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The Oak Ridge National Laboratory Whole Body Counter: Internal Operating Procedure Manual

C. D. Berger
B. H. Lane

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THE OAK RIDGE NATIONAL LABORATORY WHOLE BODY COUNTER: INTERNAL OPERATING PROCEDURE MANUAL

C. D. Berger
B. H. Lane

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THE OAK RIDGE NATIONAL LABORATORY WHOLE BODY COUNTER: INTERNAL OPERATING PROCEDURE MANUAL

Abstract

The general purpose of the ORNL Whole Body Counter is to provide a rapid estimation of the type and quantity of radionuclide deposited in the human body. This report contains a review of the equipment in use at the facility and the procedure for its operation, the standard procedure for performing a routine whole body count, and a discussion of interpretation of results.

INTRODUCTION

Whole Body Counters, also known as total-body counters, in-vivo gamma spectrometers, etc., play an integral part in general health physics and radiation safety programs. The ORNL facility, known as the ORNL Whole Body Counter, has been in operation since May 1961, and has made steady progress in satisfying ever-changing internal dosimetry requirements for Laboratory radiation workers.

DOE Order 5480.1, Chapter XI, states that radiation monitoring is required where the potential exists for an individual to receive a dose or dose commitment in any calendar quarter in excess of 10% of the quarterly standards. In many cases, the only practical approach to meeting this requirement with respect to internal dose is by whole body counting.

The general purpose of the ORNL Whole Body Counter is to provide a rapid estimation of the type and quantity of radionuclide deposited in the human body. Greater than 90% accuracy in estimating internal deposition can be achieved depending upon the energy of the photons or X rays being detected. Also, unlike bioassay analyses, estimation of body burden is independent of the route of entry of the radionuclide in question and independent of how the radioactive material behaves while in the human body.

As a rule, whole body counting has been confined to detection of photons with energies greater than 200 keV and has not been considered to be useful when there is significant external contamination on the count subject. Because of the diverse inventory of radionuclides in use at ORNL and the importance of rapid determination of a true internal deposition, the ORNL Whole Body Counter has made recent advances that have been successful in conquering these restrictions. This has required implementation of sophisticated equipment and analysis techniques, and the institution of strict, standard operating procedures in order to insure acquisition of accurate, reliable data and proper maintenance and care of the equipment.

This report contains a review of the equipment in use and the procedure for its operation, the standard procedure for running a routine whole body count, and a discussion of interpretation of results. Although the procedures contained herein will be presented in a "cookbook" fashion, operation of the ORNL Whole Body Counter by other than experienced personnel is not recommended because of the risk of equipment damage and physical injury. Because the facility is under continuing development and improvement, this document should not be considered to be static in nature.

FACILITY DESCRIPTION

Shielded Room

The primary shield is a so-called iron room in which the detectors are located. It has walls, floor and ceiling constructed of pre-World War II naval armor plate steel. Walls, etc., are laminated to a total thickness of 35.6 cm. Inside dimensions of the room are 3 x 3 x 3 meters. Fig. 1 is of a model of the iron room with the change room facilities shown in the background.

Degraded cosmic radiation from outside the shield and iron-room background gammas produce photoelectric events at the inner surface of the iron shield which result in characteristic iron X rays. Sheets of 0.32-cm-thick, special low-radioactivity lead are used to line the inside of the iron room to absorb the iron X rays. Since the lead itself also produces low-energy X rays and the detector crystals are pointed downward toward the floor, the floor has an additional graded shielding of 0.1-cm-thick sheets of tin and cadmium and a 0.03-cm-thick sheet of copper, topped by virgin vinyl floor tile.

Because much of the natural radiation background stems from radon and thoron gases and their decay products, normally present in the atmosphere, an attempt is made to reduce the admission of these radionuclides into the iron room by providing a supply of compressed, bottled air, which has been stored 30 days or more to permit the natural radioactivity to decay. A solenoid-controlled valve, actuated by opening the outer door to the iron room, permits a rapid influx of the low-background air while persons are entering or leaving the iron room. The air in the building annex, which houses the iron room, is continuously recirculated through absolute filters to reduce the concentration of dust on which daughters of gaseous radioactivities are adsorbed.

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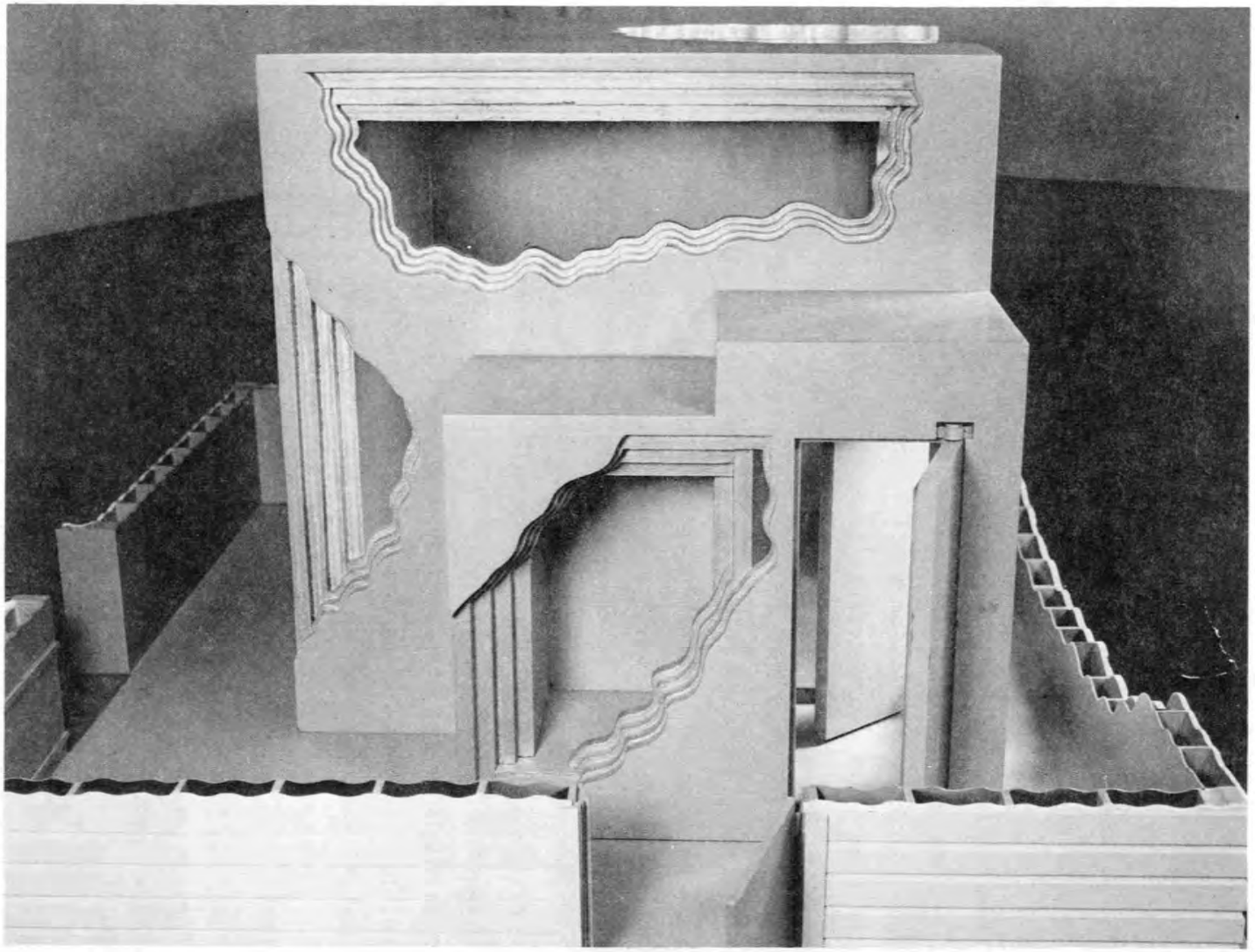

Fig. 1. Model of the ORNL Whole Body Counter.

Detectors

It is possible, at the ORNL Whole Body Counter, to detect a variety of internally deposited radionuclides which emit photons in the energy range of 15 keV to 3 MeV. In order to accomplish this, the facility is equipped with several detectors that can be calibrated and arranged to operate in a variety of combinations. The general procedure is to run a whole body count with a standard crystal configuration and energy calibration, using one phoswich detector, a large hyperpure germanium (HPGe) array, and a 23 x 23 cm NaI(Tl) detector (see Fig. 2). If a radionuclide is detected in an energy region that is not optimum for quantification with this standard setup, another count can be performed with a different set of crystal and energy parameters. The following detectors are available at the facility:

1. A 2.5 mm x 1.6 mm NaI(Tl) crystal mounted on a free-standing rack. This crystal is generally calibrated to cover the energy range from zero to 100 keV. It is quite useful as a wound probe, where suspected contamination is localized in a small area, although the advances made in the HPGe detector make it a much more efficient wound probe than this NaI crystal.
2. A 7.6 x 7.6 cm NaI(Tl) crystal, also mounted on its own moveable pedestal. This crystal is collimated in such a way that it can be positioned over specific body organs (such as the thyroid, kidneys, liver, etc.) for detection of radionuclides which could possibly concentrate in these organs.
3. A 20.3 x 10.2 cm NaI(Tl) crystal, with three 7.6-cm phototubes which can be mounted on a detector suspension system, above the subject to be counted. This detector can be used in either a stationary count mode or in a scan count mode, where the subject moves under the crystal at a rate of 1.52 meters in 20 minutes. This crystal is generally calibrated at 5 keV per channel, to cover the overlap range between the two standard counting configurations.

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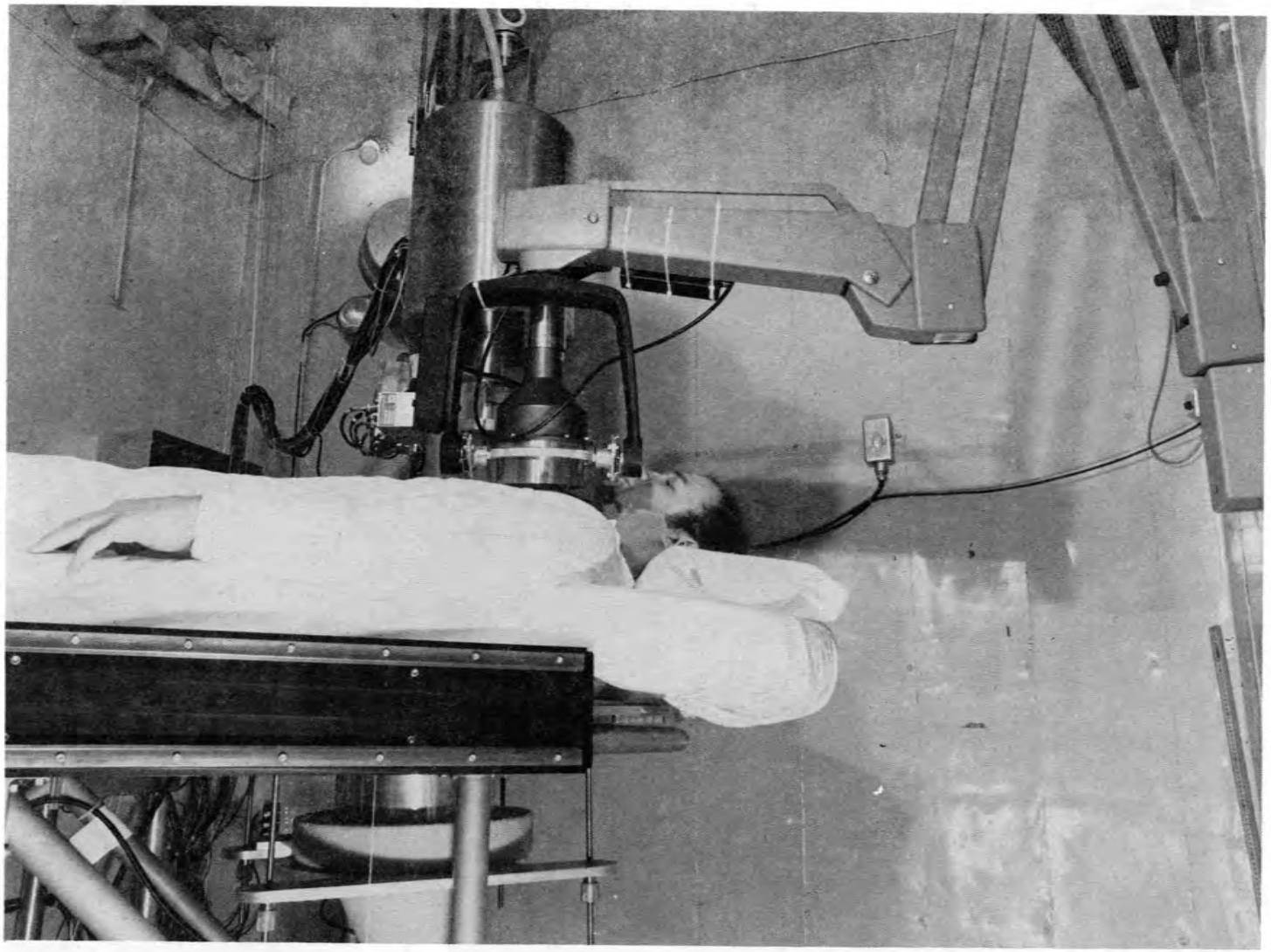

Fig. 2. Detector configuration for routine whole body count.

4. A 23 x 23 cm NaI(Tl) crystal mounted under the bed upon which the subject lies. It has a high gamma detection efficiency due to its large volume and, therefore, is used for all routine counts for high energy gamma detection. Calibration is set up routinely at 12.7 keV per channel for 256 channels.
5. For detection of low-energy gammas and X rays in general, and transuranics in particular, counting is done with either one or two 12.7-cm-diameter phoswich detectors mounted on a dental X-ray arm and positioned over the subject's chest. These detectors are composed of 0.15 cm of NaI(Tl) optically coupled to a 2.54 cm or 5.08 cm CsI mantle and a photomultiplier tube, respectively. These dual-crystal detectors are capable of detecting internal contamination which emits low energy photons, since pulse-shape discrimination techniques can be utilized to reduce the background interference. This technique takes advantage of the fact that the fluorescent decay times in the NaI and CsI differ. Therefore, the electrical signals at the photomultiplier tube have different rise times. The CsI crystal acts as a Compton supression mantle which allows one to remove from the spectrum high-energy (or cosmic ray) events and/or gamma rays that are scattered from the thin NaI crystal into the thicker CsI crystal. Sophisticated timing used in conjunction with these detectors affords a very effective means of reducing background in the low-energy region of the spectrum. These detectors are calibrated at 0.5 keV per channel for 256 channels.
6. The Whole Body Counter Facility is also equipped with an array of six hyperpure germanium detectors (80 cm^2 active area) used in the detection of low-energy photons and x rays. Its calibration is approximately 65 eV per channel for 2048 channels. It has been demonstrated that the low background typically found in semiconductor detectors, coupled with their superior resolution over NaI(Tl) has advanced the state-of-the-art of in-vivo measurement of low-energy photon emitters.[1] Its uses are for

routine chest counting, wound counting, thyroid counting, liver counting, and skull counting (to be investigated).

7. A recent addition to the detector inventory is a 70 cm^3 active volume Ge(Li) detector, with 13.6% efficiency at 25 cm source-to-detector distance relative to a 7.62 cm x 7.62 cm NaI(Tl) detector. It has not yet been fully incorporated into a standard whole body count procedure, but will be an effective tool for identification of > 100 keV photons because of its superior energy resolution over the 23 cm x 23 cm NaI(Tl).

Data Acquisition System

The ORNL Whole Body Counter is equipped with a Nuclear Data ND6620 minicomputer system for data acquisition and analysis. The system CPU is a Digital Equipment Corporation LSI-11 microprocessor with an instruction set essentially equivalent to the DEC Systems PDP 11/35. The bus (Combus) is a non-dedicated, high speed, decentralized, synchronous bus which permits direct, bidirectional communication between system components. The Combus protocol is such that "read" or "write" transfers occur in discrete 160 ns time slots. The display and acquisition system (DAS) has a display rate of 200 kHz, both linear and log display capability, a display group size of from 1 to 8192 channels per group with from 1 to 2^{29} counts/channel. The display resolution is one part in 4096 for both x and y axes. The DAS is controlled by a DEC LSI-11 microprocessor identical to that in the CPU.

The whole body counting ND6620 computer has a dual hard disk system: one cartridge is fixed (DKØ) and one is removable (DK1). Typically, the operating system, FORTRAN libraries and programs, and the FORTRAN compiler and BASIC interpreter reside on DKØ. DK1 typically serves as a data disk for whole body counts. The storage capacity of a single disk is 2.5 megabytes. The bit density is 2200 bits per inch with a track density of 100 tracks per inch. The random access transfer rate is 312.5 kilobytes per second. The spindle speed

is approximately 2400 rpm. The system is also equipped with a magnetic tape drive (9 track, 800 bpi, 25 ips). The data transfer rate is 20 kHz at 800 bpi for 25 inches per second. The total system memory configuration which is currently at its full complement, is 128 kilowords or 256 kilobytes.

The Whole Body Counter ND6620 system is also equipped with four ND570 analog-to-digital converters for accumulation of gamma spectra. These are 80 MHz units with a conversion gain range of 256 to 8000. Three ND568 gated analog routers are used in conjunction with the ND570 ADC's for multiplexing spectra.

ELECTRONICS DESCRIPTION

Phoswich System Electronics

Pulses from the dual phoswich assembly are summed at the phototube and input into an Ortec-113 scintillation preamp. Negative output pulses from the preamp go into a three-branched circuit as shown in Fig. 3. The center branch is the timing network, the upper one is an overload rejection circuit, and the bottom branch treats the energy-analyzed pulses from the phoswich. The timing branch is the most critical part and will be considered first.

Bipolar pulses from the delay line timing amplifier (Ortec 460) go into two constant fraction timing single-channel analyzers (Ortec 455) with fractions set at 0.2 and zero crossover, respectively. The outputs from the single-channel analyzers are the start and stop pulses for a time-to-amplitude convertor, TAC, (Ortec 467). The output of the TAC is an analog signal whose magnitude is proportional to the fall time of the bipolar pulse from the Ortec 460 delay line amplifier. Since NaI and CsI have different scintillation decay times (0.25 and 1.0 μs, respectively), pulses from the NaI and CsI portions of the phoswich system will, therefore, cause different timing distributions from the TAC as shown in Fig. 4.

Following the TAC is a standard Ortec 406A single-channel analyzer with a window set over only the NaI distribution. Simultaneously with the above timing considerations, pulses from the preamp are routed over the energy circuit (bottom branch), and delayed for approximately 3 μs to arrive in coincidence at an Ortec 426 linear gate with the NaI gating pulse from the timing branch. Therefore, only pulses with the time signature of NaI are routed to the computer system for analysis.

Because of the large number of overload pulses, it is necessary to devise some means of turning off the TAC when a large pulse enters the system so that ringing and other oscillations will not be interpreted as real NaI signals. One simple way to accomplish this is

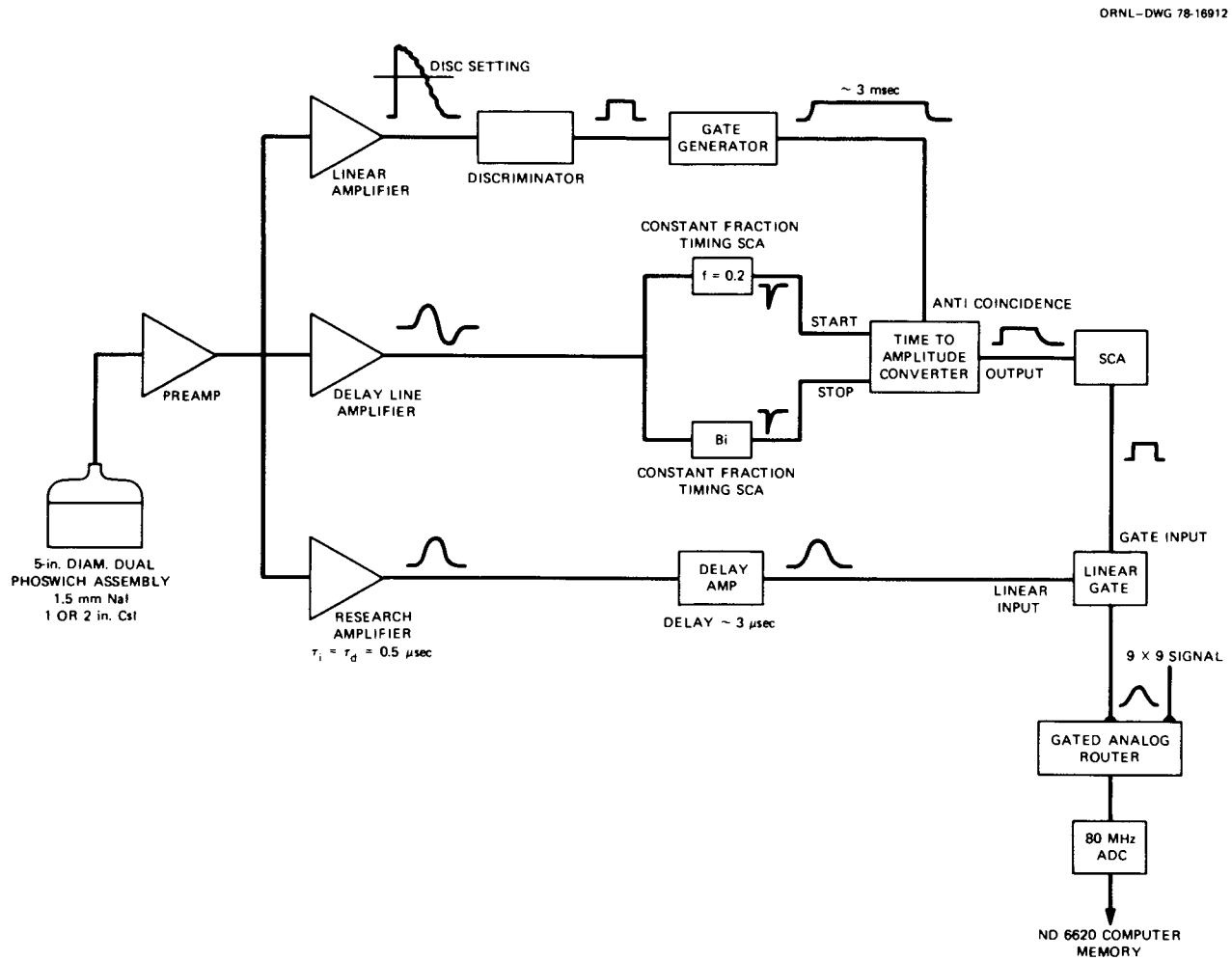

Fig. 3. Block diagram of phoswich electronics.

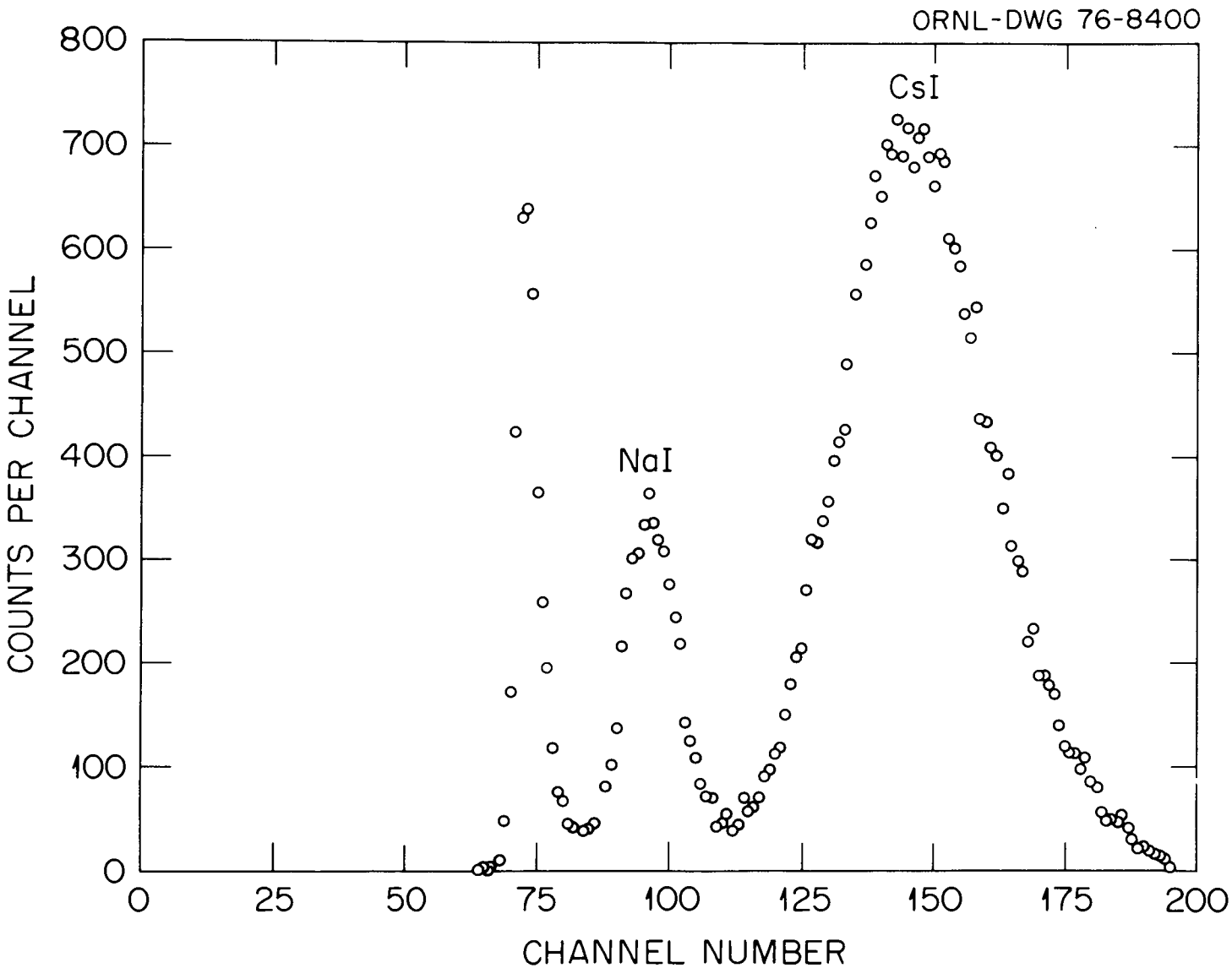

Fig. 4. Phoswich time spectrum.

to use a linear amplifier-discriminator combination to trigger a gate generator whenever an overload occurs. The gate generator has an adjustable pulse width, and should be adjusted somewhere in the range of 100 μs to 3 ms, depending on dead time considerations. The upper level logic output of one of the timing single-channel analyzers is equally effective to drive the gate generator.

For routine chest counting, phoswich pulses from the linear gate are routed to the analysis system through a Nuclear Data ND568 gated analog router along with pulses from the 23 x 23 NaI detector. The router gates the detector pulses along with routing information to an ND570, 80 MHz analog-to-digital converter connected to a ND6620 minicomputer system for storage of data.

The phoswich has very good sensitivity for low-energy photons but has poor resolution ($\Delta E/E \sim 35\%$). Typical spectra for ^{239}Pu, ^{241}Am and human background are shown in Fig. 5.

Hyperpure Germanium System Electronics

This unit consists of six detectors in a close-packed, rectangular array with an average full width at half medium (FWHM) resolution of 450 eV at 17 keV and 520 eV at 60 keV (see Fig. 6). The signal from each detector preamp output is amplified by individual Canberra Model 340 research amplifiers before entering a series of "daisy-chained" ND568 gated analog routers (see Fig. 7). These pulses are then routed to two analog-to-digital converters and finally stored in two memory locations in the ND6620 minicomputer. One memory location displays the signal from each of the six detectors separately; the other location displays the multiplexed signal from all six detectors.

Figure 8 presents typical line shapes for L_α, L_β , and L_γ from ^{239}Pu. In Fig. 9 (left) is shown a comparison of the phoswich detector (top spectrum) and the HPGe system (bottom spectrum) for an individual contaminated with approximately 4 nCi of ^{241}Am. In Fig. 9 (right) is shown a case of very slight contamination with ^{241}Am (0.1 nCi) which was evident only on the HPGe system.

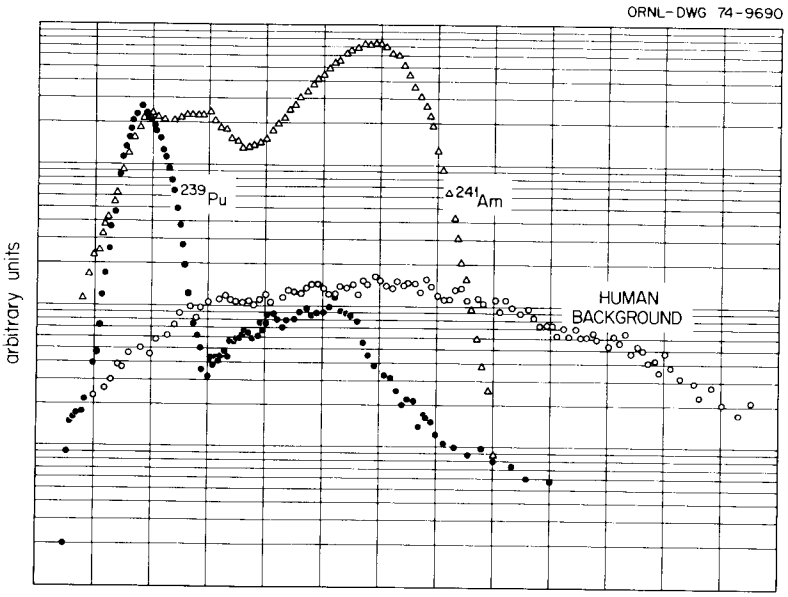

Fig. 5. Phoswich spectral data of bare ^{239}Pu and ^{241}Am sources, and a typical human spectrum. Energy range is 0 to 130 keV.

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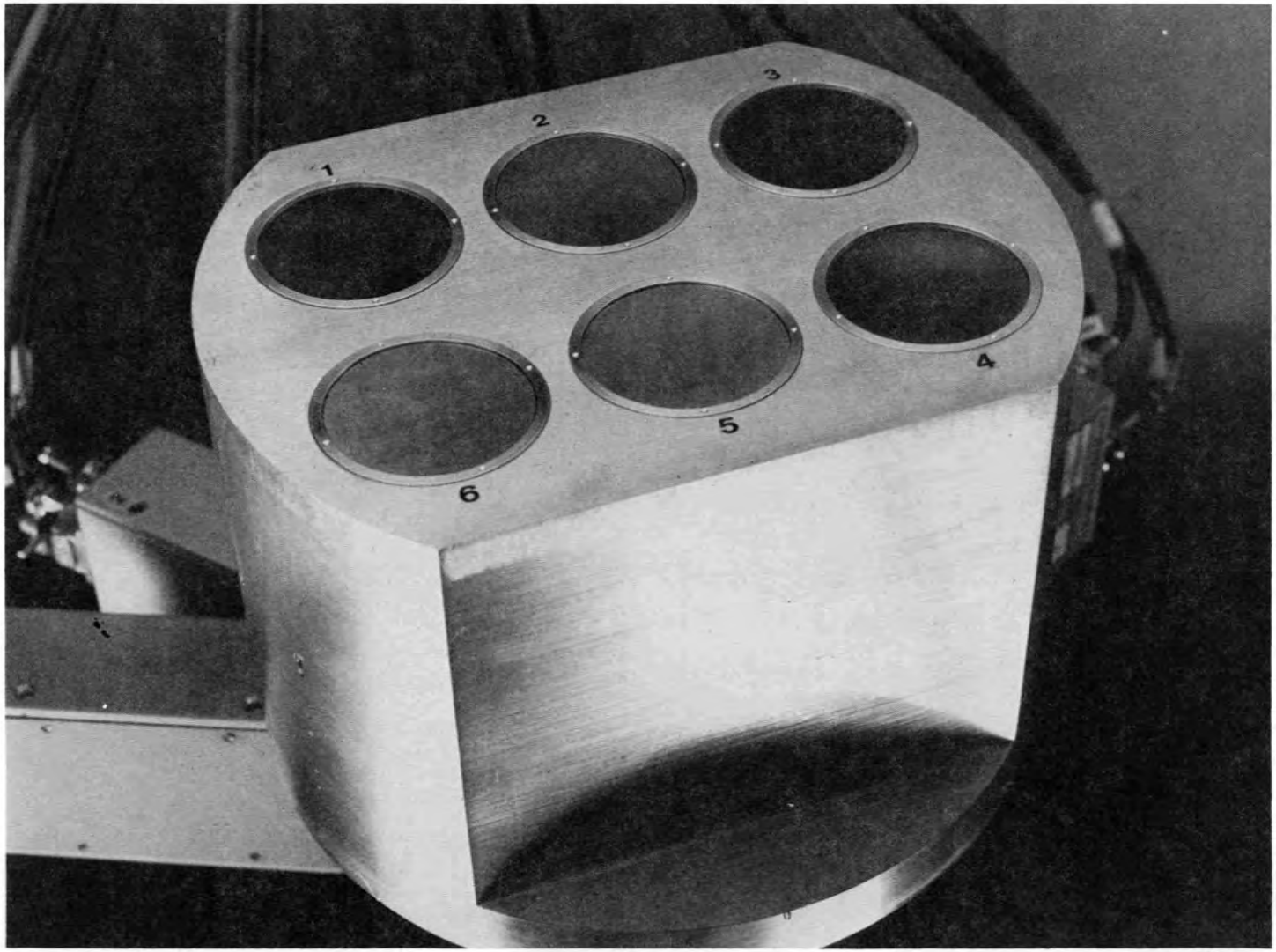
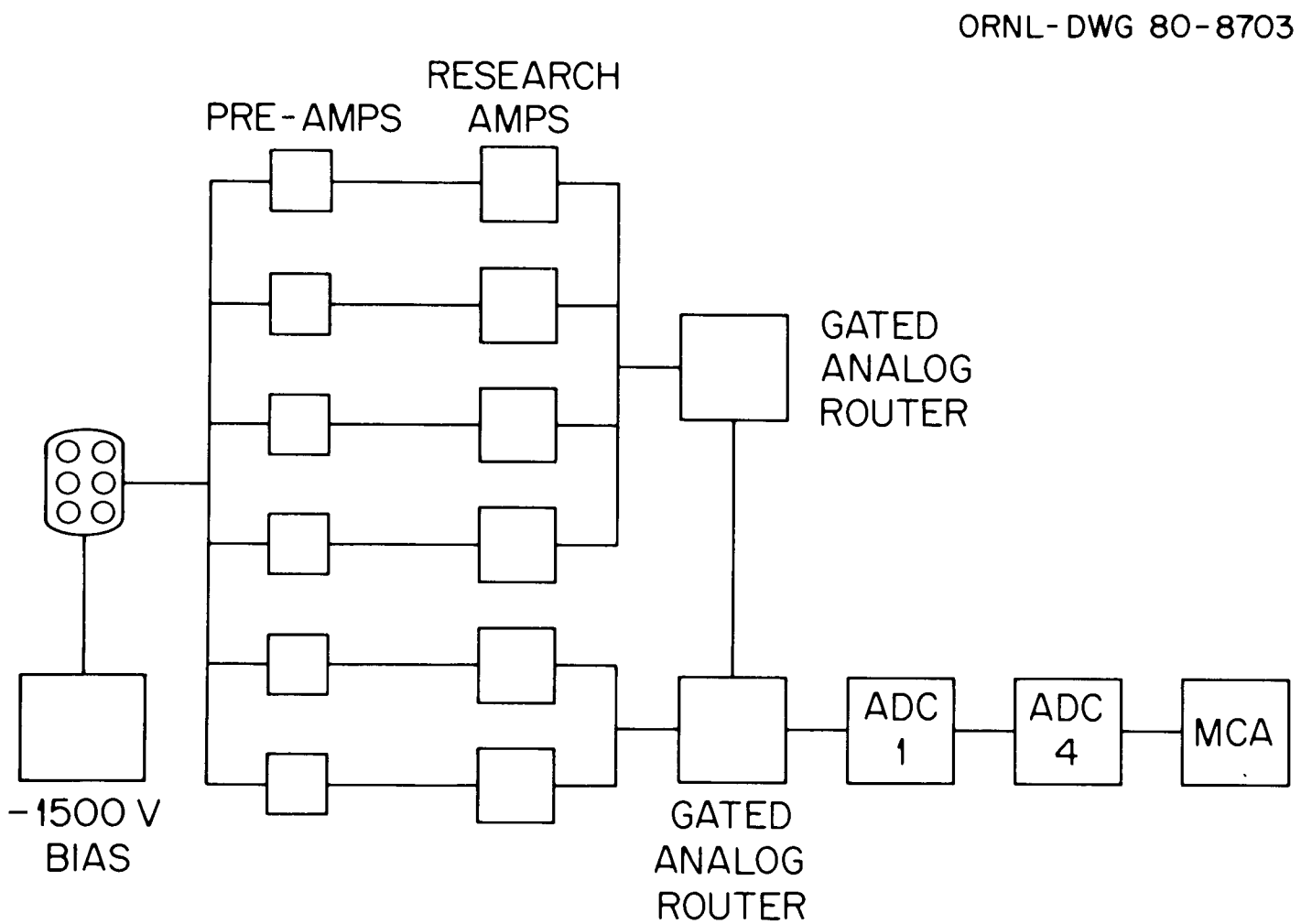


Fig. 6. Hyperpure germanium array.



Germanium Array Electronics.

Fig. 7. Block diagram of HPGe array electronics.

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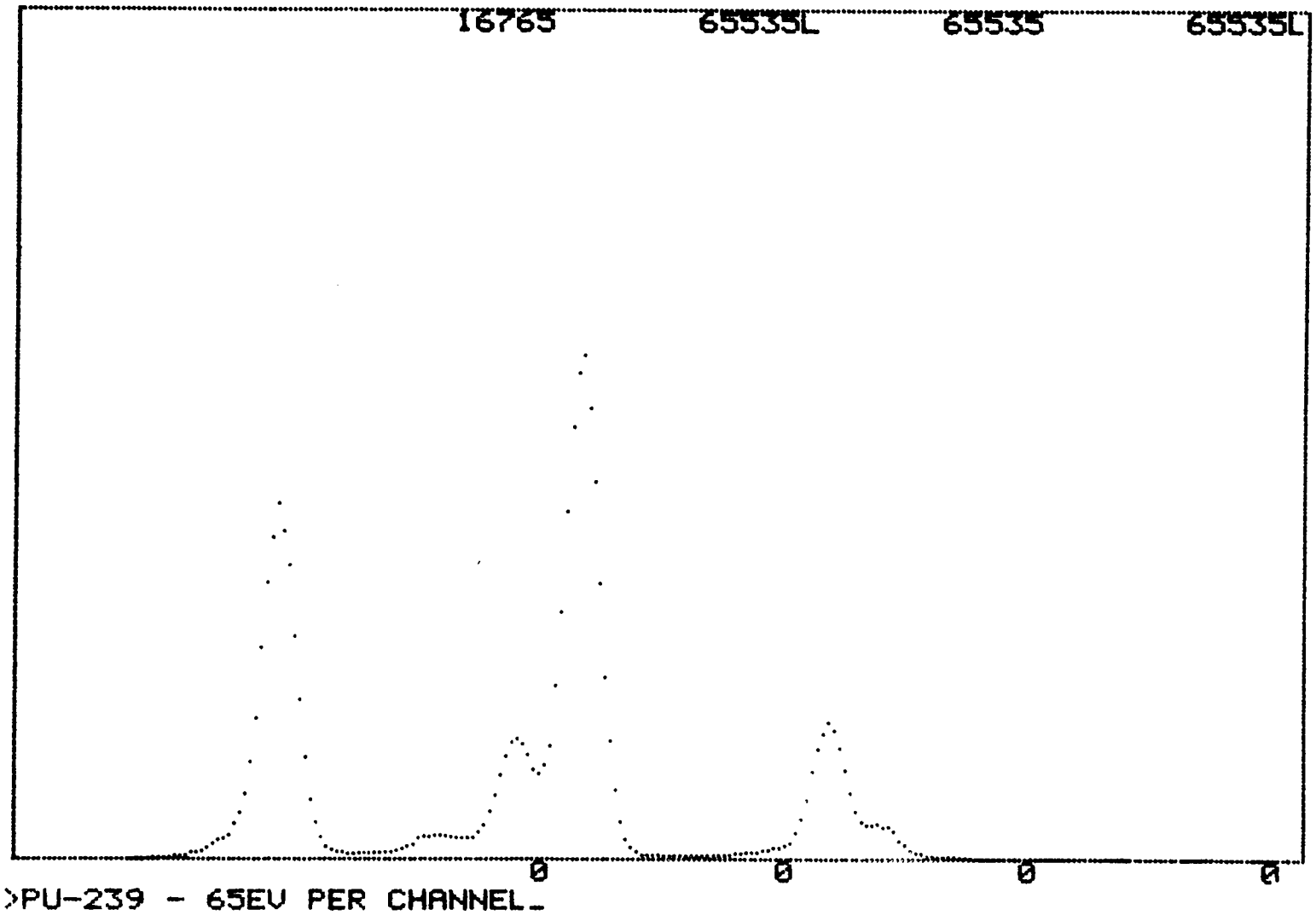

Fig. 8. Spectral data from a bare ^{239}Pu source showing the L-X rays. Peaks fall at approximately 13 keV (Lα), 17 keV (Lβ), and 21 keV (Lγ).

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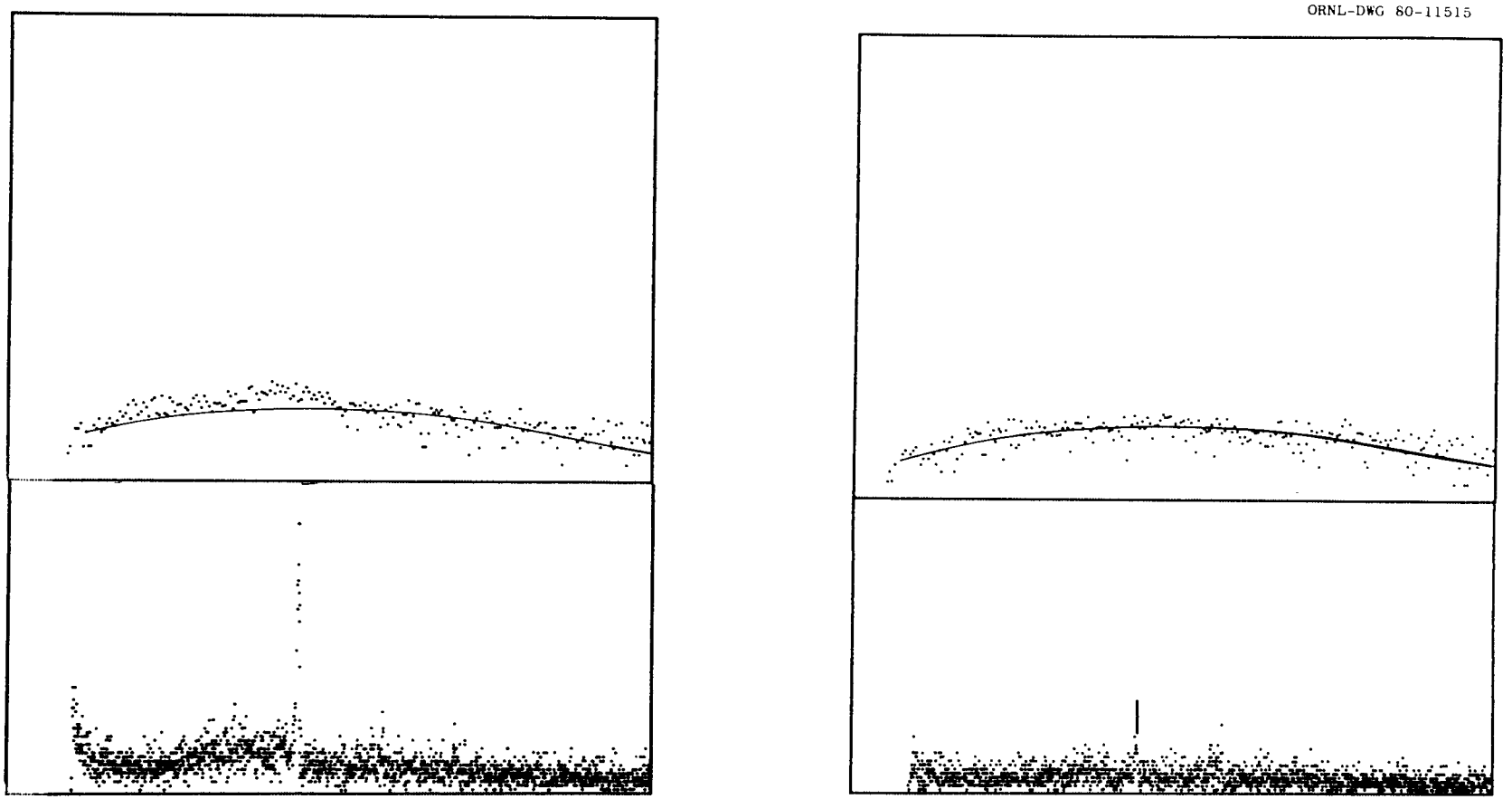

Fig. 9 Comparison of NaI/CsI Phoswich (top) and HPGe (bottom) spectral data for two human subjects with lung burdens of ^{241}Am.

In general, the HPGe array performs considerably better than a single phoswich. Compared to a single 125 cm^2 phoswich detector, sensitivity to ^{239}Pu appears to have been improved by greater than 50 percent and sensitivity to ^{241}Am by approximately a factor of 14 when referenced to human backgrounds, using the HPGe array.[2] Efforts are continuing to improve upon these values.

CALIBRATION PROCEDURE FOR PHOSWICH AND NaI(Tl) SYSTEM

The theory behind gamma-ray spectrometry is based on the fact that the signal pulses received and recorded by the multichannel analyzer are in some way proportional to the energy of the photons emitted from the source being investigated. This becomes particularly important when identifying and/or quantifying the radiations emitted from the human body. In order to do this, it is most important to know the relationship of spectrum channel number to gamma-ray energy. Therefore, as part of the whole body counting procedure, the system is thoroughly calibrated for the following modes: resolution, energy, timing, and quantification.

Resolution Calibration

To achieve the maximum resolution attainable on the dual phoswich system, the high voltage on the photomultiplier tubes is adjusted so that both detectors respond equally to a given energy. To accomplish this, a source (such as ^{137}Cs) is placed under the two detectors, the signal from each individual photomultiplier tube is input into the multichannel analyzer and a spectrum is obtained for each. The voltage applied to each tube is then adjusted so that the peak observed in both spectra falls within the same channel number. When this is accomplished, the output from both phototubes is well matched.

Energy Calibration

For accurate identification and quantification of internally deposited radionuclides, it is necessary to obtain a linear energy response. In other words, a plot of energy vs. channel number should yield a straight line passing through zero. This can be accomplished by using standard sources that emit gamma rays of different energies. These sources are placed under the detectors, and the amplifier gain adjusted so that the photopeak falls within the appropriate channel (i.e., depending on whether the calibration is 12 keV/channel, 10.5 keV/ channel, etc.). Fig. 10 (top) is a photograph of the energy calibration spectrum for the 23 x 23 cm NaI and the phoswich detector

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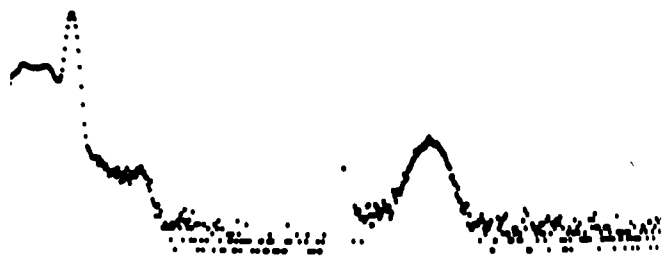

ENERGY CALIBRATION SPECTRUM – ^{137}Cs
PEAKS SHOULD FALL IN
CHANNELS 55 AND 320
RESPECTIVELY

TIME SPECTRUM – ^{239}Pu
NOTE CsI TIME PULSES UNDER
MARKER

TIME WINDOW – ^{239}Pu

TIME SPECTRUM OUT OF DOUBLE
TIMER. NOTE LACK OF CsI
TIME PULSES.

Fig. 10. Energy and timing calibration for phoswich system.

using a ^{137}Cs as a source. The peaks should fall in channel 55 for the 23 x 23 cm crystal, and channel 320 for the phoswich detectors. Using ^{40}K as a source for the 23 x 23 should also display the 1460 keV gamma line in channel 121. These calibrations correspond to a slope of 12 keV/channel for the 23 x 23 and approximately 0.50 keV/channel for the phoswich.

Timing Calibration

As stated previously, phoswich detection theory is based on the decay time differences in the phototube signals between CsI and NaI. The timing circuitry isolates and transmits only those pulses coming from the NaI not in coincidence with the CsI pulses. Therefore, the timing window requires critical adjustment. If the timing window is not set appropriately, noise pulses (i.e., background interference) will be added to the phoswich spectrum, thereby raising the detection limits. Fig. 10 is a photograph of a typical time spectrum. Note the NaI time peak. The window must be set (by the timing single channel analyzer associated with each time-to-pulse height-converter) to incorporate only the pulses falling within this peak. A picture of an appropriately set window, using ^{239}Pu pulses is seen at the bottom of Fig. 10.

Quantification Calibration

Since one of the primary purposes of a whole body counting system is to quantify as well as identify internally deposited radionuclides, the final check in the system calibration is to determine reproducibility of total counts from a given source. These should only vary within the range of normal counting statistics. It is important to note that in order to accomplish this task, one must duplicate the counting geometry as exactly as possible each time. The same source is used (preferably one with a long half-life) and is positioned the same way each time the quantification calibration is done. ^{239}Pu and ^{40}K sources are used for the phoswich and 23 x 23 cm crystals, respectively. Standard counts are taken for 120 seconds and the total energy peaks are integrated within a defined energy range. A daily log is kept of both energy and quantification calibration results.

CALIBRATION PROCEDURE FOR HYPERPURE GERMANIUM SYSTEM

As with the phoswich and NaI(Tl) systems, the HPGe array is calibrated accurately for resolution, energy and quantification. The first two are particularly important since the primary advantage of the HPGe system is its identification capabilities.

Resolution Calibration

The resolution of the multiplexed array is only as good as the resolution of the worst detector in the array, if all of the detectors are lined up appropriately. This is achieved by placing a small ^{57}Co source under the array and obtaining a spectrum. Using the "on/off" switches on the gated analog routers, the spectrum from each detector is looked at individually. The 122.06 keV peak should fall in channel 1868. Adjustments are made with the fine gain potentiometer on the individual amplifiers. After all six detectors are checked and/or adjusted, the router switches are placed in the "on" position before operations can continue. At this point, the signal outputs from each router are well matched.

Energy Calibration

The HPGe system is calibrated with a ^{57}Co source and a ^{241}Am source, by acquiring spectral data for both simultaneously. Note into which channel each of the energy peaks fall. (Do <u>not</u> adjust the amplifier gains. This has been done during the resolution calibration). Run the FORTRAN program APS.ENERGY to update the energy calibration file using the channel numbers noted above.

DATA INTERPRETATION

At the completion of a routine whole body count, the acquired data is stored on hard disk, magnetic tape and paper copy. The print-out also contains information useful for arriving at a final assessment of body burden. Much of this information is for experimental purposes only and will not be discussed here, but the features of the hard copy, applicable to data interpretation, are listed below. (The numbers refer to the numbers on the sample print-out shown in Fig. 11).

1) Header information - Used to identify the count subject, acquisition data and time, give detector specifications, and calculate chest wall thickness.
2) Results - Final assessment of body burden as determined by a staff spectroscopist. The Whole Body Counter operator places his/her initials in this section immediately at the completion of the count.
3) Net spectral data - Channels 1-255 are from the 23 cm x 23 cm NaI(Tl) detector, and channels 256-512 are from the phoswich. Channels 1 and 256 contain the ADC live time in seconds for each detector, respectively.
4) Ratio information - Counts per minute in various energy regions of interest from the phoswich. Used to estimate the quantity of ^{239}Pu, ^{241}Am and ^{90}Sr.
5) Z-values - Used to provide a rapid indication of normalcy on phoswich data. Average values were obtained from data acquired on 50 adult, uncontaminated males. A Z-value of greater than 3.0 is considered to be a positive indication of excess counts in that region of interest.
6) Fraction of human standard - Indicates what % the count subject is of a normal human standard. This value is used to correct for increased or decreased Compton scatter in low-energy channels on

the phoswich due to the weight and/or ^{40}K content of the subject.

7) Estimated burden of ^{137}Cs - A commonly occurring radionuclide, thought to be from fallout from atmospheric weapons testing. Total body content (in nCi) is obtained from the 23 cm x 23 cm NaI(Tl) detector.

8) Data analysis from the HPGe system - Used to provide a rapid indication of the presence of some commonly occurring radionuclides at ORNL. A detailed discussion of calculational techniques can be found in ORNL/TM-7925.[2]

9) Gross counts per second from each HPGe detector - Used to provide an indication of location of any radionuclide in the right lung area.

10) Net HPGe data - Counts per channel for all 2048 channels are printed out.

```
*****************************************************************
*******************12 OCT 1981 10 15 24 AM *******************
*****************************************************************

DETECTOR SETUP
SPECT(E(D9X9D012)(SPECT(E(L89D00 5)(ADC20/X256 - SINGLE TIME

NAME                                                          ❶
SOCIAL SECURITY
DIVISION/BUILDING
BODY STATISTICS
FILE IDENTIFIER

*****************************************************************

AQUISTION DATE. 12 OCT 1981  9.27.19 AM
ELAPSED LIVE TIME        0 SEC
KEV/CHNL        12.4687500
OFFSET        -26.2500000

*****************************************************************
*****************************************************************
*****************************************************************
*****************************************************************

RESULTS Normal Human Spectrum

MPOB                                                          ❷
CRITICAL ORGAN.
%MPOB

OPERATOR  W.O.

*****************************************************************
```

Fig. 11. Sample printout from routine whole body count analysis.

```
12 OCT 1981 10 15 51 AM
 SPECTRUM.BG =  0 51173E-01 TIME RATIO =  0 52115E-01
IS=     1 IC=   512 ADC=  2 GRP=  2

THE NET SPECTRUM IS                    ❸

  2626     121    8776     221     600     610     930    1229    1505    1622    1440    1518    1101    1300    1168    1118
  1012     891     961     858     871     693     644     655     592     502     467     488     414     330     385     332
   286     221     218     210     287     221     259     286     219     211     244     217     149     134     279     213
   272     168     213     220     204     197     220     186     229     211     182     168     164     158     177     161
   115     152     125     158     142     124     150     140     126     106     129     161     148     154     130     150
   172     119     121     157     152     182     174     208     180     210     164     170     189     180     221     142
   178     202     180     160     177     145     156     170     129     184     152     178     230     257     292     199
   429     525     571     684     805     650     663     614     546     425     10      425     175     112     93      48
    45       7      39      45      24       1      14      28      21      24      18      -2      14      14      21       8
    -1     -12      -2      21       2       5      -2      11     -28      -7       7     -15       7      10      -2       7
   -10       6      -6      18      11      -1       5       7      14       3       4     -13      19      22      15      20
     4      22      18       6       0       9      12      10       6     -11      -3      -5     -14     -13     -14      -5
    -4      -2     -14     -12      -2      -6       4       0      -6       7      -9       9       1      14      -3      -7
   -16     -14      11      -1      -2      -7       8     -17     -12      -1      -5      -4      -7     -11     -14       2
     1      -6      -5      -4       1      -5      -6      10      -5       1      -2      -2     -11      -3       6       1
    -1      -1      -1       0      -1      -2       8      -6     -14      -1       1       0      -0       0       0       0
  2550       4      -2       1       2      -0       0       0       0       0       0       0       0      -0       0       0
     0       0       0      -0       2       5       4      -1      -0      12       8       6       2       2       1       2
    11       1       9      17      -0       0       7       5      16       7       5       4      13      14      10       9
     9       7      15      10      10       8      12      10       7      19      17      18      19      12      14      14
    18      11      16      21      19      20      10      15      17      18      21      18      19      16      21      14
     8      15      24      15      20      14      18      22      22      21      24      15      21      27      20      17
    15      21      11      13       4      18      16      24      16      19      21      22      20      24      21      16
    -5      10      20      27      16      26      27      21      24      24      21      19      26      19      28      27
    14      21      10      24      17      27      10      15      11      23      23      20      15      23      18      17
    20      23      22      11      27      24      28      26      23      14      19      24      16      19      17      21
    10      24      19      17      13      14      20      24      15      13      16      15      17      13       9      10
     9      15      13      15      16      11       6       4      11      11      12      11      13      14       5       7
     7       5      14       9      14      14      19       4      12       3      14      11       9      16      15       7
    11      11       7       7       5       6       7      11       6      19       6      11       4      19      10       3
     7      14       6       3      12       3      19       3      16       5       7       1       3      10      10       2
     5      11       1       4       5       6       1       6       5       4       6       3       1      11      10       3

THE FOLLOWING INFORMATION REFERS TO NET VALUES
PULSE  AND UPPER END RATE, ARE      1 40      16 47      21 0      CPM    ❹
THE S/N RATE IS    211 0  CPM
THE PROGRAM RATIOS ARE 0 0161  0 1 25  0 1027
PULSEND AM SEND ARE 0 1570  1 2610
2 SMALLER PULSEPAMS AGAIN ARE
NET PULSE          1 267                  PERCENTILE =    0 494    ❺
NET AMPLIT         4 424                  PERCENTILE =    1 000
NET SEND S/S       1 238                  PERCENTILE =    0 490
NET PULSEND        0 592                  PERCENTILE =    0 720
NET AMSEND         1 051                  PERCENTILE =    0 555
IS=     1 IC=   512 ADC=  2 GRP=  4

FRACTION OF HUMANS PTO  =  0 37714E 00    ❻
ESTIMATED BURDEN OF CS-137 =  0 21513E 01 MCI    ❼
IS=     1 IC=   512 ADC=  2 GRP=  4
```

Fig. 11, Continued.

8

SOLID STATE ANALYSIS - LIVE TIME= 4[illegible] 42 MINUTES

ISOTOPE	CPM	POSITIVE CPM	RATIO	ACTIVITY(NCI)	MEMA(NCI)	MDTA(NCI)
PU239	4 [illegible]	0 00	1 44	[illegible]	4 [illegible]	[illegible]
AM241	1 [illegible]	0 [illegible]	0 [illegible]	0 02	[illegible]	[illegible]

IF THIS SPECTRUM IS POSITIVE FOR AM-241 DISREGARD ESTIMATED PU-239 BELOW UNTIL
AM-241 L X-RAYS ARE STRIPPED OUT

SD125	1 [illegible]	0 00	0 70	0 00	1 [illegible]	[illegible]
.125	1 04	0 [illegible]	0 [illegible]	0 00	0 [illegible]	[illegible]
SE79	0 [illegible]	0 00	0 [illegible]	0 00	1 [illegible]	[illegible]
EU152	1 70	0 00	0 [illegible]	0 00	1 45	[illegible]
U235	1 [illegible]	0 [illegible]	0 [illegible]	[illegible]	[illegible]	[illegible]
U237	0 07	0 00	0 00	0 00	0 [illegible]	[illegible]
I131	1 [illegible]	0 00	0 [illegible]	0 00	[illegible] 40	[illegible]

9

DET 1	GROSS INTEGRAL =	0 [illegible] 00	CPS	TIME =	0 [illegible] 04
DET 2	GROSS INTEGRAL =	0 711 18 00	CPS	TIME =	0 [illegible] 04
DET 3	GROSS INTEGRAL =	0 704.0E 00	CPS	TIME =	0 [illegible] 04
DET 4	GROSS INTEGRAL =	0 751.1E 00	CPS	TIME =	0 [illegible] 04
DET 5	GROSS INTEGRAL =	0 724.0E 00	CPS	TIME =	0 [illegible] 04
DET 6	GROSS INTEGRAL =	0 [illegible] 00	CPS	TIME =	0 [illegible] 04

NET SOLID STATE DATA

10

0	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	0	0	0	2	0	0	2	0	0	0	0	0	0
1	2	1	0	0	0	0	0	0	0	0	4	0	0	0	2
0	0	1	0	1	1	0	0	0	0	0	0	0	4	0	1
0	2	3	2	0	5	0	1	0	1	4	0	1	0	1	5
0	0	2	1	0	1	1	0	1	0	0	0	1	0	0	2
0	1	0	2	0	0	0	1	0	1	1	1	2	2	2	0
4	0	0	0	1	0	1	6	0	0	0	0	0	4	1	1
0	1	1	0	1	2	0	0	5	5	0	1	0	0	0	1
0	0	0	0	1	3	0	1	4	0	1	0	0	1	1	2
1	1	1	0	0	4	1	5	0	2	2	0	5	2	0	0
0	5	1	0	4	4	4	0	1	1	2	3	0	0	4	0
4	1	1	0	1	1	2	2	5	4	2	1	3	0	4	2
0	2	1	0	2	1	0	1	0	1	2	0	0	4	1	0
1	3	2	0	0	4	0	2	0	1	4	4	4	1	1	5
0	1	0	0	1	2	1	1	4	2	0	0	0	1	0	0
1	5	0	1	1	0	1	1	3	0	1	1	1	0	1	0

Fig. 11, Continued.

1	0	0	0	3	2	0	1	0	0	1	2	0	0	1	0
0	1	0	0	1	1	0	2	0	2	0	3	0	1	2	2
0	2	4	4	2	2	4	1	6	0	1	0	4	4	1	2
2	1	1	2	0	0	0	3	5	1	1	2	4	4	6	0
7	1	3	0	1	0	3	3	2	0	0	2	1	5	6	3
2	6	0	1	3	1	2	0	0	0	0	4	0	9	0	0
1	0	0	0	0	2	0	2	1	2	2	4	0	0	0	2
1	2	0	4	6	0	5	1	3	0	3	2	1	1	6	1
0	0	0	1	1	3	1	5	0	0	2	1	5	2	2	4
3	6	0	2	1	5	0	1	0	1	1	1	1	2	3	5
2	0	4	2	1	4	1	2	0	3	4	1	2	3	1	4
0	0	2	4	1	3	2	4	0	5	0	1	2	0	1	4
2	0	2	1	0	2	2	2	8	3	0	0	1	0	3	0
0	3	4	1	1	0	0	2	0	2	4	7	0	1	4	5
0	1	1	0	5	2	2	2	1	2	0	0	1	0	7	0
2	0	4	3	6	6	2	0	2	1	4	2	0	3	2	4
0	2	2	1	3	8	1	5	0	4	0	2	0	6	5	0
3	0	5	0	0	2	6	0	4	1	0	1	4	3	1	3
2	3	4	5	5	5	4	1	4	3	1	4	5	0	0	2
0	0	0	3	0	4	2	2	2	0	1	1	3	0	3	0
5	0	3	5	3	2	4	1	1	1	1	0	1	0	1	2
5	0	4	7	0	1	0	1	4	0	0	1	2	4	3	0
5	0	7	0	0	1	7	4	3	0	5	2	2	0	2	0
0	1	4	4	2	3	2	8	2	1	0	0	0	6	5	0
0	4	1	0	0	0	2	3	0	3	0	3	0	3	2	1
1	0	4	6	0	0	3	2	5	6	1	3	2	1	0	3
4	0	4	3	2	5	6	5	0	0	3	5	0	0	4	1
2	1	0	6	3	6	2	4	2	1	1	3	5	3	2	3
0	3	0	0	0	0	5	1	4	1	2	5	0	1	2	0
1	4	4	1	3	2	2	1	4	2	3	7	0	1	3	3
2	4	3	2	8	2	3	1	4	1	0	1	2	0	3	1
0	3	1	2	5	1	2	0	0	2	0	0	0	1	5	4
5	4	5	0	1	1	1	5	2	2	0	0	6	0	2	1
1	0	0	0	2	2	3	1	5	5	0	1	3	5	2	2
0	7	0	1	1	0	2	0	0	1	2	2	0	5	1	1
3	4	3	1	3	4	0	6	0	0	0	2	3	0	2	2
0	0	3	1	1	7	1	2	0	4	2	1	1	0	4	0
8	2	4	1	0	1	0	2	1	2	4	0	0	5	0	0
1	0	2	1	0	1	5	0	2	0	1	2	3	1	1	0
0	2	4	4	1	8	3	3	3	0	0	0	4	5	6	1
6	0	3	0	0	7	1	0	3	2	5	0	1	0	2	0
1	3	3	2	2	0	0	1	3	3	0	1	2	0	4	2
1	0	2	1	1	1	6	1	0	0	0	1	1	2	7	4
11	3	0	1	0	1	1	0	7	0	1	1	2	1	2	3
5	3	1	1	3	2	8	3	3	1	6	3	0	0	5	0
0	3	0	2	4	0	0	2	3	5	2	5	3	1	6	3
2	0	5	0	2	0	2	2	4	0	2	0	4	3	5	4
1	2	2	0	5	4	0	3	3	3	2	0	1	2	5	1
1	2	4	2	0	0	0	0	3	1	1	3	2	2	3	4
1	1	3	2	4	4	0	2	4	0	2	4	2	0	3	1
0	1	0	2	2	3	1	1	0	2	2	4	0	0	3	3
4	1	6	0	0	2	4	0	4	3	1	1	1	2	1	0
1	1	0	1	0	0	3	0	5	0	0	1	2	0	2	1
0	3	2	5	2	0	0	0	3	0	2	1	1	3	2	5
3	5	0	0	3	1	5	3	2	2	2	6	2	0	1	4
1	0	7	0	3	0	3	1	1	0	0	1	7	6	2	1
0	1	0	0	2	5	0	0	5	2	0	5	4	4	0	2
0	0	0	4	6	0	2	1	0	2	2	0	1	0	3	1
0	0	2	0	1	1	2	0	1	2	2	0	1	6	5	0
6	1	5	0	3	3	0	2	2	1	2	0	2	2	2	0
2	2	1	2	3	2	2	0	2	0	0	0	0	1	4	0
0	1	1	1	0	3	0	5	0	0	1	4	0	2	6	2
0	0	0	0	0	0	0	1	0	0	2	5	0	3	4	7
4	3	0	1	1	1	0	5	0	0	0	4	0	3	0	2
1	2	3	1	0	0	0	0	6	2	1	2	0	3	1	2
0	1	3	0	0	0	1	0	2	1	0	2	0	0	2	2

Fig. 11, Continued.

3	0	1	3	0	0	2	0	1	2	1	2	0	0	0	2
0	0	1	0	3	0	3	0	3	5	3	2	0	7	1	0
0	0	0	0	0	0	0	0	4	1	0	2	0	4	4	1
0	0	0	0	1	4	2	3	2	4	3	0	4	0	2	2
1	2	2	1	0	4	3	1	2	0	2	0	1	5	2	0
1	0	0	0	1	4	2	0	1	0	0	3	2	2	3	0
3	3	1	0	2	0	1	2	2	0	3	1	0	0	3	3
0	4	0	1	0	0	0	2	2	0	0	1	0	2	1	0
0	1	2	1	0	5	0	4	0	0	3	0	0	1	0	0
0	2	1	0	1	2	1	1	2	0	4	1	2	1	2	1
0	2	5	4	2	4	0	2	0	0	0	2	0	0	0	0
0	0	1	3	0	0	4	1	1	3	4	4	1	1	0	0
0	2	0	3	4	0	0	1	6	1	1	2	2	2	3	1
1	0	7	0	3	0	2	0	1	2	0	1	2	3	0	1
1	1	3	1	1	4	1	0	0	0	0	0	3	1	0	2
2	2	2	3	2	3	5	0	0	2	3	1	1	1	1	3
1	1	1	7	0	1	5	0	5	2	2	2	0	2	1	0
2	0	0	3	2	1	1	1	4	0	2	3	0	3	1	1
1	1	5	2	0	0	1	0	0	2	4	0	0	2	0	3
1	2	0	1	2	0	0	2	0	0	4	3	2	1	4	0
0	4	0	0	1	0	2	2	0	0	2	4	0	0	0	0
1	1	3	0	3	0	0	0	1	0	1	0	0	1	2	1
1	0	1	3	1	1	1	2	1	5	0	0	2	4	0	0
0	0	0	4	2	2	0	0	0	0	1	0	0	1	0	1
0	4	1	2	4	1	2	0	4	0	1	3	5	1	2	0
0	0	1	2	1	0	3	2	0	2	4	2	0	0	1	0
0	4	0	0	0	1	0	0	2	0	0	0	3	0	0	2
2	0	0	3	2	0	0	0	0	0	2	0	0	1	1	0
0	2	0	3	0	0	0	3	3	0	0	0	1	2	0	0
1	2	0	1	4	1	1	4	1	2	0	4	1	3	2	0
2	1	1	1	2	0	1	0	0	0	3	1	1	2	1	1
0	2	1	0	0	0	1	1	4	0	1	1	0	0	0	3
0	2	1	1	4	2	0	0	0	0	2	2	2	5	0	0
0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0
0	2	0	1	0	0	0	0	0	0	2	1	0	0	0	0

Fig. 11, Continued.

ACKNOWLEDGEMENTS

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2. Berger, C.D. and B.H. Lane, Performance of a Large Hyperpure Germanium Detector Array for In-Vivo Detection of Low-Energy Photon and X-Ray Emitters: Analytical Procedure and Current Capabilities, ORNL/TM-7925, October, 1981.

APPENDIX A

DETAILED WHOLE BODY COUNT PROCEDURE

The ORNL Whole Body Counter is used primarily for identifying and quantifying internally deposited, low-energy x-ray and gamma emitting radionuclides. A stable, low background facility is essential to accurate analysis and results. In order to keep the whole body counter "clean," certain procedures for entrance into the vault are required.

Subject Preparation

1) When subjects arrive to be counted, they will have a Count Request and Preliminary Report Card (UCN-8561) generated by their area health physics surveyor. This card is checked to ascertain that all pertinent information has been included and is correct.
2) Determine if subject smokes pipe, cigar, or cigarettes, or, if they have quit, the length of time since they last smoked. This information should be written on the back of the request card to be included in the header information.
3) The subject is then instructed to shower and shampoo and is given a disposable jumpsuit, socks and towel from WBC supplies. When they are dressed, the subject's height and weight is obtained before being escorted into the vault annex. The escort wears shoe covers and a lab coat when accompanying a count subject into the vault. Since there is an air-lock to the vault, the outer door is closed completely before opening the inner door.
4) The subject is instructed to lie on the bed on his/her back before the operator places the detectors into position. Be certain that the subject's back is centered over the NaI(Tl) crystal located beneath the bed. Adjustments are made by sliding the foam cushion under the subject.

5) The operator slowly lowers the HPGe detector, keeping a firm grip on the handle, until it is approximately 1 cm above the right lung field of the subject's chest (see Fig. 12). The latch is locked into place before releasing the handle. The phoswich is then positioned over the left lung field as close as possible without constricting the subject's breathing.

6) The subject is cautioned not to jar or bump the detectors as this can result in spurious counts. Inform the subject that an intercom system exists to monitor the subject in case of illness and/or the need to exit rapidly from the vault.

ORNL-Photo 6480-81

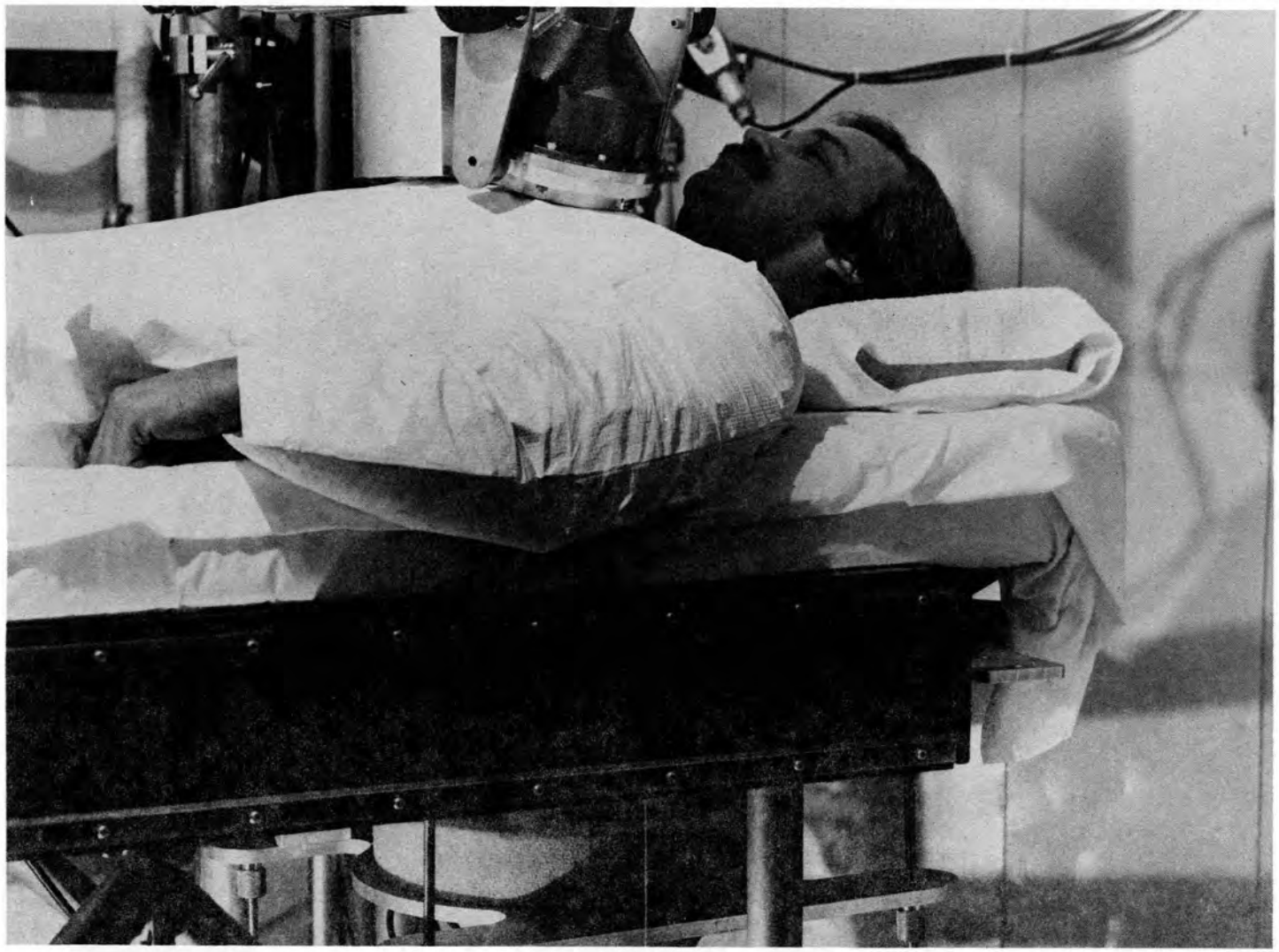


Fig. 12. Positioning of phoswich and HPGe detectors.

Routine Whole Body Count Computer Commands

The following commands (in capital letters) should be typed in exactly as shown, followed by a carriage return (CR):

1) JOB AO.HEADER,,,TTY(CR)

2) R PAMS(CR)
NA(CR)
(Input last name and initials)(CR)

SS(CR)
(Input badge number) (CR)

DB(CR)
(Input division; survey area)(CR)

ST(CR)
(Input sex - male or female)(CR)

FI(CR)
(Input file identifier - B82.P****- take number from log book)(CR)

HT(CR)
(Input height in inches)(CR)

WT(CR)
(Input weight in pounds)(CR)

PA(CR)
(Input paragraph information - reason for count, smoker or non-smoker, and current background number)(CR)
(must put in another CR after paragraph)

EX(CR)

3) R HEADER(CR)
(Check header to make sure it is correct)

4) JOB AO.GEHEAD,,,TTY(CR)

5) R PAMS(CR)
NA(CR)
(Input name)(CR)

FI(CR)
(Input file identifier - B82.G**** - same number as above)(CR)

PA(CR)
(Input background number)(CR)
(CR) (Two carriage returns after PA)

EX(CR)

6) R HEADER(CR)
(check information)

7) R TWORD(CR)
SET(CR)
(Input the number <u>before</u> the test word assigned to this count.)(CR)

8) JOB AO.MALE,,,TTY(CR)
or
JOB AO.FEMALE,,,TTY(CR)
(This is the job stream which turns on the ADC's to acquire, process, and store data at the end of the count).

9) When the line printer comes on, the count is finished and the subject can be removed from the vault. (The count time is approximately 45 minutes.)

When the count is finished, the operator (wearing shoe covers and lab coat) returns to the vault and carefully removes the detectors from the subject's chest, then escorts him/her back to the change room where the subject changes into his own clothes and returns to work.

APPENDIX B

SYSTEM START-UP PROCEDURE

The procedure for turning on the high voltage to the HPGe is one of the most critical procedures performed by the whole body counter operator. If done incorrectly, the detector can be irreparably damaged. The proper steps are as follows (see Fig. 13):

1) Check the potentiometers to see if all are set at zero. If not, release the catch and turn down to zero.
2) If the liquid nitrogen monitor is not in the dewar, place it into the top of the dewar and then slowly raise the detector, holding onto the handle firmly. The detector should be raised high enough to allow a subject to be positioned beneath it without bumping into the detector.
3) If all potentiometers are turned down to zero, press the reset button above the potentiometer panel.
4) Begin by releasing the lock on the first potentiometer (number 1) at the bottom of the box. Slowly turn it up until it reaches 10 and lock it into place.
5) The control switch on the right must be turned to #2 before releasing the lock on the second potentiometer (number 2). Slowly turn it until it reaches 10 and lock it into place.
6) The control switch on the right is switched to #3 and the third potentiometer is then turned up and locked into place.
7) The control switch is switched to #4 and the fourth potentiometer is turned up and locked into place.

The bias voltage to the HPGe array is now at the required 1500 volts.

ORNL-Photo 6479-81

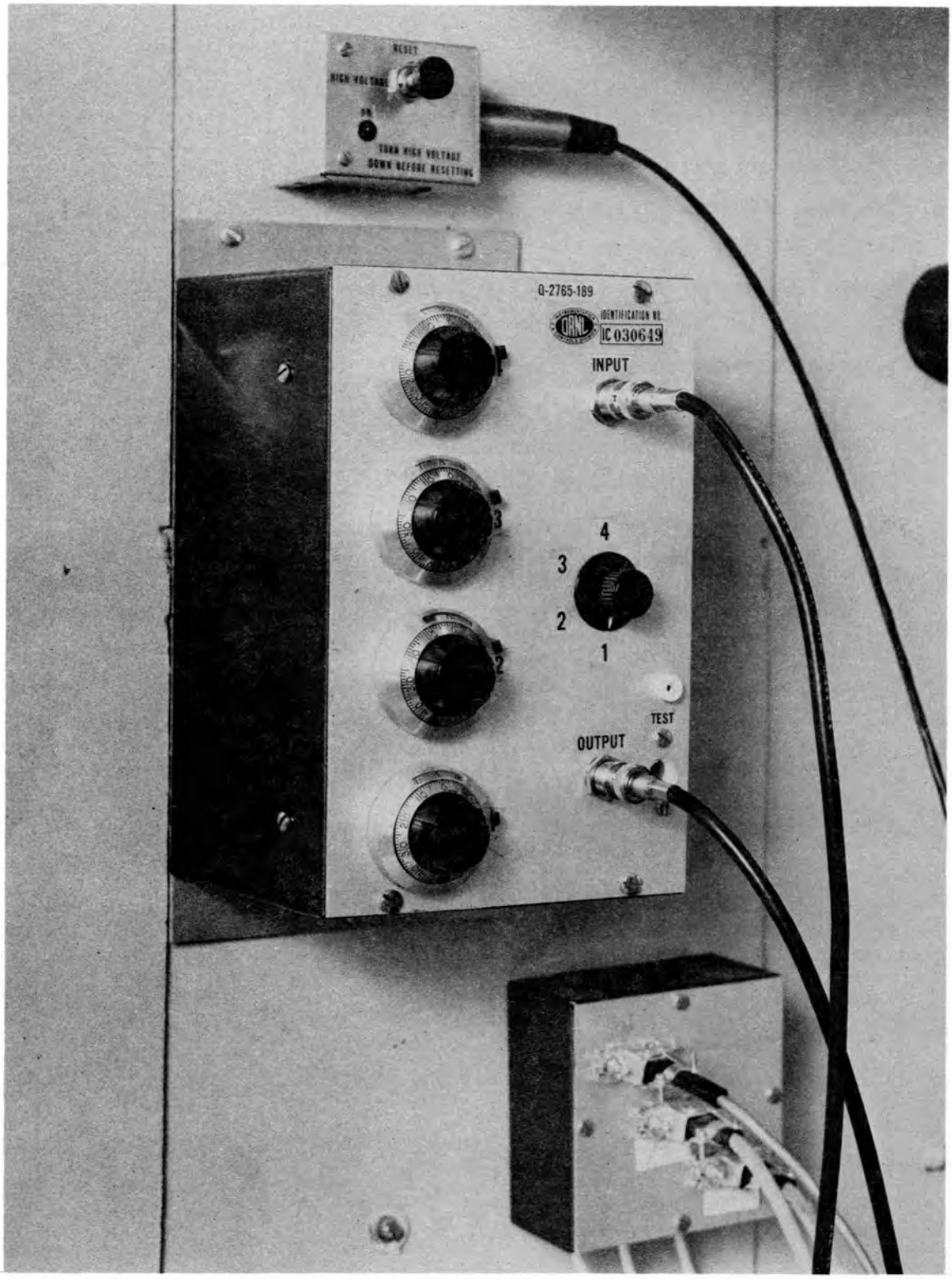


Fig. 13. High voltage supply to HPGe array.

APPENDIX C

SYSTEM SHUTDOWN PROCEDURE

The procedure for turning down the high voltage to the HpGe is the reverse of the start-up procedure.

Begin by releasing the lock on potentiometer #4. Slowly turn it down until it reaches zero. The control switch at the right should already be in position at #4. After potentiometer #4 is turned down, turn the control switch to #3, then zero the #3 potentiometer. Repeat process for all the remaining potentiometers until each reads zero. The high voltage is now off.

APPENDIX D

SUPPLIES

The WBC Facility supplies are stored in metal cabinets in the janitor's supply room. Inventory should be taken occasionally to determine whether supplies are running low. The following is a list of WBC supplies kept in stock:

1) Disposable jumpsuits (M, L, XL)
2) Towels
3) Socks
4) Soap
5) Shampoo
6) Deodorant
7) Hair spray
8) Hair oil
9) Shoe covers
10) Plastic bags (Laundry)
11) Shower clogs
12) Lab coats
13) Disinfectant
14) Sheets

APPENDIX E

LIQUID NITROGEN (LN_2) PROCEDURE

The WBC Facility receives two deliveries of LN_2 per week; on Tuesday and on Friday. The whole body counter operator must open the appropriate valves, #1 and #2 on the LN_2 system (see Fig. 14) to allow the LN_2 to be transferred from the delivery truck to the main dewar located in the vault annex. The two valves which open the lines for transfer inside the vault, #3 and #4, must be closed to prevent loss of LN_2. Gloves are usually needed when turning the valves off to prevent freeze burns on the hands.

Filling HPGe Detector

The bias voltage to the HPGe detector must be turned off before removing the LN_2 monitor and filling the detector dewar. (See Appendix C).

Open valves, #3 and #4 (see Fig. 14), to start the flow of LN_2 into the vault. The valve on the line inside the vault must be opened (see Fig. 15) and the line allowed to cool down before LN_2 can be transferred. This requires 3 to 5 minutes. When LN_2 starts to flow, remove LN_2 monitor or cover from the top of the dewar and insert the nozzle. Wait until the LN_2 begins to "bubble out" the top of the dewar (usually around 10-15 minutes), then close the valve, and remove the nozzle. After leaving the vault, close the two valves (#3 and #4) on the outside tank before leaving the annex.

ORNL-Photo 6478-81

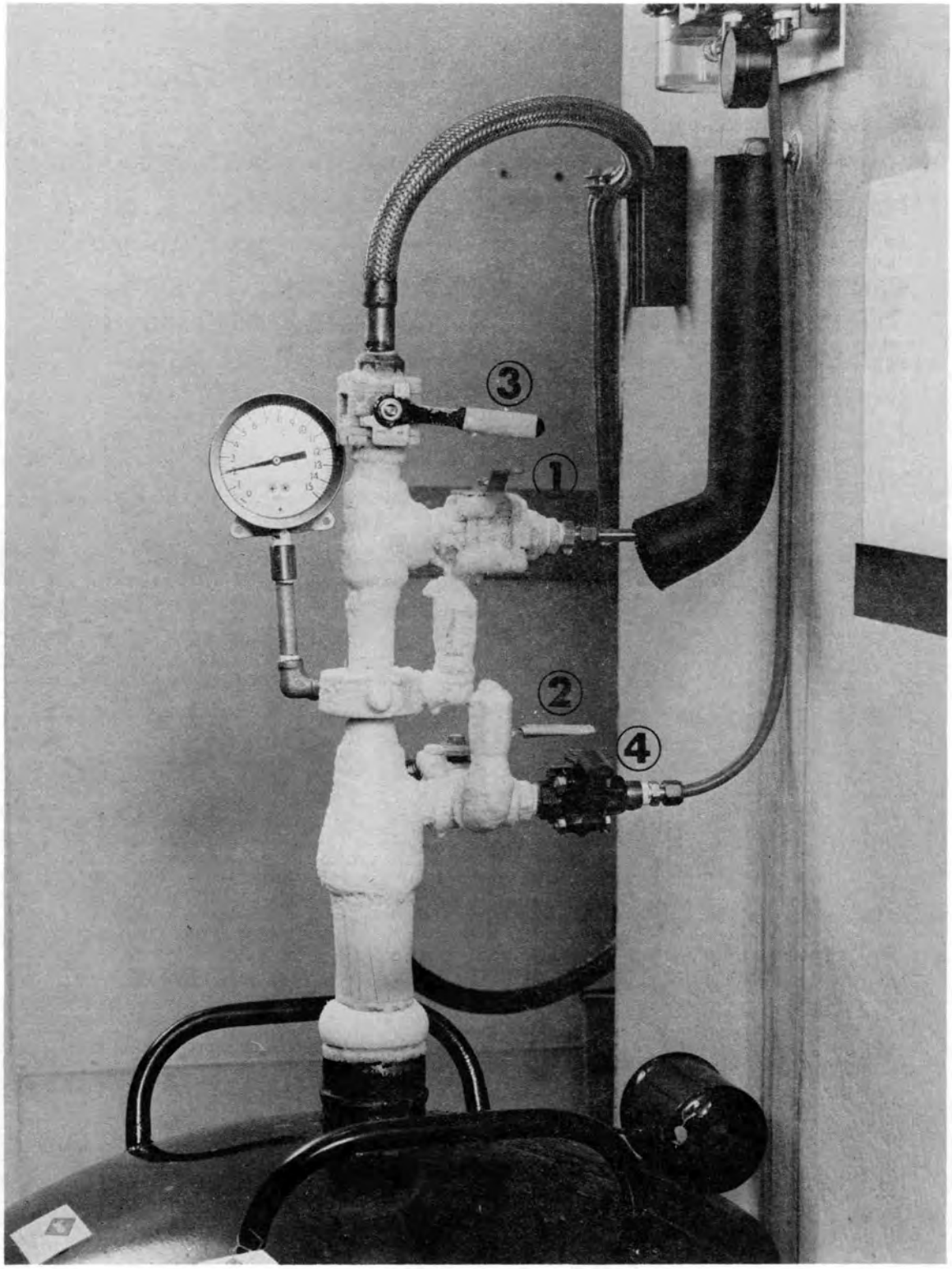


Fig. 14. Liquid nitrogen reservoir tank and controls.

ORNL-Photo 6477-81

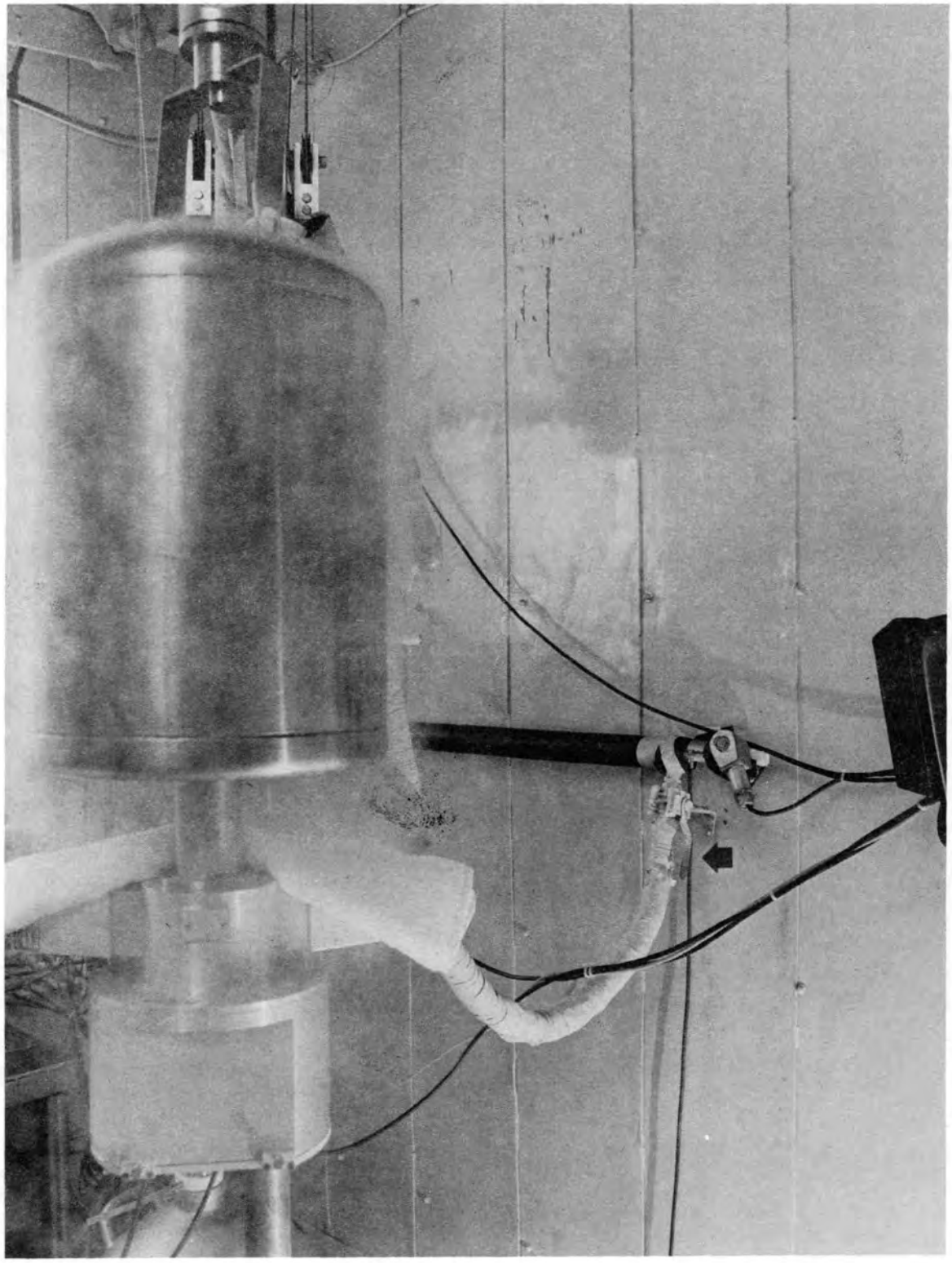


Fig. 15. Liquid nitrogen fill system showing input valve on the wall of the iron room (arrow).

APPENDIX F

LAUNDRY

The whole body counter laundry is done by a commercial firm outside the Lab, rather than by in-plant laundry to prevent contamination of towels, socks, etc. The laundry pick-up schedule is Tuesday and Friday (call Shipping and Receiving, 4-4228 or 4-4229). Laundry is sorted and counted before being placed in plastic bags. A record is maintained of the following information, a copy of which is included in one of the bags:

Date: _____

Station #: 50

Bldg. #: 2008

Charge #: 3198

Towels: (quantity) _____

Socks: (quantity) _____

Sheets: (quantity) _____

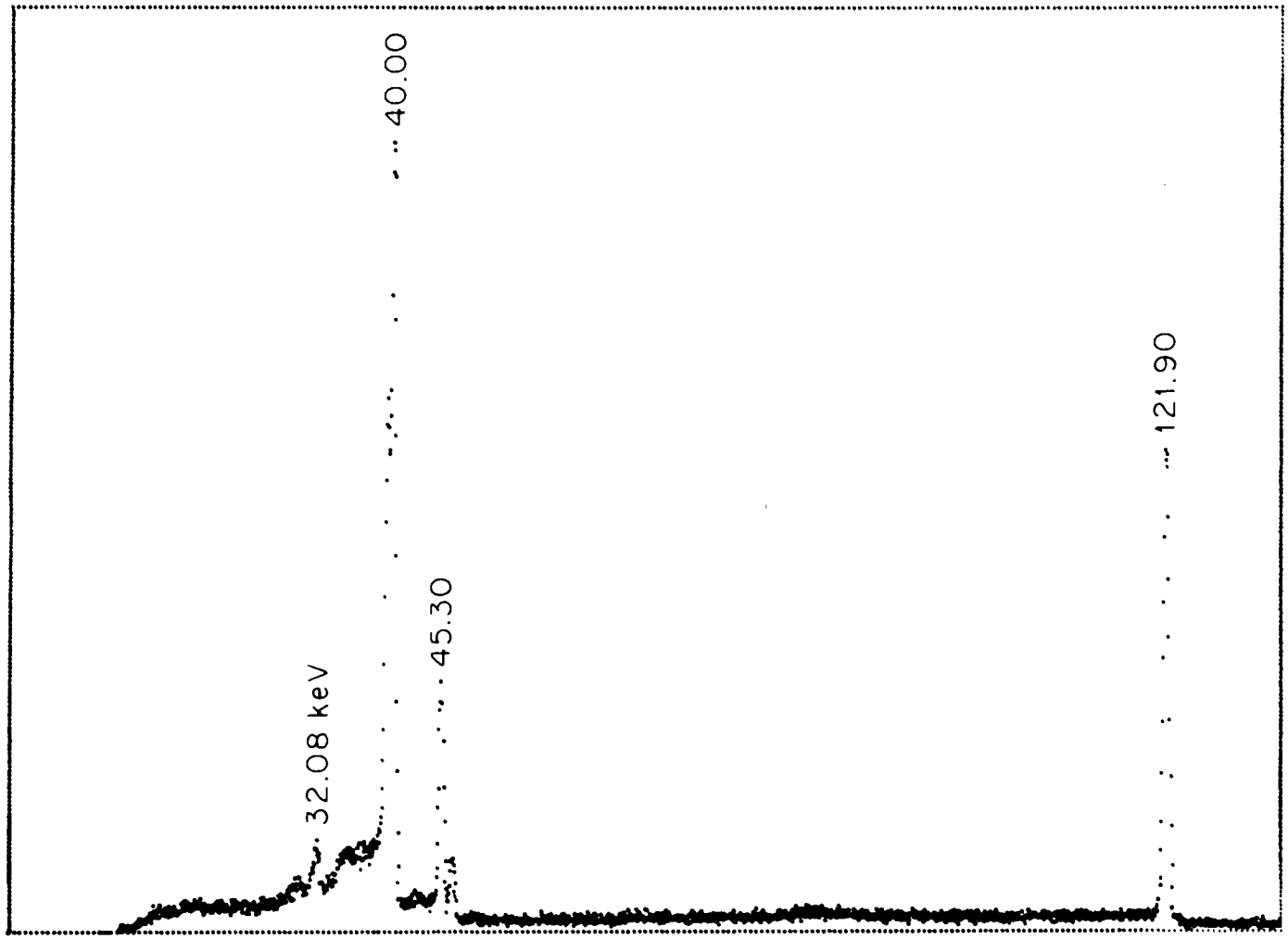
Lab Coats (quantity): _____

APPENDIX G

SPECTRAL DATA FROM COMMONLY OCCURRING RADIONUCLIDES

There are few incidents of true internal deposition of radionuclides at ORNL. Of those that are observed at the ORNL Whole Body Counter, most are cases of surface contamination. Because of the superior energy resolution of the HPGe array, identification of these radionuclides has become an easier task. The following are energy spectra of various radionuclides deposited inside a phantom to be used as an aid in identification. The energy of the higher-yield photopeaks as indicated on the CRT screen is indicated on each spectrum.

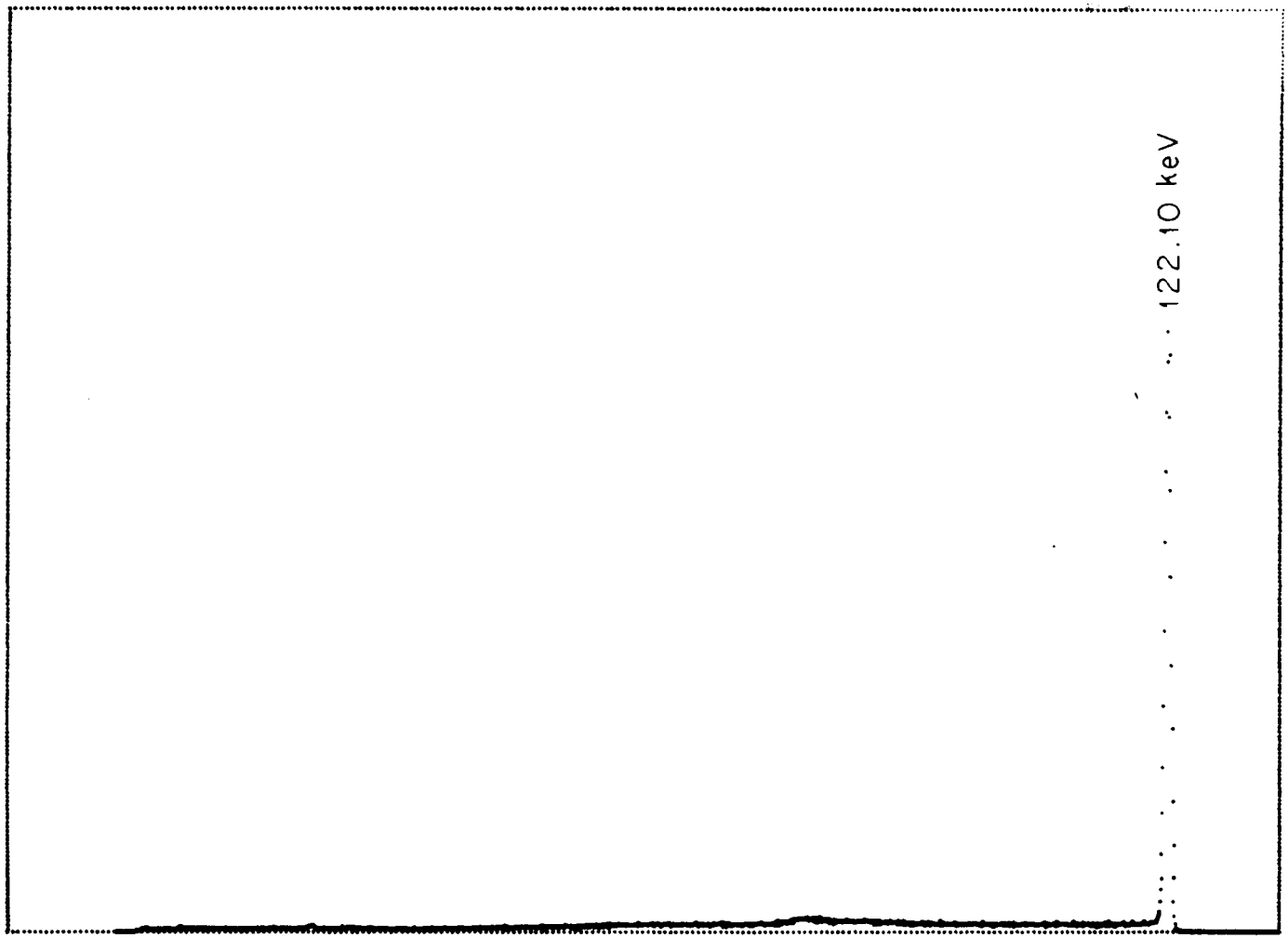
ORNL-DWG 82-8785



EUROPIUM-152

Figure 16. Europium-152 source in a REMAB phantom.

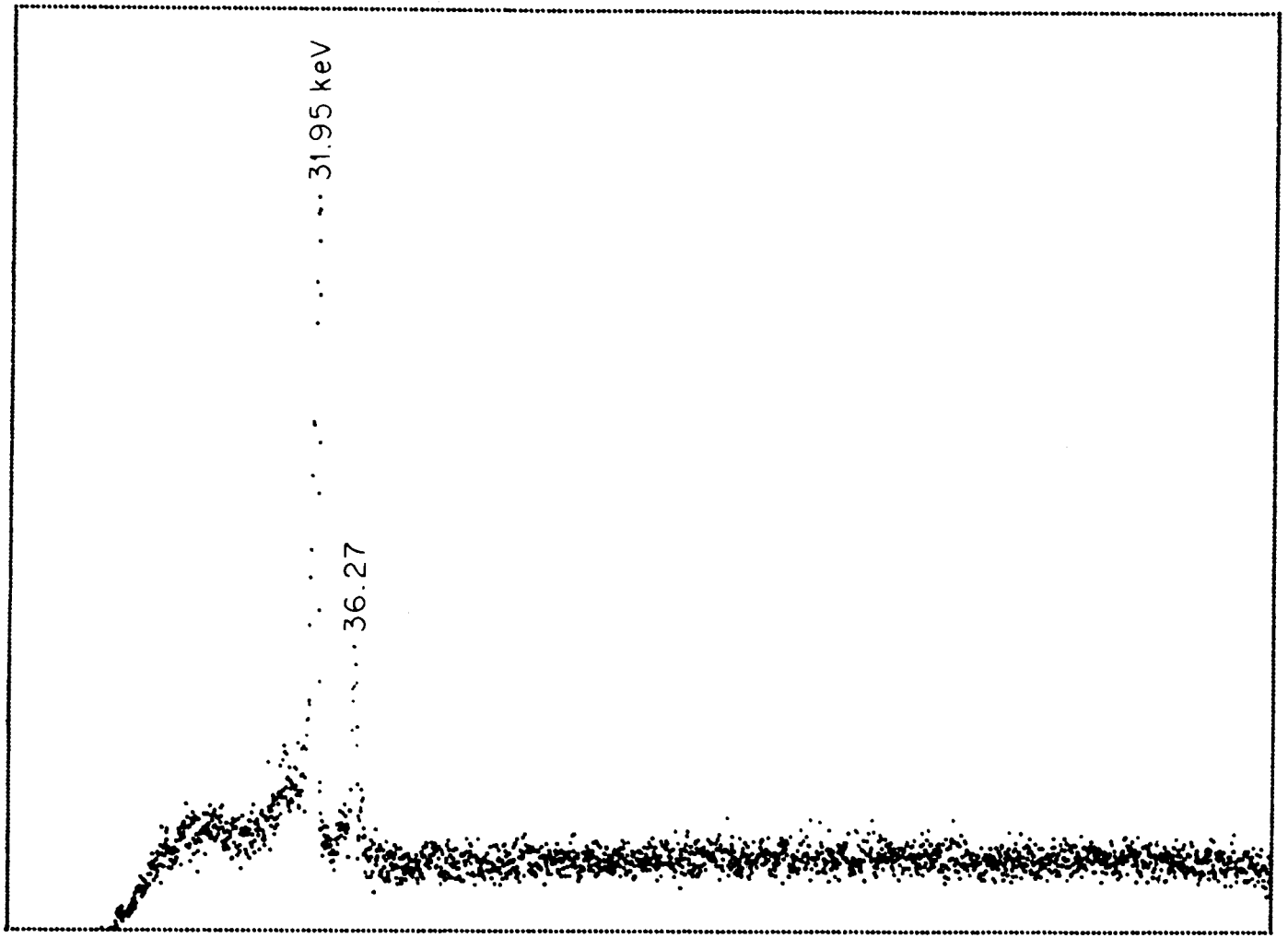
ORNL-DWG 82-8792



COBALT-57

Figure 17. Cobalt-57 source in a REMAB phantom.

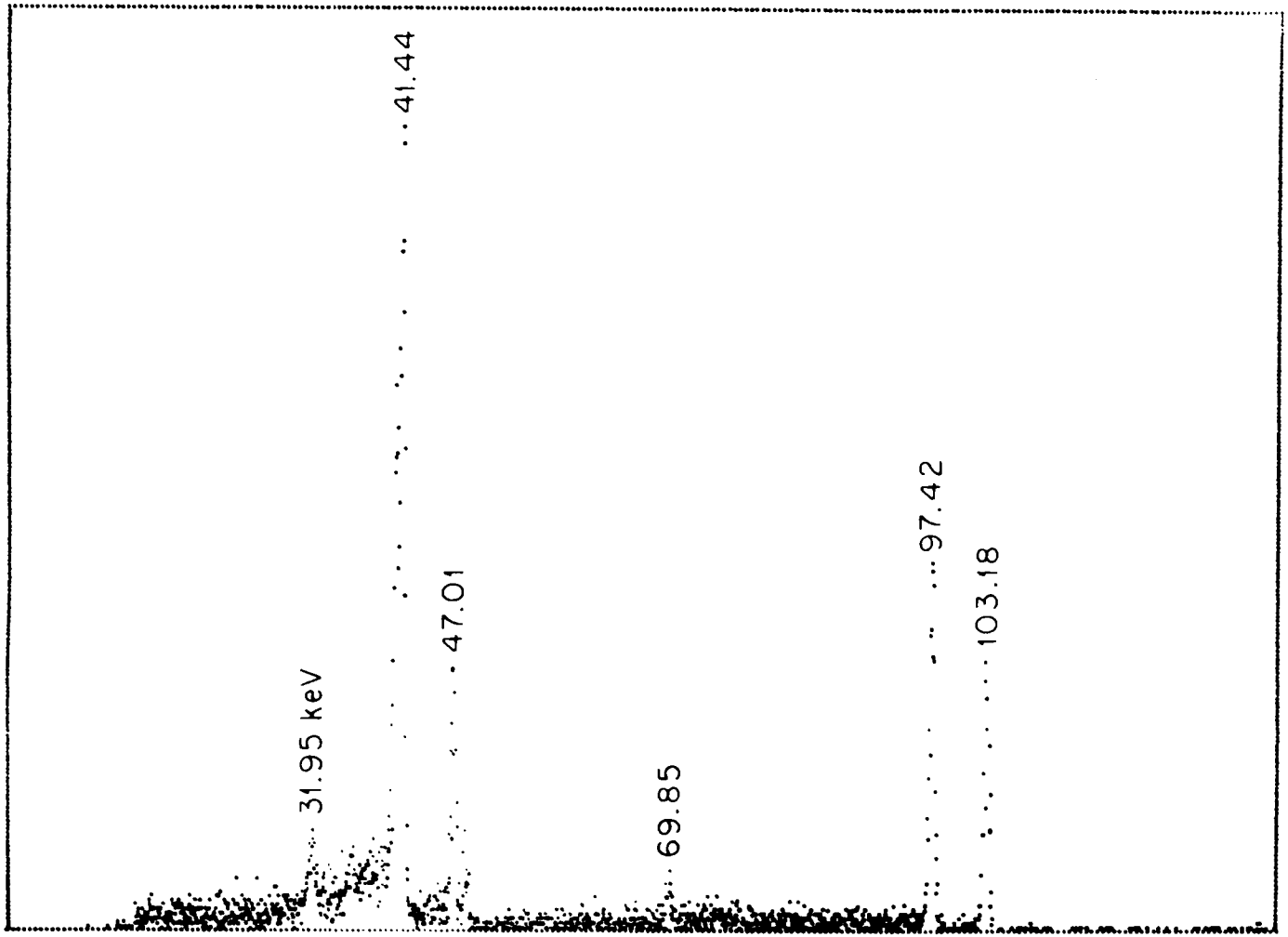
ORNL-DWG 82-8784



CESIUM-137

Figure 18. Cesium-137 source in a REMAB phantom.

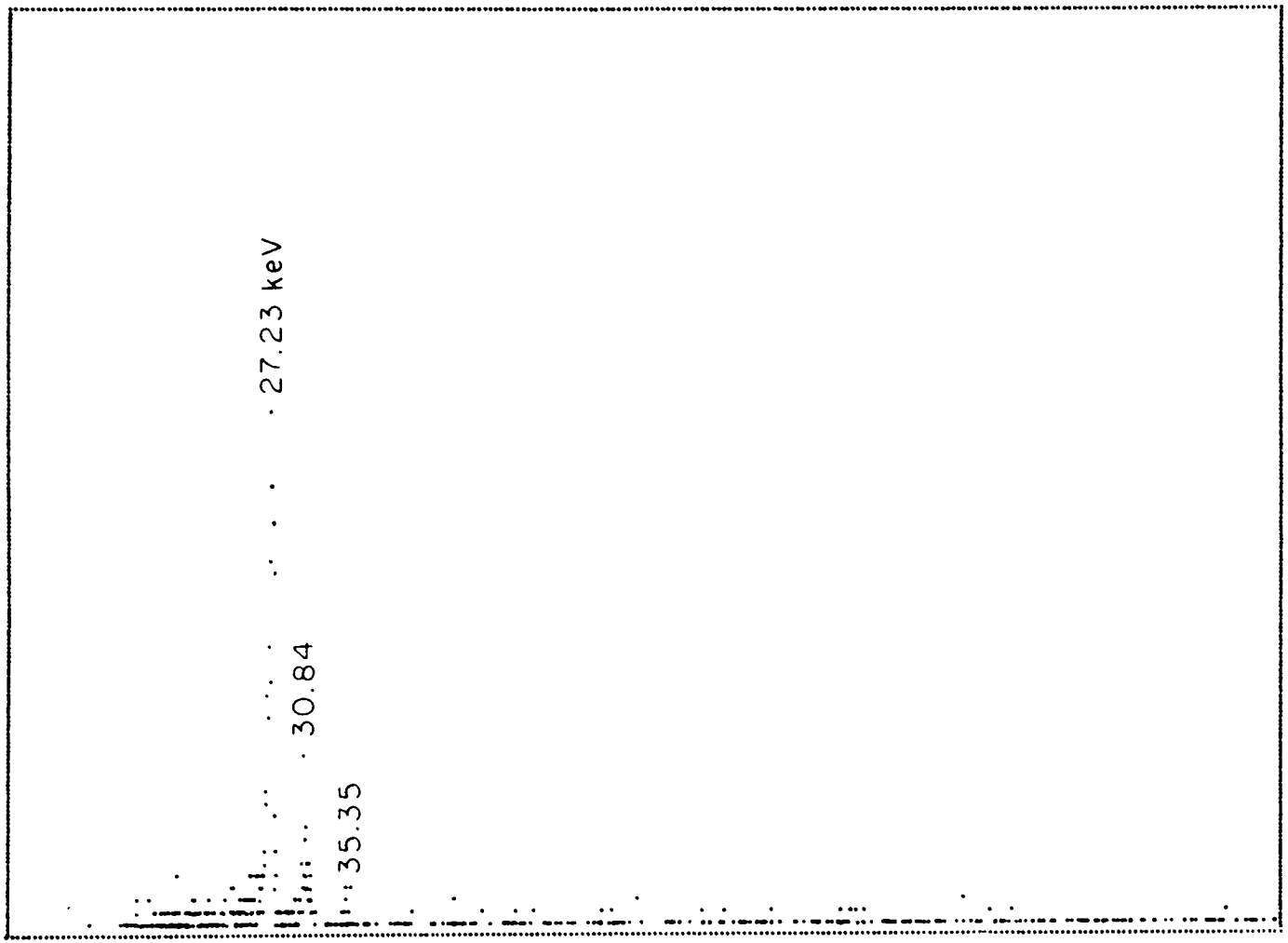
ORNL-DWG 82-8786



GADOLINIUM-153

Figure 19. Gadolinium-153 source in a REMAB phantom.

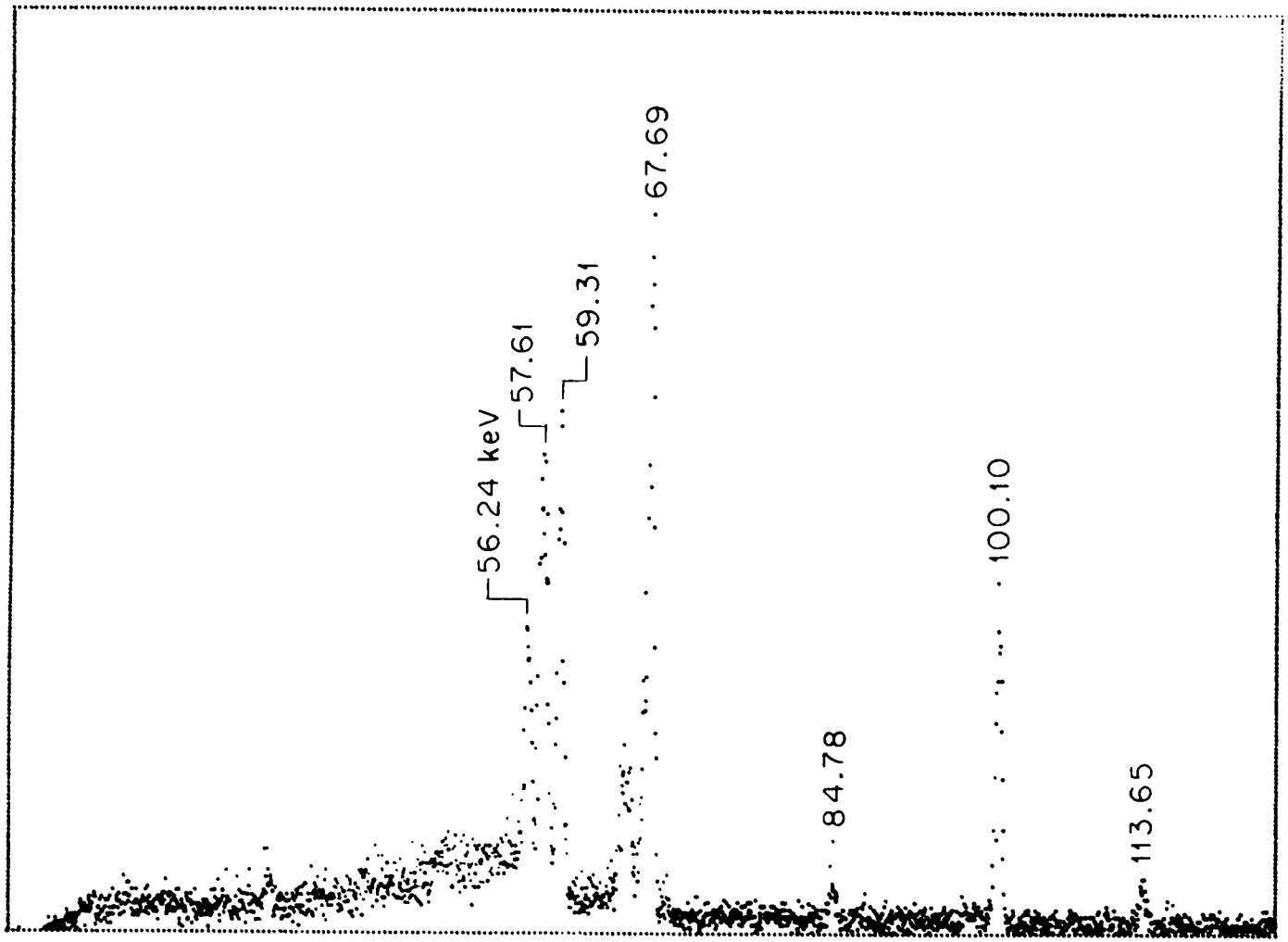
ORNL-DWG 82-8788



IODINE-125

Figure 20. Iodine-125 source in a REMAB phantom.

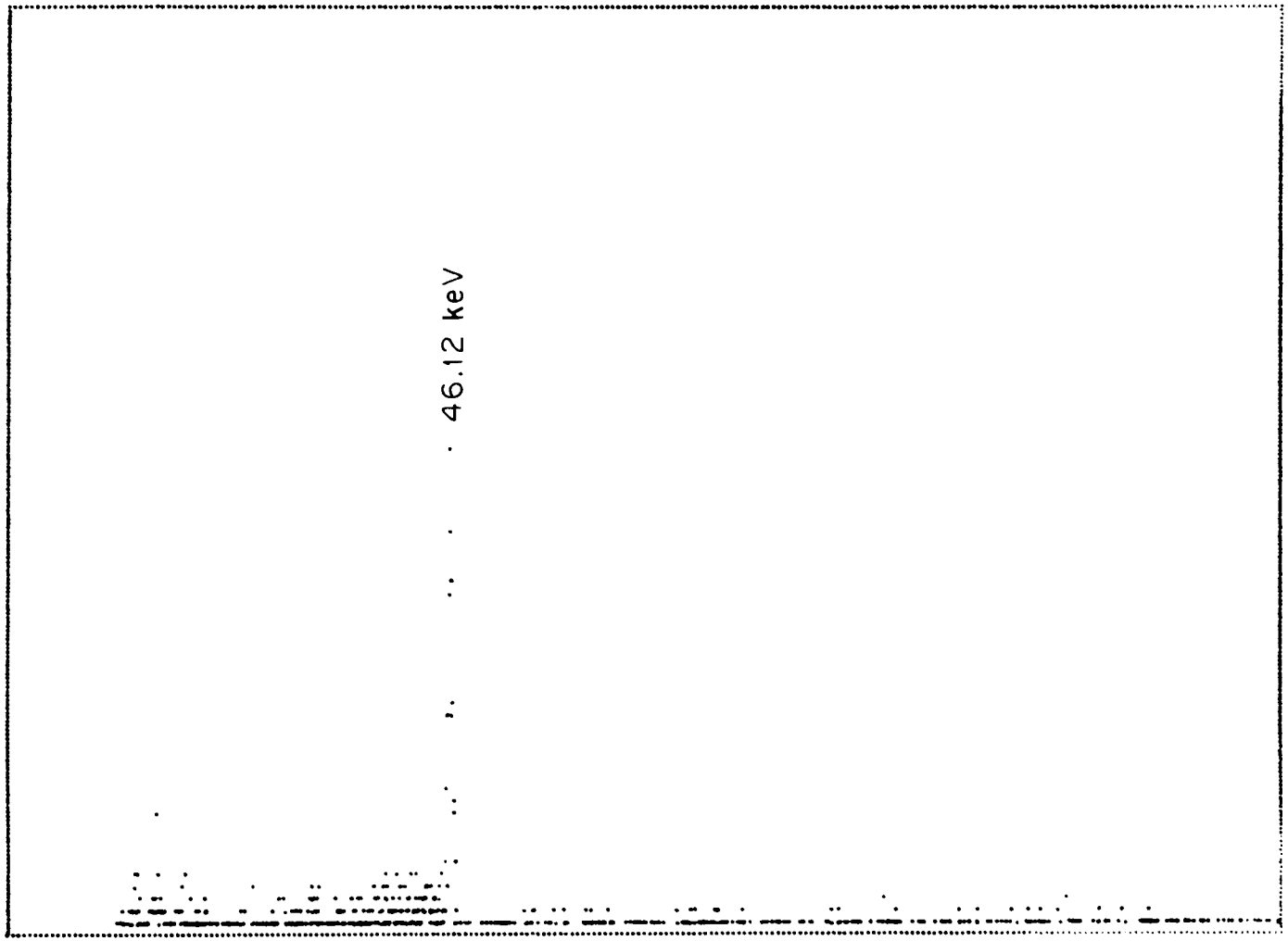
ORNL-DWG 82-8789



TANTALUM-182

Figure 21. Tantalum-182 source in a REMAB phantom.

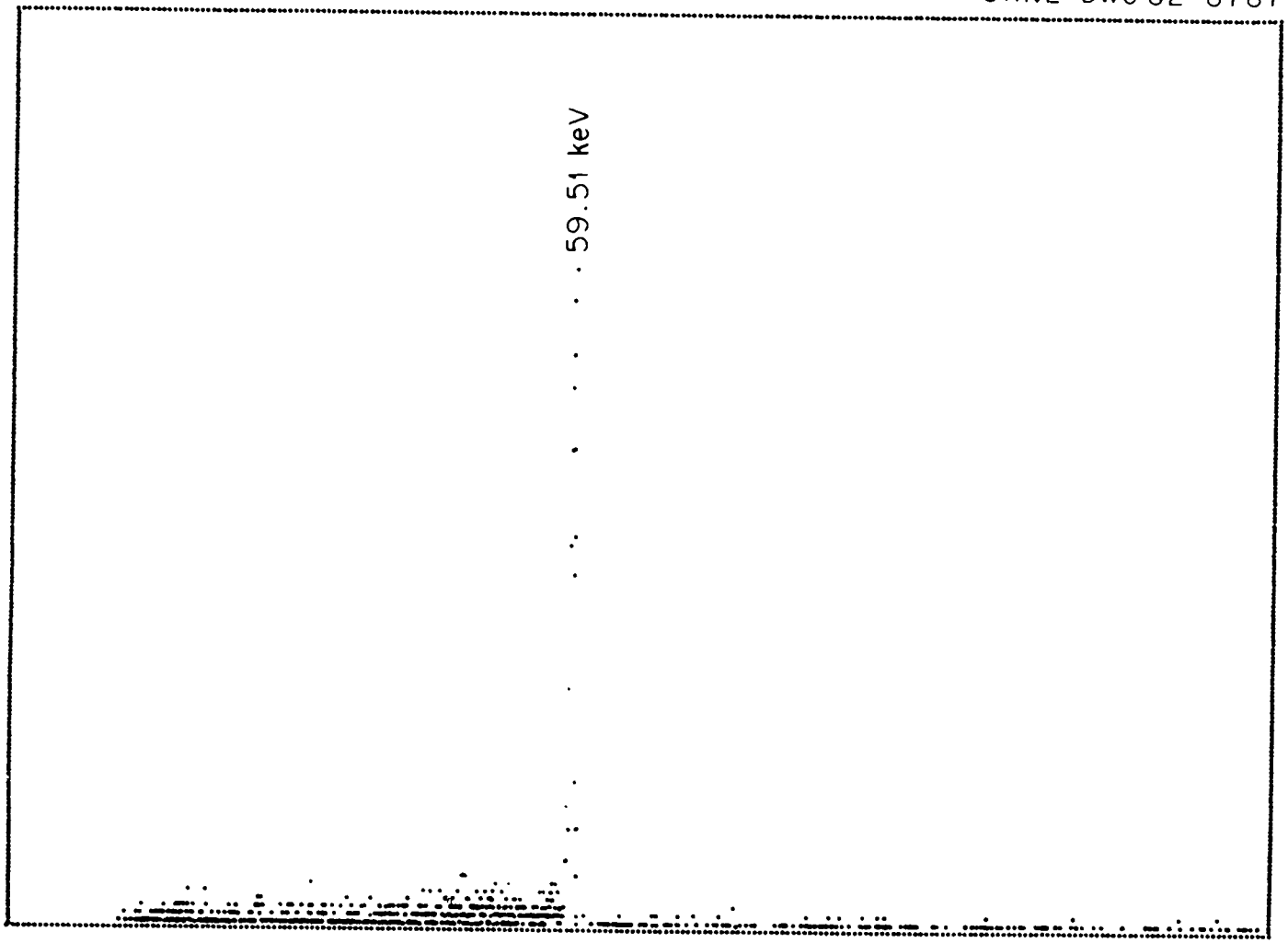
ORNL-DWG 82-8790



LEAD-210

Figure 22. Lead-210 source in a REMAB phantom.

ORNL-DWG 82-8787



AMERICIUM-241

Figure 23. Americium-241 source in a REMAB phantom.

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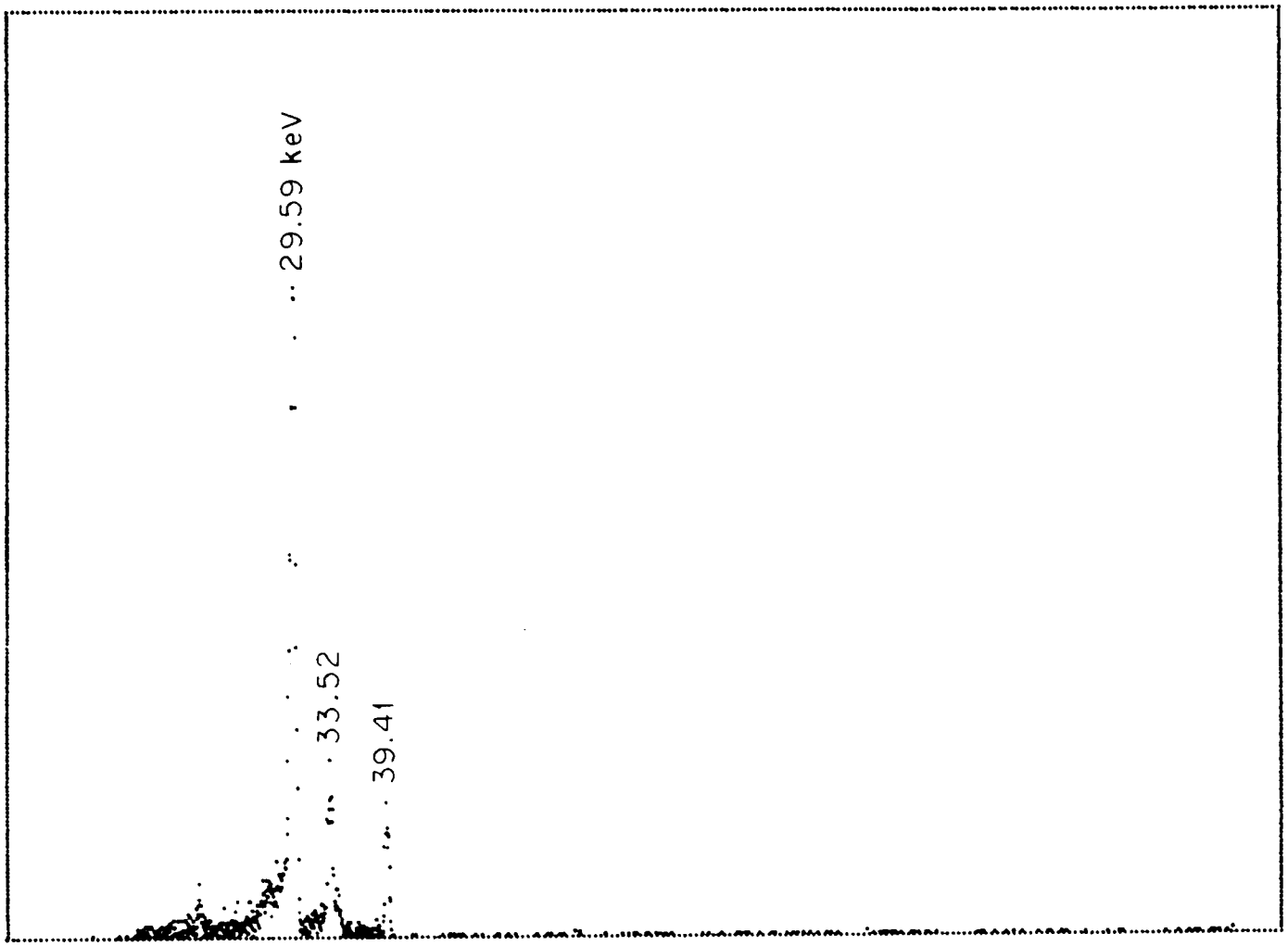

IODINE-129

Figure 24. Iodine-129 source in a REMAB phantom.

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