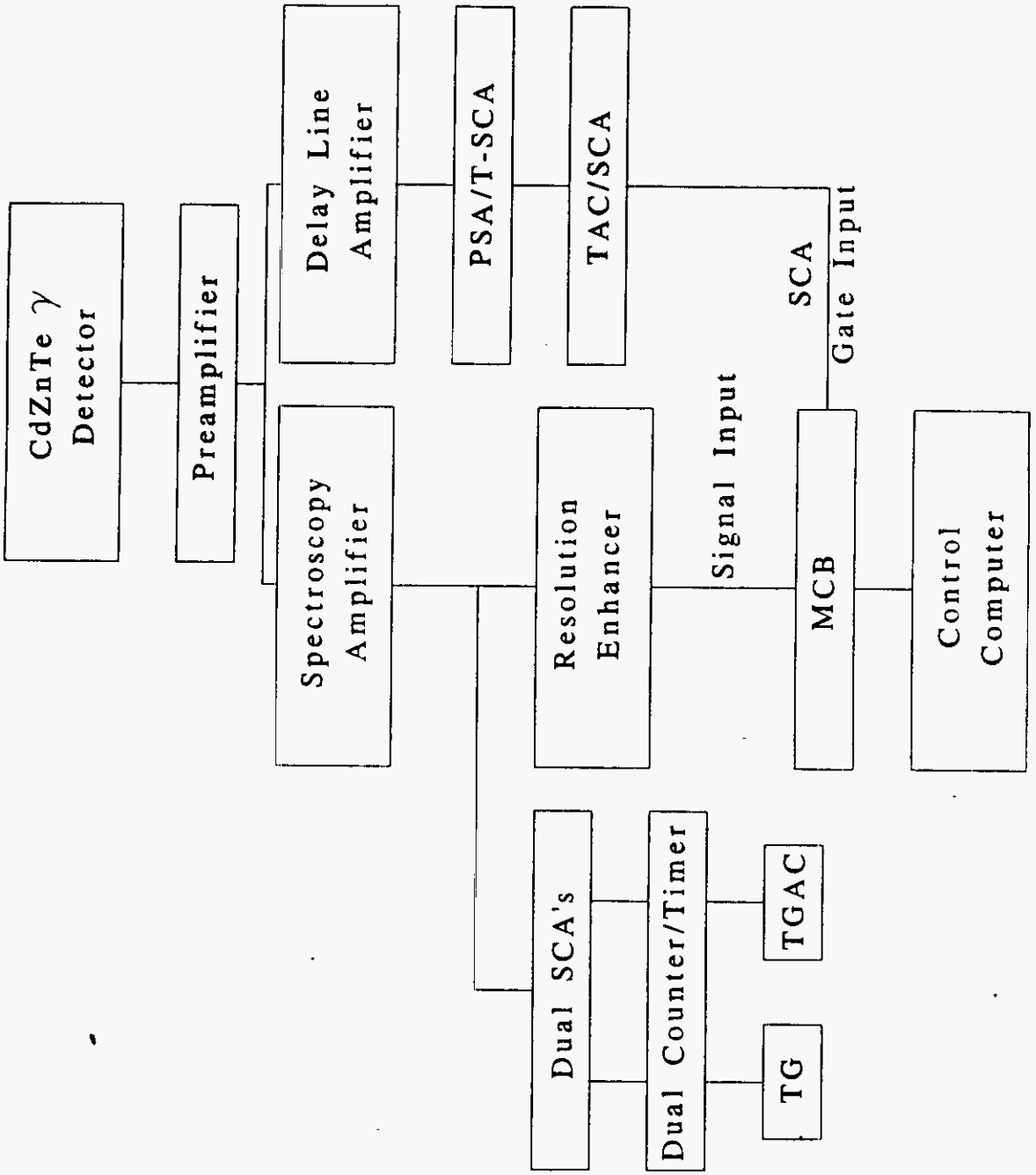
- Small size
- Room temperature operation
- High-Z material (provides good stopping power and moderate resolution)
- Low cost
- High count-rate operation.

Charge trapping within high-Z semiconductor detectors significantly degrades spectral resolution. Pulse risetime compensation (PRC) is a technique employed to compensate for charge trapping by adjusting the amplitude of the detector pulse by an amount dependent on the risetime (Addleman et al. 1991, Keele et al. 1995b, Jones 1977, Goulding and Landis 1988, and Simpson et al. 1989). A small percentage of the pulses with extremely long risetimes originating from events with a high degree of charge trapping are rejected using pulse shape discrimination (PSD)(Jones and Woolam 1975).

The electronic configuration of the system is shown in Figure 6. The signal processing electronics for the gamma system were composed of five commercially available nuclear instrument modules between the preamplifier and the multichannel analyzer (MCA). The system has two major sections, compensation and discrimination. The compensation section consists of a shaping spectroscopy amplifier, used in conjunction with an EG&G Ortec model 675 Ge resolution enhancer. The resolution enhancer adjusts the amplitude as a function of the preamplifier pulse risetime. Pulse risetime in CdTe and CdZnTe is a function of the degree of charge trapping that occurs within the detector. The corrected pulses are sent to an MCA for spectral analysis.

Figure 6. Hot Cell Gamma Spectroscopy System Schematic.

SCA	-	Single-channel analyzer
MCA	-	Multichannel analyzer
TG	-	Total gammas
TGAC	-	Total gammas above ^{137}Cs
PSA/T-SCA	-	Pulse shape analyzer/timing-single-channel analyzer
TAC/SCA	-	Time-to-amplitude converter/single-channel analyzer



The discrimination electronics are made up of a delay line amplifier, a pulse shape analyzer/timing-single-channel analyzer (PSA/T-SCA), and a time-to-amplitude converter/ single-channel analyzer (TAC/SCA). These modules are used to sort out pulses with long risetimes that originate from pulses with a large degree of charge trapping within the detector and that cannot be effectively compensated by PRC circuitry. PSD electronics produce a coincident gate pulse that enables counting only the "good" pulses in the MCA.

Using PRC, PSD, and high bias on the detectors, excellent performance was extracted from the small high-Z semiconductors. CdZnTe spectral resolutions of better than 2% full width at half maximum (FWHM) at 662 kiloelectronvolts (keV) have been obtained with a 200-V bias, PRC, and rejection of approximately 10% of the longest rising pulses with PSD. This resolution is a significant improvement over unenhanced crystals and is better than the standard sodium iodide scintillators, but is not as good as conventional germanium semiconductor detectors. With the improved spectral resolution, deconvolution of the gamma photopeaks is not necessary for analysis.

The gamma measurement system has a secondary mode of operation for the rapid acquisition of nonspectroscopic data. SCAs and counter/timers were used to efficiently collect data from selected windows. The windows selected were total gamma (TG) and total gammas above ^{137}Cs (TGAC). TG provides a measurement of the total gamma radiation from the sample, which is primarily ^{137}Cs in HLW tank material. TGAC accumulates all signals above the ^{137}Cs photopeak, providing a high-efficiency, nonselective measure of the isotopes ^{154}Eu, ^{152}Eu, and ^{60}Co.

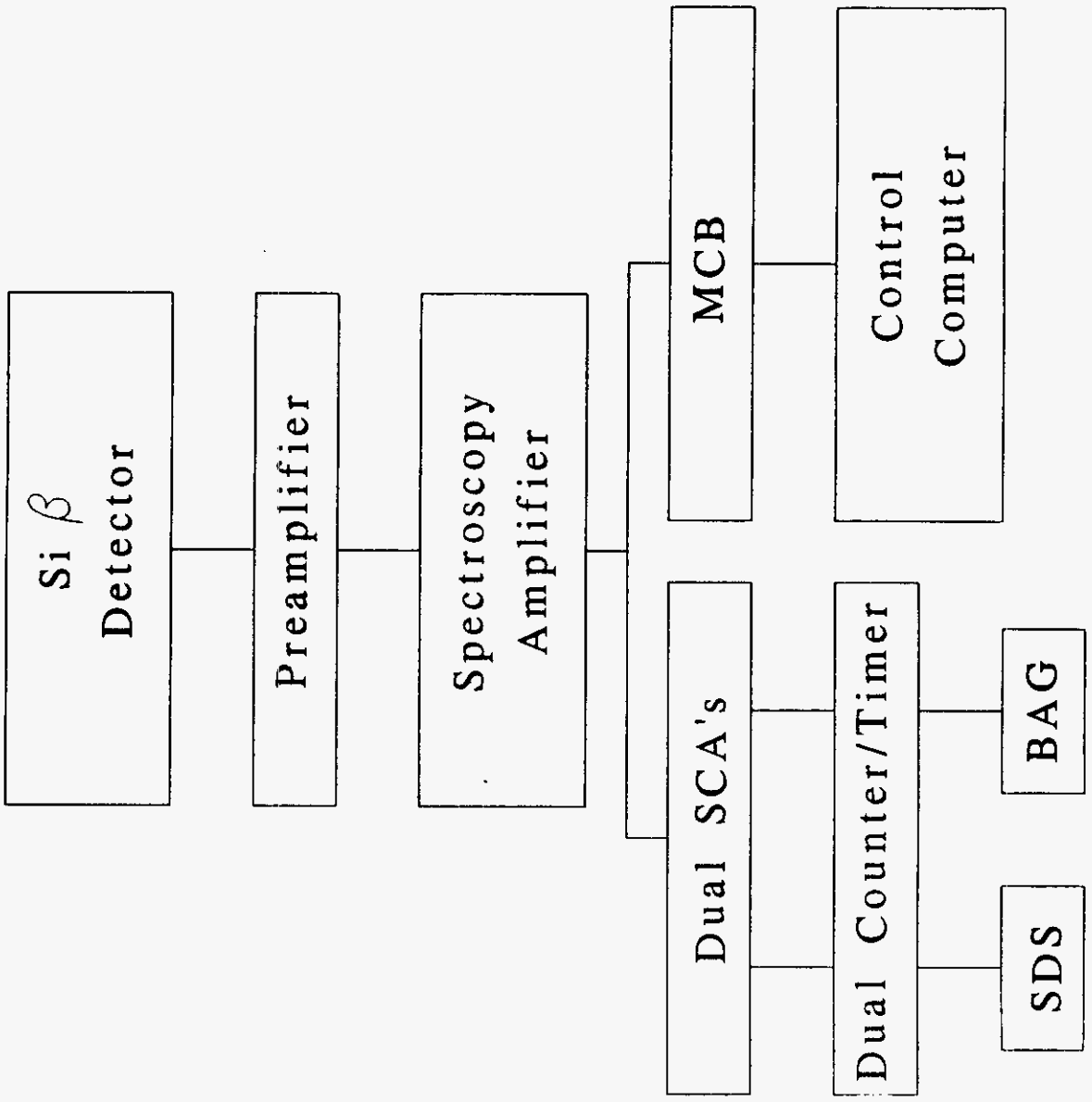
The key parameters for the hot cell detector were efficiency (allowing shorter counting times) and spectroscopic resolution for isotopic identification. The detector selection for the hot cell probe was made by comparing data from nine different CdTe and CdZnTe detectors with the same source, geometry and instrumentation settings. Manufacturing variance is large enough that detectors are individually selected for each application, but general trends were observed. Smaller crystals were found to have better spectroscopic resolution. It is postulated that this is due to reduced charge trapping. Some crystals tested were cylindrical while others were cubic. The crystal geometry did not seem to impact resolution. As expected, larger crystals, and those of CdZnTe, had higher efficiency. A 5-mm x 5-mm x -- 1-mm CdZnTe detector was selected as best suited for this application.

3.3 BETA SPECTROSCOPY

Small, ruggedized, 2- to 5-mm^2, deeply depleted (5,000 microns) Si surface barrier detectors were chosen to perform in situ beta spectroscopy within the hot cell. The deep depletion zone was required to capture the high-energy fission product beta particles. The beta spectroscopy system is shown in Figure 7. The system uses a typical spectroscopy amplifier and a fast multichannel analyzer. Additionally, the signal is split into two SCAs, and the

Figure 7. Hot Cell Beta Counting System.

SDS	-	Silicon detector signal
TBAG	-	Total betas above gamma
SCA	-	Single-channel analyzer
MCA	-	Multichannel analyzer



SCA output was directed to timer/counters. The SCAs efficiently collect two data channels from the detector--the silicon detector signal (SDS) and the total betas above gamma (TBAG).

The isotopic information that can be obtained from a beta spectrum is more limited than the photopeak information available in a gamma-ray spectra. While more complex than gross counting, beta spectroscopy is still preferred because it provides information for system diagnostics and isotopic information can be more correctly inferred from spectrum shape. The air gap between sample and probe, as well as variances in sample moisture content and geometry affect, the beta spectrum.

A measurement of the total beta signal above the energy of the gamma-ray responses for photopeak interactions from the 1,332-keV gamma ray of ^{60}Co provides a measurement of ^{90}Y, the daughter of ^{90}Sr. This measurement is called total betas above gamma (TBAG). In aged fission product waste, the only significant interference is from ^{234m}Pa, daughter of ^{238}U. However, uranium recovery efforts from the fission waste have left little uranium to generate the ^{234m}Pa daughter. Insignificantly small interferences originate from pulse pile-up, ^{152}Eu and ^{154}Eu, and the natural radionuclides, including ^{40}K and the decay products of uranium and thorium. The isotopes ^{106}Rh (daughter of 368-day ^{106}Ru), ^{144}Ce (284-day) and its daughter ^{144}Pr each have beta particles with interfering energies. However, for all practical purposes, these isotopes have decayed away (the last Hanford Site reactor was shut down in 1986), and if present, would be noted in the gamma-ray spectrum. Other isotopes have decayed away, are present only in trace quantities, or have beta and gamma-ray energies below that of concern. The beta spectral shape from ^{90}Sr/^{90}Y is visually distinctive and readily distinguishable from all interferences except ^{234m}Pa. In aged, high-level radioactive waste, the signal in the Si surface barrier detector with energies above the response from ^{60}Co is strong and overwhelming from ^{90}Sr/^{90}Y activity.

The silicon detector signal (SDS) measurement is actually a combination of the high-efficiency beta and low-efficiency gamma interactions within the Si surface barrier detector. The SDS is a very crude indication of the total radiative beta and gamma emissions from the sample. It is the most sensitive measurement to low levels of activity of all the subject radiometric measurements.

3.4 CALIBRATION, QUALITY ASSURANCE, DATA ANALYSIS

The hot cell measurements are semi-quantitative. Extruded samples typically have irregular geometries. The instrument was calibrated by measuring ^{60}Co,^{137}Cs and ^{90}Sr standards that approximate sample geometries. The standard sources had two configurations, square tray and short cylinder. The shapes were chosen to mimic the extremes of the geometry of the samples, flat slush in a sample tray or round "logs." Because the sources were not long enough to mimic a complete core segment, selected sources were counted at several positions out from the center viewing area of the detector. The resulting counts in the region of interest were later added together to simulate a "complete" core.

The instrument is checked for drift in energy and efficiency by taking spectra of a ^{154}Eu source before and after each calibration count, and also each day before the analysis of samples. A $^{137}Cs/^{90}Sr^{90}Y$ source is also available but is not normally used in daily operations. A minimum detectable concentration (MDC) is calculated as specified in DOE-RL-94-55, *Hanford Analytical Services Quality Assurance Plan* (DOE 1994), and is shown below as Equation 1:

$$MDA = \frac{2.71 + 3.3\sqrt{(R_b * T_b) * \left[1 + \frac{T_b}{T_t}\right]}}{e * b * LT * k} \quad (1)$$

where

R_b	=	background count rate
T_b	=	background count time
T_t	=	sample count time
e	=	counting efficiency
b	=	abundance
L_T	=	elapsed live time (background counting time = T_b)
k	=	37,000 disintegrations/second/μCi.

In our application, values k, b and e are combined with an concentration term, due to the nature of the standards. This MDC only applies to the measurements of ^{137}Cs and ^{90}Sr.

The minimum detectable activity (MDA) level is given in counts per second for the total beta, total gamma, and gammas-above-cesium measurements. Project data are archived in controlled laboratory notebooks (Beck 1992 and 1994).

The Quattro Pro[3] macro was qualified by noting that the results displayed were consistent with the counts reported by GammaVision[4]. Documentation resides in controlled laboratory notebooks (Greenwell et al. 1992, and DOE 1994). The GammaVision™ software was qualified by noting the consistent energy accuracy of the gamma spectrum.

The data generated by the scans are backed up to microdiskette (3.5-in. floppies) and from there they are placed on a Hanford Local Area Network drive. The U:\drive contents are periodically downloaded to floppies outside the radiological control areas.

---

[3]Trademark of Borland International, Inc., Scotts Valley, California.

[4]Trademark of Ortec, Incorporated, Oak Ridge, Tennessee.

4.0 RESULTS

Using risetime compensation and limited pulse shape discrimination, the 5-mm x 5-mm x 1-mm planar CdZnTe detector with the remote probe provided spectral resolution of 2% FWHM at 662 keV, the ^{137}Cs gamma-ray. Gamma energy spectra, acquired with the remote probe of the calibration sources, are shown in Figure 8. A selected spectrum of tank material is shown in Figure 9. ^{134}Cs is seen despite the short half-life (two years) compared to the age of the waste (approximately 10 ten years). The typical 60-second count time was sufficient to collect good spectra of the principal isotope ^{137}Cs. The small size of the detector and the tungsten shielding alleviated any high count problems that might have been encountered, but longer count times were required to resolve trace isotopes such as ^{134}Cs, ^{154}Eu, ^{152}Eu, and ^{60}Co.

The one standard deviation in MDA for the standard 60-second count time varies as the background in the hot cell varies, but is typically 1.6 microcuries per gram (μCi/g) for ^{137}Cs, 2.7 counts per second for total gammas, and 0.3 counts per second for TGAC.

The beta detector produced extremely high count rates on the HLW tank material. The computer (GammaVision™)-multichannel buffer communication pathway could handle counts rates up to approximately 90,000 counts per second. However, sample activity often exceeded 90,000 counts per second, and the initial calibrations had to be abandoned. The lower level discrimination was adjusted upwards to reduce count rate. Beta energy spectra of the calibration source with analysis regions indicated are shown in Figure 10. Beta spectra of HLW tank material taken with the probe in the hot cell are shown in Figure 11.

With the high efficiency of the detector and the high activity of the samples, beta sensitivity was a nonissue. However, the MDA for 60-second count times was calculated to typically be 2.3 counts per second for SDS and 0.15 μCi/g for ^{90}Sr.

The extruded HLW tank core sample material rarely forms ideal cylinders, but the calibrations on such cylinders are the most reasonable approximations to actual samples.

4.1 CORE PROFILE - CORE 101, BY-110

Tank BY-110 was chosen because it was being used as a test tank for a new rotary-mode sampler, and several full-core samples (seven to nine 48-cm (19-in.) core segments per full core) were planned for this tank. Segments 6a through 9 (of 9 segments) of core 101 were analyzed, and five measurements per segment were taken. Figure 12 shows the relative values total beta (TB), total gamma (TG), ^{137}Cs, ^{90}Sr (betas above gammas [BAG]), and gammas above cesium (GAC) as a function of distance from the bottom of segment 9 (which also corresponds with the bottom of the tank).

Figure 8. Gamma Energy Spectra of Calibration Sources Used.

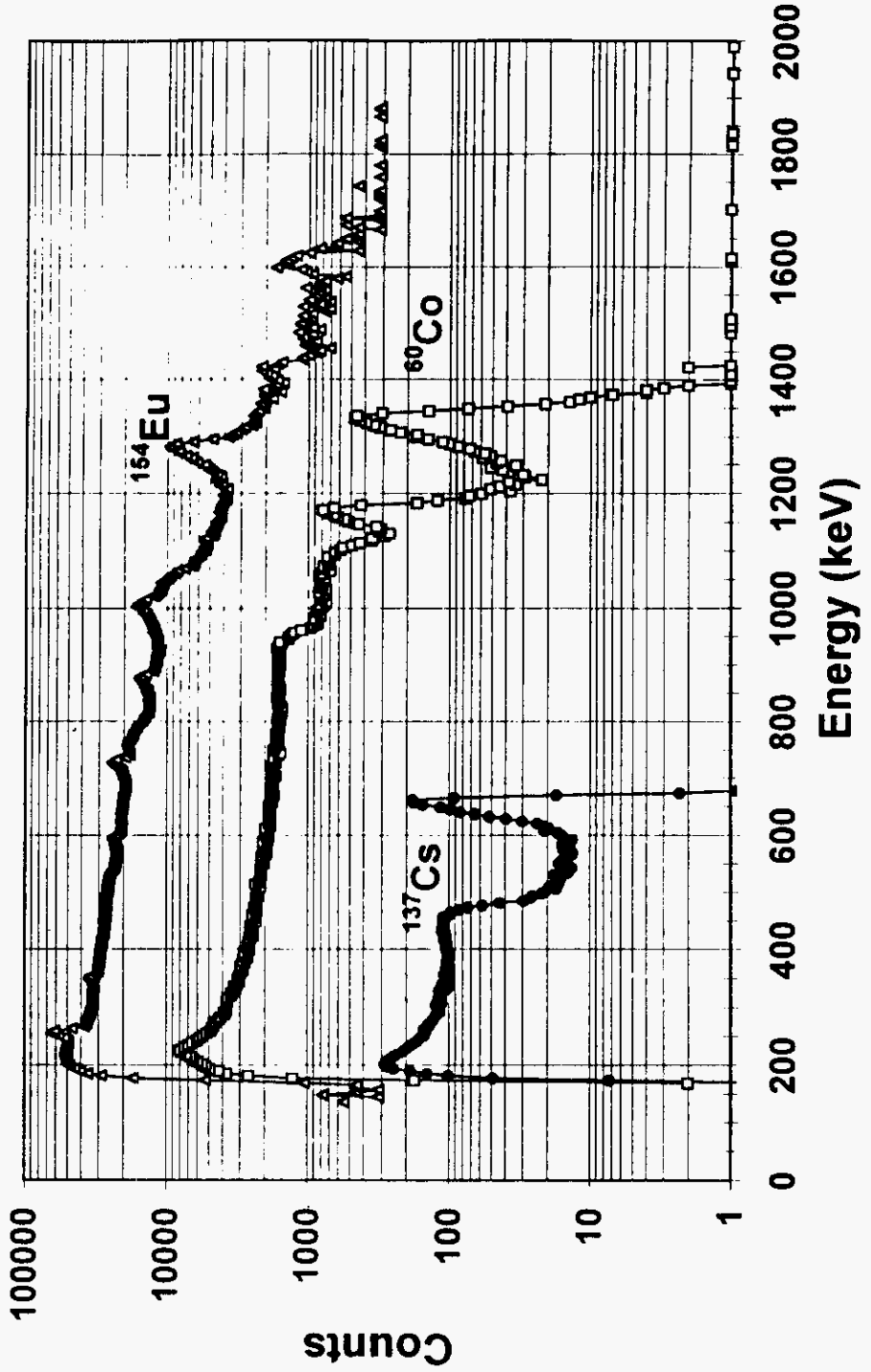


Figure 9. HLW Tank Material Gamma Energy Spectra.

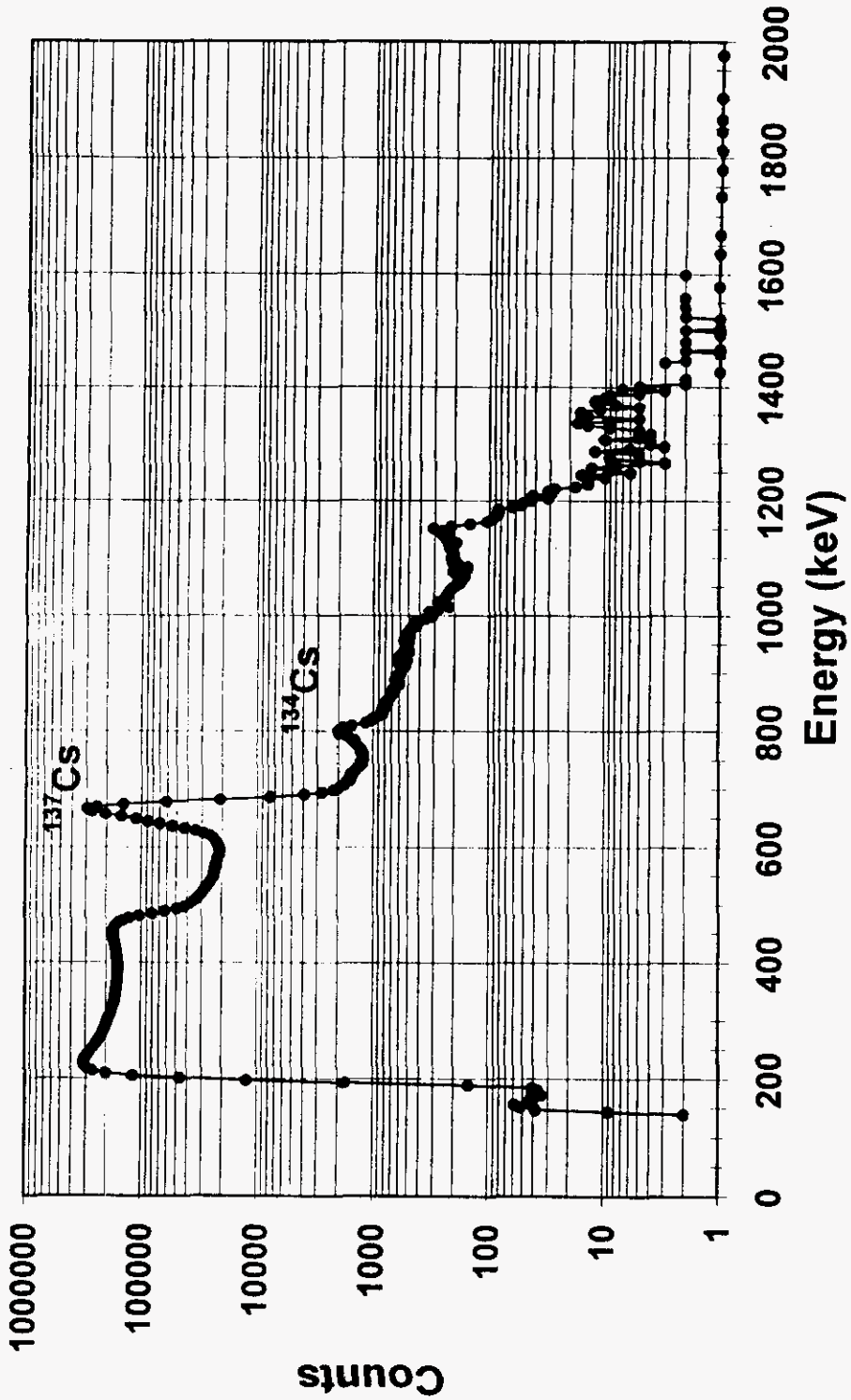


Figure 10. Beta Energy Spectra of Calibration Source. Regions used for analysis shown.

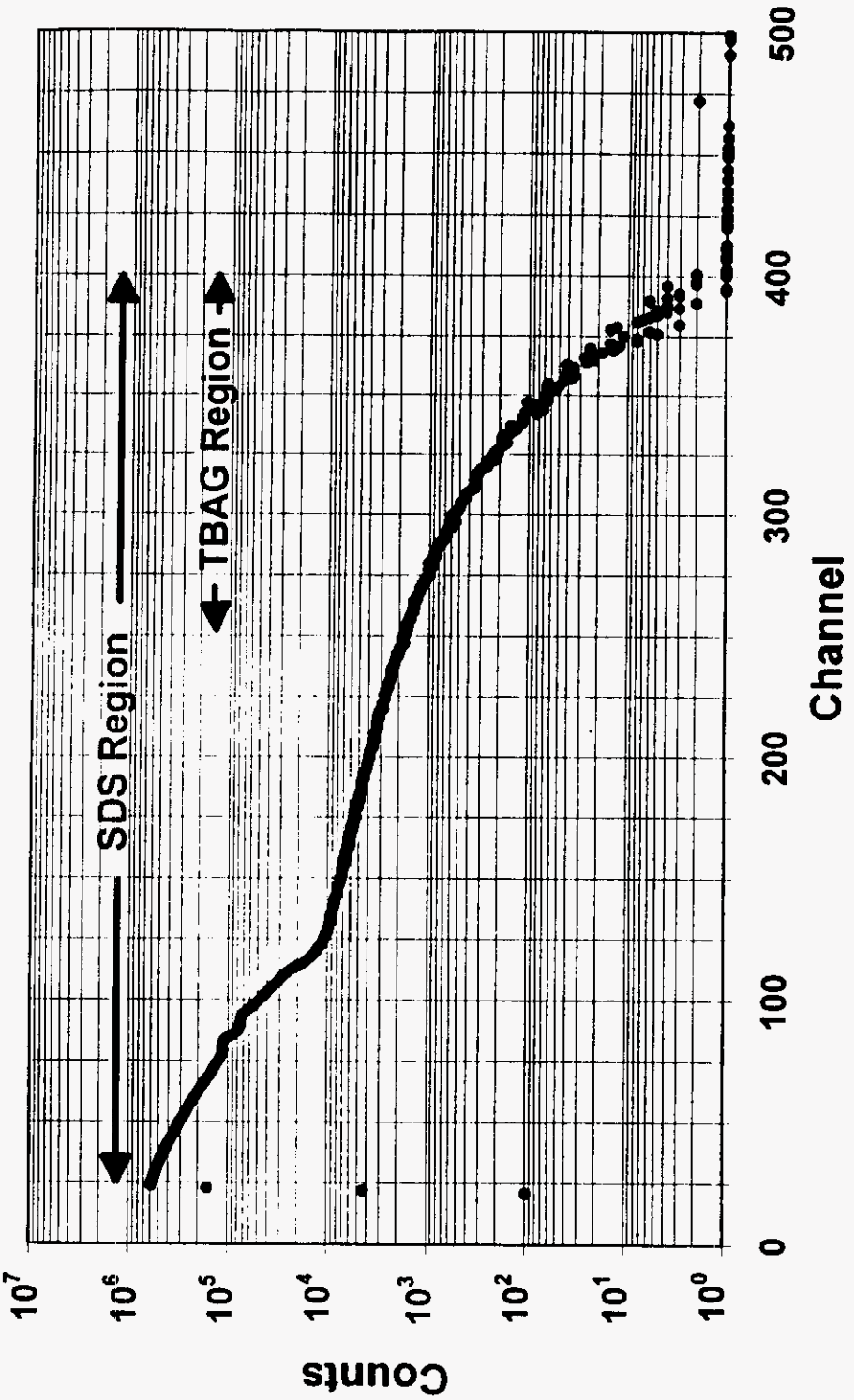


Figure 11. HLW Tank Material Beta Energy Spectra.

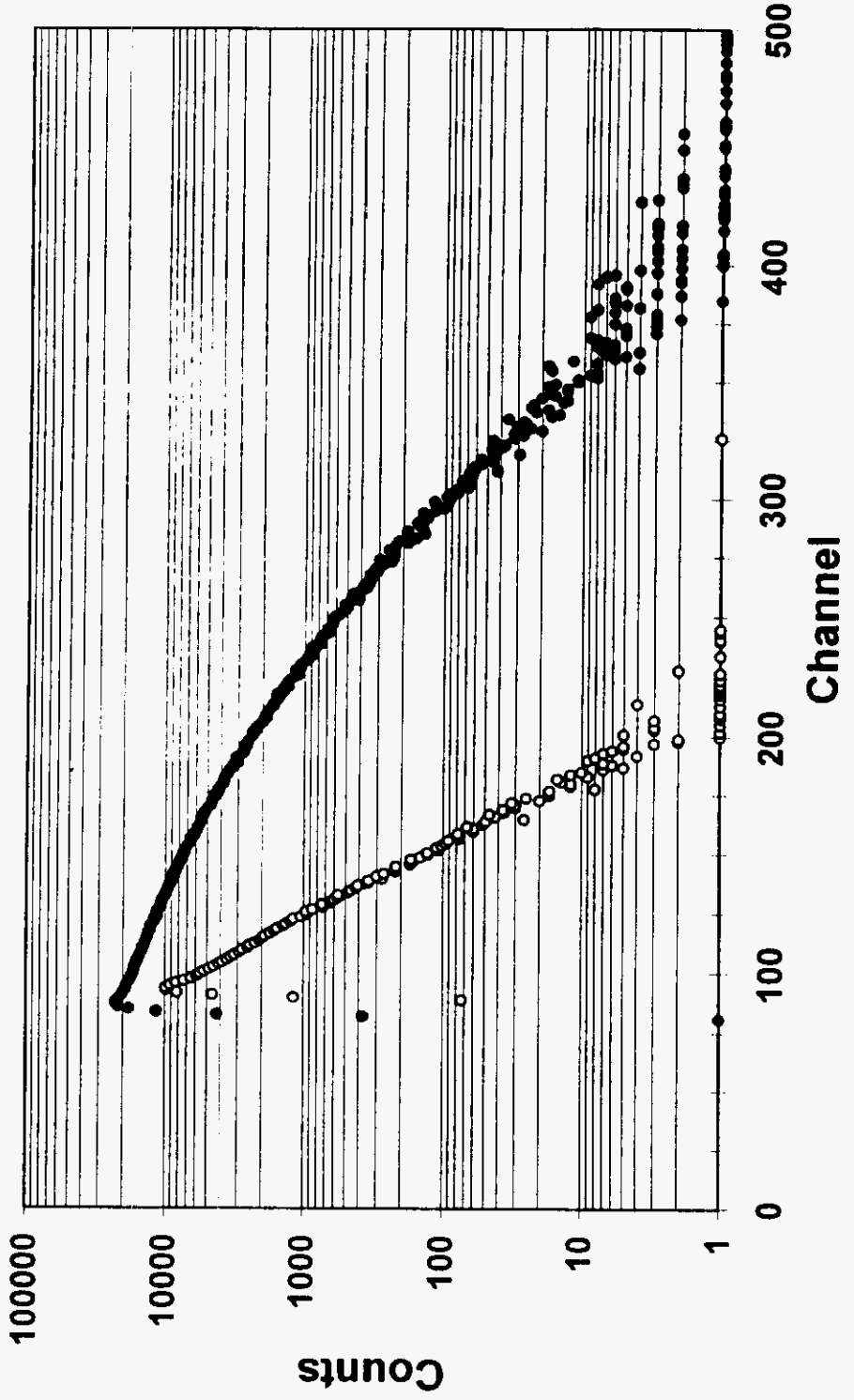
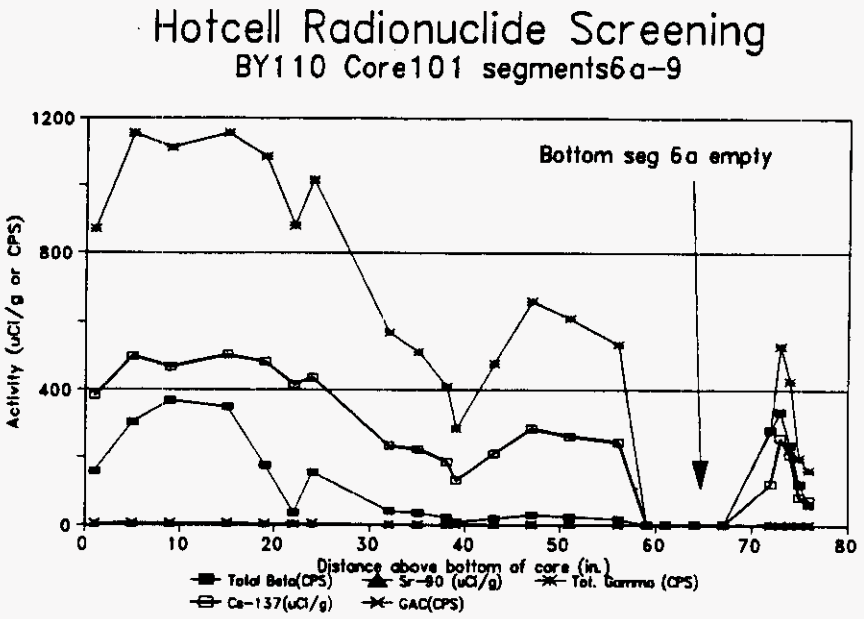


Figure 12. Profile of Core 101, BY-110.



The collected scans of tank BY-110 show that the sample becomes "hotter" as it gets closer to the bottom of the tank. This result is expected because the sample is more finely grained (meaning that it is better packed and has more mass under the detector) near the bottom, and ^{90}Sr is more likely to be found in the solids than in the liquid phase. See Appendix G for details of the extrusion process and observations.

A comparison of the tank BY-110 lab results to the probe scanning is not possible, because the analyses have yet to be started (as of 10/24/95) for the samples involved (extruded 9/8/95). The unavailability of conventional laboratory data demonstrates the difference between the probe system and conventional methods in the time required for generating similar data.

4.2 CORE PROFILE - BX-103

Tank BX-103 has a much shallower depth of waste than tank BY-110, so it had a full core with only two 48-cm (19-in.) segments.

The sample results (see Figure 13) clearly show the varying amounts of mass underneath the probe for the top segment (Segment 1, 25 cm [10 in.] and above), with "hot" spots corresponding to small clumps of material (see pictures of the segments as extruded, Figures 14 and 15). The bottom segment displayed a different picture. The bottom segment was nearly uniform in cross section, so there were no great variations in mass to cause changes in activity. The higher activity seems to be associated with dark material, as both ends of the segment were nearly pitch black in color. Note that the material in segment 1 is all pitch black.

See Appendix G for details of the extrusion process and observations.

4.3 DISCUSSION AND CURRENT STATUS

Despite the good results and quick work, not everything went perfectly. The beta detector signal shows clear signs of having grounding problems. The signal, when examined with an oscilloscope, has a high amplitude jagged baseline, making pulse shape determination impossible. A signal from the manipulators is seen when the "X" or "Y" motors are on, but the "Z" motor shows no effect. The grounding problem has been isolated as being closer to the detector than to the nuclear instrument module (NIM) interface box, because a change of interface boxes (with slightly different grounding setups) did not produce any noticeable improvement in the signal.

Figure 13. Profile of Core 87, BX-103.

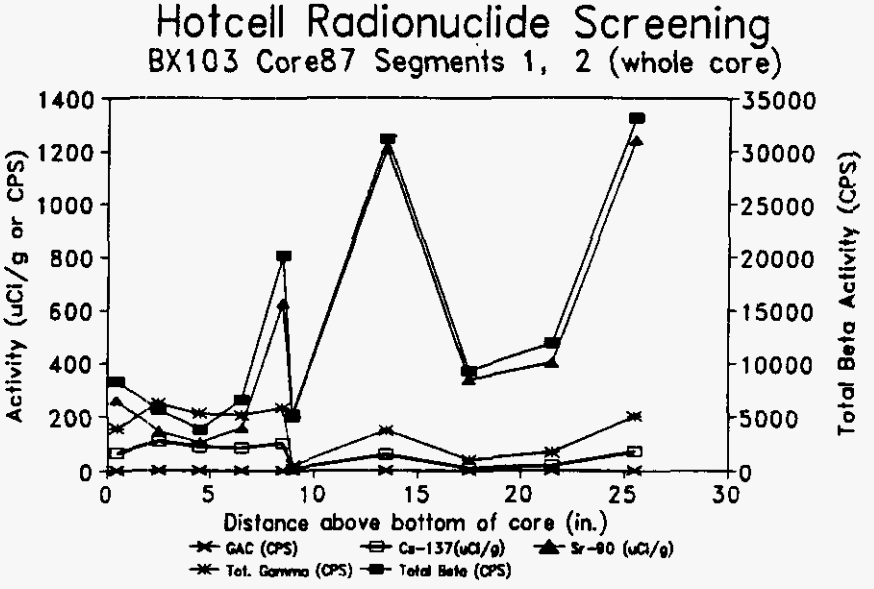


Figure 14. Segment 1, BX-103.

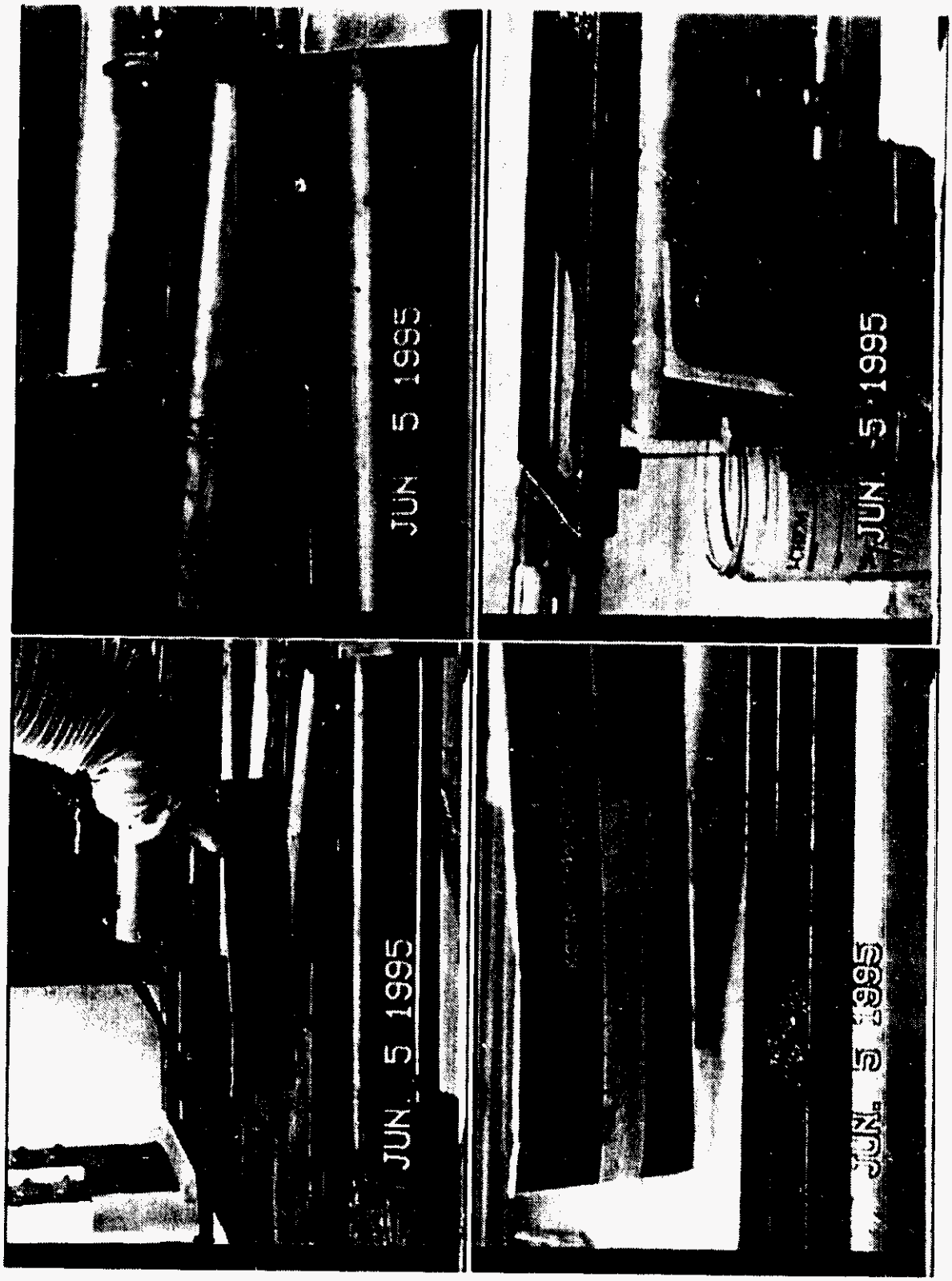
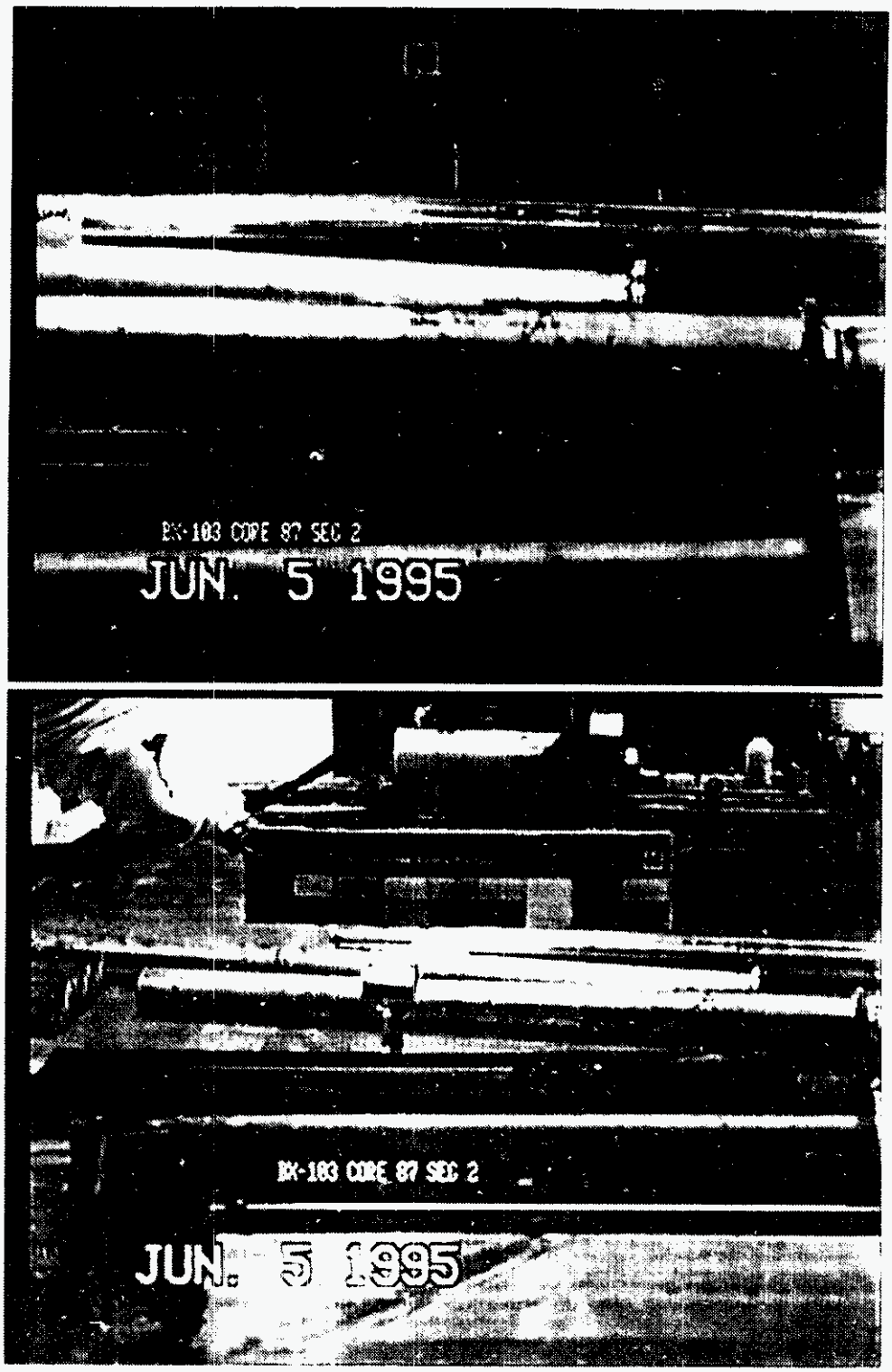


Figure 15. Segment 2, BX-103



5.0 CONCLUSIONS

A remote semi-quantitative isotopic mapping system has been developed and demonstrated in a hot cell facility.

With customized pulse risetime compensation and pulse shape discrimination signal processing, gamma energy spectra have been taken with a remote CdZnTe detector that have 2.0% FWHM resolution at 662 keV. Using the CdZnTe system remote measurement of fission isotopes such as ^{60}Co, ^{134}Cs, ^{137}Cs, ^{154}Eu, and ^{152}Eu has been accomplished.

Small, ruggedized, deeply depleted (5,000 microns) Si surface barrier detectors were chosen to perform in situ beta spectroscopy within the hot cell. Isotopic and gross beta measurements were taken of fission wastes. $^{90}Sr/^{90}Y$ was the principal isotope.

Remote analytical screening of nuclear materials in hot cells provides information on the sample material in near-real time. Real time data provides intuitive and objective information for; preliminary sample assessment, direction of sub-sampling efforts, resolution of safety issues, and material transportation. This technology has other potential applications such; as process monitoring in nuclear power and fuel processing plants, safeguards, or remote characterization at mixed waste remediation sites.

5.1 FUTURE WORK

For the discussed applications chemical information would be as valuable as radiological information. Efforts are underway to produce a single integrated remote analytical system capable of collecting both isotopic and chemical information. Principal methods being investigated to augment the existing nuclear probe are various forms of fiber optic spectroscopy (Greenwell et al. 1992). Raman, Fourier transform infrared (FTIR), fluorescence, time resolved laser-induced fluorescence (TRLIF), laser-induced breakdown spectroscopy (LIBS) and laser ablation mass spectroscopy (LA-MS) are presently being investigated for use. Fiber optic Raman, FTIR, TRLIF, and fluorescence spectroscopy could provide a wealth of molecular information. LIBS and LA-MS could provide elemental information, including actinides, at the part-per-million and possibly part-per-billion level.

A small charge-coupled device camera could be incorporated into the probe to provide visual documentation of the measurement site. Finally, data fusion methods would condense the information from the probe's instrument array, allowing an organized, near-real-time look at multiphase materials in a hazardous environment.

Troubleshooting of the beta detector, to determine the exact cause of its problems and formulate a cure, will be needed to provide more reliable beta detector information.

6.0 ACKNOWLEDGEMENTS

The guidance and support of Cliff Narquis was appreciated during the course of this work. The support by Shawn Tweedy with the laser alignment system and Todd Halter with drafting was irreplaceable. Keith Richards and Ed Selle's MCNP modeling efforts were deeply appreciated. Without the common sense and machining skill of Chuck McClellan this system could never have been built.

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APPENDIX A

CHECK LIST BETA/GAMMA HOT CELL PROBE VERSION 1.0

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CHECK LIST BETA/GAMMA HOT CELL PROBE VERSION 1.0

INTRODUCTION

This desk instruction provides checklist-style guidance on producing data with the beta/gamma hot cell probe. This instruction assumes the person has read the GammaVision™ software manual, and understands the basics of Microsoft Windows[1] operating system as well as nuclear spectroscopy.

Setup:

Cable connections:

Ensure that all power cables are connected.

Ensure that cables to the probe are connected.

Powering up:

Ensure that both bias power supplies are switched to OFF and set to 0 volts (V). Reset the beta detector bias supply if necessary.

Turn on the main power switch at the bottom of the relay rack.

Turn on the bottom NIM bin.

Turn on the computer (the bottom NIM bin power MUST be on).

Turn on the top NIM bin.

Turn on the gamma detector bias supply (top NIM bin). Slowly raise the voltage up to 800 V Positive.

Plug the beta amplifier (Top NIM crate, Canberra Fast[2] spectroscopy amp) output to an oscilloscope.

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[1]Trademark of Microsoft Corporation, Redmond, Washington.

[2]Trademark of Canberra Industries, Inc., Meridian, Connecticut.

Place a source under the beta detector. This may be needed to provide enough counts to see in the oscilloscope.

Turn on the beta detector bias supply (bottom NIM crate). Very slowly (<20 volts/sec) raise the beta detector bias voltage to 800 V, waiting until the pulse on the oscilloscope returns to normal before proceeding.

When the beta detector bias voltage is at 800 V, reconnect the amplifier output to the T-connector at channel 2 of the single-channel analyzer (SCA).

Turn the pointer on (up). The switch is in a blank NIM module in the top NIM bin.

Starting GammaVision™

At the C: prompt, enter "win" to enter Windows™.

Double-click on the GammaVision™ icon.

Switch to multichannel buffer (MCB) #1 (gamma) if not already there.

Run job "gate1cn.job".

Switch to MCB #5 (beta).

Run Job "gate5off.job"

Spectrometry:

Taking a spectrum in GammaVision™ is as easy as hitting ALT2 (STOP), ALT3 (CLEAR), ALT1 (START), and giving the program all the information it requests. GammaVision™ is set up to ask for collection live time and sample description.

Spectra for most samples will be taken using an automated .JOB file, which only requires the user to input live time and sample description.

Running the counters:

When you are ready to start a count, hit the stop button (or switch) on the timer, then hit the reset (to clear previous counts), and then hit the start button (switch) to start the count.

Daily Energy Calibration and QA Check

Perform startup.

Center the ^{154}Eu quality assurance (QA) source under the probe (at the intersection of the light beams of the pointer).

Set the live time on the MCBs and counters to 2,000 seconds.

Start the counters and the MCBs.

ON MCB #1, Recall qaeusrc.roi.

Compare the peak centroids to the published values for ^{154}Eu.

If the centroids of the peaks are shifted from the published values by more than 10 keV, adjust the amplifier fine gain to match the centroids with published values.

Stop and start the MCBs between adjustments of the fine gain controls.

If the actual values are more than 30 keV apart, consult with the scientist on whether a recalibration is necessary.

Compare the endpoint of the beta spectrum taken to the file C:\betapro\SrtdQA1.chn. If the endpoint is different, adjust the fine gain on the Canberra amplifier.

After completing the calibration and QA check, take a spectrum with both MCBs.

Run .JOB file C:\mcafile\QAcheck.job.

At the end of the count record all counter values.

Compare the current QA check source values to previous QA counts; the values should be within 20%. The values below are from page 10 (repeated on page 37) of laboratory notebook WHC-N-11151 1 (Beck 1994), and the spectra files: Gamma, C\data\gampro\srtdQA.chn; Beta, C:\data\betapro\srtdQA1.chn.

Total Beta (TB):	2,073,772	Betas Above Gammas (BAG):	377
Total Gamma (TG):	1,448,951	Gammas Above Cesium (GAC):	215,372
Cesium-137 (Cs):	72,892		

Eu-154 @248 keV	385,290 counts,	@723 keV	
85,423 counts @993 keV	10,671 counts	@1274 keV	5,667 counts

Running Samples:

If the daily QA check is OK, then samples may be run.

Run the .JOB file gammaV5.job .

Remember which scan you're on.

Scans 1 and 7 are backgrounds, so the sample must be moved away from the probe during those scans.

Label the scans appropriately at 0.5, 5, 9.5, 14, and 18 inches from the bottom of the core segment.

Align the sample with the laser beam crosshairs so as to position the sample for scans 2 through 6.

Return the sample to 11A Hot Cell Operations personnel.

After the end of the run (including backgrounds), start Quattro Pro™.

Open the file appropriate to the geometry of the sample. LogSS5.WQ1 should be used for "log" samples, and TraySS#3.WQ1 for "tray" (flat) samples.

Hit Alt A.

Change the text on the 2nd line of the graph to reflect the identity and nature of the sample.

Print-to-Fit and Print Graph. There is no need to change any settings before printing, as everything is already set up.

Save the Quattro Pro™ file in a directory appropriately named for the sample.

In Windows™ File Manager, copy all the files in the directory

C:\practjob

to a directory that is labeled in such a way as to identify the sample.

Paste all the output into the laboratory notebook.

You're done!...

Normal Shutdown:

Shut the pointer off.

Normally, everything else is left on.

Total Shutdown:

Perform the normal shutdown.

Exit Windows™.

Shut off the computer.

Slowly turn the bias supply voltages down to 0 and lock them there.

Turn off the bias supplies.

Turn off the NIM bins.

Turn off the fans (back of rack).

REFERENCE

Beck, M. A., 1994, Controlled Laboratory Notebook, *Hot Cell Beta/Gamma Probe*, WHC-N-120 7, Westinghouse Hanford Company, Richland, Washington.

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APPENDIX B

SPECTROSCOPIC SETTINGS

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APPENDIX B

SPECTROSCOPIC SETTINGS

Values taken from pg 143 of laboratory notebook WHC-N-120 7 (Beck 1992).

Power supplies
800 V each when operating. Bias control at 0 Volts and OFF when not operating.

Interface box
Pointer on or off depending on operator
Beta cables on top, Gamma cables on bottom.

Gamma System:

572 Amp
Fine Gain 10.0 (adjustable depending on peak positions),
Coarse Gain 200, Shaping Time 2 μsec.

675 Ge Resolution Enhancer
Coarse Gain 1 Fine Gain 3.10

Fine Delay, use source instead of 500 ns pulse to balance lights (setting the zero crossing offset delay) Coarse Delay 2 Mode T^2

460 Delay Line Amp
Fine Gain 0.5 Coarse Gain 50 INTEG 0.04μsec NEG input

552 PSA/T-SCA
Upper Level 10 Lower Level 1.0 Mode NORM B-fraction 0.7 ATTN X1

567 Tac SCA
Range:200ns SCA Window: 1.71 Multiplier: 10
SCA Lower Level 0 (0.06 lowest value available)
Delay pot: to match up output (logic gate on) and MCB input pulse (unipolar output of 572 Ge Resolution enhancer).

All INPUTS ANTI TAC Inhibit

850 Quad SCA
channel 1 (BAG)
Low: 5.21 High:9.99 for all
Channel 2 (TB)
Low: 0.14

Channel 3 (TG)
Low: 0.06
Channel 4 (GAC)
Low: 1.71

Values taken from pg 143 of laboratory notebook WHC-N-120 7 (Beck 1992).

Beta system:

Canberra 2024 Fast™ Spectroscopy amplifier

Fine Gain 0.50 Coarse Gain 30 Shaping Time 0.25
Amplifier Threshold; Auto Mode, Asymmetric, Uni
PUR off The PUR setting may change in the future, due to current problems with high count rate.

Timers, counters, set as needed for count times.
772 Counter set as slave 775 set as Master

Values taken from pg 143 of laboratory notebook WHC-N-120 7 (Beck 1992).

APPENDIX B REFERENCE

Beck, M. A., 1992, Controlled Laboratory Notebook, *Process Chemistry Support 4*, WHC-N-11151 1, Westinghouse Hanford Company, Richland, Washington.

APPENDIX C

WIRING DIAGRAMS

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Figure C-1. Gamma Spectroscopy System.

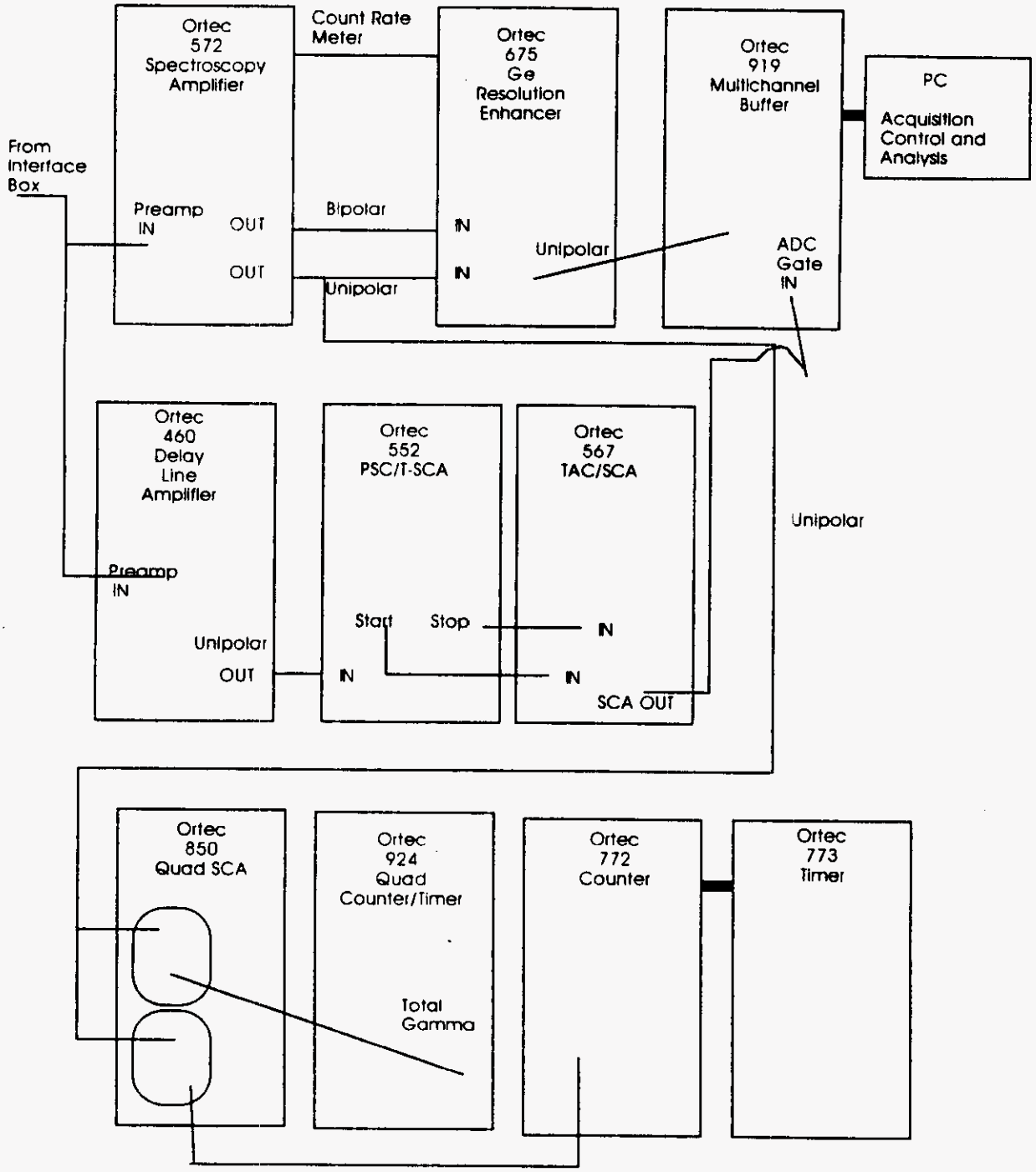


Figure C-2. Beta Spectroscopy System.

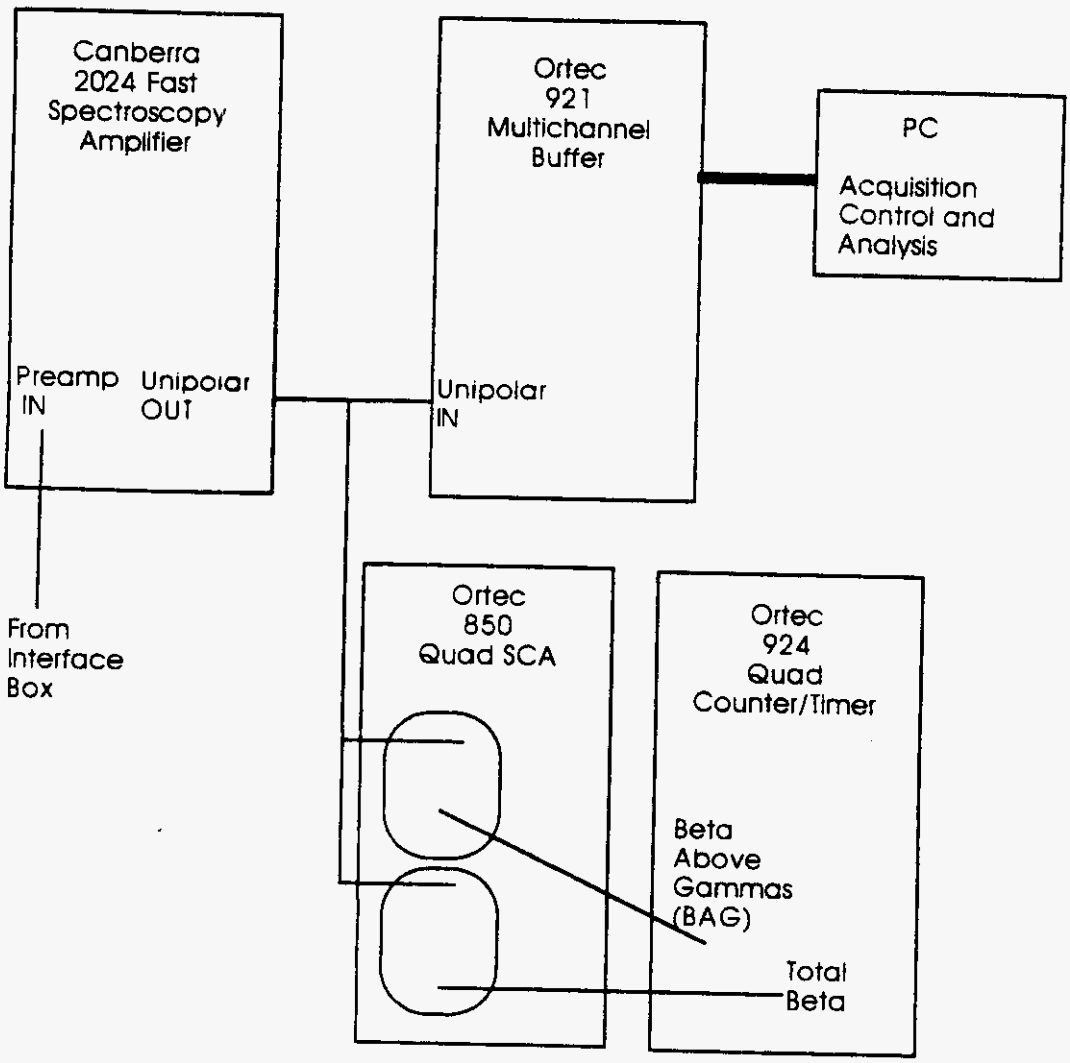


Figure C-3. NIM Interface Box #1, Grounding Style #1.

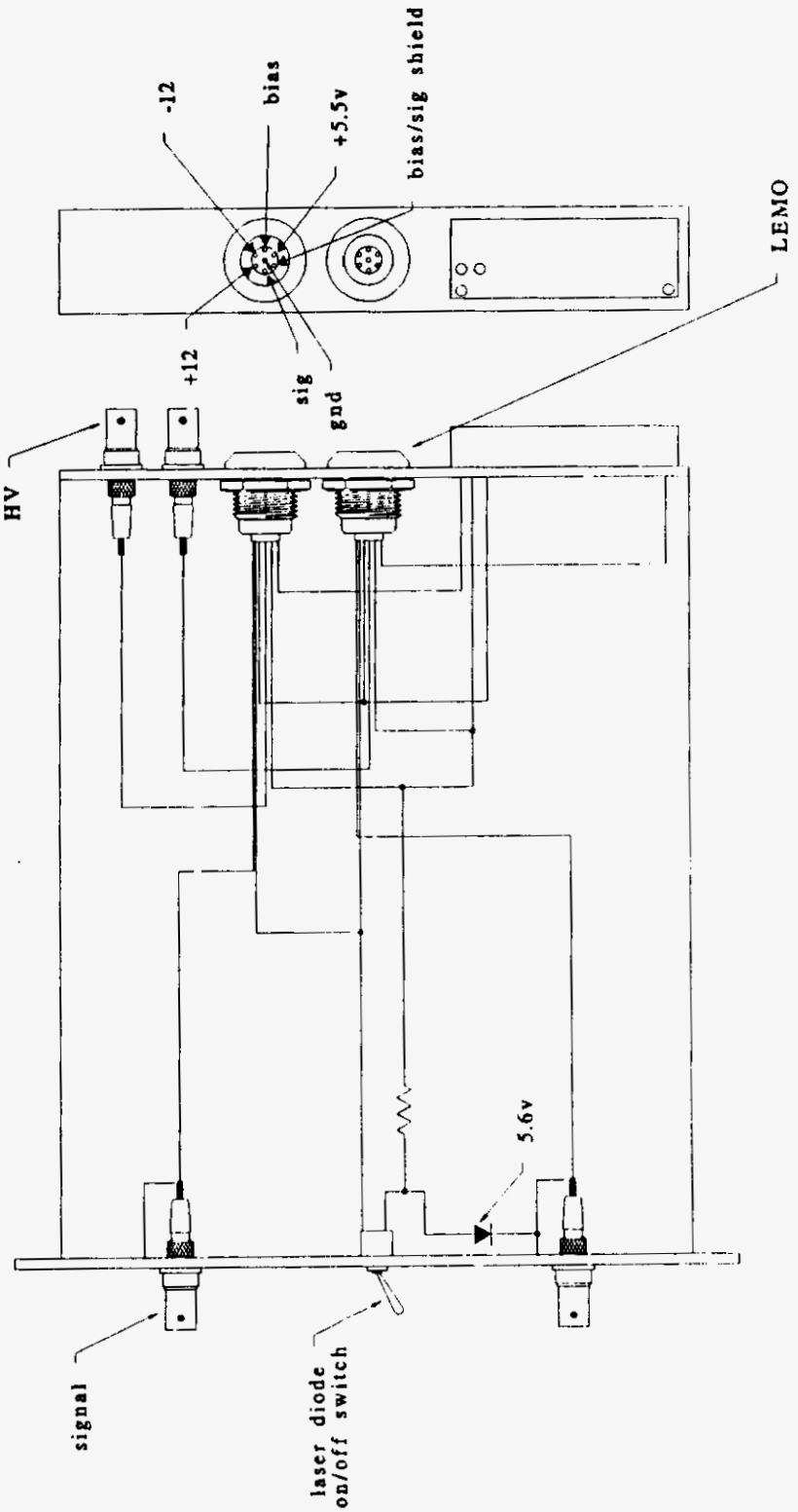
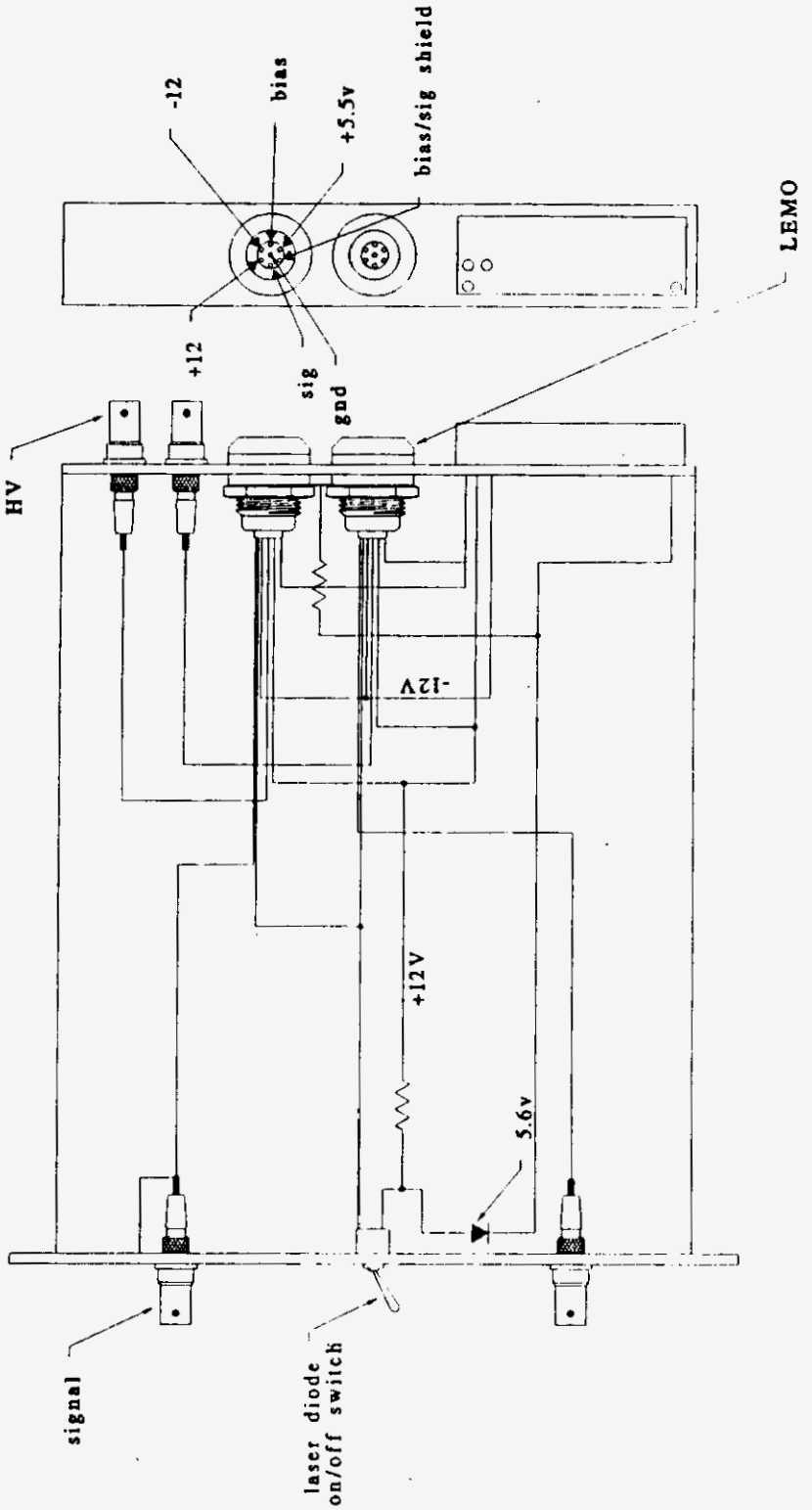


Figure C-4. NIM Interface Box #2, Grounding Style #2.



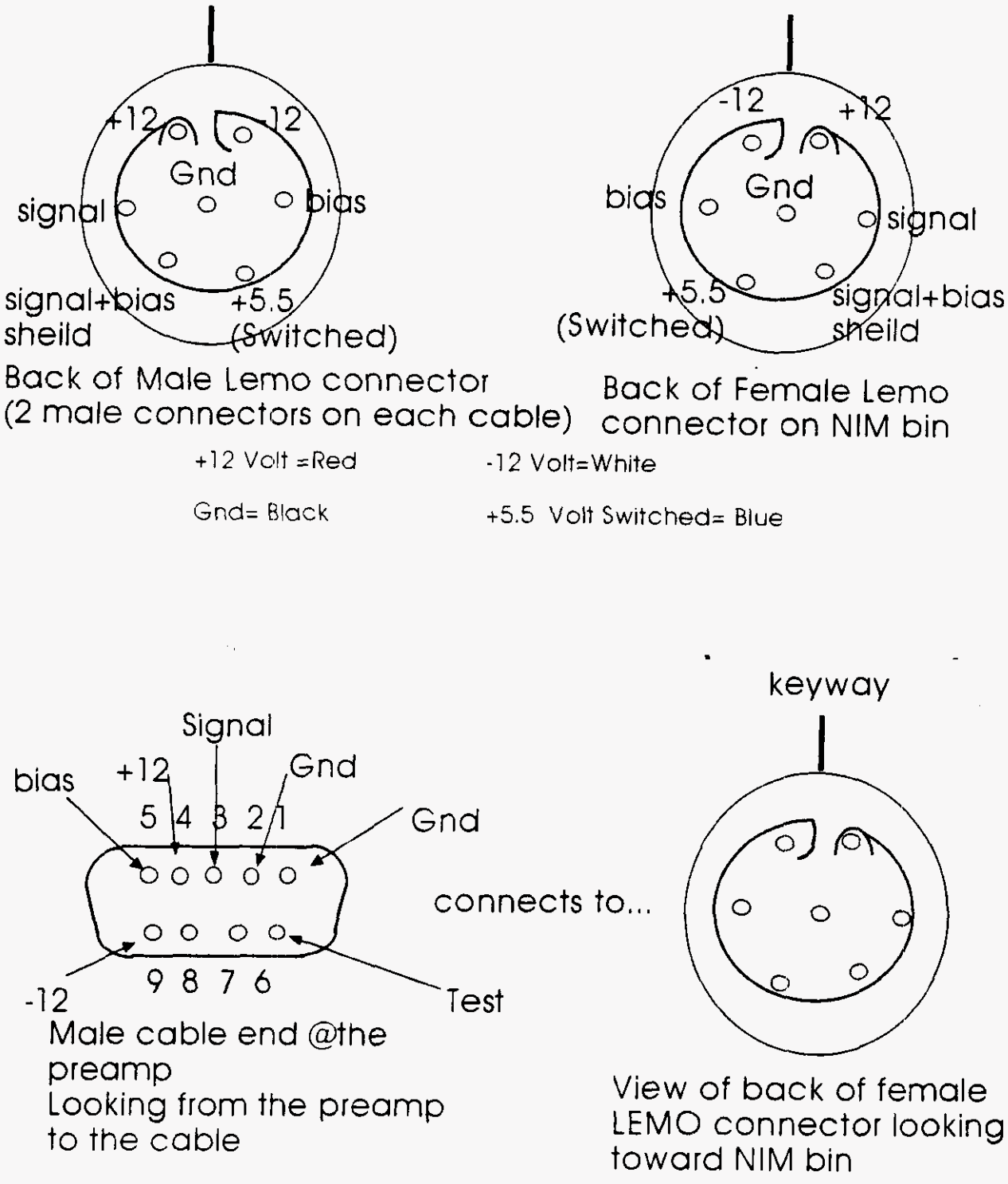
Probe Cabling:

The types of cabling and connectors that would work in a hot cell environment are constrained by small openings in the hot cell, resistance to chemical attack, and radiological contamination concerns. Two 30-foot cable segments were constructed for use with the hot cell detector. The cable segments electrically connect the hot cell probe to the NIM jumper box that was constructed as an interface between the cables and the rest of the electronics used (amps, shaping electronics, etc.). One cable is used for the beta detector inside the probe, and the other cable is used for the gamma detector. Both cables were constructed identically, because both the beta and gamma detectors require the same inputs and outputs; e.g., H.V. supply, preamp power, and signal output. The cables can be used interchangeably for either detector.

Additionally, one of the seven pins used for in both cables carries approximately 5.5 volts from the jumper box to the probe to power the small laser light pointers mentioned earlier. Environmentally sealing LEMO™ quick couplers with seven pin cores are used at both ends of the cabling that penetrates the hot cell wall. This allows the removal of the probe head from the hot cell, and enables the instrumentation rack outside the hot cell to be disconnected and moved out of the way of other projects.

Careful attention was paid to grounding of the detector system. One of the seven wires in each cable bundle is used as a ground wire between the jumper box and a preamp ground pin. This wire is not grounded at any other point, such as connectors. The coax shielding for both the H.V. and signal cables inside each bundle is grounded at the jumper box and carried through one pin in each of the two cables to termination at a second ground pin in each preamp. The two ground pins in each of the preamps are internally jumpered at the factory, and this system was left intact. Although all grounding eventually terminates in the same location, care was taken not to introduce potential ground loops into the system. Finally, a bare, stranded wire inside each cable bundle was grounded between the LEMO™ connectors at each end of the cable assemblies. The grounding accomplished with this wiring is between the jumper box (where the grounded connector attaches) and the probe housing. The probe housing is isolated from the preamps and detectors through the use of thin insulators, such as tape wrappings. This ground therefore provides a drain wire for the probe case, separate from the rest of its components, which prevents the probe housing from becoming an "antenna" with respect to those components. The inputs and outputs on the jumper box are constructed so that the gamma and beta detector connections are also interchangeable.

Figure C-5. Cable Pin Configurations.



APPENDIX D

SOFTWARE

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APPENDIX D

SOFTWARE

GammaVision™:

Gamma:
Acquisition on Detector 1

Beta:
Acquisition on Detector 5

GAMMAVISION™ MACROS:

C:\mcafile\QACHECK.JOB

This macro provides a printed and file output of the counts in the Regions of Interest (ROI) for the Europium-154 check source.

```
LOAD_LIBRARY "C:\mcafile\MARKS.LIB"
SET_MCB 5
RECALL_ROI "C:\mcafile\totbeta.roI"
REPORT "c:\practjob\QATB1.rpt"
REPORT "PRN"
RECALL_ROI "C:\mcafile\BAGAMMA.roi"
REPORT "PRN"
REPORT "c:\practjob\QABAG1.rpt"
SAVE "c:\practjob\QAbeta.chn"
SET_MCB 1
RECALL_ROI "C:\mcafile\QAEUarc.roI"
REPORT "PRN"
REPORT "c:\practjob\QAEuQA.rpt"
RECALL_ROI "C:\mcafile\TGamma.ROI"
REPORT c:\practjob\QATG1.rpt
REPORT "PRN"
RECALL_ROI "C:\mcafile\TGAC.ROI"
REPORT "PRN"
REPORT c:\practjob\QAGAC1.rpt
RECALL_ROI "C:\mcafile\Cs.roi"
REPORT "PRN"
REPORT "c:\practjob\QACs1.rpt"
SAVE "c:\PRACTJOB\QAGAM.CHN"
BEEP 1500,500
```

C:\mcafile\GAMMAV5.JOB

This macro sets up the counting options for a sample scan. It also determines the counts in the regions of interest and saves the results as ASCII format "*.RPT" files that are used in Quattro Pro™ for data calculation and printout. As shown, the macro is set up for a 5 point scan.

```
LOAD_LIBRARY "C:\mcafile\MARKS.LIB"
SET_MCB 1
CLEAR
SEND_MESSAGE "SET_GATE_COINCIDENT"
RECALL_OPTIONS "C:\mcafile\glogcal1.adf"
START
SET_MCB 5
CLEAR
SEND_MESSAGE "SET_GATE_OFF"
RECALL_OPTIONS "C:\mcafile\blogcal1.adf"
START
WAIT
RECALL_ROI "C:\mcafile\totbeta.roi"
REPORT c:\practjob\backTB1.rpt
RECALL_ROI "C:\mcafile\BAGAMMA.roi"
REPORT c:\practjob\backBAG1.rpt
SAVE c:\PRACTJOB\BbACK1.CHN
STOP
SET_MCB 1
RECALL_ROI "C:\mcafile\TGamma.ROI"
REPORT c:\practjob\backTG1.rpt
RECALL_ROI "C:\mcafile\TGAC.ROI"
REPORT c:\practjob\backGAC1.rpt
RECALL_ROI "C:\mcafile\Cs.roi"
REPORT c:\practjob\backCs1.rpt
SAVE c:\PRACTJOB\GAMbACK1.CHN
LOOP 5
SET_MCB 1
CLEAR
START
SET_MCB 5
CLEAR
START
WAIT
RECALL_ROI "C:\mcafile\totbeta.roi"
REPORT c:\practjob\TB#???.rpt
RECALL_ROI "C:\mcafile\BAGAMMA.roi"
REPORT c:\practjob\bag#???.rpt
SAVE C:\practjob\beta???.chn
SET_MCB 1
WAIT
RECALL_ROI "C:\mcafile\TGamma.ROI"
REPORT c:\practjob\TG#???.rpt
RECALL_ROI "C:\mcafile\TGAC.ROI"
REPORT c:\practjob\GAC#???.rpt
RECALL_ROI "C:\mcafile\Cs.roi"
REPORT c:\practjob\Cs#???.rpt
SAVE C:\practjob\gam???.chn
END_LOOP
SET_MCB 1
SEND_MESSAGE "SET_GATE_COINCIDENT"
RECALL_OPTIONS "c:\mcafile\gamback.adf"
CLEAR
START
SET_MCB 5
SEND_MESSAGE "SET_GATE_OFF"
RECALL_OPTIONS "C:\mcafile\bETABACK.adf"
CLEAR
START
```

```
WAIT
RECALL_ROI "C:\mcafile\totbeta.roi"
REPORT c:\practjob\backTB2.rpt
RECALL_ROI "C:\mcafile\BAGAMMA.roi"
REPORT c:\practjob\backBAG2.rpt
SAVE c:\PRACTJOB\BbACK2.CHN
SET_MCB 1
RECALL_ROI "C:\mcafile\TGamma.ROI"
REPORT c:\practjob\backTG2.rpt
RECALL_ROI "C:\mcafile\TGAC.ROI"
REPORT c:\practjob\backGAC2.rpt
RECALL_ROI "C:\mcafile\Cs.roi"
REPORT c:\practjob\backCs2.rpt
SAVE c:\PRACTJOB\GAMbACK2.CHN
BEEP 500,500
```

QUATTRO PRO™ MACRO:

File path C:\practjob\LOGSS#5.wq1
Macro name, keys Alt A
This macro imports numbers from the ASCII files produced by the preceding GammaVision™ macro. All data manipulations are done within the spreadsheet.

```
{goto}c1~
{/ File;ImportNumbers}bag#001.rpt~
{goto}c16~
{/ File;ImportNumbers}bag#002.rpt~
{goto}c31~
{/ File;ImportNumbers}bag#003.rpt~
{goto}c46~
{/ File;ImportNumbers}bag#004.rpt~
{goto}c61~
{/ File;ImportNumbers}bag#005.rpt~
{goto}c101~
{/ File;ImportNumbers}TB#001.rpt~
{goto}c116~
{/ File;ImportNumbers}TB#002.rpt~
{goto}c131~
{/ File;ImportNumbers}TB#003.rpt~
{goto}c146~
{/ File;ImportNumbers}TB#004.rpt~
{goto}c161~
{/ File;ImportNumbers}TB#005.rpt~
{goto}c201~
{/ File;ImportNumbers}Cs#001.rpt~
{goto}c216~
{/ File;ImportNumbers}Cs#002.rpt~
{goto}c231~
{/ File;ImportNumbers}Cs#003.rpt~
{goto}c246~
{/ File;ImportNumbers}Cs#004.rpt~
{goto}c261~
{/ File;ImportNumbers}Cs#005.rpt~
{goto}c301~
{/ File;ImportNumbers}TG#001.rpt~
{goto}c316~
{/ File;ImportNumbers}TG#002.rpt~
{goto}c331~
{/ File;ImportNumbers}TG#003.rpt~
{goto}c346~
{/ File;ImportNumbers}TG#004.rpt~
{goto}c361~
{/ File;ImportNumbers}TG#005.rpt~
{goto}Q75~
{/ File;ImportNumbers}GAC#001.rpt~
```

{goto}Q90~
{/ File;ImportNumbers}GAC#002.rpt~
{goto}Q105~
{/ File;ImportNumbers}GAC#003.rpt~
{goto}Q120~
{/ File;ImportNumbers}GAC#004.rpt~
{goto}Q135~
{/ File;ImportNumbers}GAC#005.rpt~
{goto}Y66~
{/ File;ImportText}Bag#001.rpt~
{goto}Q150~
{/ File;ImportNumbers}backGAC1.rpt~
{goto}Q165~
{/ File;ImportNumbers}backGAC2.rpt~
{goto}Q180~
{/ File;ImportNumbers}backTB1.rpt~
{goto}Q195~
{/ File;ImportNumbers}backTB2.rpt~
{goto}Q210~
{/ File;ImportNumbers}backBAG1.rpt~
{goto}Q225~
{/ File;ImportNumbers}backBAG2.rpt~
{goto}Q240~
{/ File;ImportNumbers}backTG1.rpt~
{goto}Q255~
{/ File;ImportNumbers}backTG2.rpt~
{goto}Q270~
{/ File;ImportNumbers}backCs1.rpt~
{goto}Q285~
{/ File;ImportNumbers}backCs2.rpt~
{goto}ab1~

APPENDIX E

CALIBRATION AND STANDARD INFORMATION

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Calibration and Standard Information

Source Type	Source strength (μCi)	Source ID and Id marks	Current Location
Cesium "Tray" ^{137}Cs	27	13B53-H	222-S 5A
Cobalt "Tray" ^{60}Co	64	13B53-G	222-S 5A
Strontium "Tray" ^{90}Sr ^{90}Y Combined (Sr/Y)	1266 1266 2533	58B53-A	222-S 5A
Cesium "Log" ^{137}Cs	42	13B53-D	222-S 5A
Cobalt "Log" ^{60}Co	84	13B53-C	222-S 5A
Strontium "Log" ^{90}Sr ^{90}Y Combined (Sr/Y)	506 506 1012	48B53-B	222-S 5A
Eu QA ^{154}Eu 13% ^{154}Eu impurity Certificate suspect, BDK, GRB previous experiments	10,000	A-246 stamp- EU154 black band on top	222-S 11A1A Hot cell
Cs/Sr/Y ^{137}Cs, ^{90}Sr ^{90}Y Combined Source Total:	1290 75.5 75.5 1445	60B53 stamp -CSSRY black band in middle	222-S 11A1A Hot cell
Tray Blanks	0	13B53-E 13B53-F	222-S 5A
Log Blanks	0	13B53-A 13B53-B	222-S 5A

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APPENDIX F

SYSTEM COMPONENT LIST

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APPENDIX F

SYSTEM COMPONENT LIST

Gamma System Components:
Aurora 5 x 5 x 1mm CdZnTe
EG&G ORTEC 572 Amplifier
EG&G ORTEC 675 Ge Resolution Enhancer
EG&G ORTEC 919 MCB
EG&G ORTEC 460 Delay Line Amplifier
EG&G ORTEC 552 PSA/T-SCA
EG&G ORTEC 567 TAC/SCA
EG&G ORTEC 850 Quad Single-Channel Analyzer*
EG&G ORTEC 924 Quad Counter/Timer*
EG&G ORTEC 772 Counter
EG&G ORTEC 773 Timer/Counter

Beta System Components:
EG&G Surface Barrier Silicon Detector
5000 Micron Depletion, 25mm Surface Area, E Connector
Model HA-030-025-5000
Serial Number 31-9550
Canberra 2024 Fast™ Spectroscopy Amplifier
EG&G ORTEC 921 High-Rate MCB
EG&G ORTEC 924 Quad Counter/Timer*
EG&G ORTEC 850 Quad Single-Channel Analyzer*

Hot Cell Probe:
304 Stainless Steel Casing
Tungsten Collimator, Kulite Tungsten Alloy K1801
PVC base piece/beta collimator
2 EuroRad™ PR6 Preamps
2 Diode Laser Line Generators (670nm, 2.5mW, 60°, Class IIIa)
App. Laser Systems #LG-02
Edmund Scientific J52,267

Instrument Rack, Cabling and Connectors:
Standard 19" Relay Rack
850 Interface cable pack, PCBCLB1
2 NIM bins, 4001C, 4001A
2 NIM Power supplies, 4002D, 4002E
BNC cables to connect everything as per the drawings.
4 Male LEMO™ Connectors FGG.SK.307.CLC-K90-Z
2 Female LEMO™ Connectors PKG.2K.307.CLM-K90-Z (Jumper Box)

2 Female LEMO™ Connectors EGG.2K.307.CLM (Probe head)
Cables RG Electronics 6504-A

Computer:
Rack mount 486 PC with VGA monitor and mouse,
Industrial Computers 7400 486/33DX
Epson FX-286 dot-matrix printer

Software:
Windows™
GammaVision™ Spectroscopy Software, A66-BI
Borland Quattro Pro™ 4.0
FullShot[3]

* NIM components used by both systems
All computer and software components are necessary for both beta and gamma systems.

[3]Trademark of Inbit, Inc., Mountain View, California.

APPENDIX G

EXTRUSION REPORTS - BY-110
CORE 101, SEGMENT #6A, RISER 7

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APPENDIX G

EXTRUSION REPORTS BY110
CORE 101 SEGMENT # 6A RISER 7
(AS RECEIVED)

Date:	September 6, 1995
Sample number:	95-147A
Sampler serial #:	94-202
Cask serial #:	1037
Logbook #:	WHC-N-1185 (Fuller 1995a)
Labcore #:	S95T001864

Notes:

* Hot cell temperature 25.6 °C (78.2 °F). Humidity 31%.
* Check weights: 20 gms = 19.98 grams 500 gms = 499.73 grams
* Dose rate through the drill string was 450 mR/hr.
* No liner liquid.
* Sampler valve was closed before and after cutting cables.
* Performed extrusion and photography.

Sample information:

* No drainable liquid. Extruded approximately 10 cm (4 in.) of sludge. Sample was dark brown and retained its shape, although the sample broke apart into 3.8- to 5-cm (1.5 to 2 in.) sections. Sample was smooth and somewhat grainy, but was not pitted. Solids were damp.

Subsample information:

* Subsampled **Solids: Immediate unhomogenized TGA sample**
  BY-110 Core 101 Segment #6A Riser 7 :
  -Vial # 7842 (20-ml vial size)
  -2.9 grams net weight.

* Subsampled **Solids: Complete Segment**
  BY-110 Core 101 Segment #6A Riser 7 :
  -Vial # 7632 (250-ml jar size)
  -127.1 grams net weight.

Notes: Collected 130.0 grams of solids.

BY110 Core 101 Segment # 7 Riser 7

Date:	September 8, 1995
Sample number:	95-148
Sampler serial #:	94-276
Cask serial #:	1009C
Logbook #:	WHC-N-1185 (Fuller 1995a)
Labcore #:	S95T001865

Notes:

* Hot cell temperature 25.6 °C (78.2 °F). Humidity 53%.
* Check weights: 20 gms = 19.99 grams 500 gms = 499.72 grams
* Dose rate through the drill string was 1,000 mR/hr.
* No liner liquid.
* Sampler valve was closed before and after cutting cables.
* Performed extrusion and photography.

Sample information:

* No drainable liquid. Extruded approximately 46 cm (18 in.) of dark gray/brown sludge chunks, which held its shape. Sample had a slurry material which appeared to have small discreet pieces dispensed throughout. Sample was grainy.

Subsample information:

* Subsampled **Solids: Quarter Seg. (A)**
  BY-110 Core 101 Segment #7 Riser 7 :
  -Vial # 7726 (125-ml vial size)
  -101.5 grams net weight.

* Subsampled **Solids: Quarter Seg. (B)**
  BY-110 Core 101 Segment #7 Riser 7 :
  -Vial # 7722 (125-ml jar size)
  -83.1 grams net weight.

* Subsampled **Solids: Quarter Seg. (C)**
  BY-110 Core 101 Segment #7 Riser 7 :
  -Vial # 7721 (125-ml vial size)
  -83.4 grams net weight.

* Subsampled **Solids: Quarter Seg. (D)**
  BY-110 Core 101 Segment #7 Riser 7 :
  -Vial # 7619 (125-ml jar size)
  -64.0 grams net weight.

Notes: Collected 437.8 grams of solids.

BY110 Core 101 Segment # 8 Riser 7

Date:	September 8, 1995
Sample number:	95-149
Sampler serial #:	94-233
Cask serial #:	C-1034
Logbook #:	WHC-N-1185 (Fuller 1995a)
Labcore #:	S95T001866

Notes:

* Hot cell temp 25.6 °C (78.2 °F). Humidity 46 %.
* Check weights: 20 gms = 19.99 grams 500 gms = 499.72 grams
* Dose rate through the drill string was 1.5 R/hr.
* No liner liquid.
* Sampler valve was closed before and after cutting cables.
* Performed extrusion and photography.

Sample information:

* No drainable liquid. Extruded approximately 47 cm (18.5 in.) of sample. Sample consisted of a sludge material that ranged from a grey-black sludge with slurry (upper 28 cm (11 in.). To a medium dark brown sludge (lower 19 cm (7.5 in.).

Subsample information:

* Subsampled **Solids: Quarter Seg. (A)**
  BY-110 Core 101 Segment #8 Riser 7 :
  -Vial # 7725 (125-ml vial size)
  -117.2 grams net weight.

* Subsampled **Solids: Quarter Seg. (B)**
  BY-110 Core 101 Segment #8 Riser 7 :
  -Vial # 7723 (125-ml jar size)
  -109.5 grams net weight.

* Subsampled **Solids: Quarter Seg. (C)**
  BY-110 Core 101 Segment #8 Riser 7 :
  -Vial # 7617 (125-ml vial size)
  -118.6 grams net weight.

* Subsampled **Solids: Quarter Seg. (D)**
  BY-110 Core 101 Segment #8 Riser 7 :
  -Vial # 7724 (125-ml jar size)
  -74.2 grams net weight.

Notes: Collected 419.5 grams of solids.

BY110 Core 101 Segment # 9 Riser 7

Date:	September 8, 1995
Sample number:	95-150
Sampler serial #:	94-234
Cask serial #:	C-1047
Logbook #:	WHC-N-1185 (Fuller 1995a)
Labcore #:	S95T001867

Notes:

* Hot cell temperature 25.5 °C (77.9 °F). Humidity 48%.
* Check weights: 20 gms = 19.99 grams 500 gms = 499.72 grams
* Dose rate through the drill string was 1.5 R/hr.
* No liner liquid.
* Sampler valve was closed before and after cutting cables.
* Performed extrusion and photography.

Sample information:

* No drainable liquid. Extruded approximately 46 cm (18 in.) of material. Solids were medium brown color. The texture of the material resembled sludge. Solids retained their shape.

Subsample information:

* Subsampled **Solids: Quarter Seg. (A)**
  BY-110 Core 101 Segment #9 Riser 7 :
  -Vial # 7618 (125 ml-vial size)
  -134.9 grams net weight.

* Subsampled **Solids: Quarter Seg. (B)**
  BY-110 Core 101 Segment #9 Riser 7 :
  -Vial # 7636 (250-ml jar size)
  -137.5 grams net weight.

* Subsampled **Solids: Quarter Seg. (C)**
  BY-110 Core 101 Segment #9 Riser 7 :
  -Vial # 7727 (125-ml vial size)
  -128.4 grams net weight.

* Subsampled **Solids: Quarter Seg. (D)**
  BY-110 Core 101 Segment #9 Riser 7 :
  -Vial # 7633 (250-ml jar size)
  -122.4 grams net weight.

Notes: Collected 523.2 grams of solids.

BX-103
EXTRUSION REPORT

BX-103 Core 87 Segment #1 (Riser #2)

Date:	June 05, 1995
Sample number:	95-083
Cask serial #:	C1034
Logbook #:	WHC-N-1173 (Fuller 1995b)
Labcore #:	S95T001004

Notes:

* Hot cell temperature 26.8 °C (80.4 °F). Humidity 20%.
* Check weights: 20 gms = 19.99 grams 500 gms = 499.98 grams
* Dose rate through the drill string was 440 mR/hr.
* Expected sample length is 48 cm (19 in.).
* No liner liquid collected or observed.
* Sampler valve closed before and after cutting cables.
* Extruded sample and performed photography.

Sample information:

* Extruded about 18 cm (7 in.) of solid sample (70.10 grams of upper-half solids and 24.54 grams of lower-half solids: total solids collected was 94.64 grams). Drainable liquid collected was approximately 190 mL (214.51 grams), which was turbid and black in color. Solids were shiny black-wet-grainy in texture. During the first part of the extrusion process, 5 cm (2 in.) of solids was collected as the lower-half segment. Near the end of the extrusion, collected an additional 13 cm (5 in.), which was collected as the upper-half segment.

Subsample information:

* Drainable Liquid:
  BX-103 Core 87 Segment #1 Drainable Liquid:
  -Jar # 7140 (250 mL)
  -214.51 grams collected

* Subsampled Solids: Lower Half
  BX-103 Core 87 Segment #1 Lower Half Solids:
  -Jar # 6799 (125 mL)
  -24.54 grams collected

* Subsampled Solids: Upper Half
  BX-103 Core 87 Segment #1 Upper Half Solids:
  -Jar # 7070 (125 mLs)
  -70.10 grams collected

Notes:

* A total of 309.15 grams of solid and liquid sample was collected. The dose rate through the drill string was 440 mR/hr. No problems with sampler valve. Valve was easy to open.

BX-103 Core 87 Segment #2 (Riser #2)

Date: June 05, 1995
Sample number: 95-084
Cask serial #: C-1045
Logbook #: WHC-N-1173 (Fuller 1995b)
Labcore #: S95T001005

Notes:

* Hot cell temperature 26.7 °C (80.2 °F). Humidity 25%.
* Check weights: 20 gms = 19.99 grams 500 gms = 499.98 grams
* Dose rate through the drill string was 320 mR/hr.
* Expected sample length is 42.54 cm (16.75 in.).
* Collected < 5 mLs of liner liquid. Did not retain.
* Sampler valve closed before and after cutting cables.
* Extruded sample and performed photography.

Sample information:

* Extruded about 23 cm (9 in.) of solid sample near the end of the extrusion process, which was subsampled as the upper half (244.71 grams of solids collected). Drainable liquid collected was approx. 15 mLs (18.25 grams), which was turbid and dark brown in color. Solids were very dark brown and swirled with yellow material. Most of the yellow appeared in the middle 13 cm (5 in.) of sample. Yellow material is somewhat crumbly in some areas with a smooth consistency in other areas.

Subsample information:

* Drainable Liquid:
  BX-103 Core 87 Segment #2 Drainable Liquid:
  -Jar # 7169 (40 mLs)
  -18.25 grams collected

* Subsampled Solids: Upper Half
  BX-103 Core 87 Segment #2 Upper Half Solids:
  -Jar # 7141 (250 mLs)
  -244.71 grams collected

Notes:

* A total of 262.96 grams of solid and liquid sample was collected. The dose rate through the drill string was 320 mR/hr. No problems with sampler valve. Valve was easy to open.

APPENDIX G REFERENCES

Fuller, R. K., 1995a, *241-BY-110*, Laboratory Notebook WHC-N-1185, Westinghouse Hanford Company, Richland, Washington.

Fuller, R. K., 1995b, *241-BX-103*, Laboratory Notebook WHC-N-1173, Westinghouse Hanford Company, Richland, Washington.

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