

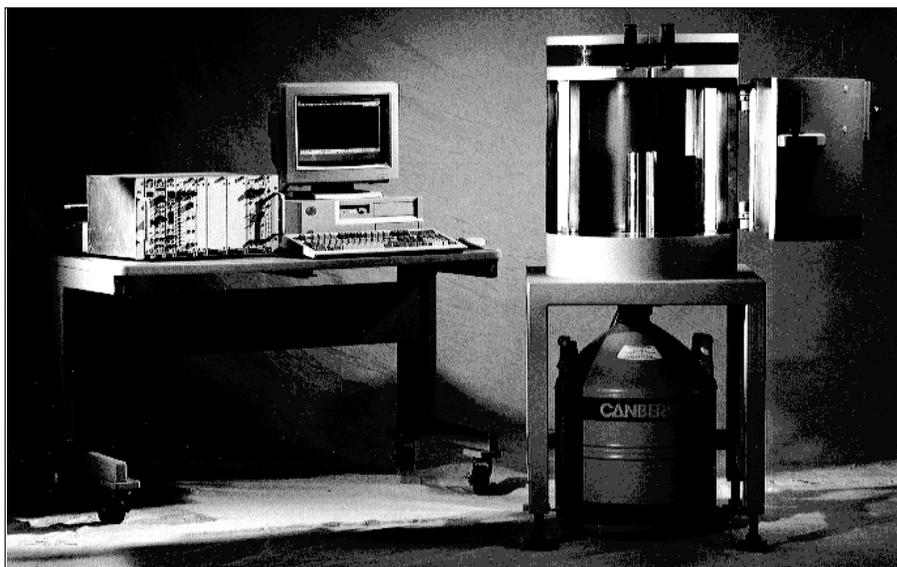
ULTRA LOW-BACKGROUND DETECTOR SYSTEMS

Introduction

Standard Canberra cryostats and shields are built with materials which are screened for extraordinary levels of natural and man-made radioactive impurities. By this means we are assured that our standard systems have relatively low background levels and are suitable for routine use in normal applications such as Radiochemistry, Internal Dosimetry, Activation Analysis, Waste Assay and Environmental Counting. Ordinary construction and shielding materials, however, do contain trace amounts of naturally occurring and man-made radionuclides which result in prominent peaks and an elevated background continuum, with a resultant compromise in Minimum Detectable Activity (MDA).

The design or configuration of cryostat-shield systems is another factor in system performance. Some cryostat and shield designs do not adequately prevent streaming from the outside environment nor do they provide self-shielding from their own relatively "hot" components. Worst of all, through an inappropriate choice of material types and/or thicknesses they may actually contribute to the background or compromise system performance and/or reliability.

Canberra has many years of experience in materials selection and in the design and fabrication of low level counting systems. We have found and developed reliable sources for select materials and we have invested in the laboratory facilities necessary to screen materials and to test complete systems. This effort has led to the development of standard Ultra Low-Background Detector Systems which are described herein. While these standard systems do not



entirely eliminate the need for custom design systems, they provide predictable high performance at modest cost and can save users the immense expense and struggle associated with designing, specifying, and testing of custom systems.

Apologies are due those who have pushed detector system backgrounds to the utmost limits. These systems better deserve the "Ultra" superlative but they are far beyond practical limits for commercial applications.

Cryostat Design

Five factors are of paramount concern in the design of a low background cryostat:

- 1) Background from materials in close proximity to detector element must be minimized.
- 2) There must be self-shielding from "hotter" materials used in construction.

- 3) Streaming from the outside environment must be reduced or eliminated.
- 4) Materials having high cross sections for cosmic neutrons with attendant gamma emission should be kept away from the detector element.
- 5) The design should not compromise performance and reliability.

Canberra has two cryostat designs which satisfy these five concerns adequately. They are the Model 7500SL-RDC and the 7915-30.

Refer to Figure 1 and consider the following explanation of the benefits of these designs.

- A. The detector chamber is simple and of low mass. The variety of materials is kept to a minimum so that background contribution can be controlled.

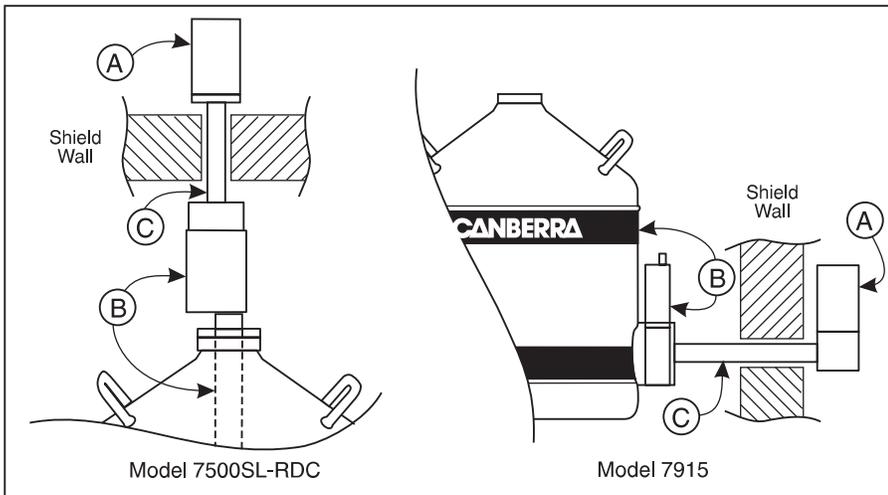


Figure 1

Cryostat designs suitable for low-background detector systems

- B.** The preamplifier body which contains fiberglass printed-circuit boards, aluminum hardware, and a wide variety of components, is located remotely and is shielded from the detector by the full shield thickness – not by some token internal lead shield of inadequate thickness and compromising location.
- C.** Offset between the detector element and the outside world prevents streaming and reduced background from the hotter cryostat materials such as molecular sieves or activated charcoal. This offset is common to U-style cryostats like the 7915. Among dipstick cryostats, only the Canberra 7500SL is built with this offset. Internal lead shields are sometimes proposed to overcome this fault but they are usually of inadequate thickness, they can produce unwanted X rays in close proximity to the detector element, and they can compromise reliability of the detector system.

manufacturers for various detector types. Canberra too, has struggled to find materials which provide low backgrounds without compromising normal detector performance and without compromising long-term reliability. Our choices, and comments on the alternatives, are illustrated in Figure 2.

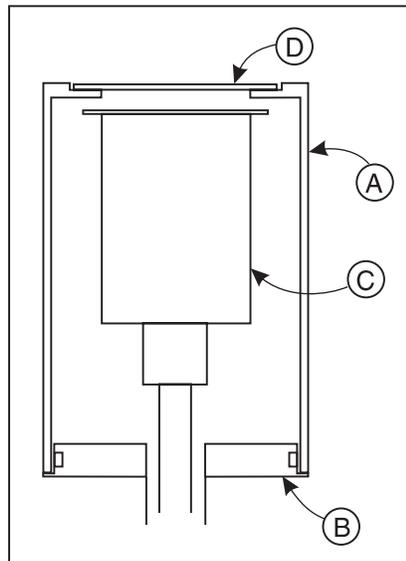


Figure 2

Detector chamber, identifying key materials

A. Endcap

The endcap, which is designed to provide high geometric efficiency for a variety of sample configurations, made from 99.999% pure aluminum with guaranteed uranium and thorium

content of less than one part per billion. This material is much more expensive than the high purity magnesium which has been used for endcaps. Corrosion problems with magnesium, however, are endemic and use of this material in thin cross-section for vacuum systems is pure folly. In addition, magnesium with guaranteed limits of primordial radionuclides is not available.

B. Vacuum Chamber

The vacuum chamber is fabricated from selected stainless steel or from high purity copper.

Post World War II steel is contaminated by ⁶⁰Co which was widely used in blast furnace crucible liners to monitor wear or breakthrough. Since stainless steel is a heavily recycled material there is virtually no such thing as virgin stainless. By batch testing, however, we can select stainless with diminishingly small ⁶⁰Co content.

The alternative to stainless steel is high purity copper. Canberra uses copper which is 99.99% pure. Standard OFHC (Oxygen-Free, High-Conductivity) copper, which is often mentioned as a material of choice for low-background detectors, can have up to five times the impurity concentration of the Canberra copper.

It is Canberra's choice to use stainless steel for the detector chamber whenever the material supply allows and to substitute high purity copper only when a supply problem exists. The advantage of stainless steel is that no passivating coatings are necessary to prevent corrosion.

C. Detector Holder

The detector holder has two functions: It must physically contain the detector element in good thermal contact with the cold finger and it must provide an infrared radiation shield for the detector element to reduce IR generated leakage current and noise. For the latter function, the detector holder or a separate IR shield must surround the detector element.

High purity copper is a good choice of

Cryostat Materials

The difficulty in building low background detectors is nowhere more evident than in the choice of materials offered by some detector

holder material for Coaxial, XtRa, and Well detectors because these detectors have a substantial Ge dead layer on the cylindrical surface which limits low-energy response from the side. These Canberra detectors generally have a dead layer of less than 0.5 mm which stops 60% of 50 keV photons. Much thicker dead layers have been found on detectors made by other manufacturers.

The additional attenuation by the copper holder, while not insignificant (75% at 50 keV) is not prohibitive in the energy range where these detectors are most often used. Canberra provides an appropriately thin IR shield at the normal entrance window in any case.

For reverse-electrode (REGe) detectors, however, copper is not the best choice of holder material. These detectors are most often purchased because of their thin dead layer for low-energy response and/or for Compton-Suppressed Spectrometers which require efficient capture of escaping scattered photons. Low energy efficiency for the Marinelli (re-entrant) beaker counting geometry is compromised by the use of a copper holder.

Low-Energy Ge (LEGe) detectors, optimized for very low energies, are designed to detect radiation entering the window (front) only.

For these reasons Canberra uses high-purity aluminum for REGe detectors and the less expensive high-purity copper for other types. If your application warrants the use of high-purity aluminum with other detector types it can be supplied as an option.

D. Entrance Window

For Coaxial detectors the aluminum end-cap, which is made seamless and thus demonstrates excellent vacuum integrity, is the obvious choice.

The aluminum window, which can be made as thin as 0.5 mm on request, transmits 60% of 20 keV photons but only 2% of 6 keV photons. Our low-

energy detectors, the XtRa, REGe and LEGe types, are normally equipped with a beryllium window which, at 0.5 mm thickness, transmits 65% of 6 keV photons. Beryllium, however, even in the purest grade available, is not low background.

The best commercially available high purity beryllium foil is 99.8% pure and contains significant level of primordial radionuclides (several parts per million). While it is far better than commercial grades of beryllium foil which may have up to 100 PPM uranium content, it is not a good choice of Ultra Low-Background systems.

Faced with this dilemma, Canberra has mastered the use of space-age composite materials in this application. The resultant window is a carbon-fiber composite which is light yet strong. It is conductive and therefore provides EMI resistance. It is helium leak-tight and it is virtually free of radioactive contaminants.

it can be supplied as an option.

Shields

As in the case of cryostats, shield design and material choices have a drastic effect on system performance when it comes to low-level counting. Shield design also has a big impact on ease of detector installation and use. And, as the most massive objects found in most counting systems, shields affect the overall appearance of the laboratory where they are located.

Canberra shields provide a balanced combination of performance, ergonomics, and appearance. The Ultra Low-Background versions of the standard shields differ only in the materials used in construction so both standard and low-level shields are compatible with a wide variety of standard and low-background cryostats.

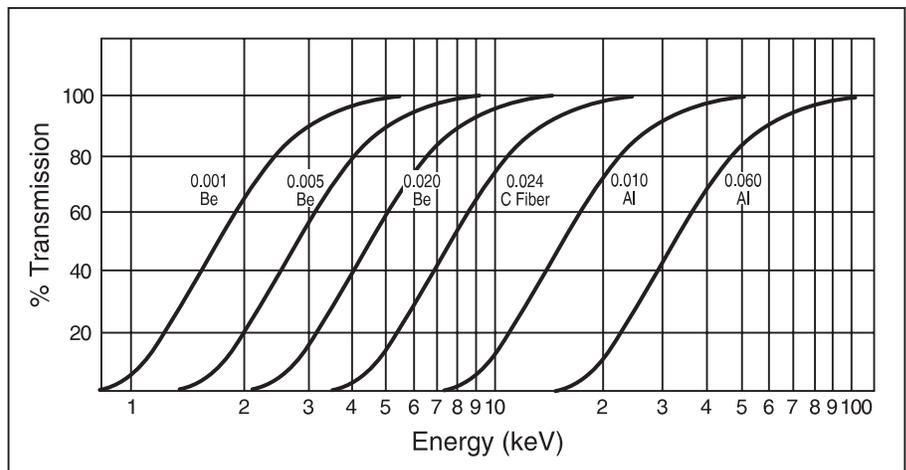


Figure 3
Window transmission characteristics

In the standard 0.5 mm thickness it transmits 80% of 10 keV photons. Finally, this window does not corrode, is virtually unbreakable, and unlike beryllium, is non-toxic.

For all these reasons Canberra's carbon-composite window should be used whenever possible in low energy, low background systems. If an alternative window is necessary,

Materials

Bulk - The best choice for the bulk shielding for low-level counting is lead. Canberra has a source of ⁶⁰Co free steel and this material is suitable for many applications, but for ultra low-level counting it is a poor choice because of the increased Compton scatter and resultant continuum of background counts in the range of

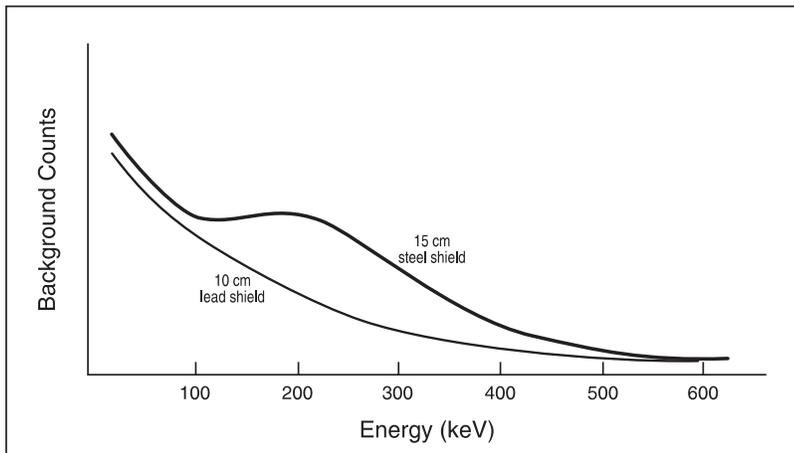


Figure 4
Background continuum vs shield material

100-300 keV. This effect is shown in Figure 4 which compares the background continuum from a detector operating in a 15 cm thick steel shield to that of the same detector operating in a 10 cm thick lead shield.

This continuum can be reduced by adding a lead liner to the steel shield. Our experiments have shown that such a liner, even as great as 25 mm in thickness, does not reduce the continuum to the level obtained with lead bulk.

Lead contains ^{210}Pb in varying concentrations. The refining process does not separate ^{210}Pb from the stable isotope, but since ^{210}Pb has a half life of 22 years, "old" lead can be notably lower in ^{210}Pb than "new" lead. The source of the lead ore is also a big factor in ^{210}Pb concentration.

Now the 46.5 keV gamma ray from ^{210}Pb is readily stopped by the graded liner used to suppress lead K-shell X rays. However, the ^{210}Bi daughter of ^{210}Pb is a beta emitter with an end-point energy of 1161 keV. It has been suggested that bremsstrahlung from this beta leads to a significant increase in the background continuum up to several hundred keV. The normal graded liner would be ineffective in this energy range. To check this theory we tested samples of lead with varying ^{210}Pb content on a low-background LEGe detector with 20 cm² active area.

The sample was in the shape of a Marinelli beaker with a wall thickness of 1.5 cm. The detector and sample were shielded by 4 inches of lead (Model 737 shield). Results are shown in Figure 5. It can be seen that the 46.5 keV peak intensity and the K-shell X rays vary together with ^{210}Pb levels (the beta obviously excites the K-shell X rays). However, the continuum differences are fairly small, even with the roughly 3:1 difference in ^{210}Pb content. Above 500 keV, there is no difference in backgrounds. Since the graded liner

is designed to stop the K-shell X rays and everything below them in energy, there is no huge advantage to old lead in applications where background continuum from cosmic interactions dominates, as is the case for most above-ground systems having inert shielding only. For systems operating underground or with active cosmic guard detectors, the beta bremsstrahlung contribution to background may become significant.

If the effects of ^{210}Pb are misunderstood, the solutions proposed for lead background range from the sublime to the ridiculous. "Virgin" lead is suggested but in this case the ^{210}Pb will have had little or no chance to decay. "Doe Run Mine" lead is sometimes specified but this mine closed around the turn of the century. Indeed some lead deposits may be less active in primordial radionuclides, but no "clean" virgin lead is known to exist so selection is the rule for the lead bulk.

If the operating conditions warrant the use of lead with certified low ^{210}Pb content, we can supply shields made from selected lead. Depending on the ^{210}Pb content, this can drastically increase the cost.

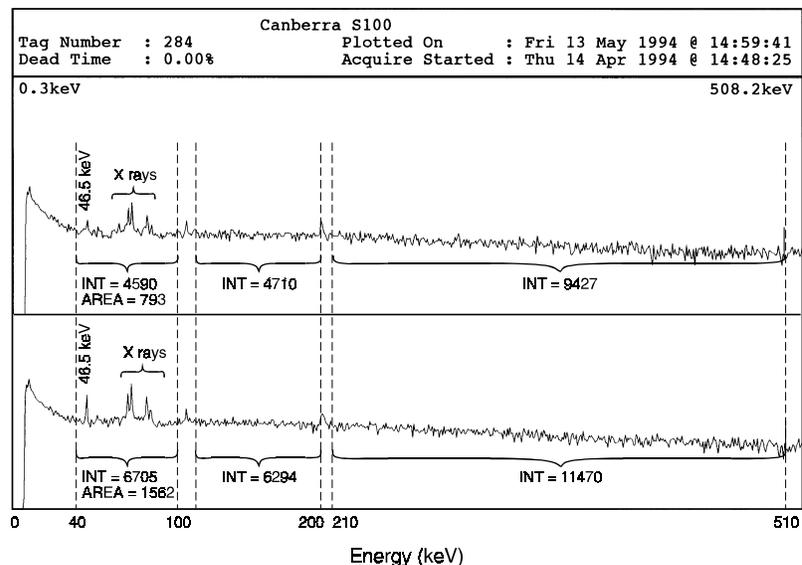


Figure 5
Background spectra from lead samples
Top - ^{210}Pb content \approx 20 mBq/gm
Bottom - ^{210}Pb content \approx 60 mBq/gm

Liner

Again there are trade-offs between background continuum and lead X-ray peaks. The graded liners typically used to suppress the lead X rays (75-85 keV) consist of 0.5 to 1.5 mm thick layers of cadmium and copper. The cadmium is an effective filter for lead X rays while the copper attenuates the cadmium X rays and prevents personnel exposure to the toxic cadmium.

This graded liner has the undesirable effect of increasing the background continuum however. This effect is illustrated in Figure 6 which shows that copper alone in the thickness necessary to stop lead X rays (5 mm for 98%) will almost double the background continuum in the 200 keV range.

If the lead X-rays were of no concern in the application, and if toxicity and decontamination were of no concern, shields would perform better without a liner. Generally this is not the case, however, so Canberra shields are equipped with graded liners – but with a difference. Canberra shields are built with a tin and copper liner. In the interest of the environment and in the safety of our workers and customers we have eliminated cadmium entirely.

Many shields are equipped with 0.5 mm of cadmium but this will stop only about 70% of the lead X rays. One mm of tin will stop about 95% of the lead X rays. With an additional 1.5 mm of copper, the total attenuation of lead X rays in the Canberra shields is about 98.5%. Another disadvantage of cadmium is high cross-section for neutrons from cosmic radiation. For example, the $^{113}\text{Cd}(\eta, \gamma)^{114}\text{Cd}$ reaction results in a prominent background peak at 558.2 keV and a lesser peak at 651 keV.

Important features of the detector/shield system are illustrated in Figure 7.

- A. Door closes tightly against shield body to prevent streaming and to allow shielding against radon.

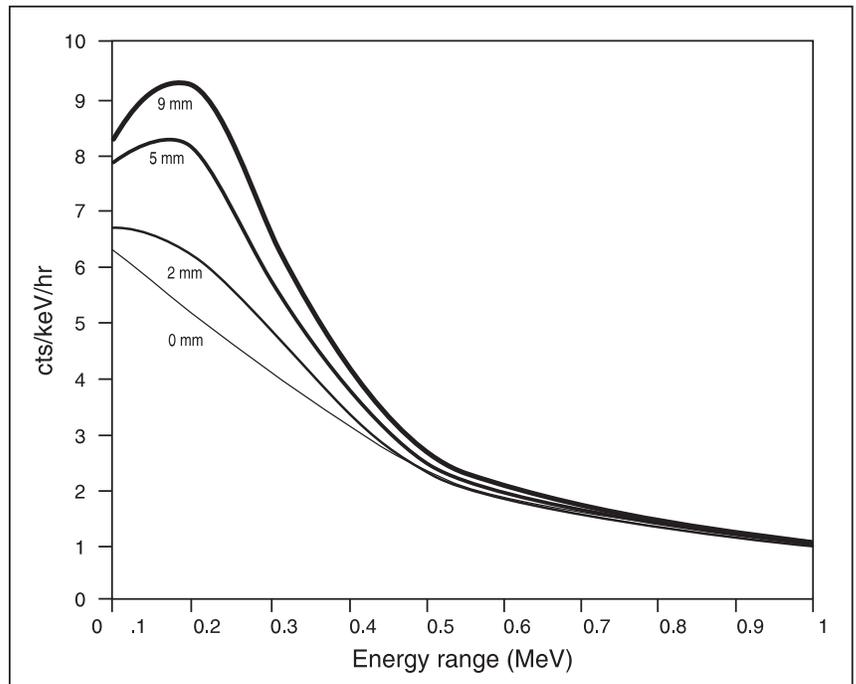


Figure 6
Background continuum as a function of copper liner thickness

- B. Shielding materials chosen for attenuation, background contribution, and scattering properties.
- C. Shield penetration for detector entry held to a minimum.
- D. Preamplifier and Dewar located remotely.
- E. Detector located near center of shield volume.
- F. Port for purge gas (N_2) to reduce radon background.

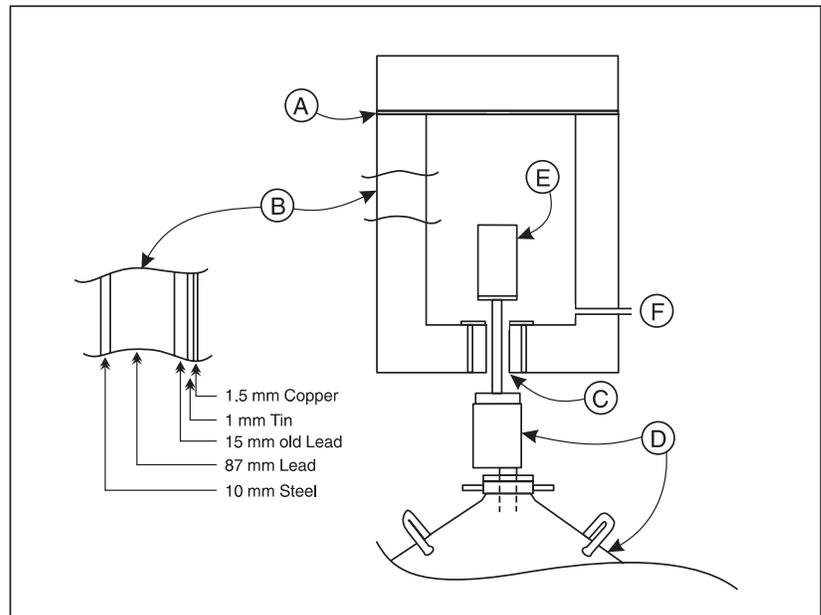


Figure 7
Ultra low-background shield design and cross-section of materials

System Performance

These overlapped spectra (Figure 8) show backgrounds from a 40% coaxial detector (1) unshielded (2) with standard cryostat in 4 inch thick shield and (3) with Ultra Low-Background 7500SL-RDC cryostat in 4 inch thick shield. Virtually no peaks due to cryostat materials appear in spectrum (3). Further reduction in the continuum and in the ⁴⁰K and ²⁰⁸Tl (Nat. Th) high energy lines require thicker shielding, active shielding (cosmic guard detectors) or subterranean operation.

Cryostat Options

Table 1 lists the Ultra Low-Background cryostat hardware options and model numbers. The base cryostat and hardware options are the same for all detector types. The materials options are different for different detector types. Consult the factory for a specific proposal for detectors, cryostats and shields.

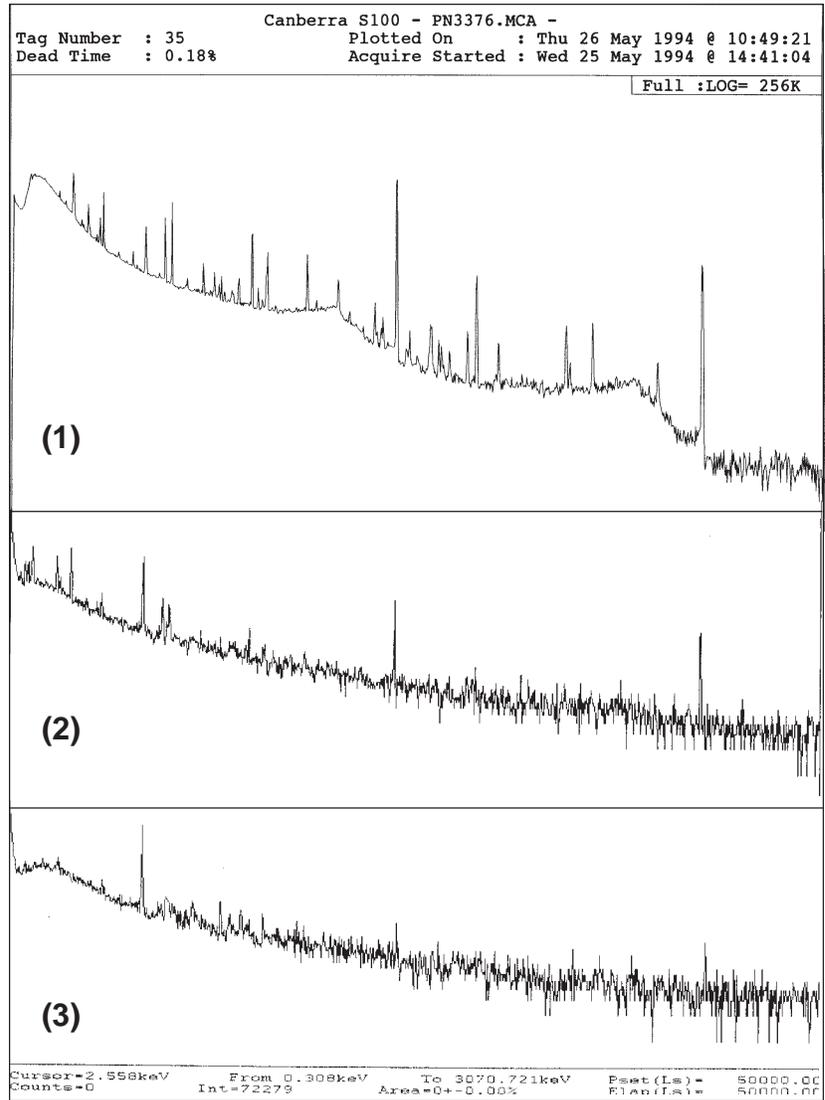


Figure 8
Background from 40% coaxial detector (1) unshielded (2) shielded with standard cryostat and (3) shielded with Ultra Low-background cryostat

Table 1 - Model List For Ultra Low-Background Cryostat Options			
Cryostat Type	Base Cryostat	Hardware Option	Ultra Low-Background Material
Vertical Dipstick U-Style	7500SL 7915-30	RDC SL	ULB-GC (Coaxial) ULB-GR (REGe) ULB-GL (LEGe) ULB-GW (Well)

For example a coaxial detector in a vertical dipstick cryostat requires the following items:
Cryostat: 7500SL, Remote Detector Chamber: RDC, Low-Background materials: ULB - GC



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