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THE WALTER REED ARMY BODY COUNTING FACILITY

DETAILS OF CONSTRUCTION
GAMMA RADIOACTIVITY IN PEOPLE AND FOODSTUFFS
JULY 1958 TO JULY 1960

266007



WALTER REED ARMY INSTITUTE OF RESEARCH

WALTER REED ARMY MEDICAL CENTER

WASHINGTON 12, D.C.

THE WALTER REED WHOLE BODY COUNTING FACILITY

Details of Construction

Gamma Radioactivity in People and Foodstuffs

July 1958 to July 1960

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THE WALTER REED WHOLE BODY COUNTING FACILITY

1.0 Introduction

The rapid and maximum development of the atomic energy industry is in no small measure contingent upon knowledge of the qualitative and quantitative effects of ionizing radiation on biological materials. One major aspect of radiation exposure concerns the distribution of radioactive fission fragments in the biosphere and the ultimate content of radioactivity in the human subject. The safety requirements necessary to maintain presently acceptable health practices and exposure tolerances contribute significantly to engineering, installation, and operational costs. In the immediate future, however, safety requirements may well represent the limiting factor in feasibility and design for certain applications of nuclear energy.

The investments of the military services encompass every aspect of the atomic energy industry including weaponry, reactors for power and propulsion, irradiation sources for materials and foodstuffs, radio-luminescent materials, radioactive isotopes in tracer chemistry and material fatigue studies, and in medical research, diagnosis, and therapy. The services are immediately concerned with the installation and operation of power reactors at remote stations. Consequently the techniques and tools in health physics and radiation protection must be available and must progress with future plans and operations.

In the United States over 200 reactors are planned or are now operational and estimates of the U. S. nuclear power production rate increase from 1300 megawatts by 1963 to between 20,000 and 40,000 megawatts by 1975. The United Kingdom and Western Europe will have an installed nuclear capacity of about 16,000 megawatts by 1965. With this release of nuclear energy the attendant production of radioactive material is overwhelming, for within five

years 15 to 20, 000 megawatts of nuclear power will create a disposal problem of about one-hundred-thousand megacuries of radioactivity annually. Our current precepts for disposal are: with high level radioactive wastes, concentrate and contain; with low and intermediate level radioactive waste, dilute and disperse to nature. Disposal of reactor debris must be made eventually and the necessity for studying distribution mechanisms in the biosphere is common to all fission debris.

It is apparent that there is an urgent need for radiation detection instruments capable of measuring small changes in the environment and in the human subject. Sensitive instrumentation will also ensure significant reductions in the dose of radiolabels administered in diagnostic procedures. This is particularly important since diagnostic radiological procedures constitute the largest source of ionizing radiation exposure to the human subject. Scintillation detectors developed over the past six years for the study of gamma activities in the human subject particularly apply to these problems.

Because of the inherent difficulties in the low-level assays of large numbers of bulk samples and the uncertainties in estimating total body burden from excretion levels, a facility for determining gamma-ray activity directly in humans was constructed during 1957 at the Walter Reed Army Institute of Research. This facility includes a large NaI crystal gamma-ray spectrometer and a 4π liquid scintillation counter. The Walter Reed location was selected because of population density, and a large hospital complex ensured the use of the facility in clinical medicine and metabolic research. The experiences and techniques of whole body counting evolved by Marinelli and Miller (1) and Anderson (2) have been followed closely.

Figure 1 is a general view of the Walter Reed Whole Body Counting Facility showing the liquid scintillation counter on the left, the shielded room for the crystal spectrometer, and the associated instrumentation.

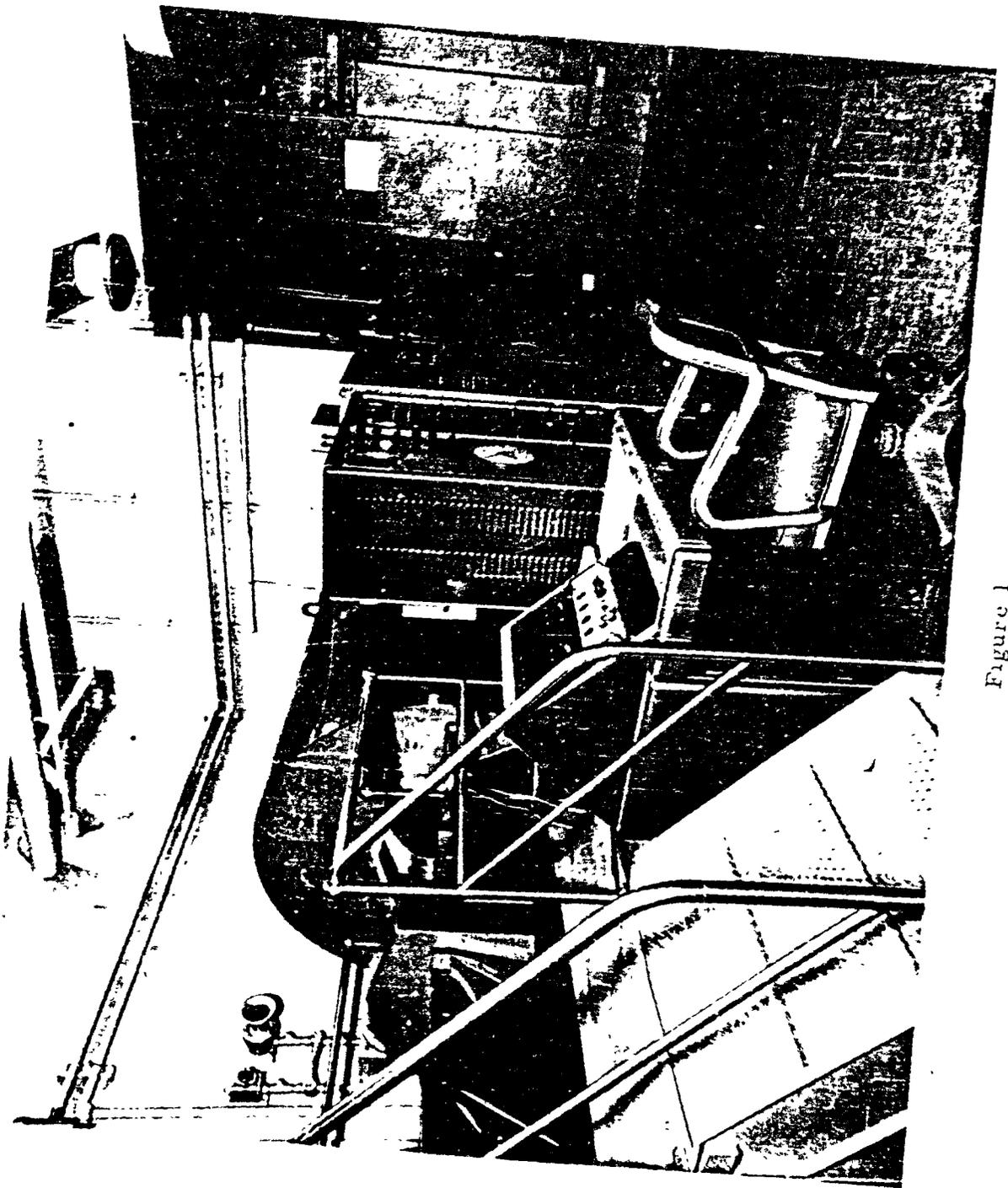


Figure 1

2.0 Description of the 4π Liquid Scintillation Counter

The 4π liquid scintillation counter is essentially a horizontal well counter and is designed after the Los Alamos Human Counter (2). The counter consists of a horizontal detector tank and well, a loading trough, a cylindrical shield, organic scintillators and solvent, electronic instrumentation, plumbing for filling and emptying the detector, and safety devices.

2.1 The Horizontal Detector

The horizontal detector tank is a milled steel cylindrical tank 72 inches long and 32 inches in internal diameter. The detector well is formed by a 20 inch diameter cylinder of #304 stainless steel which runs the length of the detector. This cylinder accommodates the subject or sample, and also forms the inner wall (0.050 inch) of the detector tank. The detector tank thus surrounds the detector well (except at the ends) and is filled with approximately 144 gallons of scintillation solution (thickness of 6 inches).

The interior of the scintillation detector tank is coated with a white reflective paint (Appendix A).

Mounted radially through the outer wall and looking into the detector tank are six rows of seamless steel tubes (7" OD x 6 5/32" x 2 3/8") with five tubes in each row. Each row is 60° apart and the tubes are weld mounted on 14 3/8" centers with the end tubes 7 1/4 inches from the end of the detector. Each multiplier phototube is placed in a 5 1/2 inch ID seamless steel sleeve which has a Luster glass (3/16 inch thick) window recessed at the end (Appendix B). This sleeve is then inserted into the tube and bolted to the detector tank by means of mating flanges. A flat neoprene gasket (Appendix C) between the flanges provides a liquid tight seal. Approximately

85 inch-pounds of torque are applied to each bolt holding the sleeve to the detector tank. Using windowed sleeves enables the replacement of multiplier phototubes without draining the detector tank. The multiplier phototube is covered with a light-tight spun brass hood which bolts to the flange of the insert sleeve. The multiplier phototube face is positioned flush with the sleeve window and the tube base is secured to the hood by means of a retaining clamp (Figure 2).

A pair of precision machined flanged rails are welded to the under surface of the detector tank providing support and allowing movement of the tank (Figure 3). The tank moves on rollers mounted in channel iron supports which run the length of the shield and extend 85 inches outside of the shield, thus giving access to the detector tank for installation and maintenance. Small rollers mounted vertically apply lateral force to the sides of the detector tank rails and keep the tank centered.

A small overflow tank (6 x 5 x 20 inches) is located on top of the detector tank. This permits complete filling of the detector tank and a small excess of solution for degassing and liquid contraction. An overflow line leads from the overflow tank to an underground reservoir.

2.2 Loading Trough, Sling Mechanism, and Shield for Detector Well

The loading trough is a horizontal stainless steel half-cylinder 95 1/4 inches long with a 9 15/16 inch radius and is shown in Figure 4. The trough is mounted between the pair of channel iron tracks and abuts evenly with the detector well. A canvas sling rides in the loading trough and is pulled into and out of the detector well by a chain loop. The chain is driven by a reduction gear powered by a 1/3 horsepower reversible

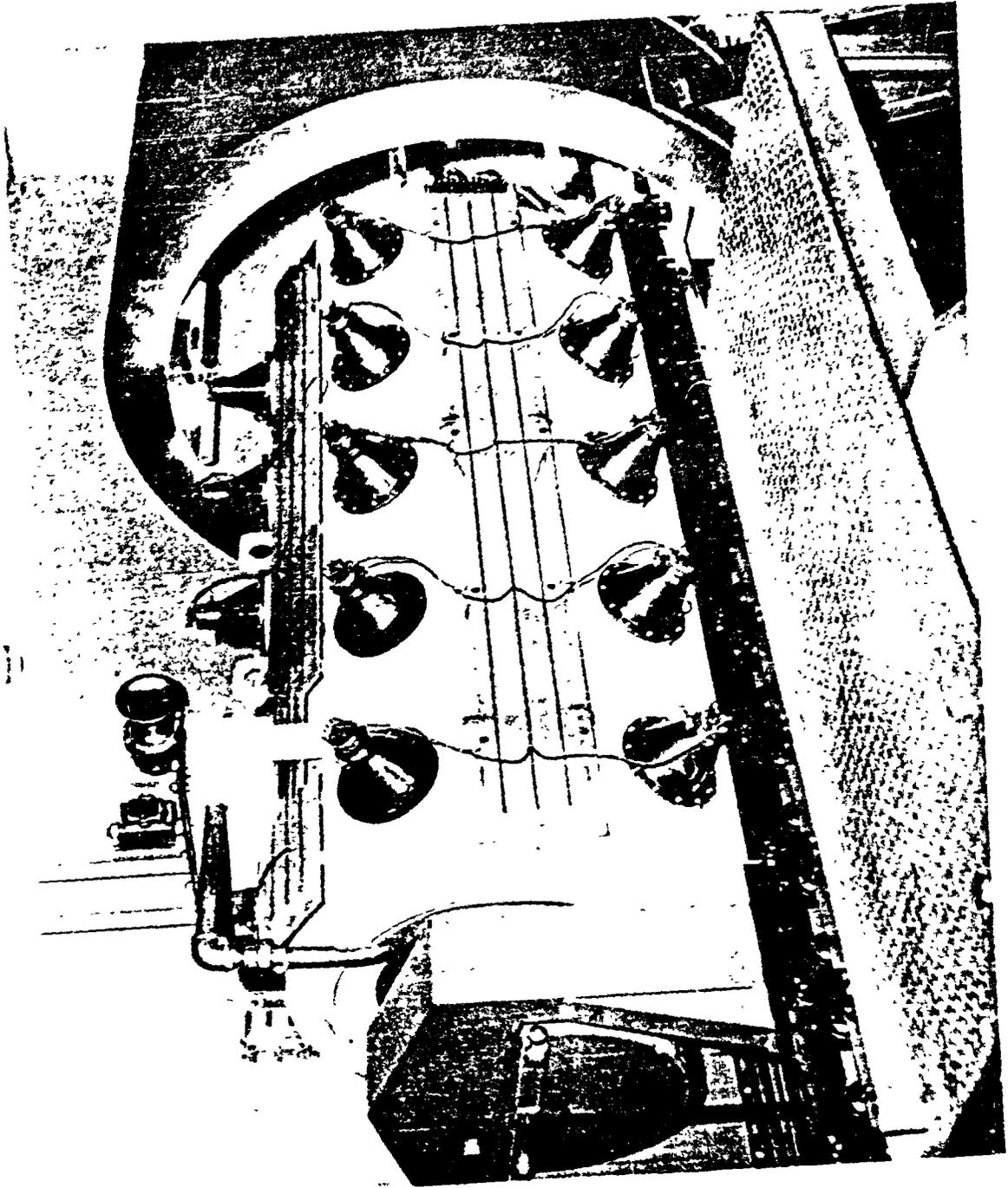


Figure 2

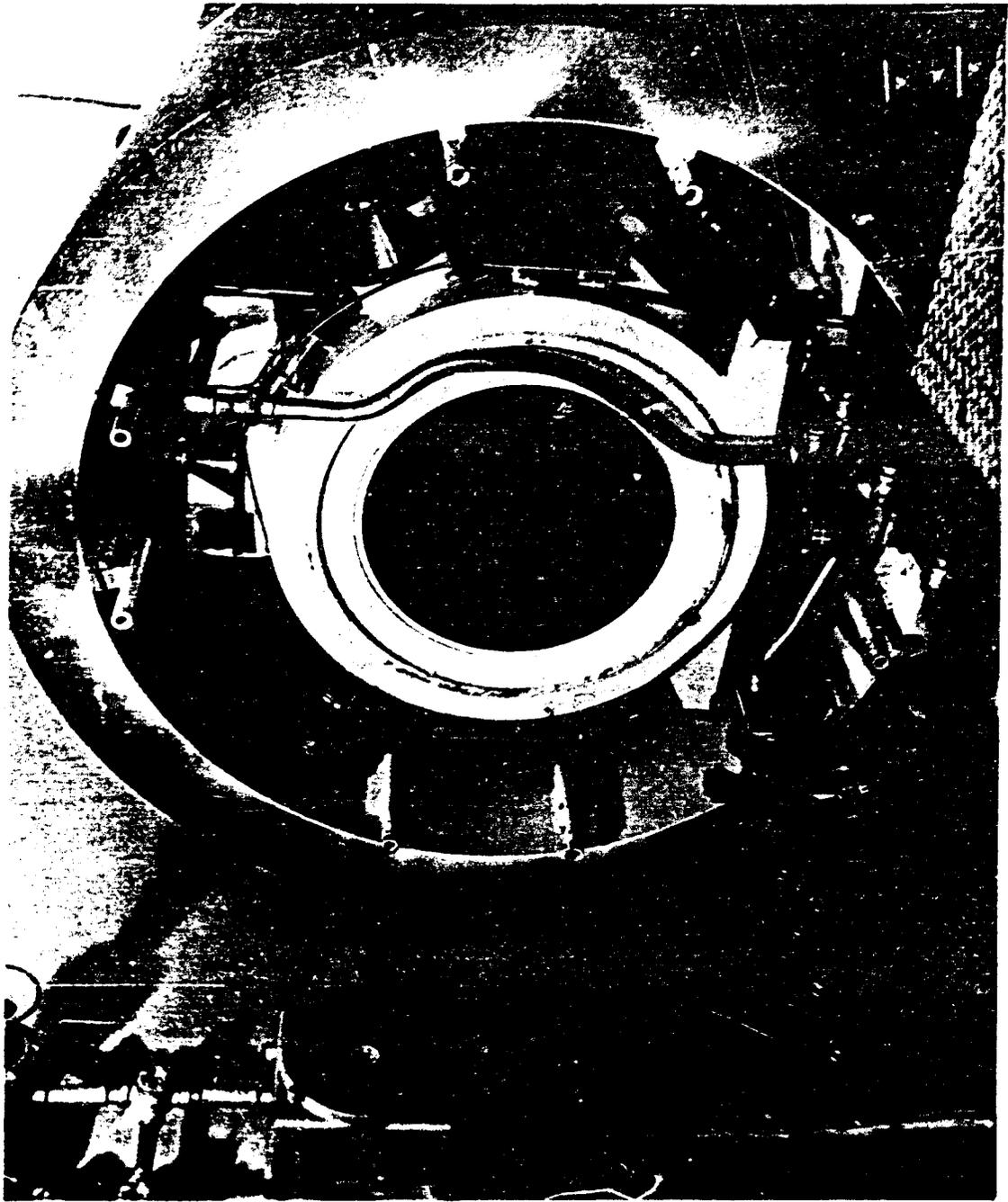


Figure 3

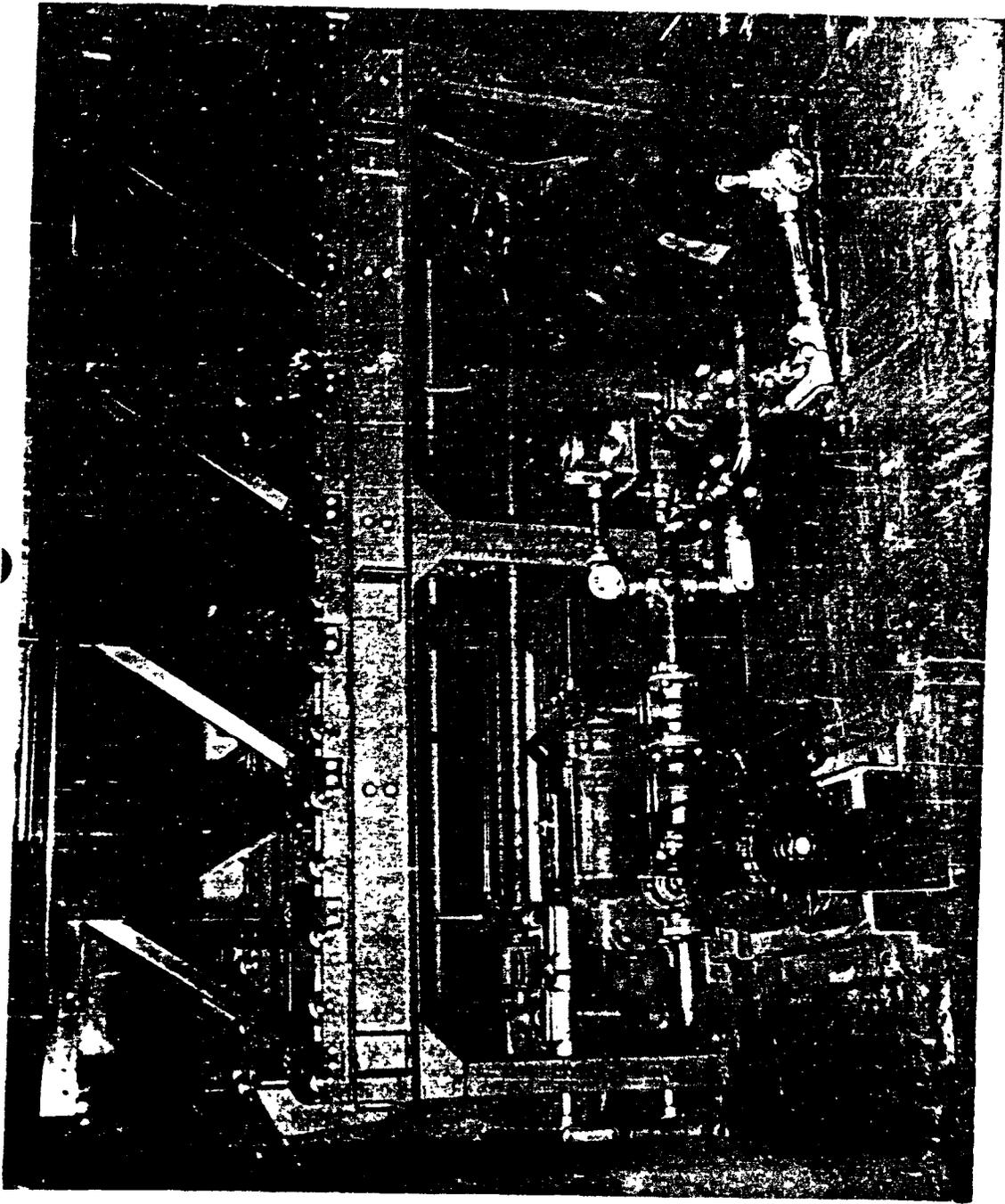


Figure 4

electric motor (Master Electric Co.). A manual crank is also provided in case of power failure. The extremes of movement of the canvas sling are controlled by limit switches. The sling is bolted at one end to a 6 inch thick iron shield which follows the sling and occludes the opening of the detector well when the sample is in the counting position. This mobile shield straddles the loading trough and rides on the same rollers used in moving the detector tank.

2.3 Shielding for the Detector Tank

A cylindrical shield (Class B-armor) surrounds the detector providing 5 1/2 inches of shielding. The shield measures 83 3/4 inches in length and 65 inches OD. For ease in handling and placement, the cylinder was cut into two pieces. The match marked ends were accurately machined with slightly tapered male and female joints. Figure 5 shows the machined cylinder halves before final placement and assembly.

The support for the 12.5 ton shield is shown in Figure 6. One end of the shield is closed by means of two 3 inch thick circular plates of steel, one bolted inside the shield and the other overlapping the end. The end with the loading trough is shielded by laminated steel plates as shown in Figure 7. The pattern for each layer staggers the location of the butt joints, so that through and through cracks are avoided.

2.4 Organic Scintillators, Solvent, Plumbing, and Safety Devices

The scintillation solution is 4 grams per liter p-terphenyl plus 0.1 grams per liter POPOP (1,4-bis-[2-(5-phenyloxazolyl)]-benzene) in reagent grade toluene. Toluene with 98-99 per cent transmission using a 10 cm light path at 365 to 420 mu, as compared to spectrographic grade cyclohexane is

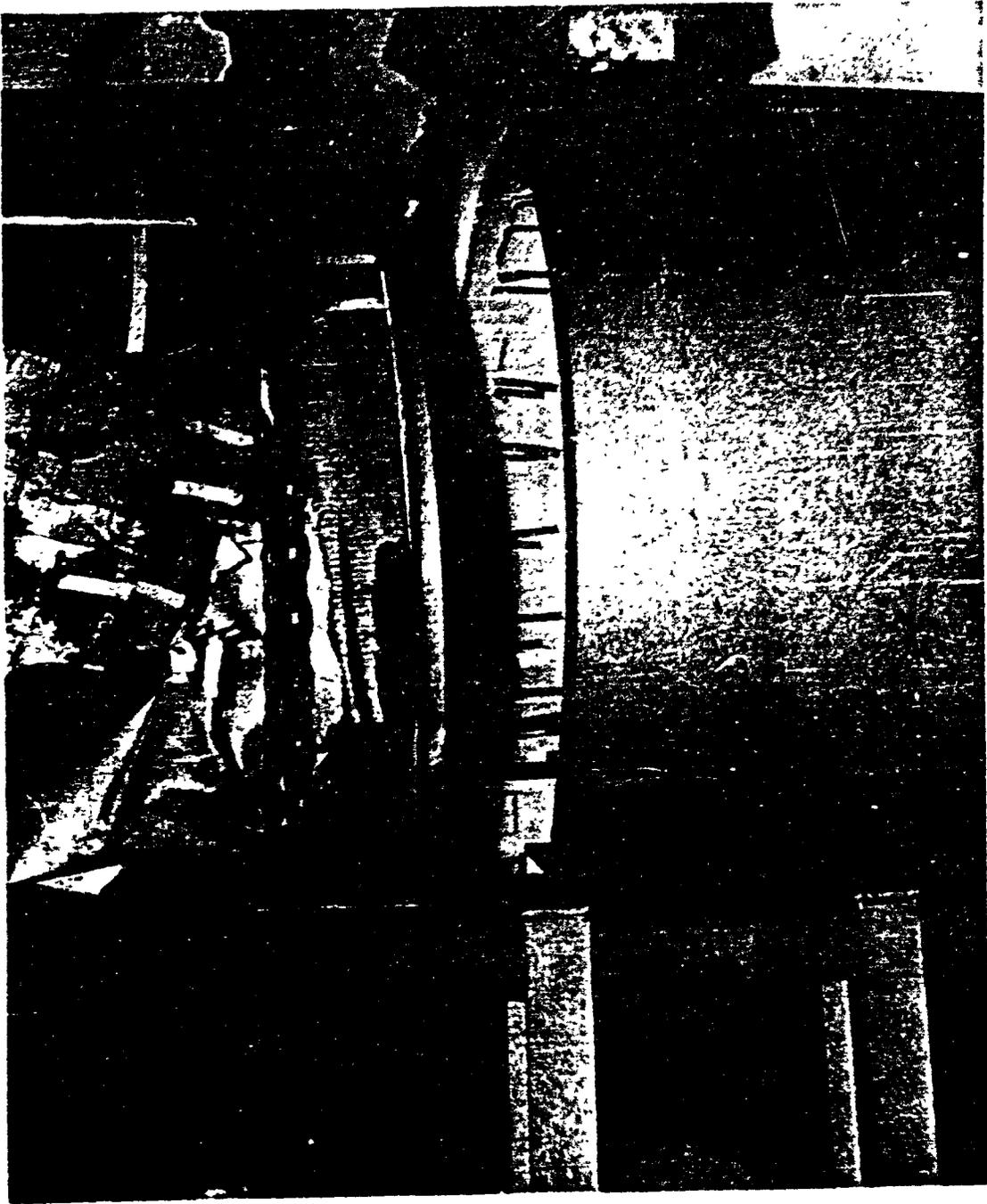


Figure 5



Figure 6



Figure 7

suitable. The toluene should be obtained in glass carboys rather than steel drums to avoid possible coloration from rust.

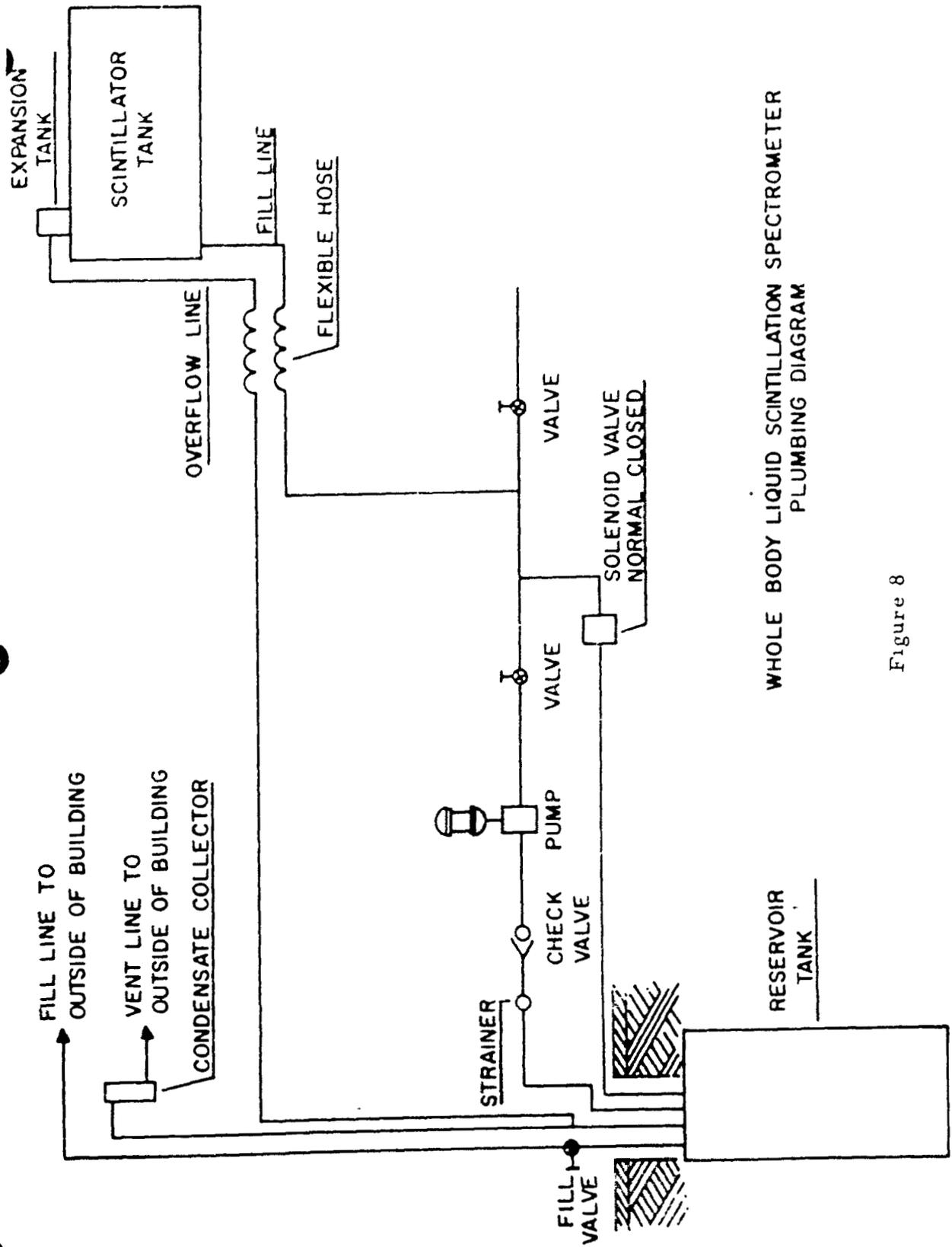
Because of the toxic and flammable nature of the scintillation solvent a piping system for filling and emptying the detector tank is required as well as certain safety devices (Figure 8).

The detector tank is filled from a 160 gallon sump or reservoir tank which is buried in the ground. The sump is also used as an emergency reservoir should the need arise for emptying the detector tank. The solution is lifted from the reservoir to the detector tank by a motor driven pump with an output of about 12 gallons per minute. The pump is of the impellor type with teflon bearings and impellors. Teflon is toluene resistant and does not require a lubricant which might color the solution.

The reservoir tank is gravity filled through a line to the outside of the building. A separate line vents the reservoir tank through a condensate collector.

Flexible (1" ID) stainless steel hoses are used to connect the fill and overflow lines to the detector tank. This eliminates the need for disconnecting any piping when the detector is rolled out of the shield. All pipes and valves are stainless steel with flanged joints and teflon gaskets. A one-way valve and a strainer are inserted between the sump tank and pump. A gate valve is also located between the pump and detector tank to prevent retrograde loss through the pump.

Returning directly to the reservoir tank is a line with a solenoid operated valve which is normally closed. If a leak occurs in the system this valve is automatically opened and the solution returns to the reservoir tank with a drainage time of about 12 minutes. Since the light shield covering the



WHOLE BODY LIQUID SCINTILLATION SPECTROMETER
PLUMBING DIAGRAM

Figure 8

multiplier phototube greatly limits the escape of solution through a break in a glass window, the 12 minute drainage time seems adequate.

An inside line also connects to the detector tank fill line through a gate valve. This is primarily used for checking the level of the detector tank and for topping the detector after pumping.

A continuously operated turbo-compressor (Spencer Turbine Co.) samples air in the room and inside the shield and feeds a Combustible Gas Detector (Mine Safety Appliance). The gas detector is calibrated for toluene. When the gas detector is activated it automatically opens the solenoid dump valve, shuts off all power in the room including air conditioner, withdraws the sling from the detector well, and energizes explosion proof lighting, alarm horn, and exhaust fan. This condition prevails until the cause is cleared and the vapor detector is reset by the operator.

2.5 Electronics for Liquid Scintillation Counter

The use of thirty multiplier phototubes (5 inch - Dumont #6364) provides approximately 5.8 per cent photo-cathode coverage of the area presented by the scintillation solution. The multiplier phototubes are wired in parallel in two banks of fifteen tubes each. The multiplier phototubes in a given row are alternated between the two banks producing a checkerboard pattern. Scintillations within the detector tank are viewed by at least one multiplier phototube in each bank, and by observing coincident events between the two banks random phototube noise is reduced.

Dynacon Insulator (Westinghouse) strips 72 inches long and approximately 8 inches wide are mounted on channels welded to the tank (Figure 2) and are used for mounting signal and ground busses, high voltage leads and

filters, and signal coupling capacitors. Four strips are placed so as to have all leads to the phototubes approximately the same length. Leads are inner connected with buss wires.

The output of each bank is fed to a preamplifier through eighteen inches of (RG-62/u) coaxial cable. The stray capacitance to ground of each bank is approximately 300 micro-micro-farads. Since the amplifiers require input pulses approximately 30 micro-seconds wide the preamplifier input resistance is 17,500 ohms, giving a time-constant of 5.25 micro-seconds or a pulse width of 31.5 micro-seconds. The preamplifier is normally used at a gain of ten.

The signal from each preamplifier is then fed to an amplifier used at a gain of 1100. The output of the amplifiers are then fed to both coincidence units.

Each coincidence unit contains two pulse height analyzers. One is fed from the bank I amplifier and one from the bank II amplifier. The output signals from both pulse height analyzers are then fed to a coincidence circuit. A front panel switch selects the mode of operation of the coincidence unit. This may be set so that single channel pulses from either pulse height analyzer or coincidence pulses appear at the output.

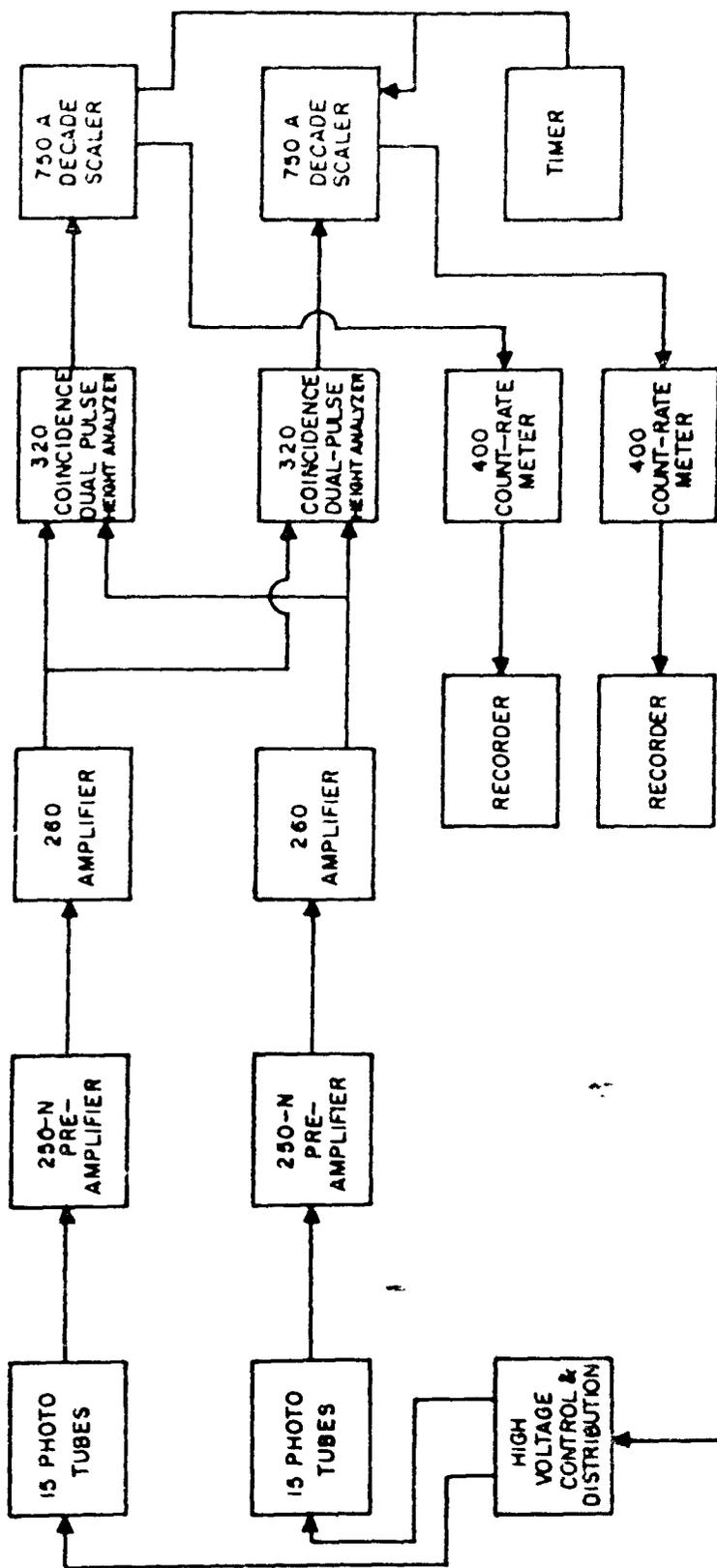
Two coincidence units are used and Channel I accepts pulses between 3 and 7 volts (0.3 to 0.8 mev). Channel II accepts pulses between 8 and 30 volts (0.9 to 2.0 mev).

Coincidence units in turn feed Channel I and Channel II scalars. Pulses are reshaped for the Dual Channel Count Rate Meter, which also drives two strip-chart recorders. The scalars are controlled by an electronic timer which has preset time of 1 through 1000 seconds.

Voltage is supplied to the multiplier phototubes through a Control and Distribution panel, from a 30 ma high voltage supply. The high voltage panel allows the phototubes to be used individually or in any combination. Voltage to each tube is regulated by a potentiometer on the Control and Distribution panel.

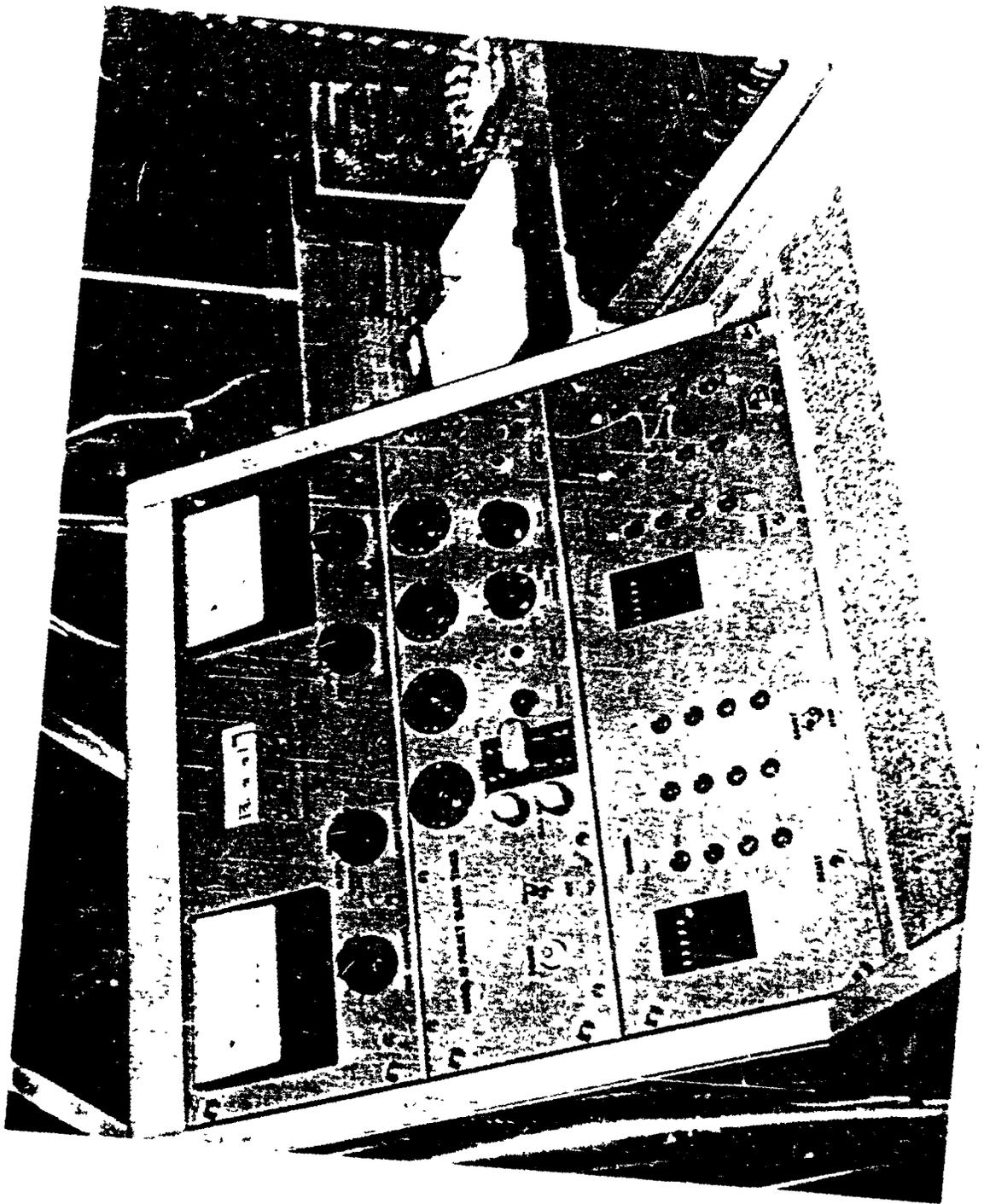
Two AC circuits provide 45 amperes for the electronics. Each AC circuit has a radio interference filter (Hopkins, type 109-S2), voltage regulators (Sorenson, 1000 S), and a noise suppression filter (Miller, #7843).

A block diagram of the electronics system for the liquid scintillation counter is shown in Figure 9. The console and electronic instrumentation are shown in Figures 10 and 11.



WHOLE BODY LIQUID SCINTILLATION SPECTROMETER
ELECTRONIC SYSTEM

Figure 9



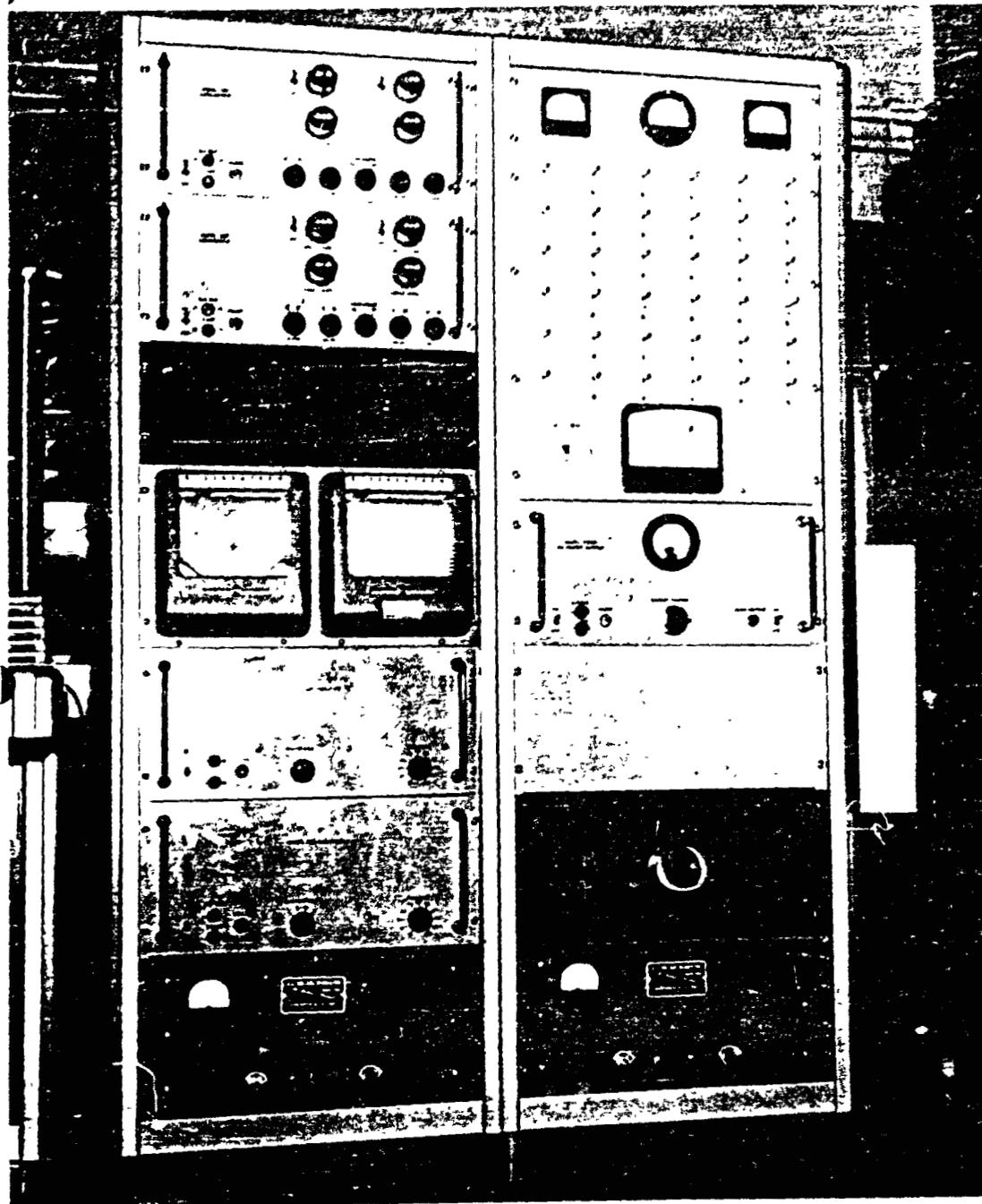


Figure 11

3.0 Performance Characteristics of the 4 π Liquid Scintillation Counter

The performance characteristics of large volume liquid scintillation detectors have been well documented (2, 3). The detector at Walter Reed, however, was the first human counter to use 5 inch multiplier phototubes with a 20 inch diameter well, and the characteristics of this detector are recorded in some detail.

3.1 Multiplier Phototube Balance

Ideally the multiplier phototubes used in a large volume detector would have identical characteristics, particularly uniform photo-cathode sensitivity and high signal to noise output. Because of the variability of gain and noise level, some process of selecting phototubes was necessary. High gain phototube performance was judged by the amplifier gain setting required to locate the photo-peak from Cs-137 in a specific channel, using a multi-channel analyzer and a 1 3/4 x 2 inch thallium activated NaI crystal centered on the tube face.

After the installation of the selected phototubes in the detector, the high voltage to each phototube was carefully adjusted (this ranged from 1140 to 1540 volts) to produce a background count rate of 30 c/s using low amplifier gain and discriminator gate settings of 3 and 30 volts. Inordinate noise levels with low amplifier gain incriminate a noisy multiplier phototube, otherwise the 30 c/s noise level adjustment is made. To determine the relative balance of phototube performance, i. e., light collecting efficiency, a Cs-137 source (250 ml volume in a 6 inch long plastic vial) was placed at various distances along the length of the detector well. The curve obtained, Figure 12, shows the relative counting efficiency of this source as compared to the geometrical -

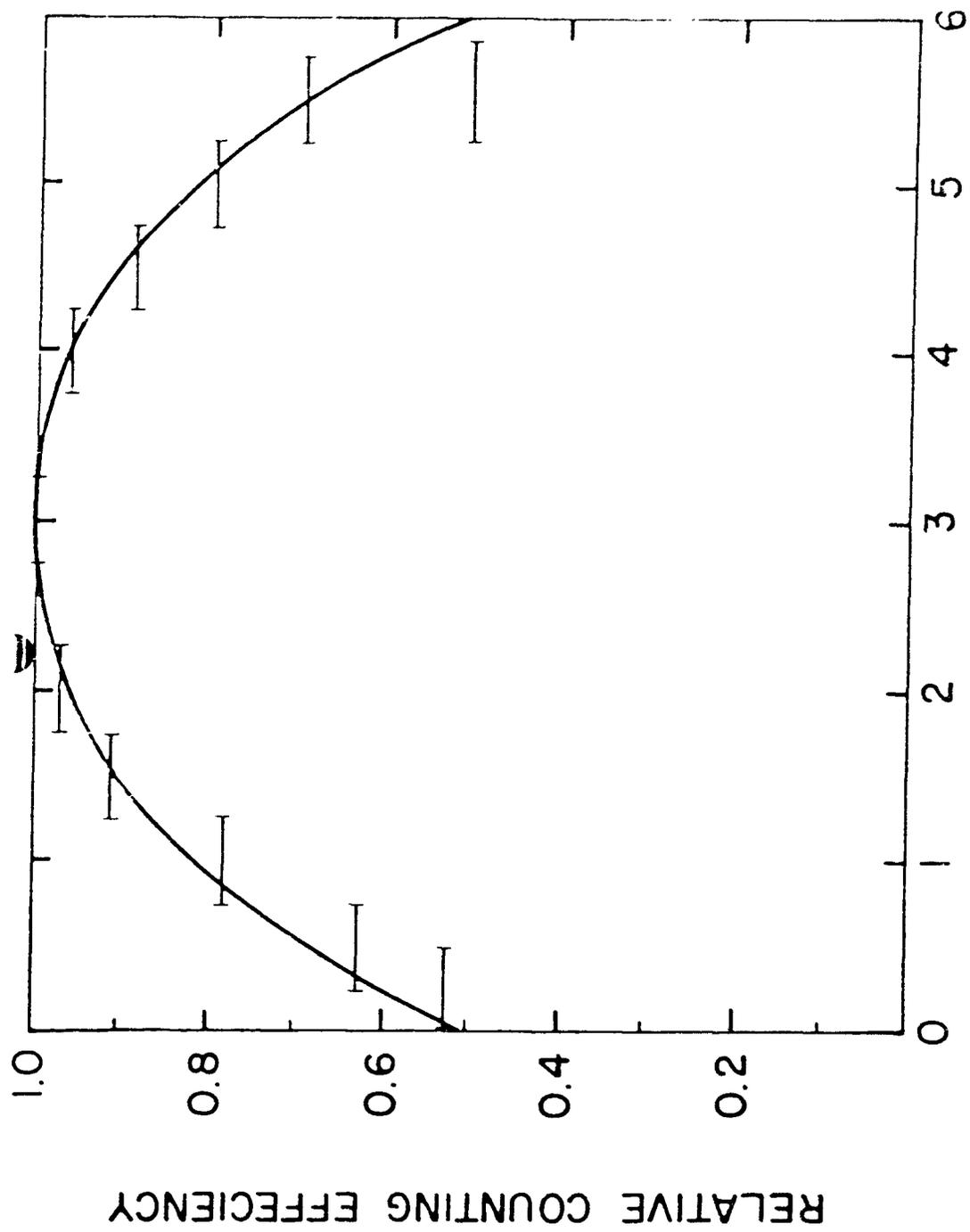


Figure 12
 DISTANCE ALONG DETECTOR WELL (FEET)

loss at the open ends of the detector well. The agreement between relative counting efficiency and geometrical loss indicates uniform phototube performance along the entire detector well.

3.2 Differential Energy Spectra

With a photo-cathode area of about 5.8 per cent of the scintillation surface, good resolution of Cs-137 and K-40 gamma-ray energies was expected. Since the construction of the Walter Reed detector, Anderson (3) has shown however, that the photo-cathode to scintillation area must be about 18 per cent for resolution of the order of 20 per cent with intervals of about 0.5 mev separating the Compton energy peaks. The photo-cathode area of the Walter Reed detector is considerably less than optimum, however the required photo-cathode area imposes serious design problems unless 16 inch phototubes are used. Sixteen inch phototubes increase the diameter of the shield required.

The differential spectrum for Cs-137 and K-40, is shown in Figure 13. The spectral width at half height is about 48 per cent. Also the response from Cs-137 extends into the region of high background from thermionic pulses. Since one of the major functions of the detector was to measure the Cs-137 gamma activity of the human subject, coincidence counting was necessary to reduce random background noise for Cs-137 pulses to be detected. Consequently the multiplier phototubes were arranged in two banks of 15 tubes each as previously described.

With two coincidence units, each having dual pulse height analyzers, two broad energy bands were selected with each energy bank recording only coincident events. For each energy band the upper gate setting was

approximately twice that of the lower gate, and these widths correspond to about 0.3 to 0.8 mev and 0.9 to 2.0 mev. Although the upper and lower discriminator gate settings for each energy band were selected to maximize the net count rate of Cs-137 or K-40 as compared to background (S^2/B), compromises were necessary in order to obtain acceptable counting efficiencies in the two channels.

3.3 Background Stability and Depression

The differential spectrum of the background count rate obtained using the 30 phototubes in parallel is plotted in Figure 13. The spectrum extends from the region of thermionic noise up to about 3 mev.

For either system of 15 multiplier phototubes, using two broad energy bands, the non-coincidence background count rate is several thousand per second, whereas coincidence background is about 120 c/s in the Cs-137 energy band and about 250 c/s in the K-40 energy band. From these coincidence background rates statistical accuracies of 1.0 to 0.5 per cent of the average background should be obtainable in 100 seconds of counting time. Figures 14 and 15 show the typical frequency distribution of 100 consecutive background determinations (each of 100 seconds duration) which required about three hours of counting time. The observations are normally distributed about the mean value for each energy band; one standard deviation is 1.1 per cent for the low energy band and 0.7 per cent for the high energy band. The observed values closely approximate the statistical accuracy expected and indicate that the stability of the background count rate extends over periods of hours.

The background count rate of the liquid scintillation counter is reduced when inert samples of large mass are placed in the detector well.

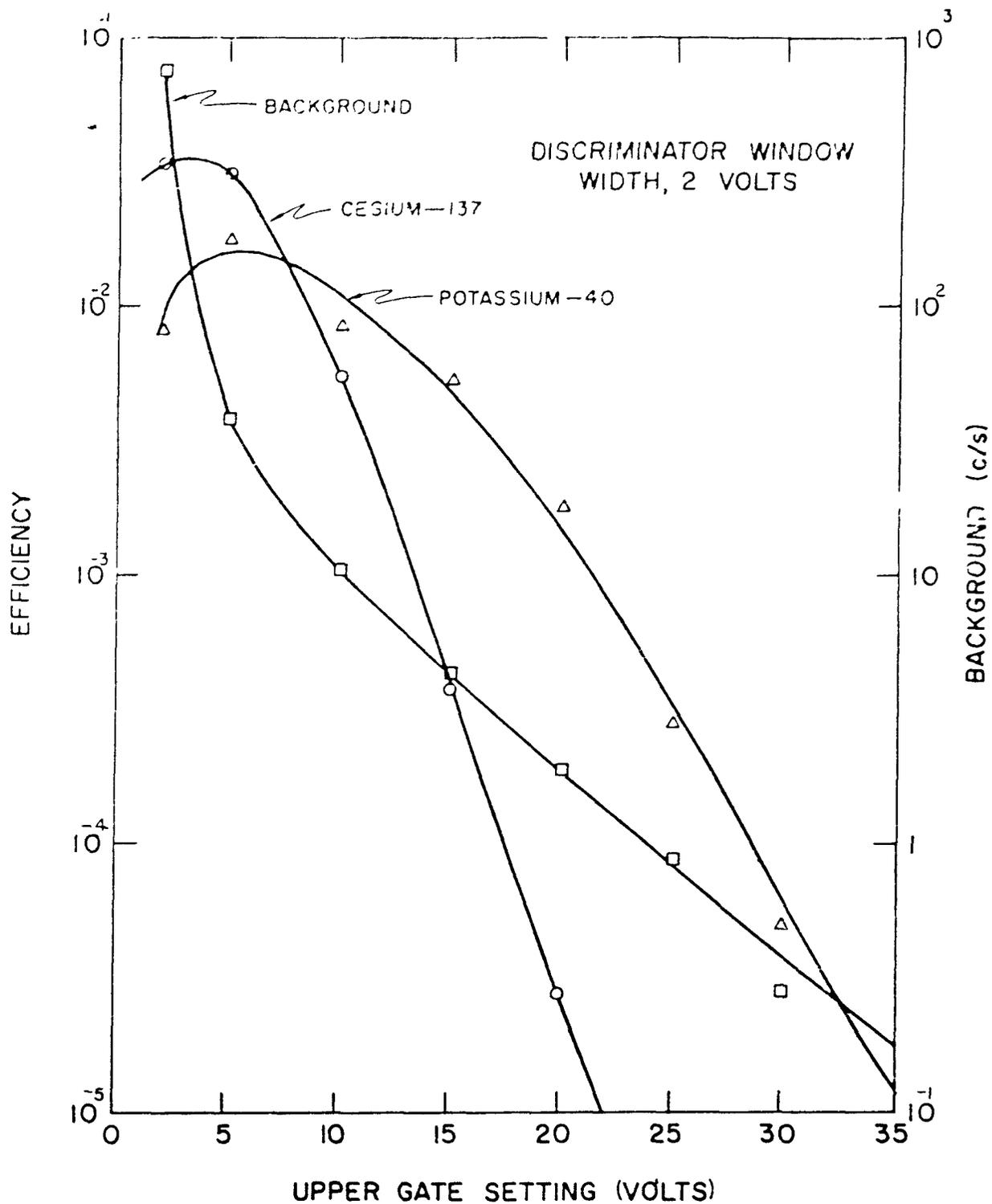


Figure 13

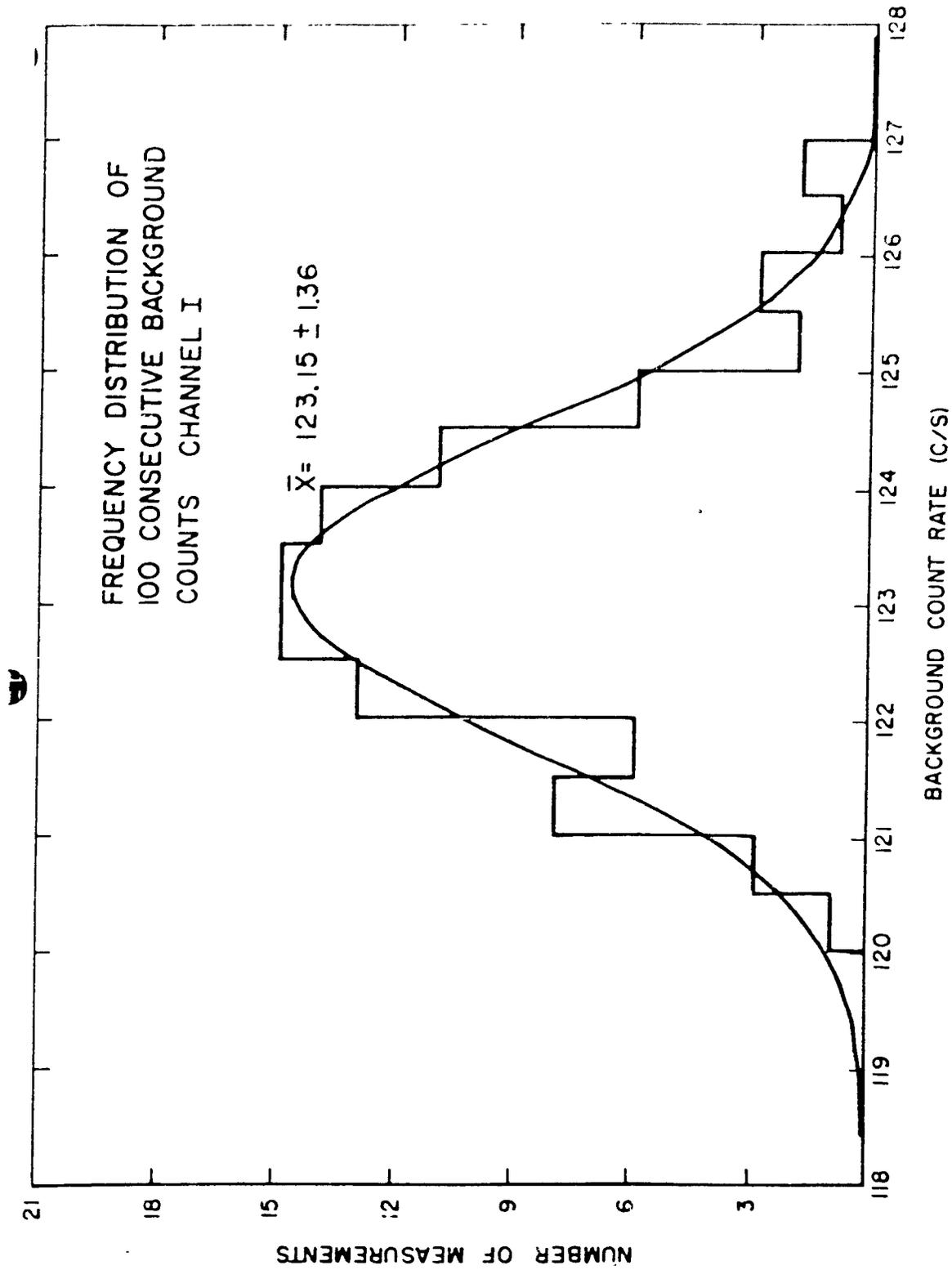
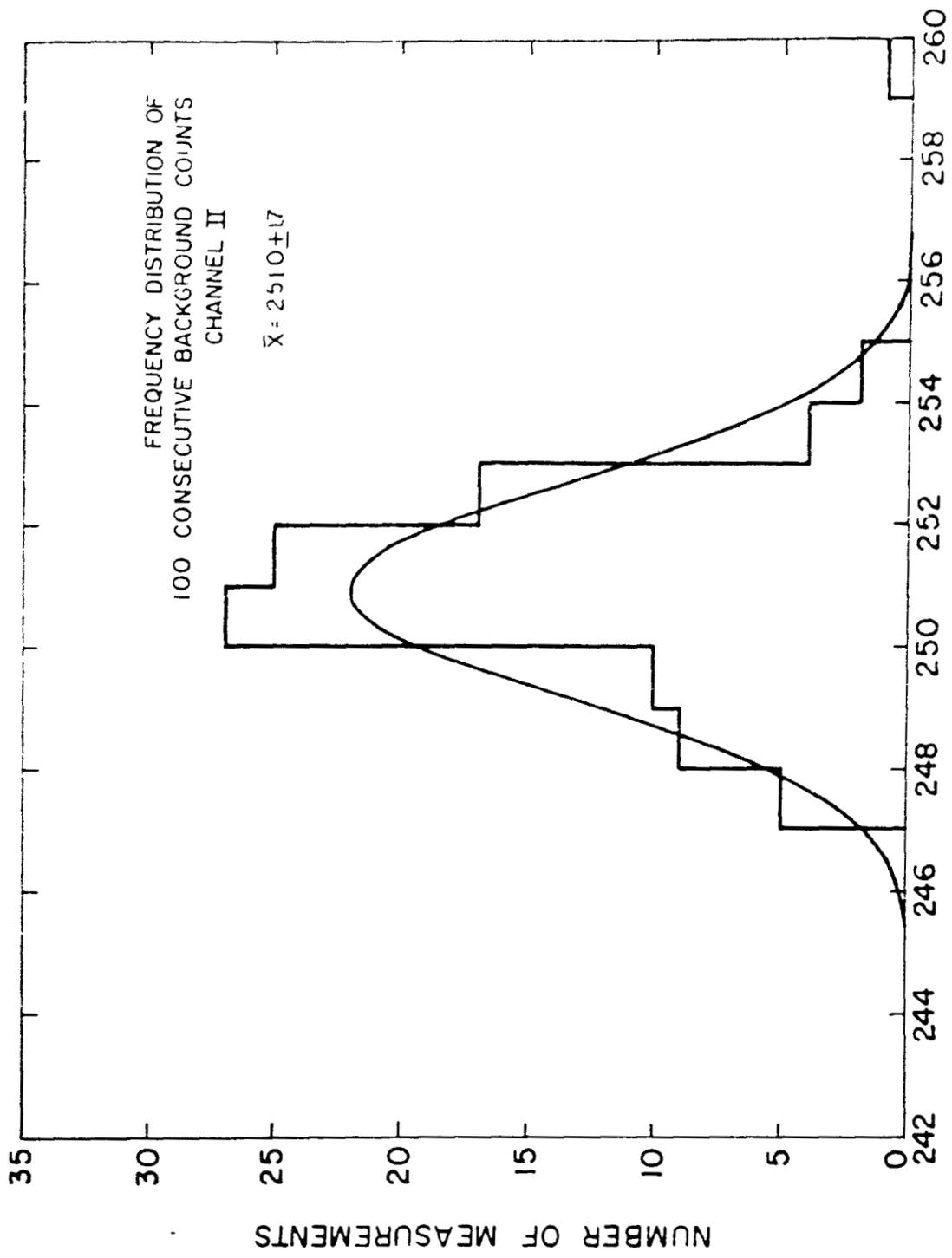


Figure 14



BACKGROUND COUNT RATE (C/S)

Figure 15

filtered through an ion exchange column and counted in a gas flow
ethylene carboys. The results of two series of measurements show that
the reduction in background count rate is directly related to sample mass
(Figure 16). In Channel II the decrease is 6.3 c/s for a 150 lb. sample
or about 10 per cent of the average count rate of K-40 in the human subject.
For Channel I the value is uncertain even for large masses, since the
maximum decrease for 240 lbs. was 2 per cent of the average background
with the detector well empty. For a large subject the correction could be
of the order of 10 per cent of the average Cs-137 count rate and is currently
in use, since the potential error is a conservative one.

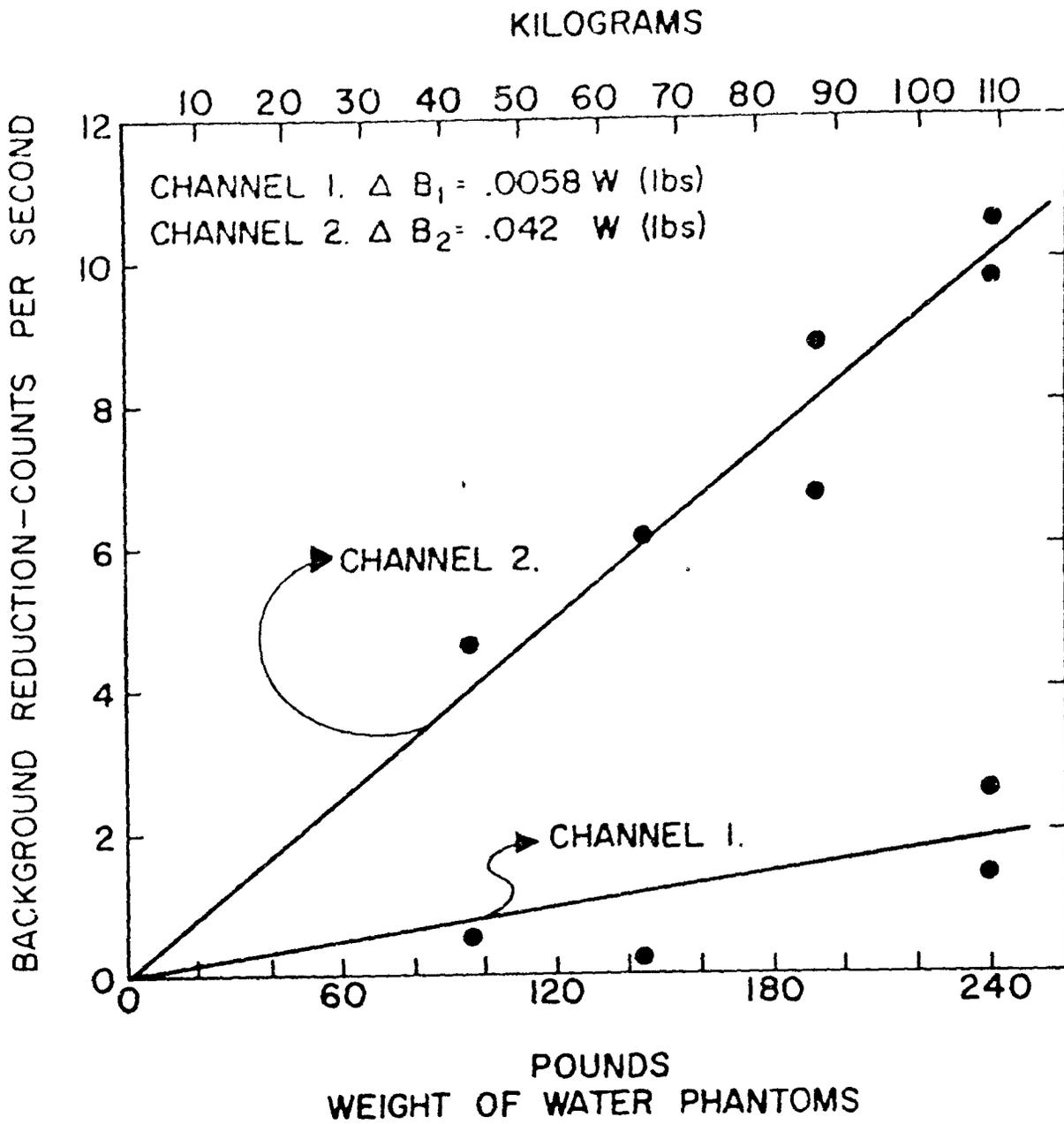


Figure 16

4.0 Calibration of the Liquid Scintillation Counter

The calibration of a gamma-ray spectrometer for the determination of absolute disintegration rates in small samples can be a difficult and tedious task. In the case of low-level whole-body counting, the human subject does not prove to be an ideal source because of size and mass variations, the low-levels of activity encountered, and the distribution of the activity within the body. Primary concern has been with cesium-137 and potassium-40 determinations and the calibration studies included in this report are for these two radio-elements. Both are considered to be rather uniformly distributed in the human.

Calibration for the simultaneous determination of two radio-elements is further compounded by the limited energy resolution afforded. To resolve the absolute amounts of radioactivity from the count rate recorded in each channel the counting efficiency for each radio-element in both channels must be known and must be known as a function of the mass of the human subject or sample of interest.

4.1 Calibration Sources

The procedures used to obtain counting efficiencies for Cs-137 and K-40 have been (a) the assembly of diffuse homogeneous sources of varying mass from 2.5 liter plastic bottles containing small quantities of the radio-element under study, (b) the use of a plastic manikin (REMCAL, Alderson Research Laboratories), and (c) the determination of the counting efficiency in the normal human subject at some time after equilibrium distribution.

4.1.1 Plastic Bottle Phantoms

Multiple determinations of Cs-137 and K-40 counting efficiencies, using homogeneous sources assembled from 2.5 liter plastic bottles, have been made as a function of mass. The K-40 activity levels most frequently used were 90.8 gm K Cl (142 K-40 gamma disintegrations per second) in each bottle dissolved in triple distilled water with a total weight of 5 lbs. per bottle. For cesium-137 each bottle contained 100.6 gamma disintegrations per second obtained from a National Bureau of Standards solution of Cs-137. Three hundred second counting times were used for each measurement and the weight range investigated was from 5 to 240 lbs. for the plastic bottle assemblies. The counting efficiency of cesium-137 or potassium-40 gamma-rays in the bottle geometry decreases with mass and between 40 and 240 lbs. self-absorption is linear. During the time period July-December 1958, nine calibration studies were made and the best fit straight line was obtained for each series by the least squares method. The results are shown in Tables 1 and 2. The counting efficiency for each radio-element is:

$$\text{K-40 efficiency (Channel I)} = 0.0649 - 0.000059 W$$

$$\text{(Channel II)} = 0.2458 - 0.000256 W$$

$$\text{Cs-137 efficiency (Channel I)} = 0.1095 - 0.000132 W$$

$$\text{(Channel II)} = 0.0563 - 0.000102 W$$

Variations encountered in using these homogeneous sources depend upon the way in which the bottles are loaded into the detector and day-to-day electronic drifts. To obviate these differences a loading plan is routinely

Table 1

CESIUM¹³⁷ COUNTING EFFICIENCY STUDIES USING 2.5 LITER
PLASTIC BOTTLE ASSEMBLIES

<u>DATE</u>	<u>CHANNEL I</u>		<u>CHANNEL I I</u>	
	<u>INTERCEPT VALUE</u>	<u>SLOPE (X 10⁻⁴)</u>	<u>INTERCEPT VALUE</u>	<u>SLOPE (X 10⁻³)</u>
21 July 58 ⁽²⁾	0.1093	- 1.43 W	0.0492	- 0.29 W
4 Aug 58 ⁽²⁾	0.1117	- 1.76 W	0.0543	- 4.17 W
11 Aug 58 ⁽²⁾	0.1093	- 1.55 W	0.0486	- 0.42 W
2 Sep 58 ⁽²⁾	0.1069	- 1.18 W	0.0591	- 0.82 W
8 Sep 58 ⁽²⁾	0.1072	- 1.19 W	0.0575	- 0.53 W
15 Sep 58 ⁽²⁾	0.1080	- 1.14 W	0.0603	- 0.88 W
23 Sep 58 ⁽²⁾	0.1108	- 1.05 W	0.0551	- 0.28 W
10 Nov 58 ⁽²⁾	0.1090	- 1.14 W	0.0575	- 0.62 W
13 Dec 58 ⁽²⁾	0.1105	- 1.45 W	0.0657	- 1.48 W
1958 DATA	0.1095 ± 0.0015	- 1.32 W ± 0.23	0.0563 ± 0.0051	- 1.02 W ± 1.16
1 June 59 ⁽³⁾	0.1109	- 1.84 W	0.0555	- 0.42 W
18 Apr 60 ⁽⁴⁾	0.1097	- 1.47 W	0.0578	- 0.48 W
19 Apr 60 ⁽⁴⁾	0.1109	- 1.37 W	0.0586	- 0.48 W
ALL DATA	0.1099 ± 0.0013	- 1.42 W ± 0.25	0.0567 ± 0.0039	- 0.77 W ± 0.90

W = Subject or Sample weight in pounds.

(1) Bottle assemblies of 1 June 1959, 18 April 1960 and 19 April 1960 were completely filled with no air space, each individual bottle weighing 6.67 pounds. All others were approximately two thirds full, each individual bottle weighing 5 pounds.

- (2) 97.8 γ dps Cs-137 per bottle
- (3) 18.82 γ dps Cs-137 per bottle
- (4) 1932 γ dps Cs-137 per bottle.

Table 2

POULSIUM⁴⁰ COUNTING EFFICIENCY FINDINGS IN 2.5 LITER
ELASTIC BOTTLE ASSEMBLIES

DATE	CHANNEL I		CHANNEL II	
	INTERCEPT VALUE	SLOPE ($\times 10^{-3}$)	INTERCEPT VALUE	SLOPE ($\times 10^{-3}$)
25 July 58 ⁽²⁾	0.0662	- 0.80 W	-	-
4 Aug 58 ⁽²⁾	0.0639	- 0.55 W	0.2507	- 0.272 W
11 Aug 58 ⁽²⁾	0.0697	- 1.23 W	0.2451	- 0.213 W
2 Sep 58 ⁽²⁾	0.0629	- 0.36 W	0.2457	- 0.268 W
8 Sep 58 ⁽²⁾	0.0657	- 0.72 W	0.2376	- 0.159 W
15 Sep 58 ⁽²⁾	0.0634	- 0.49 W	0.2401	- 0.240 W
10 Nov 58 ⁽²⁾	0.0671	- 0.72 W	0.2462	- 0.278 W
13 Dec 58 ⁽²⁾	0.0616	- 0.13 W	0.2462	- 0.276 W
23 Sep 58 ⁽²⁾	0.0656	- 0.59 W	0.2522	- 0.305 W
1958 DATA	0.0649 \pm 0.0024	- 0.59 W \pm 0.30	0.2458 \pm 0.0047	- 0.256 W \pm 0.041
19 May 59 ⁽³⁾	0.0654	- 0.41 W	0.2536	- 0.284 W
18 Feb 60 ⁽⁴⁾	0.0605	- 0.23 W	0.2439	- 0.303 W
19 Apr 60 ⁽⁴⁾	0.0632	- 0.41 W	0.2471	- 0.259 W
ALL DATA	0.0638 \pm 0.0025	- 0.45 W \pm 0.25	0.2470 \pm 0.0046	- 0.265 W \pm 0.039

W = Subject or Sample weight in pounds.

(1) Bottle assemblies of 19 May 1959, 18 February 1960 and 19 April 1960 were completely filled with no air space, each individual bottle weighing 6.67 pounds. All others were approximately two thirds full, each individual bottle weighing 5 pounds.

- (2) 142.8 γ dps K-40 per bottle
- (3) 37.5 γ dps K-40 per bottle
- (4) 840 γ dps K-40 per bottle.

used as shown in Figure 17a and the counting efficiencies of 80 lb. Cs-137 and K-40 assemblies are determined daily. Tables 1 and 2 also show results obtained for several specific activities and with bottles completely filled, i. e., 6.67 lbs., having no air spaces. Because of the change in mass and fluid volume of each bottle, a different loading plan was used (Figure 17b).

4. 1. 2 Plastic Manikin

The plastic manikin is constructed of cellulose acetate butyrate with moveable extremities and segmented at the waist. Within the appropriate body cavities are hollow plastic shells simulating thyroid, lungs, stomach, liver, spleen, and kidneys. Male gonads are also simulated. The entire assembly weighs 8.1 kg and is free ($< 3 \times 10^{-11} \text{C}$) of gamma activity. The total volume of the phantom is 50.9 liters, including the organs.

The phantom was filled with 50.791 liters of distilled water (excluding thyroid, kidneys, and gonads) containing 165.21 grams of potassium. The K-40 counting efficiency curve obtained for various anatomic phantom parts and the assembled phantom (Figure 18) using the 4 π liquid scintillation counter was

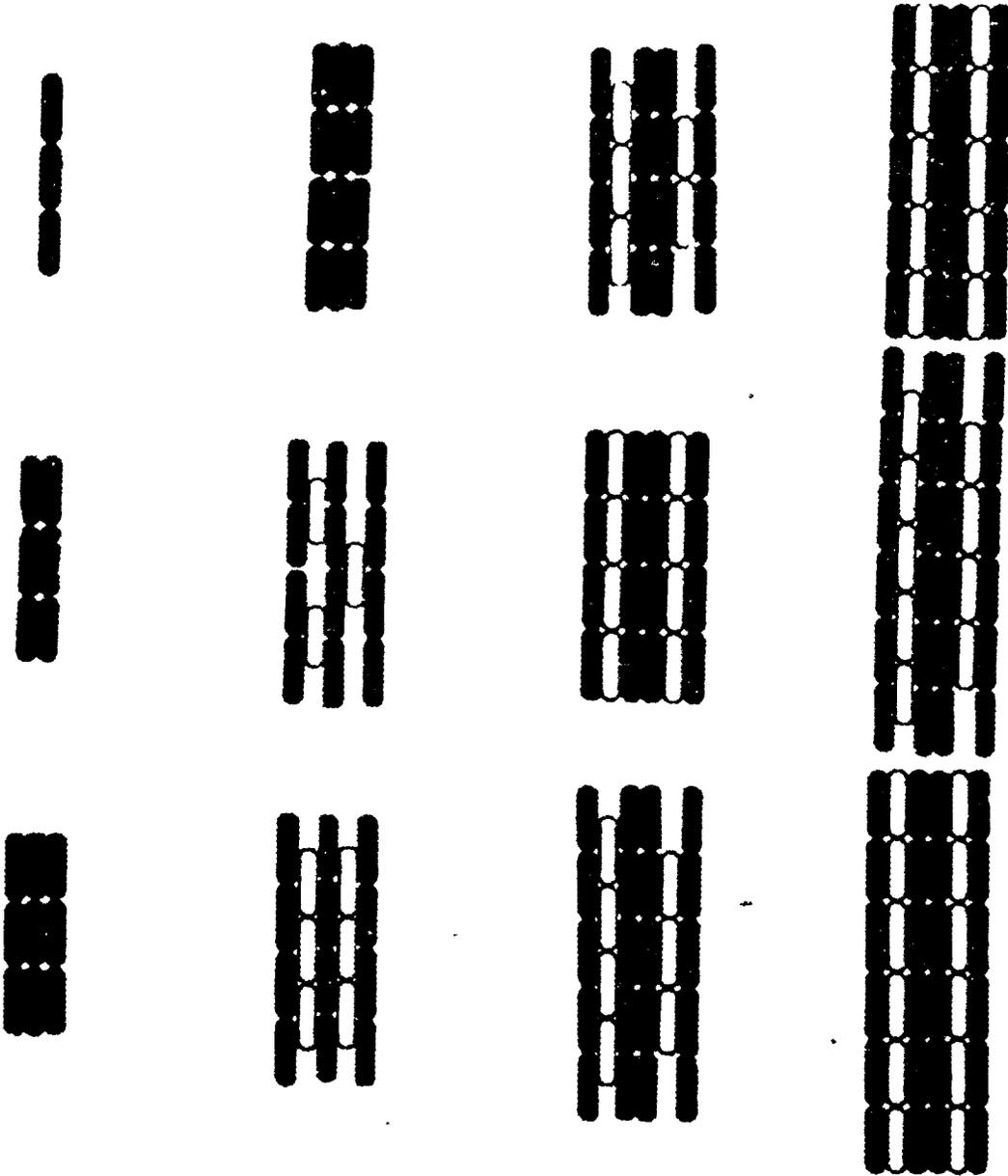
$$\text{K-40 efficiency (Channel II)} = 0.2155 - 0.000260 W (\text{lbs})$$

The intercept value is about 12.4 per cent less than the mean intercept for the bottle assemblies, however, the slope constants are in good agreement.

4. 1. 3 K-42 Calibration Studies

Figure 19 shows the results of K-42 calibration studies using 2.5 liter plastic bottle assemblies, the plastic man, and nine normal human

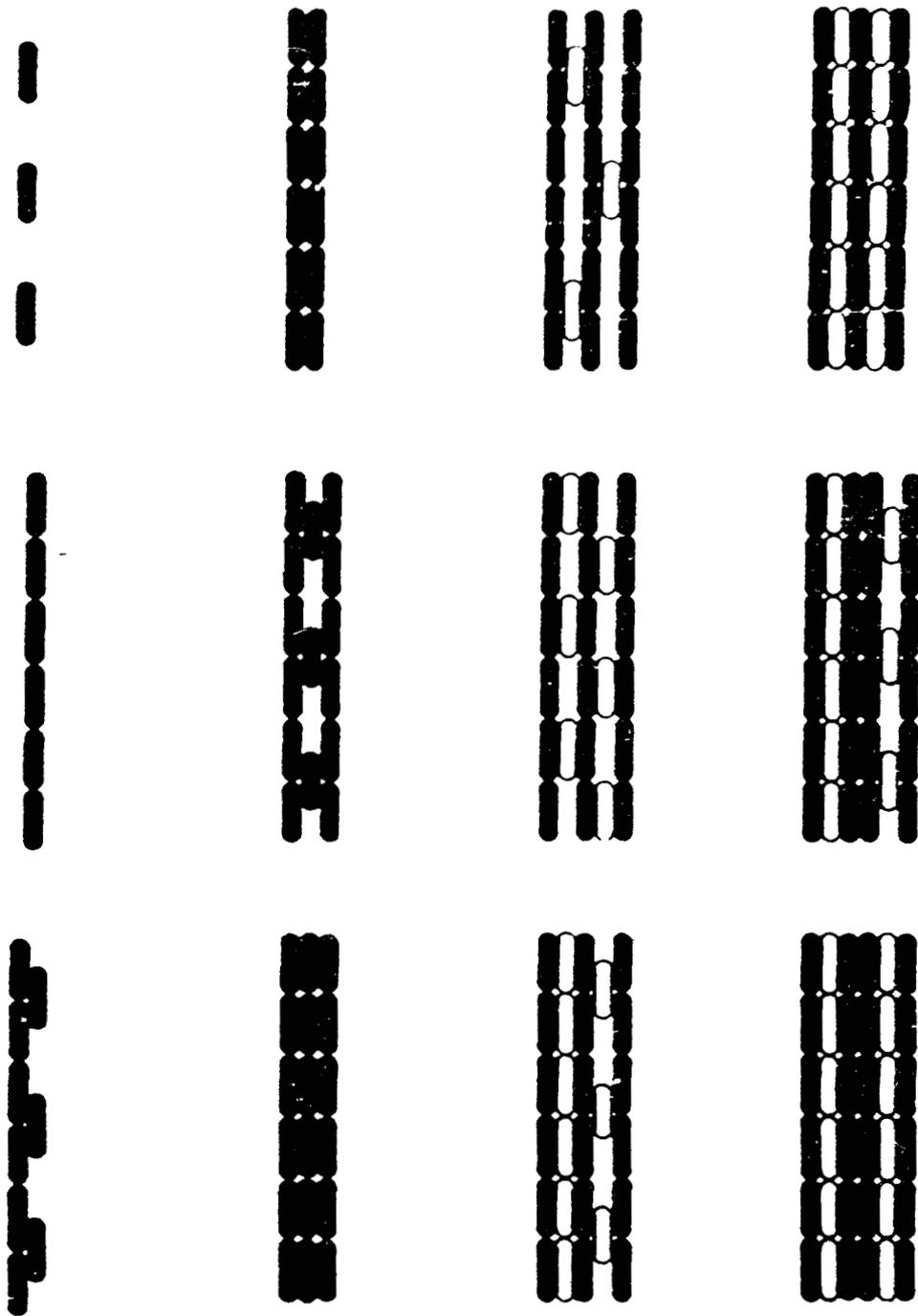
HUMAN COUNTER LOAD PLAN



SHADED BOTTLES ARE BOTTOM LAYER

Figure 17a

HUMAN COUNTER LOAD PLAN



SHADED BOTTLES ARE BOTTOM LAYER

Figure 17b

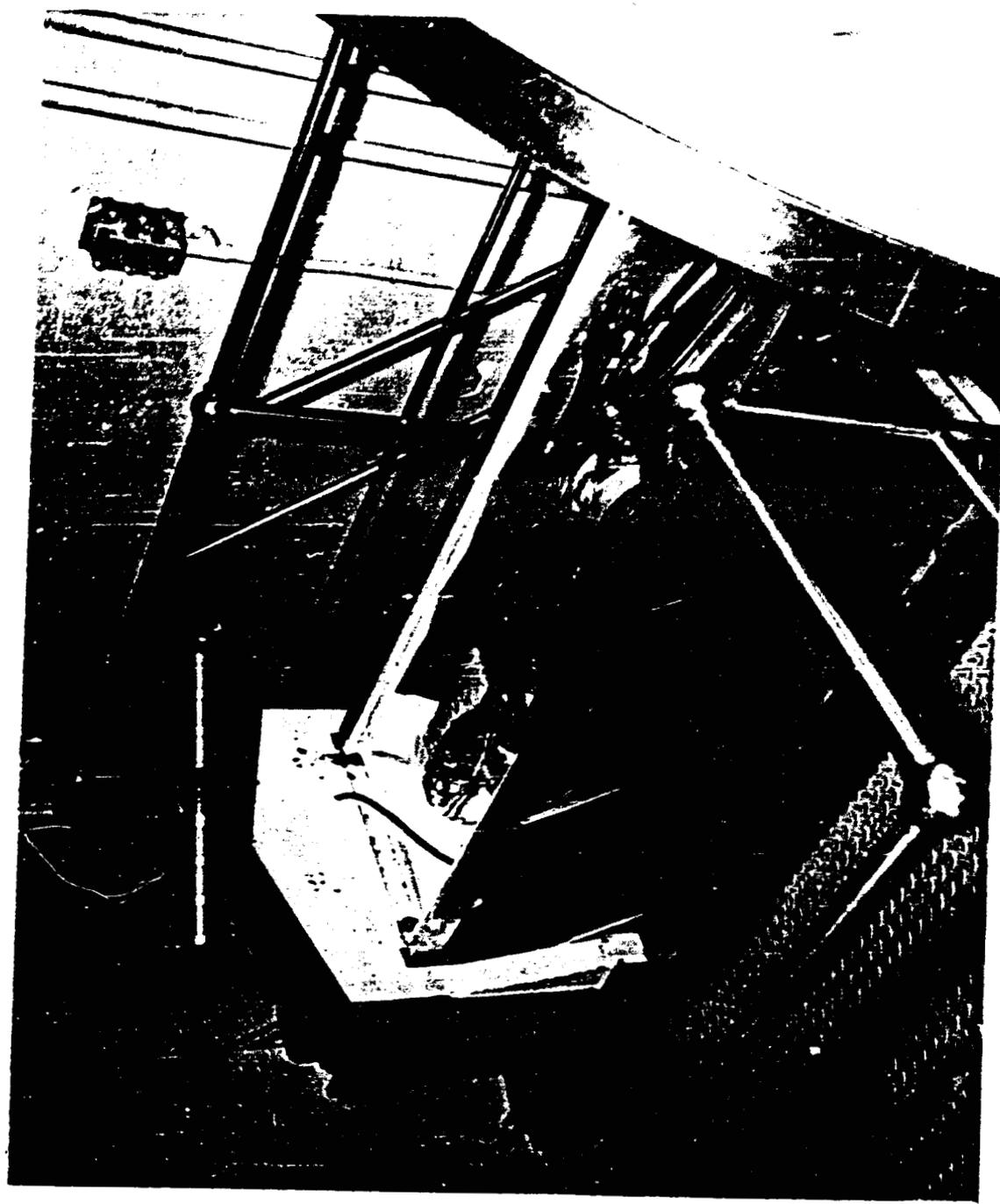


Figure 18

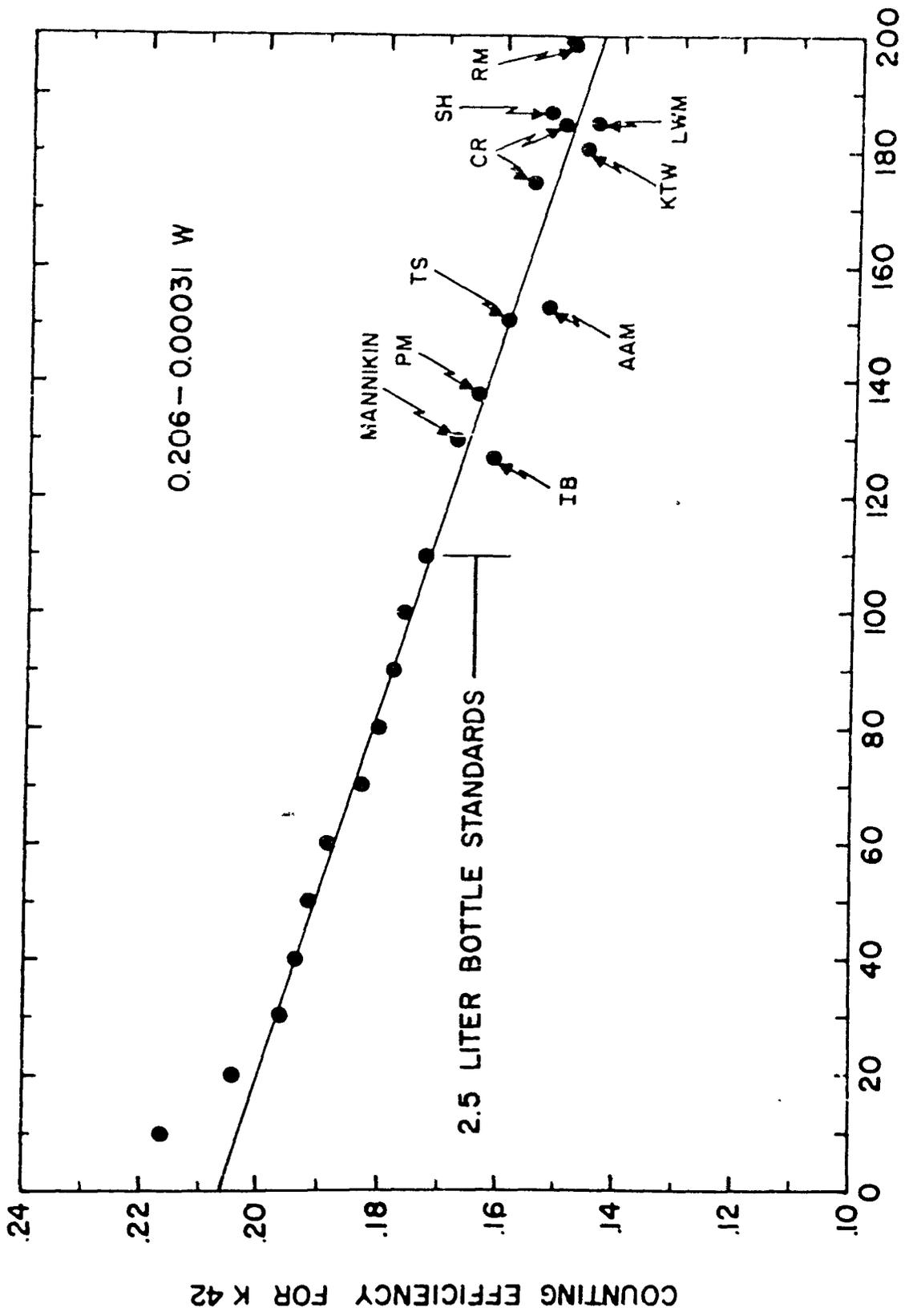


Figure 19

subjects administered oral K-42.

At t_0 each plastic bottle contained 0.102 microcuries or 754.8 gamma disintegrations per second. The plastic man contained 2.104 microcuries K-42, and the nine human subjects ingested 2.104 to 2.152 microcuries after fasting. Whole body count rates were obtained from 45 minutes to 54 hours after administration and no change in counting efficiency of the human subject was evident after twelve hours. All excreta were collected and assayed for K-42 content in appropriate geometries. Excretory loss was considered in determining whole body counting efficiencies.

The expression for K-42 counting efficiency obtained from the composite data was

$$\text{K-42 efficiency (Channel II)} = 0.206 - 0.00031 W \text{ (lbs)}$$

The K-42 intercept value is again lower (16%) than the value obtained using 2.5 liter plastic bottles and is more nearly in agreement (4%) with the K-40 value for the plastic man.

5.0 Methods of Calculating Cs-137 and K-40 Activity in the Human Subject

From the net count rate recorded in each energy band or channel the absolute amount of radioactivity is determined using the counting efficiency for each radio-element in both energy bands. By definition

$$(1) \quad \text{Efficiency} = E = \frac{\text{Counts/second}}{\text{Disintegrations/second}}$$

Let $x = \text{Cs-137 (disint/sec)}$ and $y = \text{K-40 (disint/sec)}$

The total net count rate recorded in each channel is the sum of activities from both radio-elements or

$$(2) \quad T_{\text{Net}}^{\text{I}} = E_{\text{Cs}}^{\text{I}} (x) + E_{\text{K}}^{\text{I}} (y)$$

where E_{Cs}^{I} is the counting efficiency for Cs-137 in Channel I, and E_{K}^{I} is the counting efficiency for K-40 in Channel I. For Channel II the total net count rate is

$$(3) \quad T_{\text{Net}}^{\text{II}} = E_{\text{Cs}}^{\text{II}} (x) + E_{\text{K}}^{\text{II}} (y)$$

The two equations are:

$$(4) \quad x = \text{cesium-137 (ln d/s)} = \frac{E_{\text{K}}^{\text{II}} T_{\text{Net}}^{\text{I}} - E_{\text{K}}^{\text{I}} T_{\text{Net}}^{\text{II}}}{E_{\text{Cs}}^{\text{I}} E_{\text{K}}^{\text{II}} - E_{\text{K}}^{\text{I}} E_{\text{Cs}}^{\text{II}}}$$

$$(5) \quad y = \text{potassium-40 (ln d/s)} = \frac{E_{\text{Cs}}^{\text{I}} T_{\text{Net}}^{\text{II}} - E_{\text{Cs}}^{\text{II}} T_{\text{Net}}^{\text{I}}}{E_{\text{Cs}}^{\text{I}} E_{\text{K}}^{\text{II}} - E_{\text{K}}^{\text{I}} E_{\text{Cs}}^{\text{II}}}$$

Since the background count rate is actually lower during a sample measurement than when the detector well is empty, the decrease in count rate due to mass is added to the net sample count rate (See 3.3).

Let

B_d^I = depression in background count rate in Channel I for subject of weight, w.

B_d^{II} = depression in background count rate in Channel II for subject of weight, w.

then

$$(6) \quad T_{Net}^I + B_d^I = S_{Net}^I$$

$$(7) \quad T_{Net}^{II} + B_d^{II} = S_{Net}^{II}$$

and

S_{Net}^I = true net count rate in Channel I for subject of weight, w.

S_{Net}^{II} = true net count rate in Channel II for subject of weight, w.

Substituting in (4)

$$(8) \quad x = \text{cesium-137 (in d/s)} = \frac{E_K^{II} S_{Net}^I - E_K^I S_{Net}^{II}}{E_{Cs}^I E_K^{II} - E_K^I E_{Cs}^{II}}$$

and in (5)

$$(9) \quad y = \text{potassium-40 (in d/s)} = \frac{E_{Cs}^I S_{Net}^{II} - E_{Cs}^{II} S_{Net}^I}{E_{Cs}^I E_K^{II} - E_K^I E_{Cs}^{II}}$$

The slope constants for the counting efficiency vs. mass curves shown for 13 December 1958 have been used to calculate ALL SUBJECT AND SAMPLE Cs-137 AND K-40 DATA OBTAINED FROM JULY 1958 TO JULY 1960. Counting efficiencies for Cs-137 and K-40 at 80 lbs, using 2.5

liter plastic bottles, are measured daily to obtain intercept constants using the 13 December 1958 slope constants. The daily efficiency values are substituted in equations (8) and (9) for the appropriate subject or sample weight.

The specific activity of potassium-40 used throughout this report is 3 gamma disintegrations per second per gram of K. For cesium-137, 0.823 gamma-ray per disintegration is used (4).

6.0 Description of the Crystal Gamma-Ray Spectrometer

The crystal gamma-ray spectrometer consists of a walk-in shield housing an 8 x 4 inch sodium iodide crystal detector. Associated electronic instruments are a 100 channel pulse height analyzer and variable read-out devices.

6.1 Low Background Walk-In Shield

Measurements of gamma-ray activity are made within a room constructed of seven inch thick (Class B-Armor) plate having interior dimensions of 11 by 5 by 7 feet. The entrance is 3 feet wide by 7 feet high and the door is a hinged, manually-operated, 7 inch thick plate weighing 4 tons.

The subject is counted in an adjustable, tilting, chair of stainless steel tubing with canvas back and seat (Figure 20). Communication between operator and subject is maintained by an intercom system. Room air is circulated and cooled by an air conditioning unit mounted on the ceiling.

6.2 Detector Assembly

The detector is an 8 by 4 inch thallium activated sodium iodide crystal, (Harshaw Chemical Co.), canned in electrolytic copper, and having a quartz window. The crystal is protected by a one-half inch thick disc of lucite which also serves as a beta shield. Four 3 inch multiplier phototubes (Dumont #6363) are optically coupled to the quartz window using silicone compound (Dow Corning QC-2-0057). A 1/2 inch thick teflon disc serves as a light reflector and positions the multiplier phototubes. Each multiplier phototube has a teflon base (Figure 21) and each tube is surrounded by a mu-metal shield (Figure 22). A light-tight stainless steel cover encloses the multiplier phototube assembly. The crystal detector assembly is

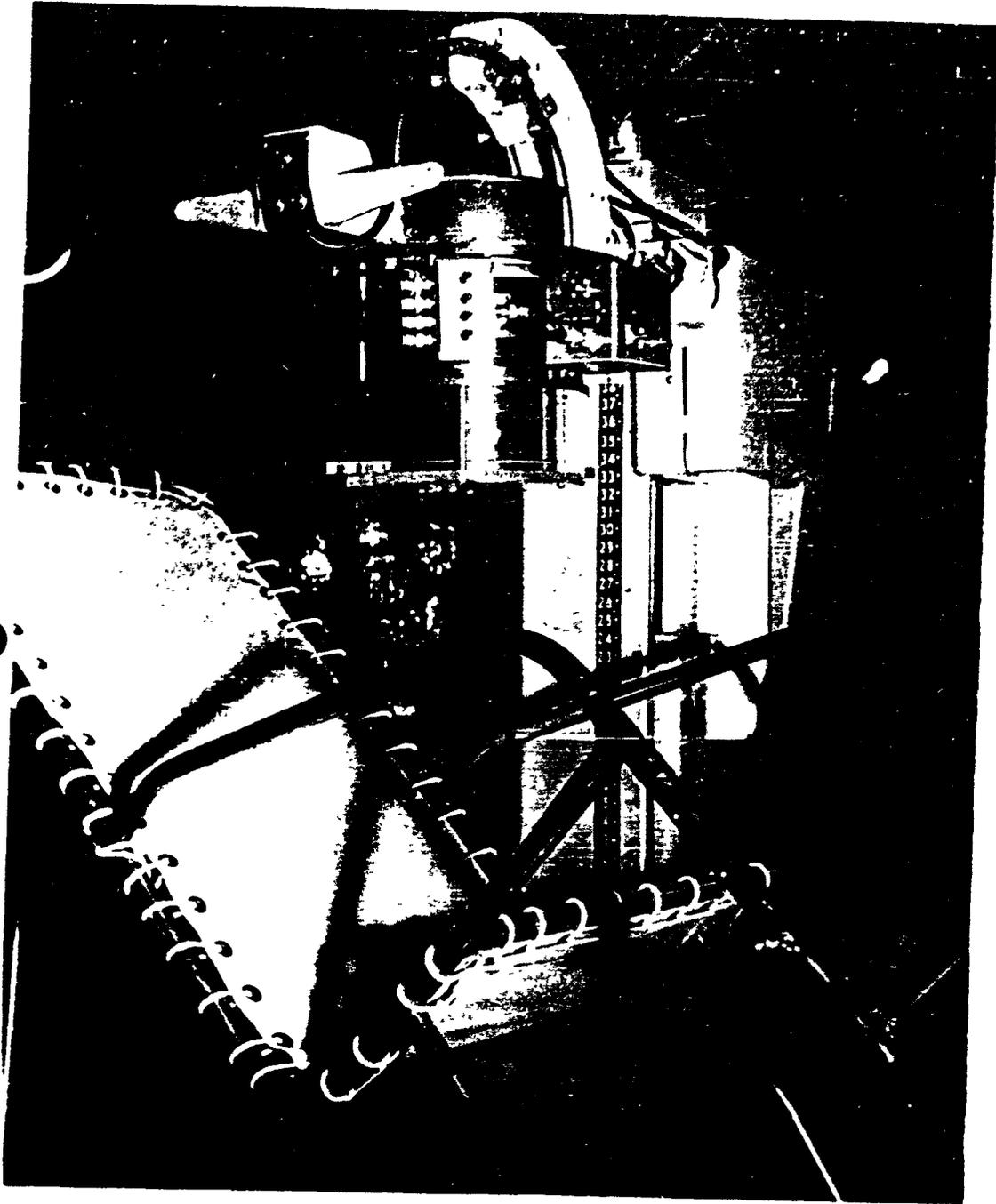


Figure 20

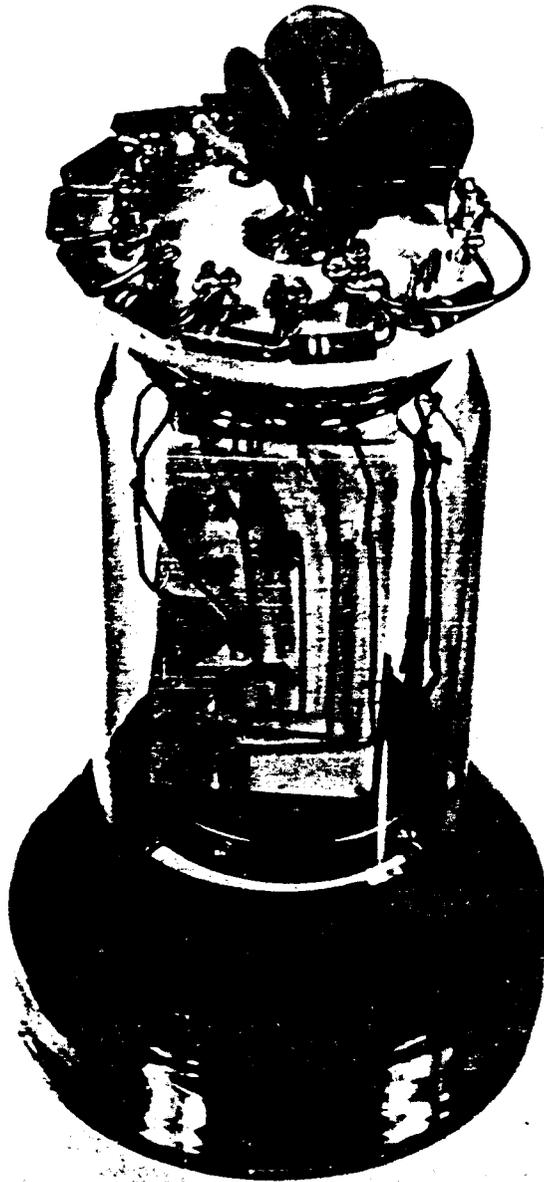


Figure 21

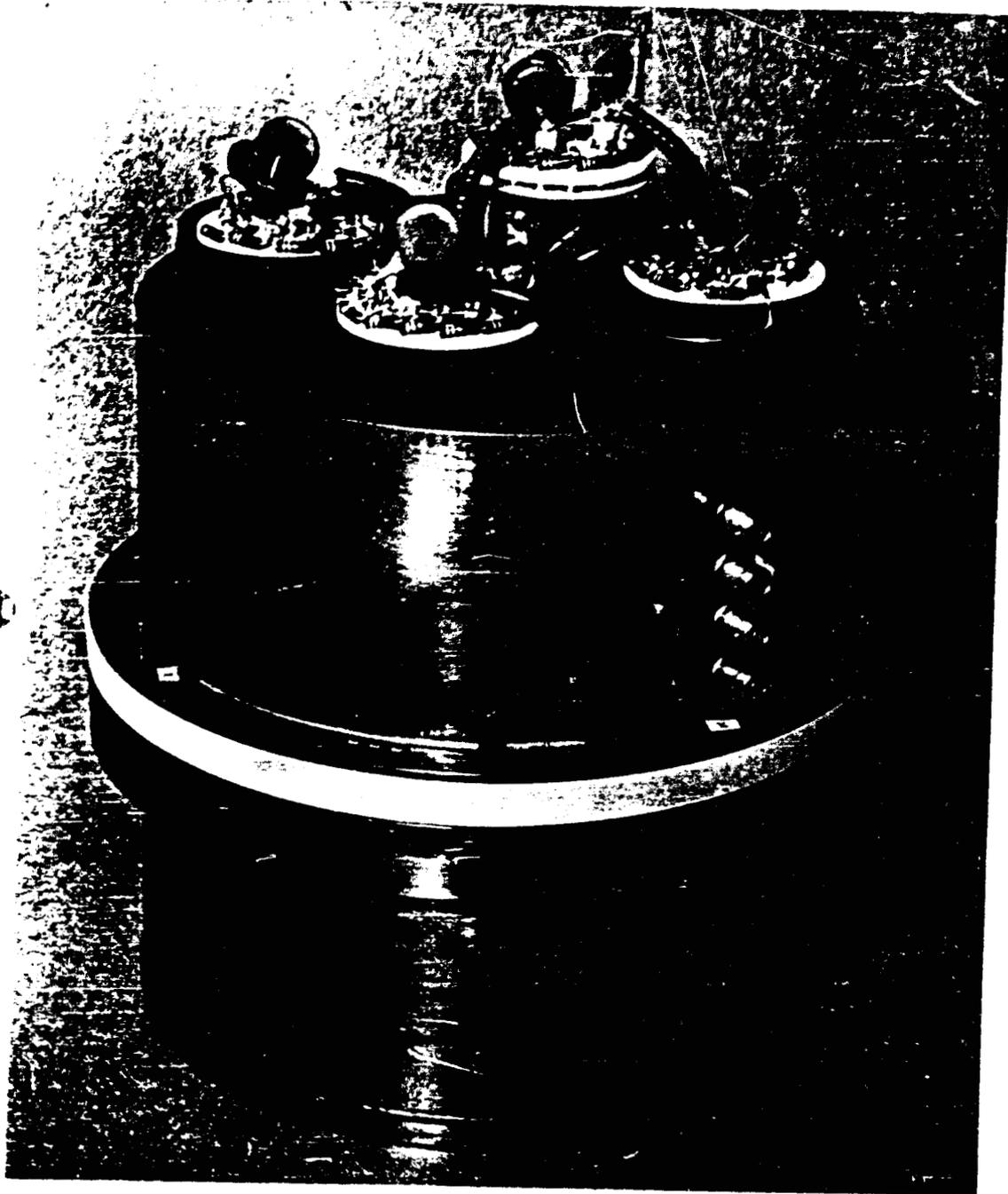


Figure 22

6-4

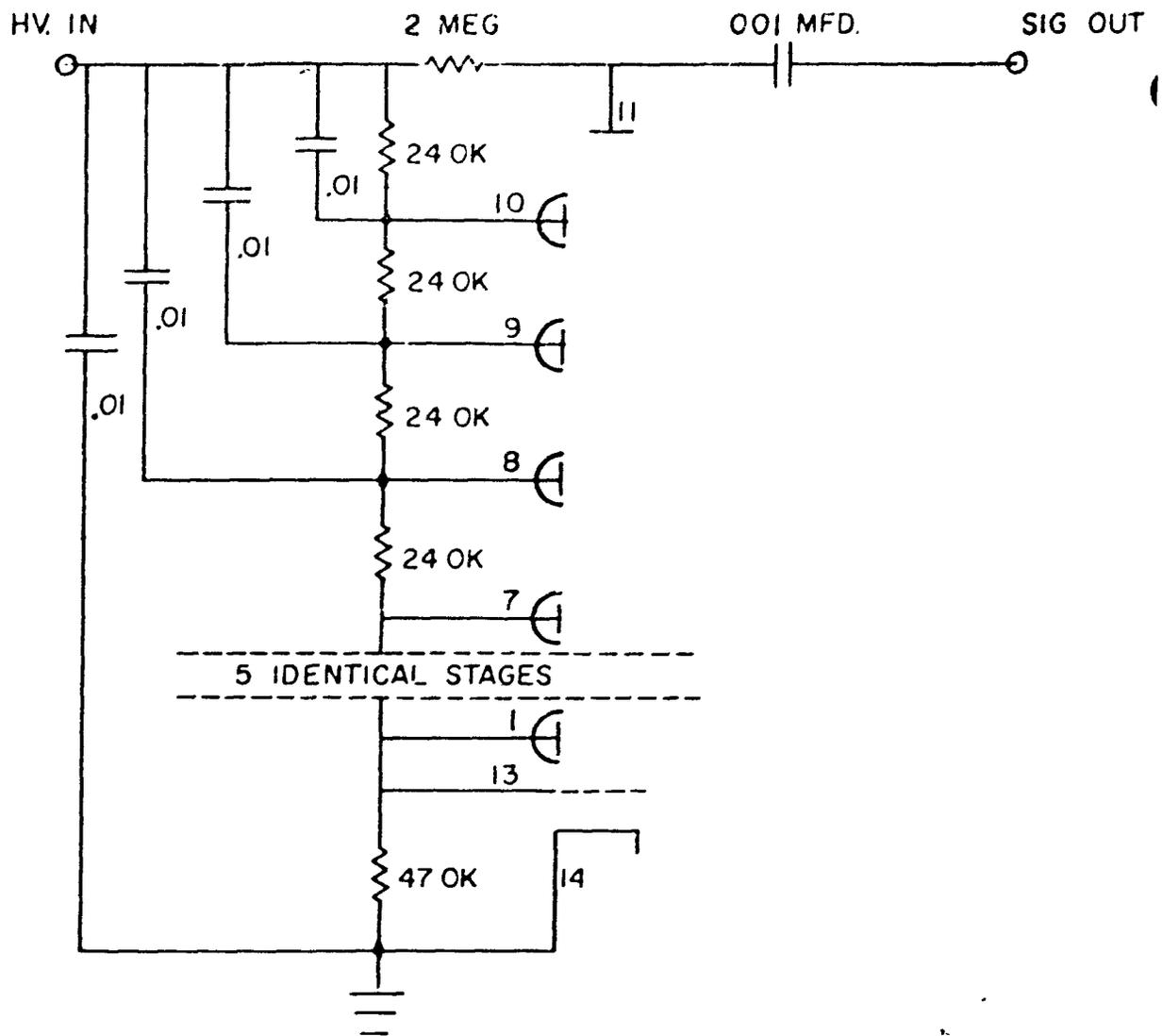
supported by a modified Westinghouse radiographic tube stand that slides along horizontal tracks mounted on the floor and ceiling (Figure 20). This support permits considerable flexibility in positioning the detector.

6.3 Electronics for the Crystal Scintillation Detector

Two separate AC lines power the system. A voltage regulator (Sorenson Model 1000S) and noise suppression filter (Miller #7843) is installed in each line (Figure 23).

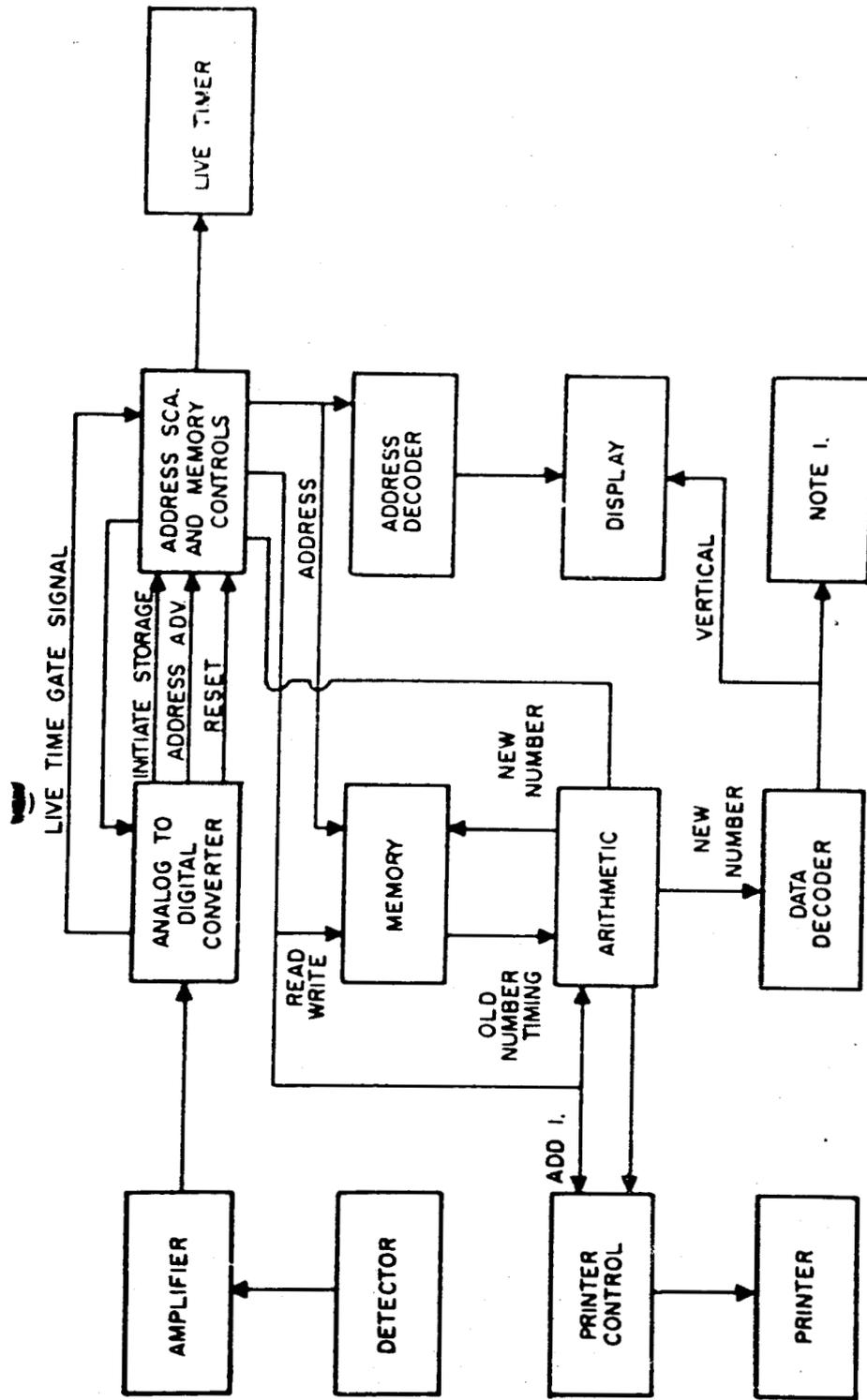
The power supply (Radiation Instrument Development Laboratory, Model 212) has a range of 500 to 1800 volts at 5 milliamperes. Voltage to each multiplier phototube is adjusted by a ten-turn helipot (with a switch in series with each potentiometer for convenience). This feature is important for regulating multiplier phototube gain. The bleeder circuit is shown in Figure 24. Signal leads (RG-62/U) are as short as possible and of low impedance. Each signal cable terminates in a switch bank providing access to the output of any multiplier phototube or combination of multiplier phototubes for test purposes. Preamplifier (Los Alamos, Type 250-N) input and output pulses are negative.

The remainder of the system (Figure 25) consists essentially of a 100 channel analyzer (Radiation Instrument Development Laboratory, Model 3300). Amplifier gain is adjustable from 50 to 1600 and has a built-in pulse generator for calibration and test purposes. At the converter, pulse height discrimination is afforded by two level controls. The converter dead time is about 70 microseconds and the effective gain of the system can be varied to either 16 or 80 volts per 100 channels. The live timer controls the start and stop of information storage by the analyzer and no count rate corrections



DUMONT 6363 MULTIPLIER PHOTOTUBE BLEEDER SCHEMATIC
CRYSTAL SPECTROMETER

Figure 24



NOTE I. A RECORDER OR POINT PLOTTER MAY BE USED AT THIS POINT.

R. I. D. L. MODEL 3300 PULSE HEIGHT ANALYZER BLOCK DIAGRAM

Figure 25

for dead time are necessary. Pre-set counting times are from 0.1 to 1000 minutes. The address scaler initiates the storage of counts in memory, with a maximum capacity of 65,535 counts per channel. The address scaler also controls the manner of the display of the memory content. The spectrum is displayed on an oscilloscope. The stored count is printed out on adding machine tape by means of an Add-Punch (Friden Model APT) or the Add-Punch provides the data on punched tape. The punched tape drives an X-Y Point Plotter or is used as input for the LGP-30 computer. The electronic equipment is shown in Figure 26.

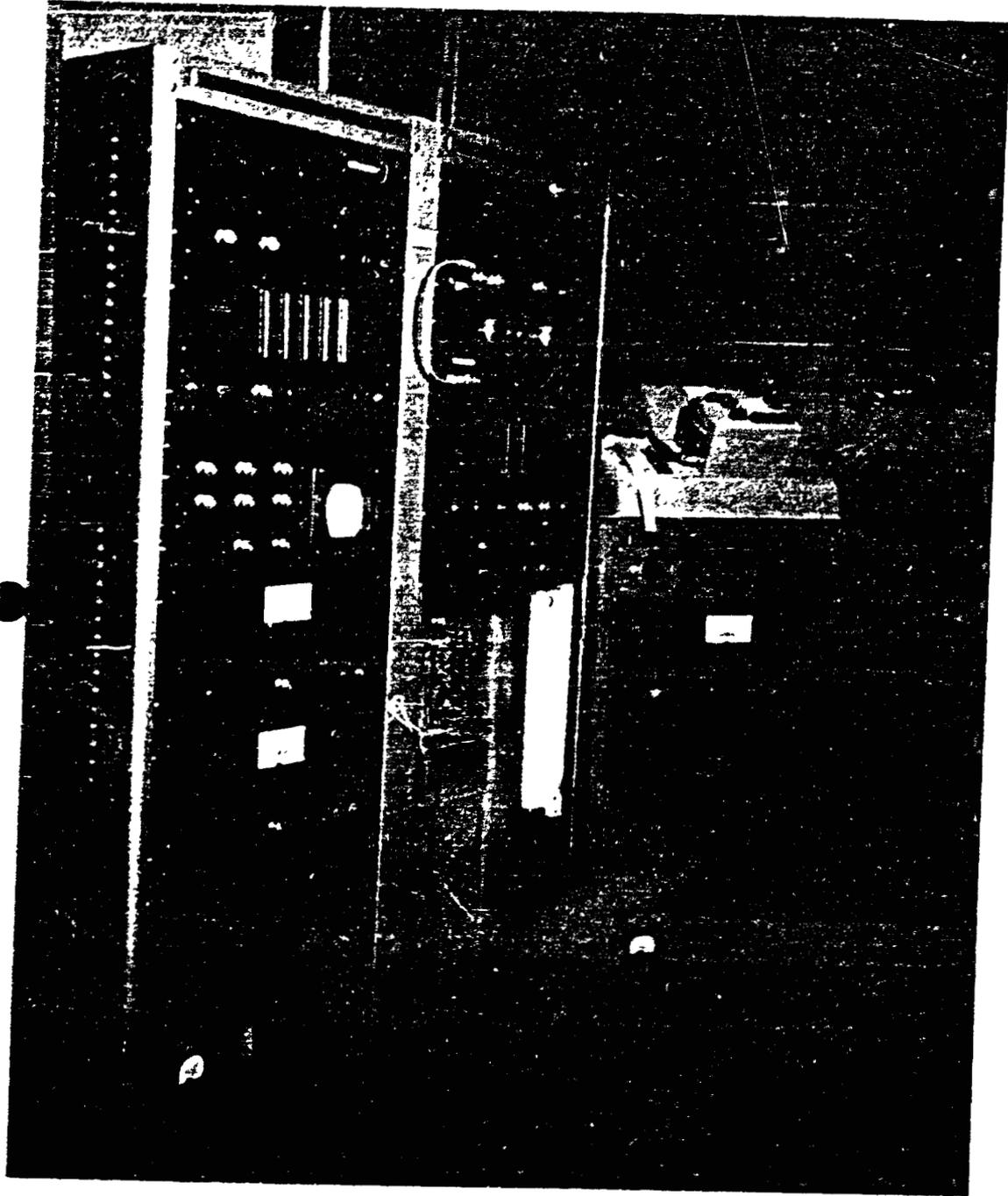


Figure 26

6-10

7.0 Performance Characteristics of the Crystal Scintillation Detector

7.1 Multiplier Phototube Balance

The four multiplier phototubes used with the 8 x 4 inch NaI crystal were selected for similar signal to noise ratios. For each tube, spectra were obtained using the photo-peak from an uncollimated cesium-137 source.

The output signal of each tube is normalized by a high voltage adjustment. This is facilitated by a voltage divider incorporating fixed and variable series resistors.

7.2 Energy Resolution

Originally, a 5 inch (Dumont #5364) multiplier phototube was coupled to the 8 x 4 inch NaI crystal. The photo-cathode to scintillation window area was 27.2% and resolution for an uncollimated cesium-137 source was about 18%. The four 3 inch multiplier phototubes now in use provide photo-cathode coverage of 33.4%. Resolution is 12% for cesium-137 and 9% for potassium-40 gamma-rays.

7.3 Energy Calibration

The energy band routinely used for spectral analysis of the human subject is from 0.10 to 1.8 mev. Calibration adjustments are made daily by using photo-peaks of cesium-137 and potassium-40. Figure 27 shows the two photo-peaks. A straight line intercepts channels 5 and 99 at 0.10 and 1.80 mev. The slope and intercept of the calibration curve are varied by amplifier gain and the lower level setting of the converter. The contents of the first four channels are usually discarded because of non-linear pulse

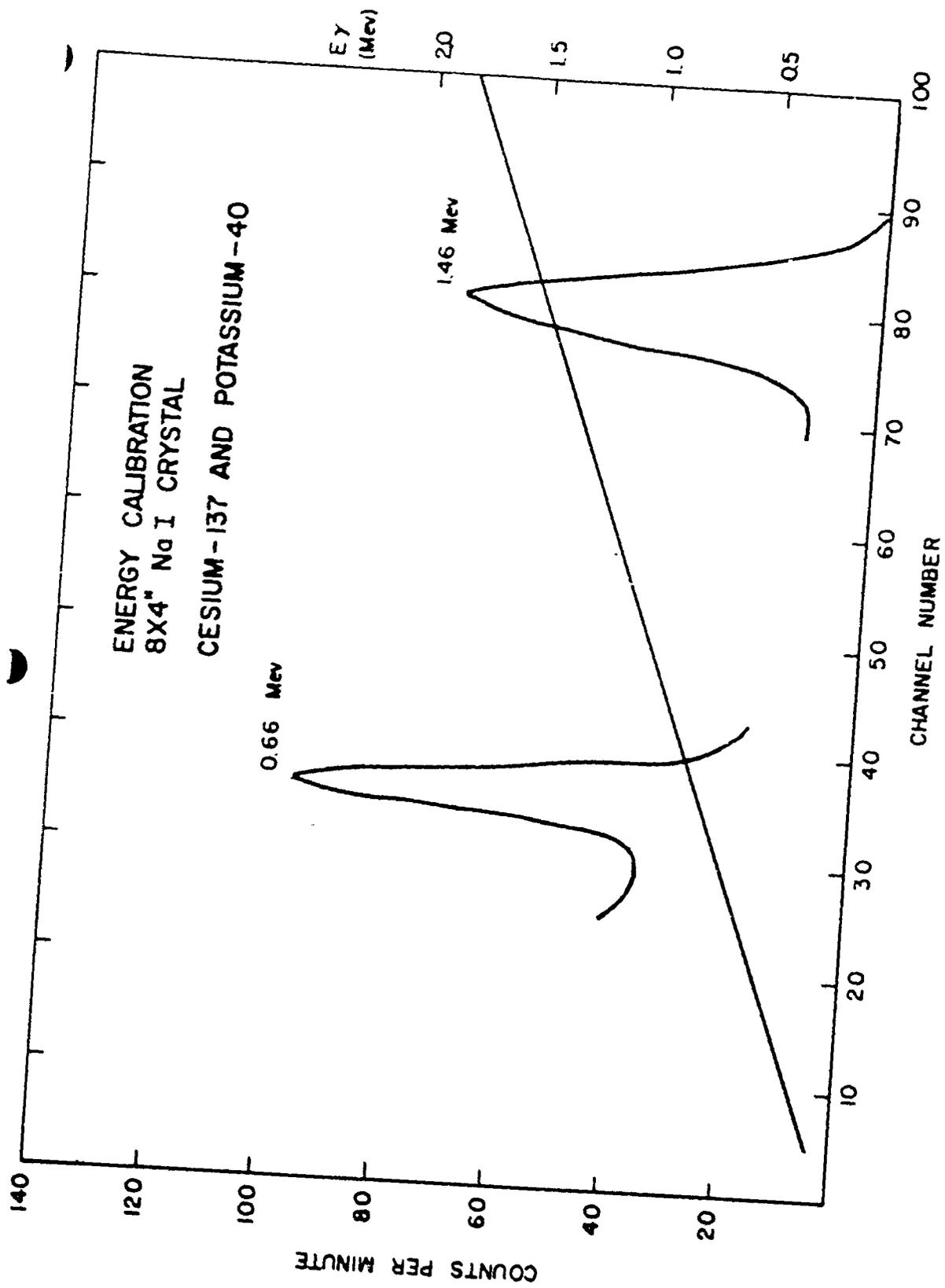


Figure 27

height amplification.

Pulse height is sensitive to variations in source strength. Increases in pulse height occur with increasing gamma activity and the shift in photo-peak is more marked for higher energy sources at equivalent count rates (5). The pulse height sensitivity is largely dependent on the voltage applied to the multiplier phototubes and can be effectively minimized by reducing voltage. Amplifier gain is used to obtain the desired pulse height.

7.4 Background Characteristics

The background count rate for the 8 x 4 inch NaI crystal within the walk-in shield is about 1250 c/m (100 kev to 1.8 mev). A typical background spectrum is shown in Figure 28. Three photo-peaks are noted with energies of 0.51, 0.60, and 1.46 mev. The first is due to positron annihilation and the latter two presumably from bismuth-214 (PaC) and potassium-40 respectively. The detector was brought out of the shield and spectra were obtained to determine background attenuation by the walk-in shield Figures 29 and 30. An overall reduction of about 17 is observed and is more pronounced for the 2.19 and 2.65 mev photo-peaks from bismuth-214 and thallium-208. With 1/8 inch sheet lead surrounding the detector in the walk-in shield a reduction in background of about 12% is noted from 0.08 to 0.70 mev. Additional thicknesses of lead show no appreciable reduction in background.

Radioactivity within the detector assembly contributes significantly to the background. This is primarily due to radium-226 and potassium-40 within the multiplier phototubes.

An overall decrease of 166 c/m was obtained by removing the Bakelite bases and sockets from the four multiplier phototubes used in the detector

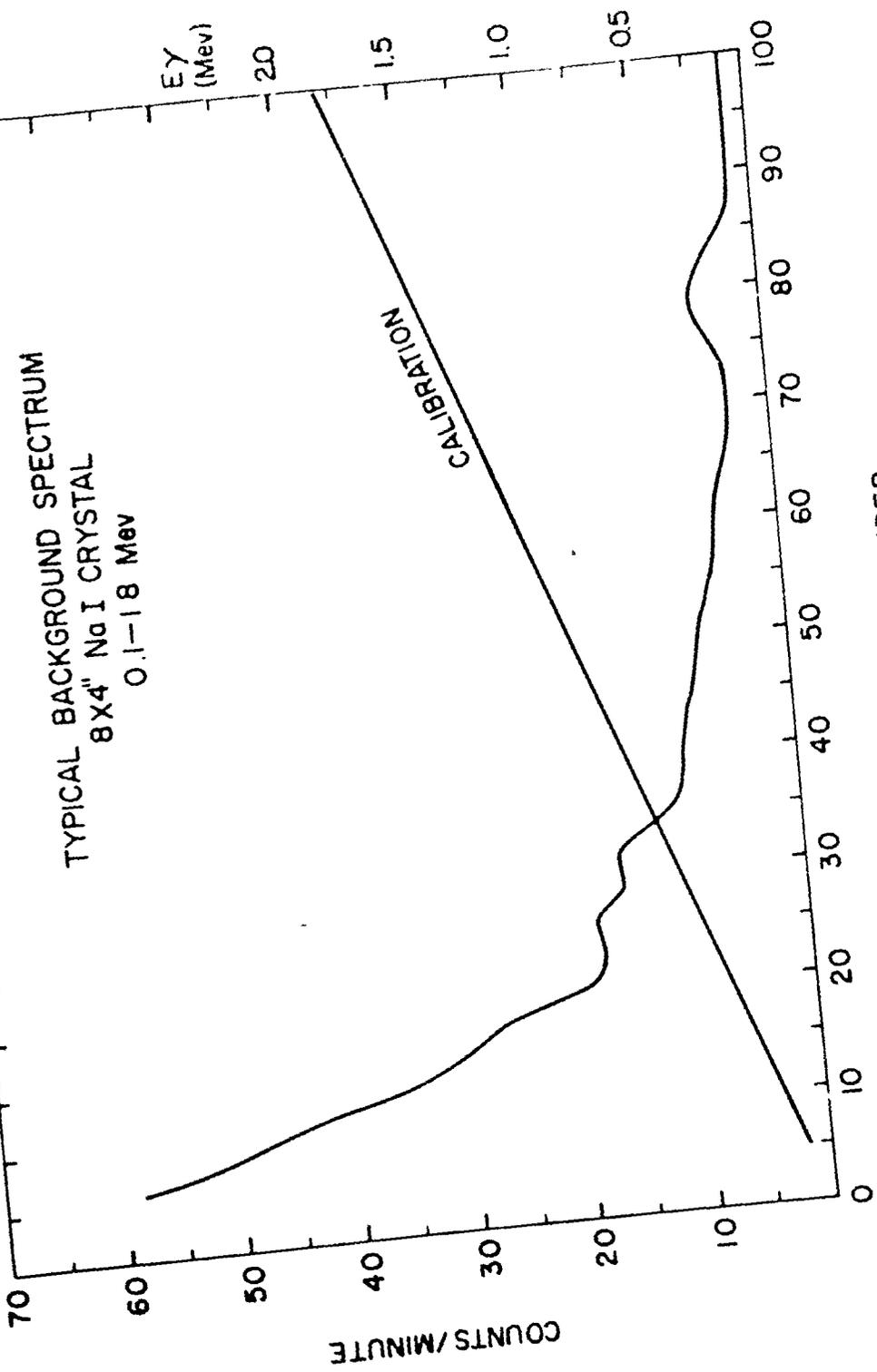


Figure 28

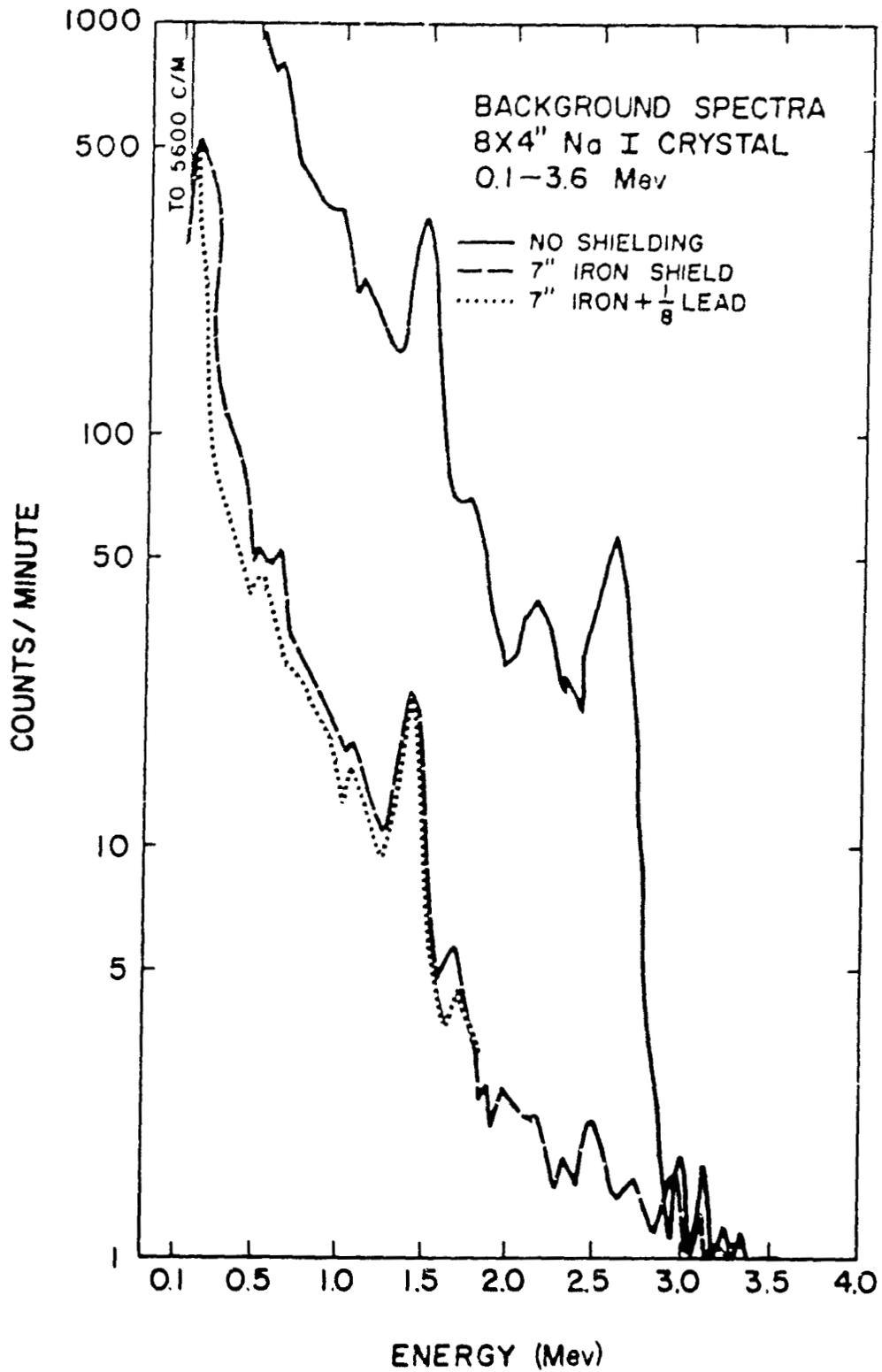


Figure 29

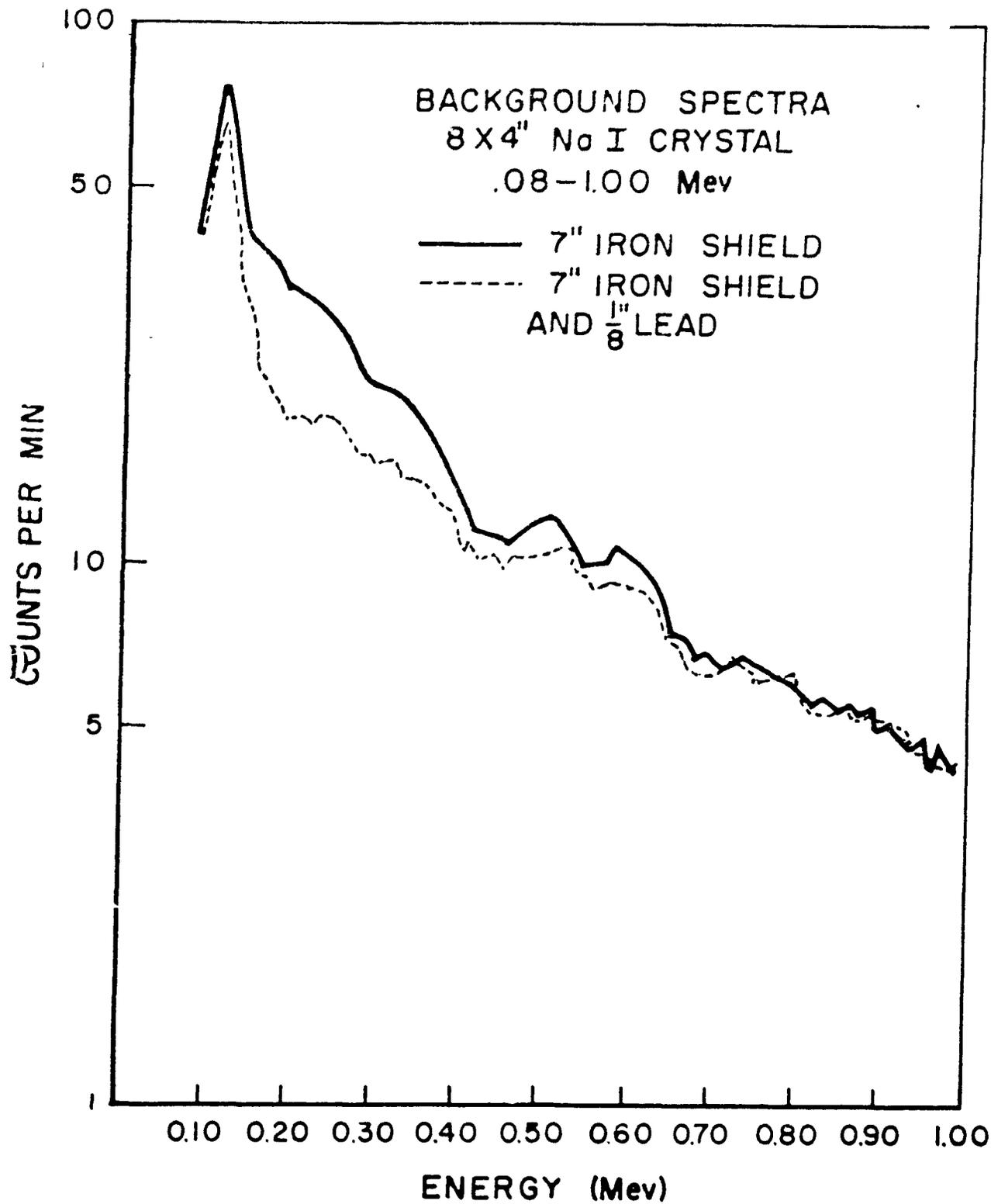


Figure 30

assembly. The potassium-40 photo-peak decreased by 31 c/m or 26%.

7.4.1 Background Stability

The background count rate of the crystal gamma-ray spectrometer is normally stable for long periods of counting time. Typical results for 50 minute background determinations (0.10 - 1.30 mev) during the day are 1250, 1265, 1250, 1259, 1246, 1264 and 1254 c/m, with a mean and standard deviation of 1255 ± 7 c/m. The observed standard deviation is 0.58% as compared to an expected 0.39%. For energy bands 0.55 - 0.72 mev and 1.30 - 1.55 mev the background count rates over the same time interval are 137 ± 1.7 and 67 ± 1.9 c/m respectively. These data indicate a 95% probability that background count rates for 50 minute periods are normally distributed within ± 2 SD of the mean count rate.

Subjects are routinely counted for 10 minutes. A background count rate from a 50 minute period is subtracted from the gross spectrum for each subject. For K-40 determinations, the counting error is less than 4% in a subject with a net count rate (K-40 photo-peak) equal to background.

7.4.2 Absence of Background Depression

The background count rate with the 4π liquid scintillation detector is slightly depressed with large masses in the detector well. No change in background is evident with the crystal spectrometer using water phantoms in the counting chair.

8.0 Calibration of Crystal Gamma-Ray Spectrometers

The Crystal Spectrometer has been used largely to confirm or establish the identity of gamma-emitting nuclides in selected subjects and samples after assay in the Liquid Scintillation Counter.

Whole-body gamma-ray spectra are obtained with the subject seated in a reclining chair. By adjusting the foot rest the thighs and knees are flexed and maintain a right angle between the trunk and thighs. This position is comfortable for periods up to one hour.

With the crystal suspended above the subject the crystal axis bisects a 90° angle formed by the back and the seat of the chair. By counting K-40 gamma-rays in normal individuals with the crystal at varying distances from the chair, the crystal-chair distance least sensitive to variations in body build was 58 cm. With the crystal-chair position fixed at 58 cm the crystal-subject (anterior surface) distance varies with body build. The decrease in crystal-subject distance with stout individuals, however, largely compensates for greater self-absorption in the stout subject.

8.1 Total Body Potassium

The relative counting efficiency for K-40 and K-42 in the normal human subject has been determined using a plastic manikin (See Section 4.1) as the primary standard. For potassium-40 the phantom contained 165.21 grams of potassium in 50.791 liters of distilled water. Eighteen determinations (50 minute counting times) made over several days with the plastic manikin in the reclining chair position show a K-40 photo-peak count rate of 0.453 c/m ($\pm 2.3\%$) per gram of potassium.

Subjects who participated in potassium-42 calibration studies for the Liquid Scintillation Counter (See Section 4.1.3) were also counted with the Crystal Spectrometer. Gross count rates obtained with the Crystal Spectrometer 24 hours after K-42 administration were corrected for excretion loss and radio-isotope decay, and base line K-40 count rates were subtracted. The results of the K-42 study are shown in Table 3. Individual count rates for equivalent amounts of K-42 activity show variations from the group mean considerably greater than expected from counting statistics alone. Two subjects (J. S. and C. R.) received K-42 on two different occasions and two determinations on the same individual differ by less than 2 per cent. The K-42 count rate for each subject was compared to the manikin. In each case the count rate of the subject was less than the manikin and the ratio for the group was 0.89 ± 0.05 . Seven of the nine determinations were within one standard deviation of the mean. The ratio for the tallest subject (R. vH.) interestingly enough was 0.97, whereas the heaviest subject (R. M.) was only 0.82. These variations in subject-manikin ratio indicate that potassium in the human subject may differ significantly from the homogeneously distributed source presented by the manikin. Further trial and error effort will be required to approximate this distribution in a manikin. Body potassium values were obtained for each subject using individual subject-manikin ratios and also the group's average ratio in the equation:

$$\text{Body potassium (in grams)} = \frac{\text{Subject K-40 count rate}}{\text{Subject-Manikin K-42 ratio}} \times \frac{1}{0.453 \text{ c/m/gm K}}$$

Results are shown in Table 3 with body potassium measurements obtained with the Liquid Scintillation Counter.

Table 3

Potassium⁴² Results In Humans And Estimated Body Content Of Elemental Potassium

Subject	Age	Sex	Ht (In)	Wt (lbs)	c/m per uc K ⁴²	Subject/ Mannekin	Body Potassium (In Grams)		
							Individual Ratio	Group Ratio (0.89)	Liq. Scint. Counter
A. B.	28	F	65	127	778	0.929	100.8	105.2	106.1
J. S.	24	M	69	151	787	0.921	139.1	143.9	142.3
	24	M	69	151	776	0.927	139.9	145.7	142.3
R. v H.	33	M	74	180	807	0.975	133.1	145.7	137.8
J. A.	37	M	67	180	698	0.839	149.4	140.8	146.7
K. W.	36	M	67	181	734	0.878	153.3	151.2	140.3
C. R.	34	M	70	185	716	0.867	153.2	154.1	150.0
	34	M	70	185	726	0.862	165.1	161.0	150.0
R. M.	50	M	71	199	683	0.817	178.8	164.2	157.5
				745 ± 43		0.890	146.4	145.8	140.1
						± 0.05			

9.0 Data Processing

Multi-channel gamma-ray spectrometry frequently requires considerably more time for data handling and computing than for actual sample counting. To reduce laborious and repetitious tasks and the time involved in data processing, the following flow scheme was instituted.

All samples and subjects assayed at Walter Reed are indexed by name and by number. Identity numbers are assigned serially from a master log book. The identity number has 5 digits and remains the same for the sample regardless of the number of times assayed, changes in prefix, or other historical information. Multiple determinations on the same subject are distinguished by dates and times of assay. The Identity Prefix is a one digit code indicating the nature of the sample or subject, as follows:

1. Human, General Population
2. Human, Control Group
3. Human, Contaminated - (with negative radiological history)
4. Human, Patient Status: Radiolotope administered
5. Animal
6. Food
7. Water
8. Other

After assigning a prefix and identity number to the sample, an 8 x 5 inch history card (Figure 31) is filled out with certain vital information.

Place of residence: A five (5) letter code is used to identify the place of residency of the subject or origin of sample. The first four letters abbreviate the state or country and the fifth letter indicates the major geographic area (Appendix D). The area in which the individual has spent the

longest period of time during the previous 30 months determines the place of residence. For periods less than 30 months, the actual number of months in residency is shown.

Sex: One digit indicating:

- 0. Neuter
- 1. Male
- 2. Female

Medical: A three digit code indicates up to three organ or system diseases.

Dietary: A one digit dietary code for each of four foodstuffs is used to record relative amounts of dairy products, meat, fruit and vegetables, and seafood consumed. The following amounts are considered average.

Dairy Products: Two to four servings of milk, cheese, or butter per day. One 8 ounce glass of milk, two pats of butter, or 2 slices of cheese equal(s) one serving.

Meat: Three servings of meat or eggs per day. One egg is one serving.

Fruit and Vegetables: Eight servings per day. One slice of bread, one small dish of fruit or vegetable equals one serving.

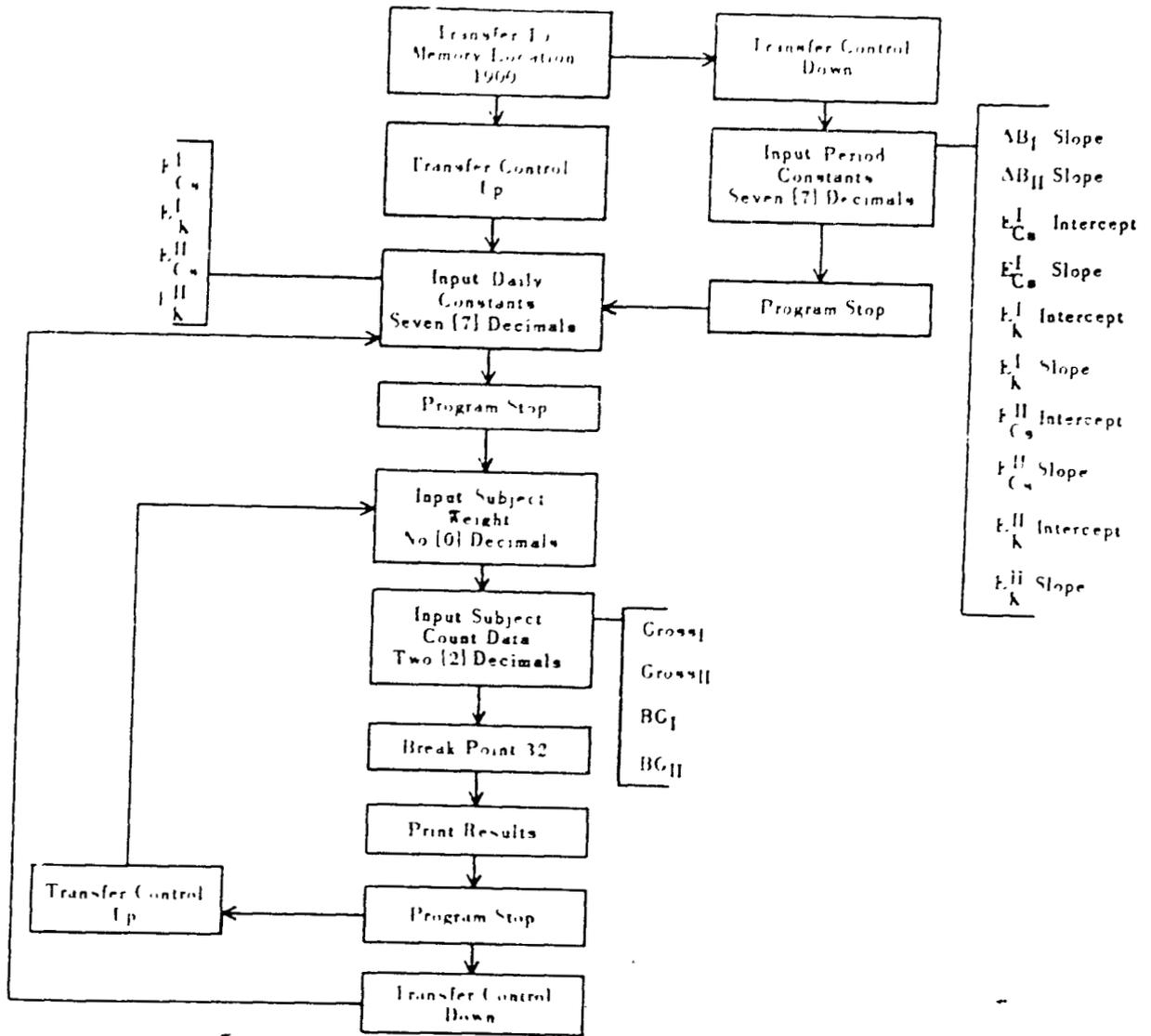
Seafood: One to two servings of seafood per week.

The history card accompanies the subject or sample to the counter and in the case of the liquid scintillation detector, the count time, gross count rates, and background count rates are entered on the card. For the crystal spectrometer, the run number, background run number, energy calibration, and geometry considerations are recorded.

The computer program flow scheme for data obtained with the liquid scintillation detector is shown in Figure 32. By entering the code number 1900, the appropriate memory location is obtained for this program. Information stored in memory includes the background suppression slope for both channels, and slopes and intercepts of the counting efficiency for cesium-137 and potassium-40. Input constants for cesium-137 and potassium-40 are determined and entered daily.

The operator enters the weight of the individual involved, the gross count rates, and background count rates for the two channels involved. Computer results are automatically typed on the history card as to cesium-137 and potassium-40 disintegration rates, cesium-137 and potassium-40 disintegration rates per kilogram of body mass, body potassium in grams per kilogram, and the cesium to potassium ratio. These data along with medical and radiological history and other vital statistics are transferred to an IBM data loading sheet (Figure 31), and consequently entered on IBM cards for listing and sorting.

In the case of the gamma-ray spectrometer, Figure 33 shows the flow scheme involved, in that the 100 channel analyzer output can be printed out as well as punched out on decimal tape. The tape is used with an X-Y Point Plotter (F. L. Moseley, Model 2A X-Y Recorder, Model 50 Tape Translator), (Figure 34) to display the gross spectrum obtained, or the punched tape is fed to the computer to reduce the gross count rate to gross counts per unit time per channel. Background or any other stored spectrum, may then be subtracted. Finally the computer typewriter output shows the net count rate per channel. Output is also punched on tape for X-Y Plotter display.



III VAN COUINTER COMPUTER PROGRAM

Figure 32

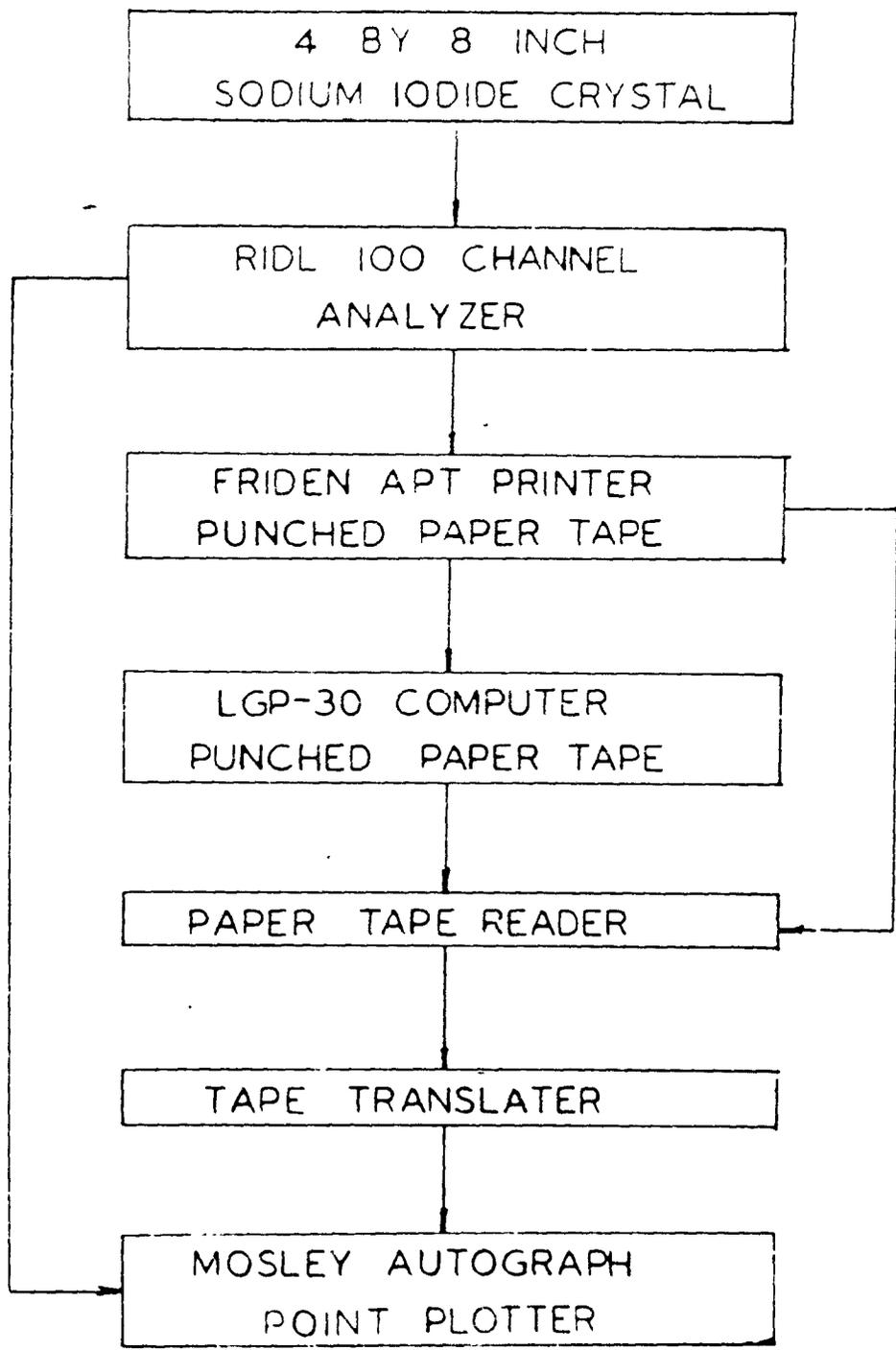


Figure 33



Figure 34

Figure 35 shows the computer selected, namely, the LGP-30 (Royal McBee). Considerations in the selection of this computer were the alphanumeric memory with both typewriter and paper tape input and output, short computing time, and an adequate memory capacity.

The computer is also extremely useful for statistical determinations where large numbers of samples are involved. Frequent uses of the computer include least squares curve fitting, determination of means and standard deviations, and frequency distributions.

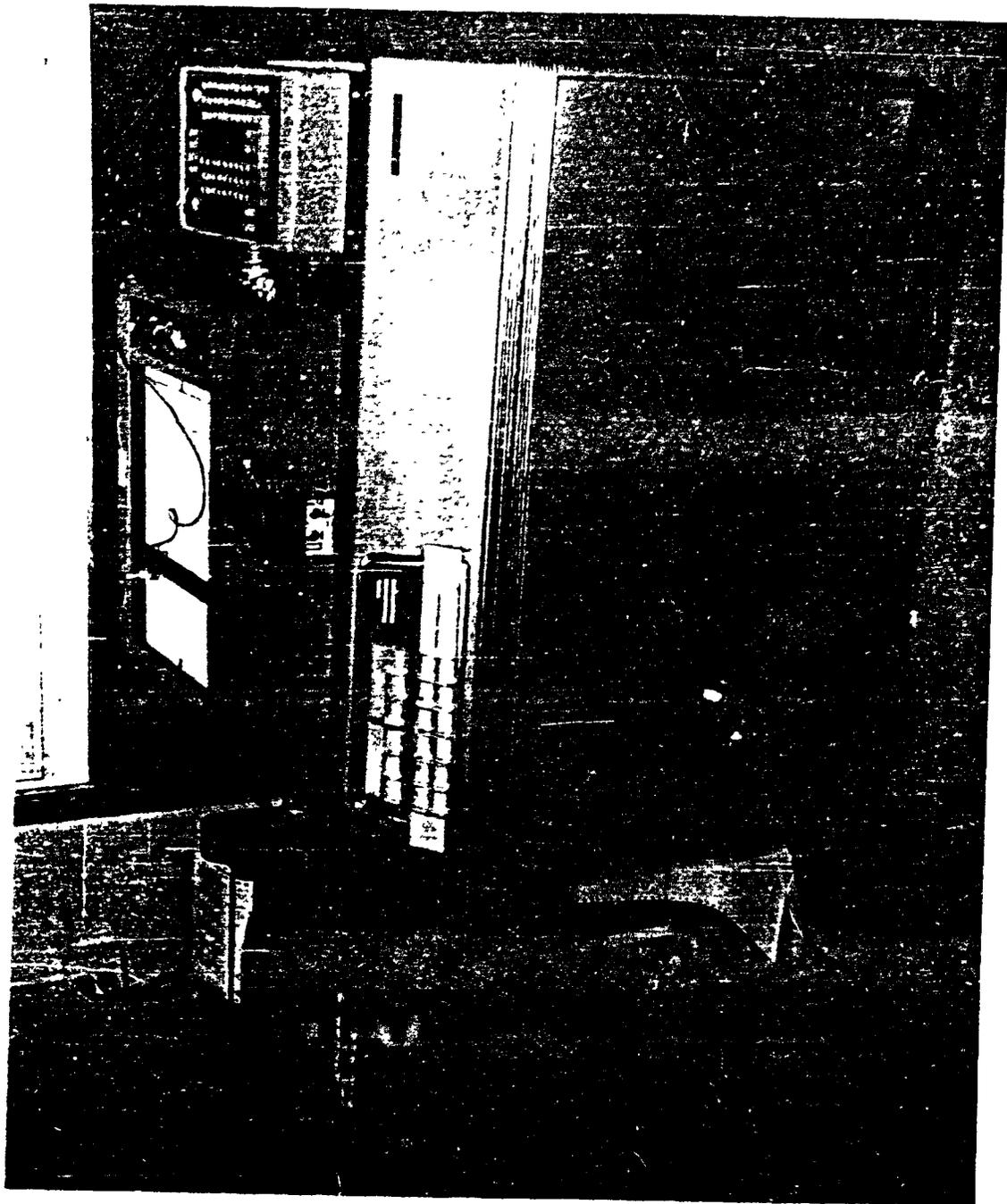


Figure 35

10.0 Gamma Radioactivity in People and Foodstuffs to July 1960

Over 4000 measurements of people and certain foodstuffs for gamma radioactivity have been made over the past two years to study the spatial and temporal distributions of cesium-137 fallout. Part of these results, i. e., July 1958 - March 1959, have been summarized previously (7). Quarterly values for each state are listed for convenient reference in Table E-1 and for various countries in Table E-2. A composite list of cesium-137 levels reported by various investigators since 1955 is also included in Table E-3. Future determinations will be listed periodically in "Radiological Health Data" published by the U. S. Public Health Service.

Simultaneous measurements of cesium-137 and potassium-40 were performed as these are the two gamma-emitting nuclides consistently detected in people and most foodstuffs. Detailed spectral analyses were also obtained periodically using the crystal gamma-ray spectrometer. Individual determinations were made with the subject vested in a cotton surgical scrub suit. Counting time was 200 seconds for each subject. Cesium-137 levels are reported in micromicrocurie units per gram of potassium. The potassium values are expressed as grams of elemental potassium per kilogram of sample or subject weight.

The reproducibility of Cs-137 and K-40 measurements of an adult male subject (#2-00043) are indicated in Figures 36 and 37. Ninety-two assays over a sixteen month period show a standard deviation of 4.1 per cent for potassium and nine per cent for the Cs-137 to K-40 ratio. That the variability in activity measured in the human subject (without showering before

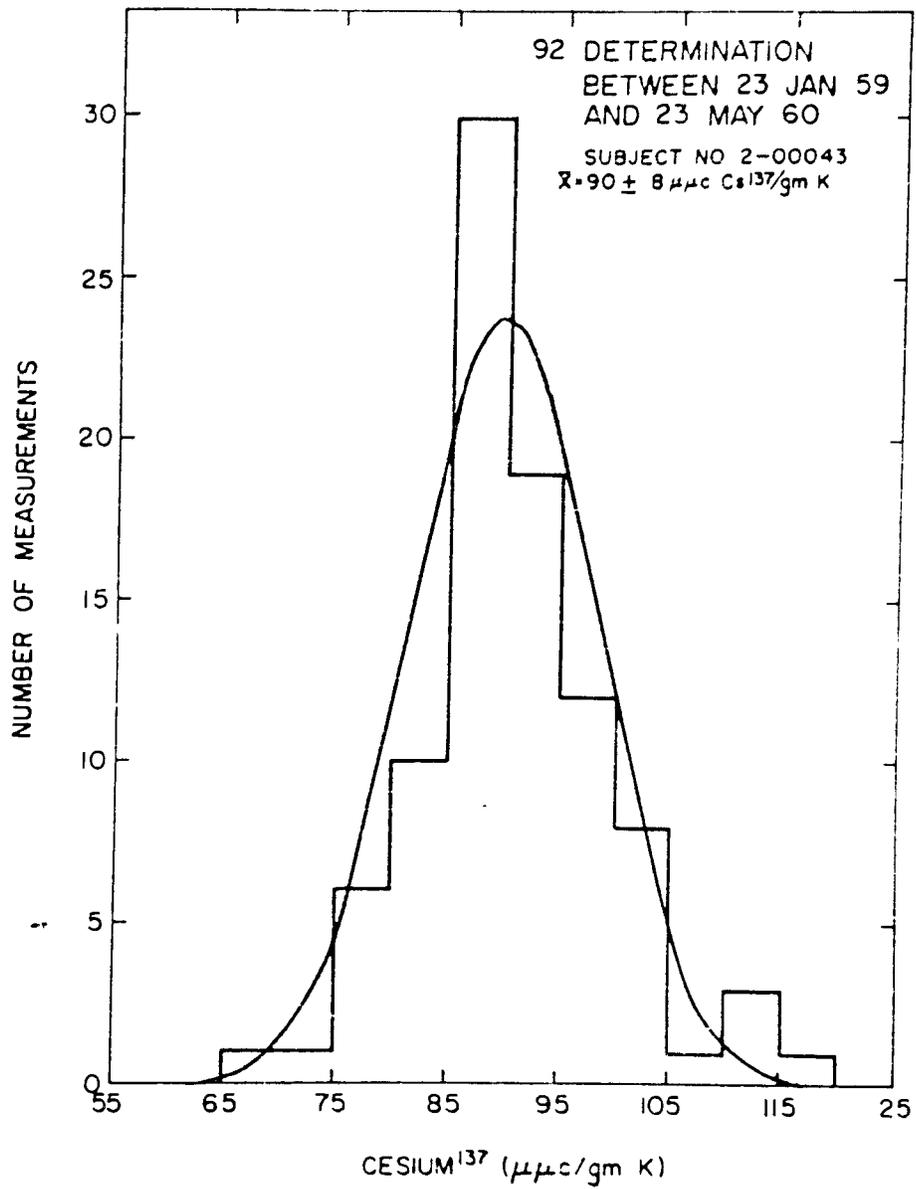


Figure 36

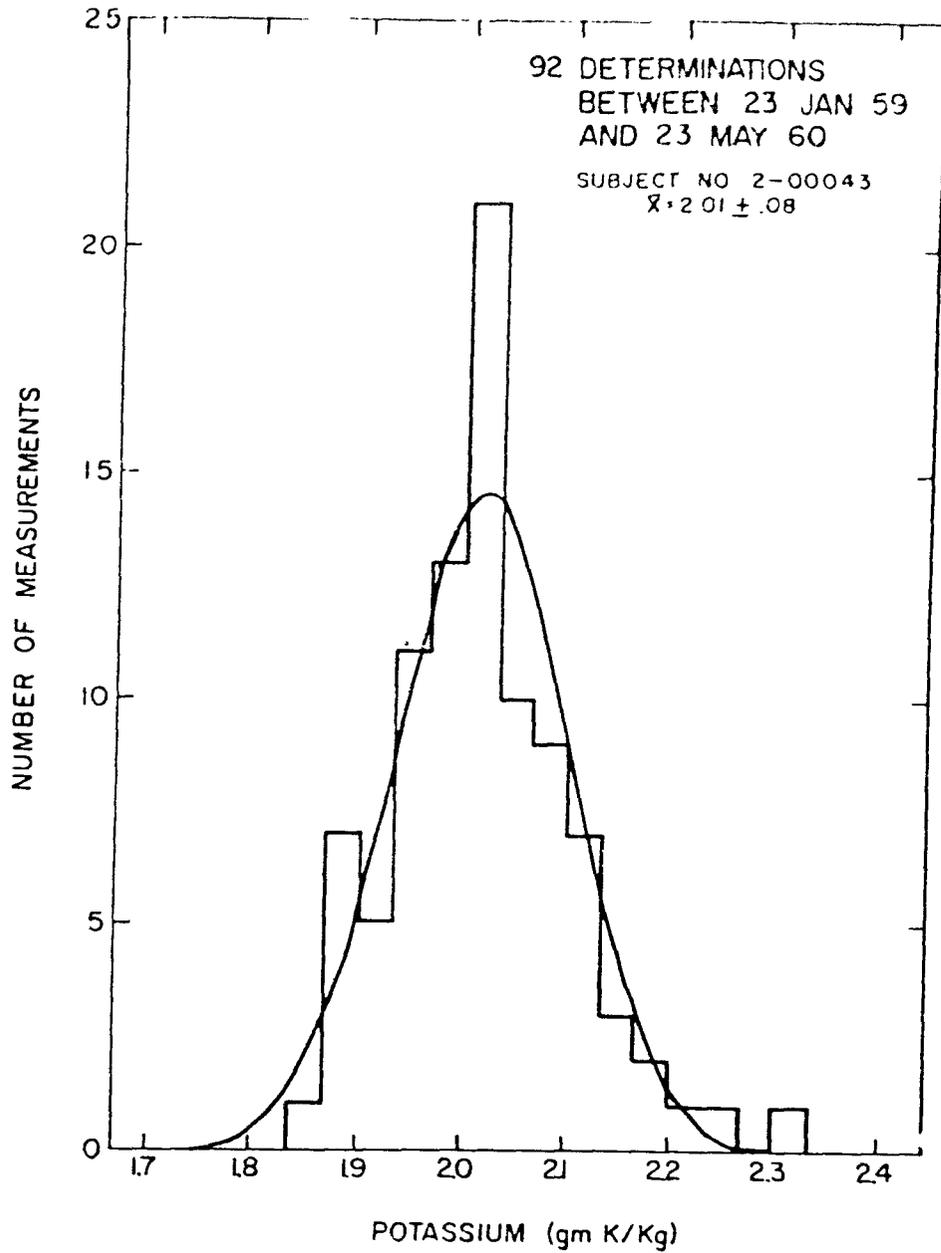


Figure 37

each measurement) may be due in part to traces of surface contamination is suggested by a standard deviation of 1.2 per cent obtained from 47-49 measurements in the plastic phantoms (Table 4). A shower bath before each assay is time consuming and is not normally required. Obviously great care and supervision is necessary however, when assaying nuclear energy personnel. To compare the results of radioassays at the Los Alamos Scientific Laboratory and the Walter Reed Army Institute of Research, sixteen subjects were measured at each laboratory using liquid scintillation counters. Average Cs/K values obtained at each laboratory compare favorably (Table 5), however, the average potassium value at Walter Reed is eight per cent less than Los Alamos. The reason for this difference is not entirely clear, but is presumably related to geometrical differences in primary calibration phantoms.

The highest Cs-137 value recorded was 291 $\mu\text{c/gm K}$ on 29 January 1960 in a 20 year old soldier (#1-02350) from the state of Florida. Zinc-65 was identified in one subject and the source of this radio-nuclide was found to be canned Pacific oysters. Zinc-65 has been reported in subjects from the Marshall Islands (8) and in certain U. S. foodstuffs, principally Chesapeake Bay oysters (9). In this laboratory micromicrocurie quantities of zinc-65 and manganese-54 have been repeatedly noted in certain Pacific Ocean fishes.

10.1 Radioactivity Levels in U. S. Subjects

Sixteen hundred and fifty subjects residing in the United States were assayed; a majority of them from the military service. The mean age of the group including both sexes is 30 years. The 20 - 24 year age interval is

Table 4

Reproducibility of Potassium Results for A Plastic Man
Using The Liquid Scintillation Detector

<u>Date</u>	<u>K⁴⁰ (d/s)</u>	<u>K (gm/Kilogram body wt.)</u>
8 Feb 60	467.0	2.64
9 Feb 60	467.6	2.66
9 Feb 60	447.5	2.56
10 Feb 60	466.5	2.65
11 Feb 60	460.3	2.62
12 Feb 60	463.2	2.61
15 Feb 60	459.8	2.61
16 Feb 60	461.9	2.63
17 Feb 60	459.7	2.61
19 Feb 60	463.5	2.64
23 Feb 60	452.8	2.57
24 Feb 60	<u>462.1</u>	2.63
	461.2 ± (1.2%)	

Table 5

Comparison of Cesium¹³⁷-Potassium Results at Walter Reed
and Los Alamos With The Liquid Scintillation Detector.

Subject & Identity No.	WRAIR Date	Age & Sex	WRAIR Weight	Potassium gm K/kg		Cesium ¹³⁷ μCi Cs-137/gm K	
				WRAIR	LASL	WRAIR	LASL
1. S. W. C. #1-00925	14 Nov 58	45 M	134	1.98	2.19	66	53
2. B. C. #1-01126	28 Feb 58	39 F	122	1.49	1.34	58	99
3. M. V. #1-01281	2 Apr 59	28 M	199	1.53	1.71	69	55
4. C. S. #1-01282	2 Apr 59	37 M	186	1.95	2.13	76	70
5. J. A. N. #1-01284	2 Apr 59	49 M	163	2.00	2.27	62	49
6. J. E. H. #1-01285	2 Apr 59	36 M	173	2.12	2.27	48	52
7. W. D. D. #1-01286	2 Apr 59	30 M	219	1.99	2.11	69	73
8. S. W. L. #1-01288	3 Apr 58	30 M	165	1.78	2.06	74	66
9. E. C. M. #1-01289	3 Apr 58	29 M	173	2.01	2.28	78	67
10. W. G. #1-01290	3 Apr 58	28 M	161	2.03	2.06	60	51
11. J. E. T. #1-01291	3 Apr 58	30 M	140	1.95	2.31	73	63
12. H. B. M. #1-01292	3 Apr 58	35 M	170	1.83	1.92	61	79
13. H. A. C. #1-00337	12 Aug 58	38 M	169	1.73	1.73	81	91
14. R. v H. #1-01345	11 May 59	32 M	185	1.69	1.89	69	58
15. R. L. S. #1-02472	26 Feb 60	35 M	171	1.69	1.88	58	-
16. E. C. A. #1-02581	15 Apr 60	39 M	146	1.81	2.00	77	86
				1.84	2.00	67	67

biased because of the predominant military population. The weight distribution with a mean of 71 kilograms is illustrated in Figure 38.

The average disintegration rate of Cs-137 in U. S. subjects for the period July 1958 through June 1959 (Figure 39) was 3.75 gamma d/s per kilogram, corresponding to a body burden of seven m μ c. The frequency distribution for Cs-137 during July 1959 through June 1960 is shown in Figure 40 with a statistically significant decrease in the mean to 3.48 d/s per kilogram. The standard deviation was 1.2 d/s per kilogram for both periods.

Potassium measurements for comparable time periods are 1.78 and 1.88 grams of potassium per kilogram (Figures 41 and 42). The standard deviation for both periods is identical, 0.28 grams per kg; however, the difference in the mean potassium values is 5.5 per cent. This is statistically significant and is due to variations in the arrangement of K calibration sources within the detector (See Section 4.1.1). After December 1958 the calibration sources were arranged in a constant pattern as shown in Figure 17. This resulted in internally consistent potassium values for specific age groups and the 1.88 gram per kilogram value is the best estimate of the population mean.

10.2 Regional Variations in Cs-137 Body Burden in the U. S.

Cs-137 body burdens averaged over each 12 month period for various regions are plotted in Figures 43 and 44. The numerical value in parentheses indicates the number of people in each regional sample. The minimum period of residency for each subject was six months. The division of the Continental United States into ten major geographical regions is arbitrary, with no intended

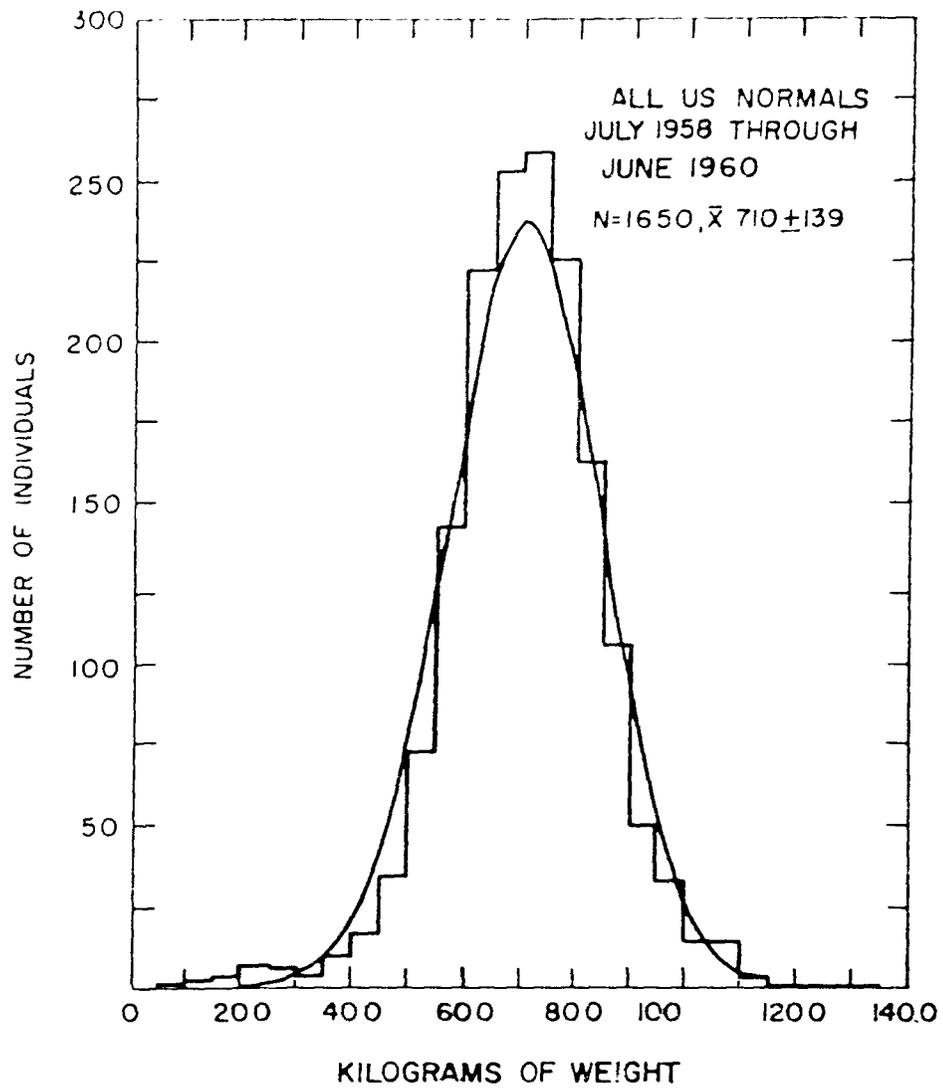


Figure 38

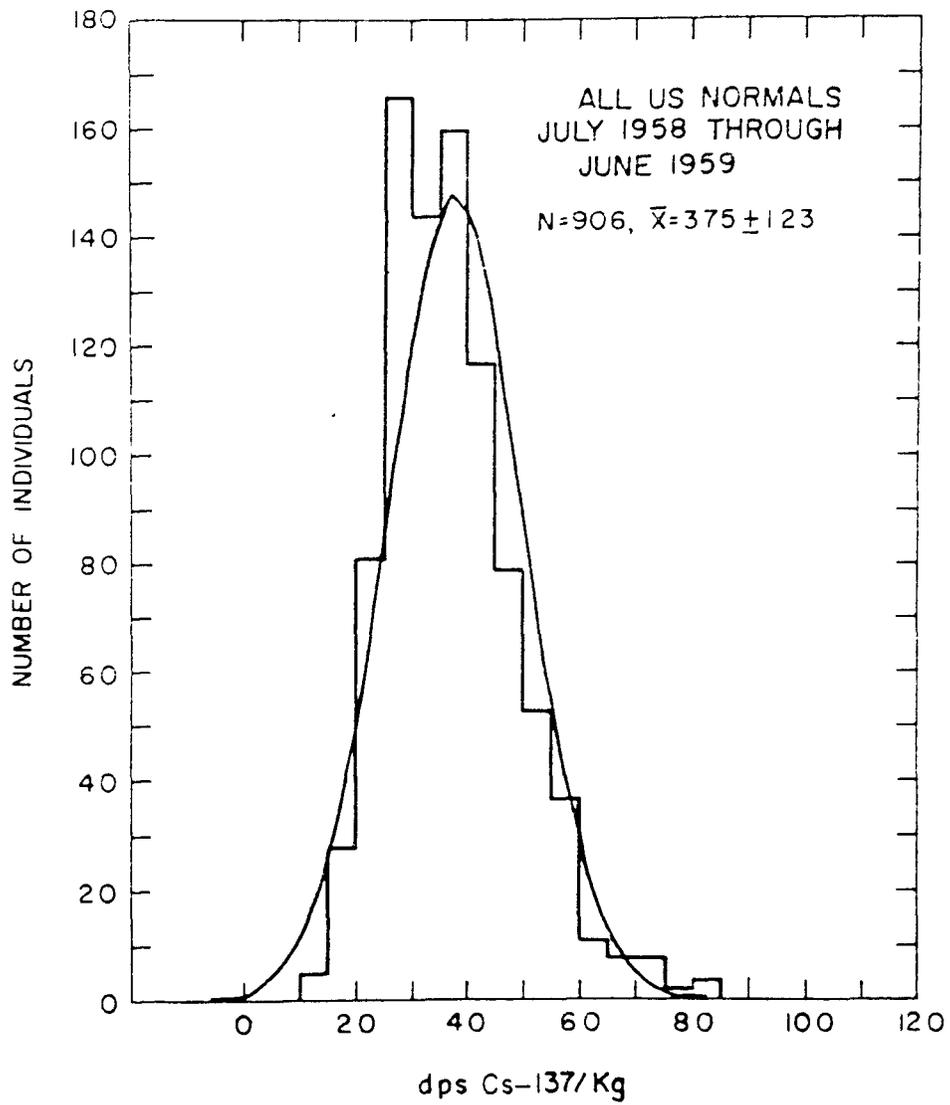


Figure 39

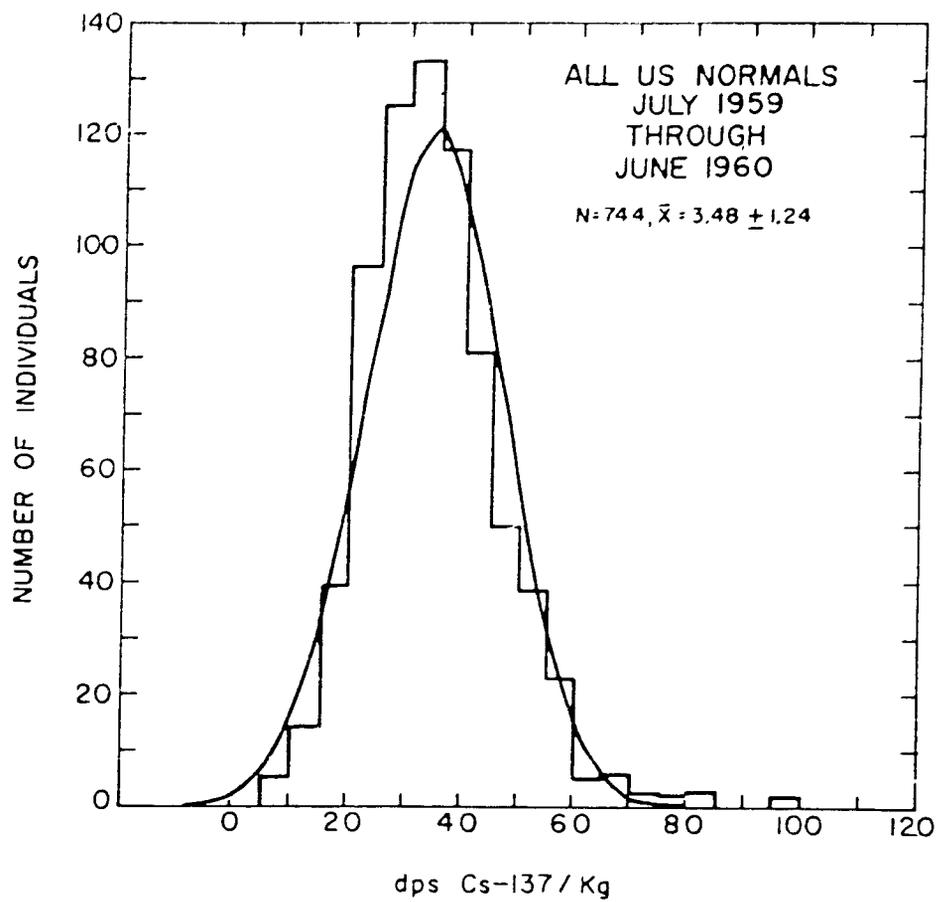


Figure 40

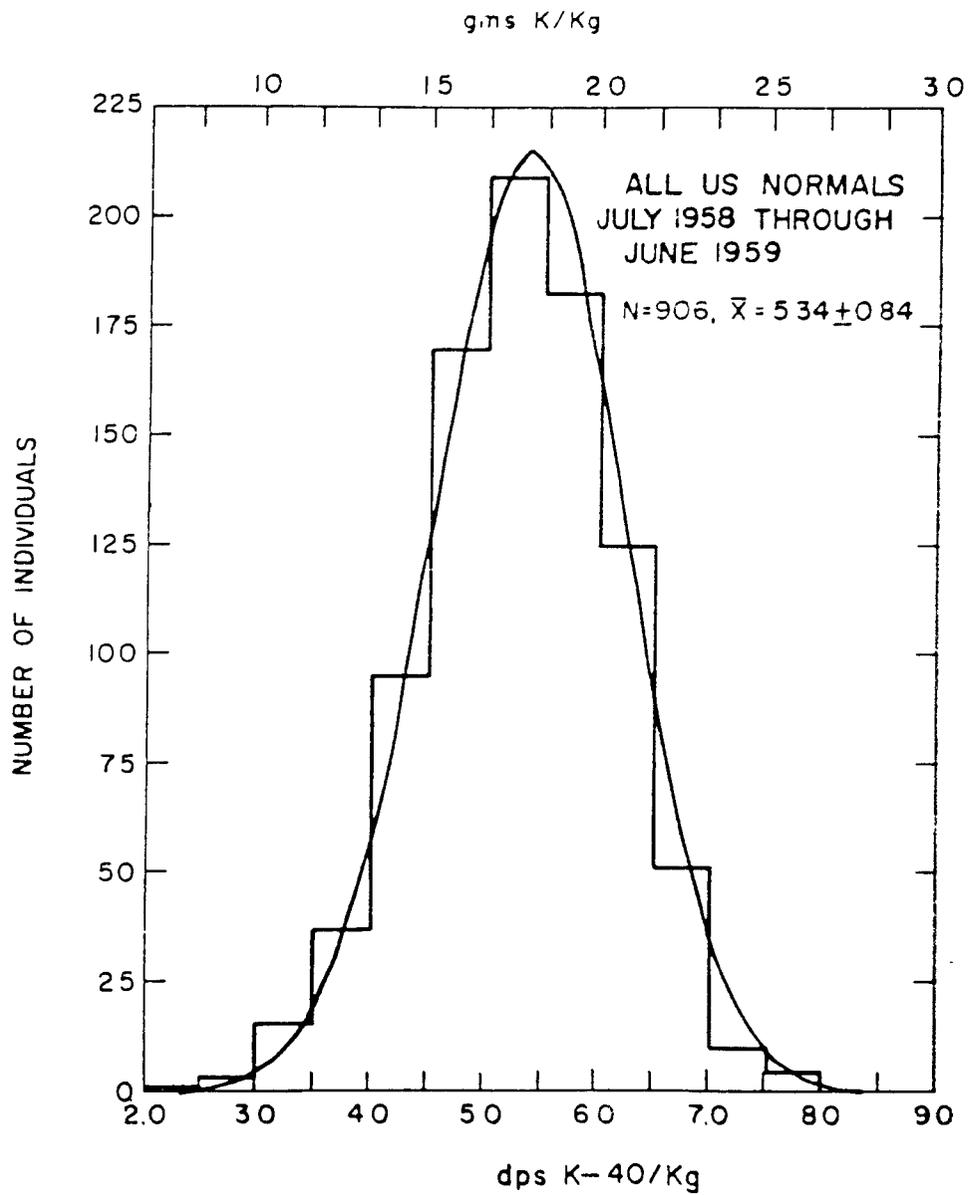


Figure 41

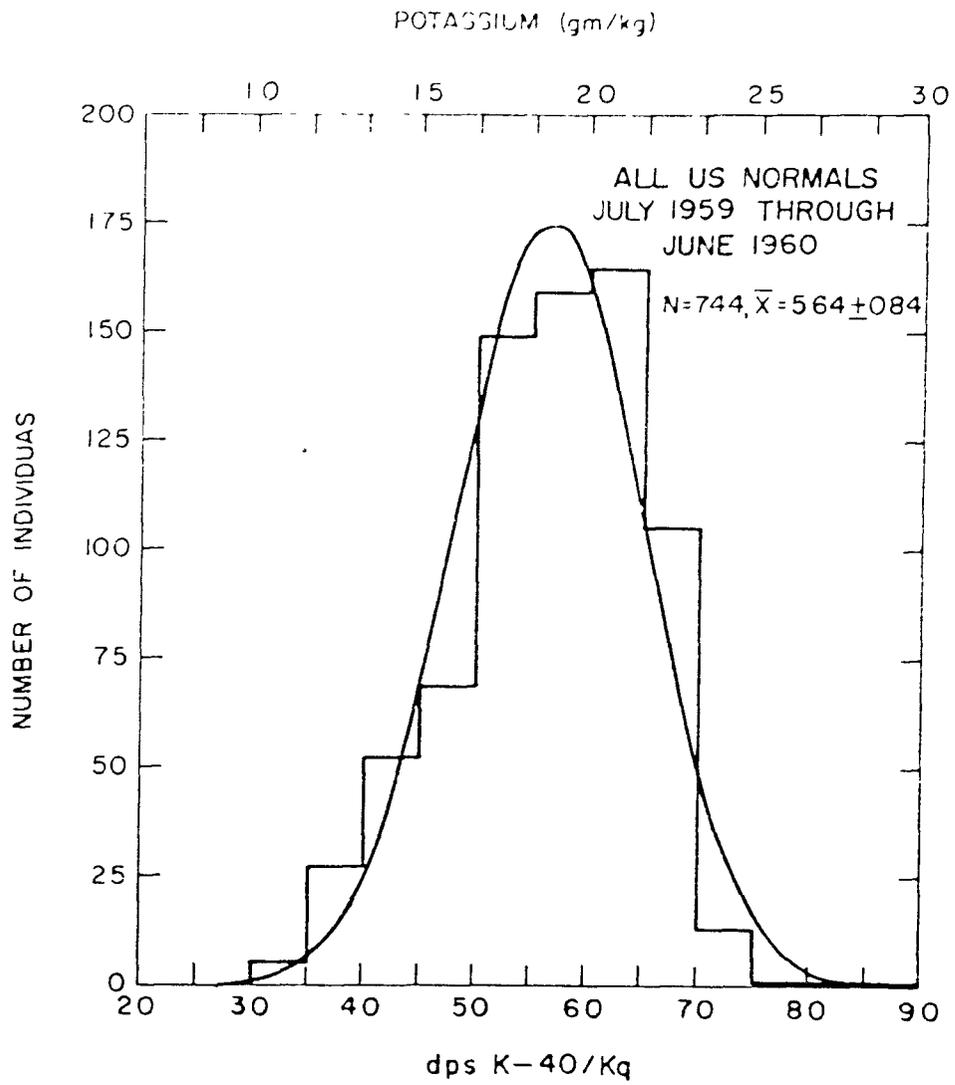
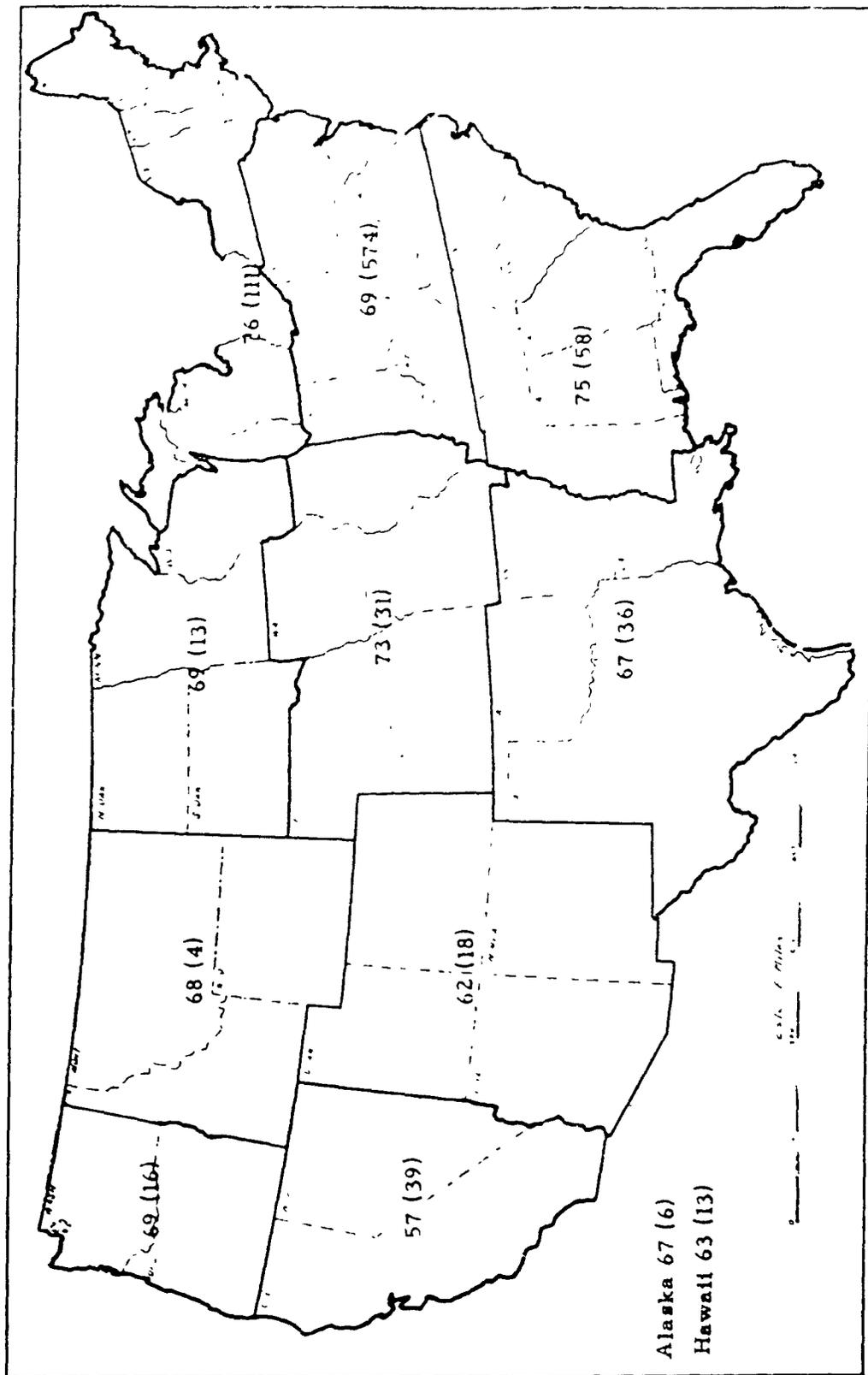
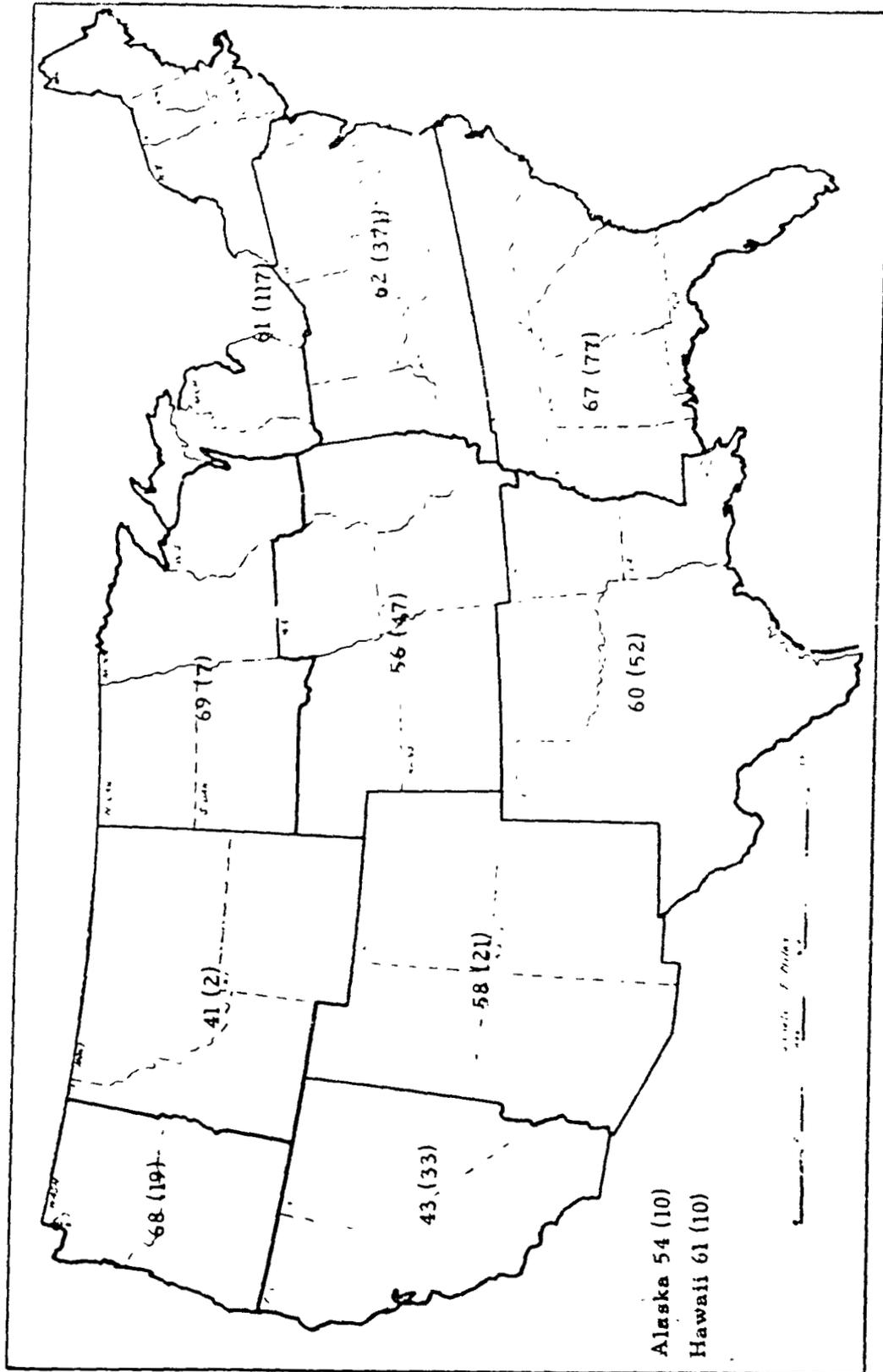


Figure 42



July 1958 thru June 1959

Figure 43



July 1959 thru June 1960

Figure 44

reference to meteorological or topographical differences.

The mean U. S. value of 69 μ C Cs-137 per gram for July 1958 through June 1959 is an increase of about 57 per cent over the 1957 level of 44 micromicrocuries per gram reported by Anderson (10). Proportional increases are noted in all regions with the highest being the northeast, followed by the southeast. The region of lowest Cs-137 activity was the Pacific southwest. The moratorium on nuclear weapons testing became effective 31 October 1958 and apparently has been observed, except for several announced 1959 tests of nominal yields conducted in North Africa. As indicated previously, Cs-137 levels decreased during July 1959 through June 1960 and almost all U. S. areas reflect this change. Still, these values are near or above 1957 levels.

A more detailed analysis of the temporal changes in Cs-137 levels is possible by comparing quarterly assays for the Washington, D. C. area where the sample size is relatively large. Initially Cs-137 levels vary from 66 to 70 μ C per gram and remain at the latter value through 1959 (Figure 45). This static or equilibrium period coincides with high fallout intensity, particularly in the spring of 1959, from the U. S. S. R. detonations of 1958 (11). During the first six months of 1960, Washington, D. C. levels decrease about 28 per cent and at this rate the effective half-time for Cs-137 elimination would be about 14 months.

Quantitative estimates of the intake of certain foods were obtained by history taking (Section 9.0). Six people out of 757 in the initial U. S. sample excluded milk and dairy products from the diet, and the difference between the mean Cs-137 body burden for non-consumers and consumers of large amounts of dairy products is significant (Figure 46). The

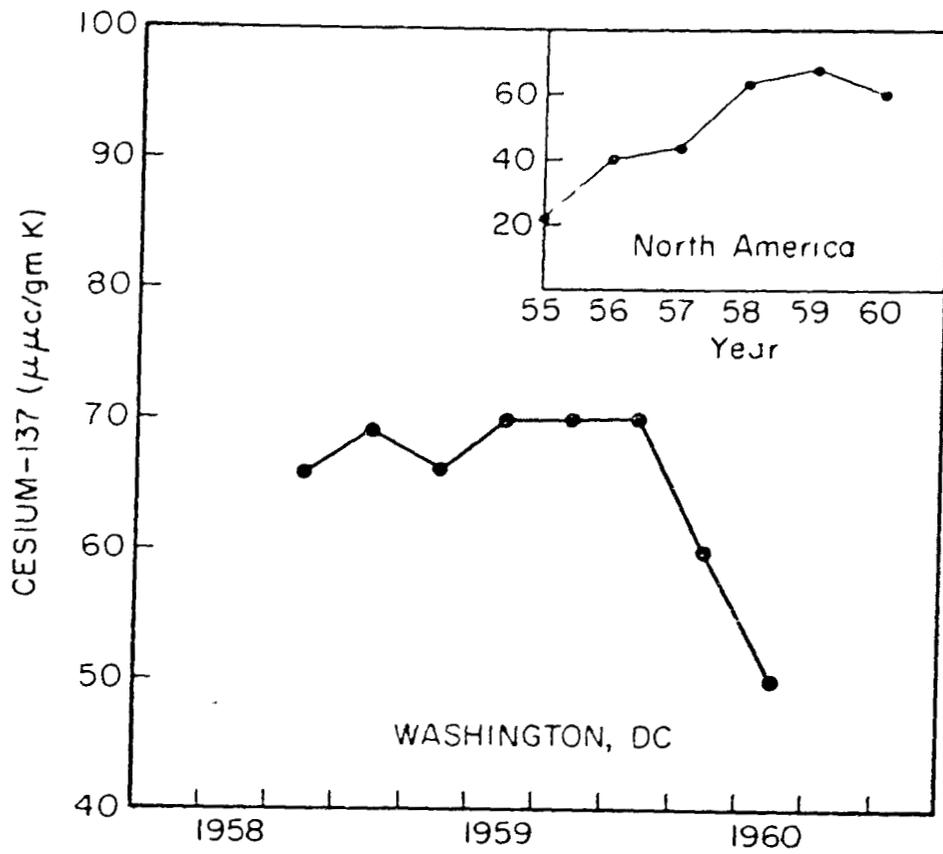
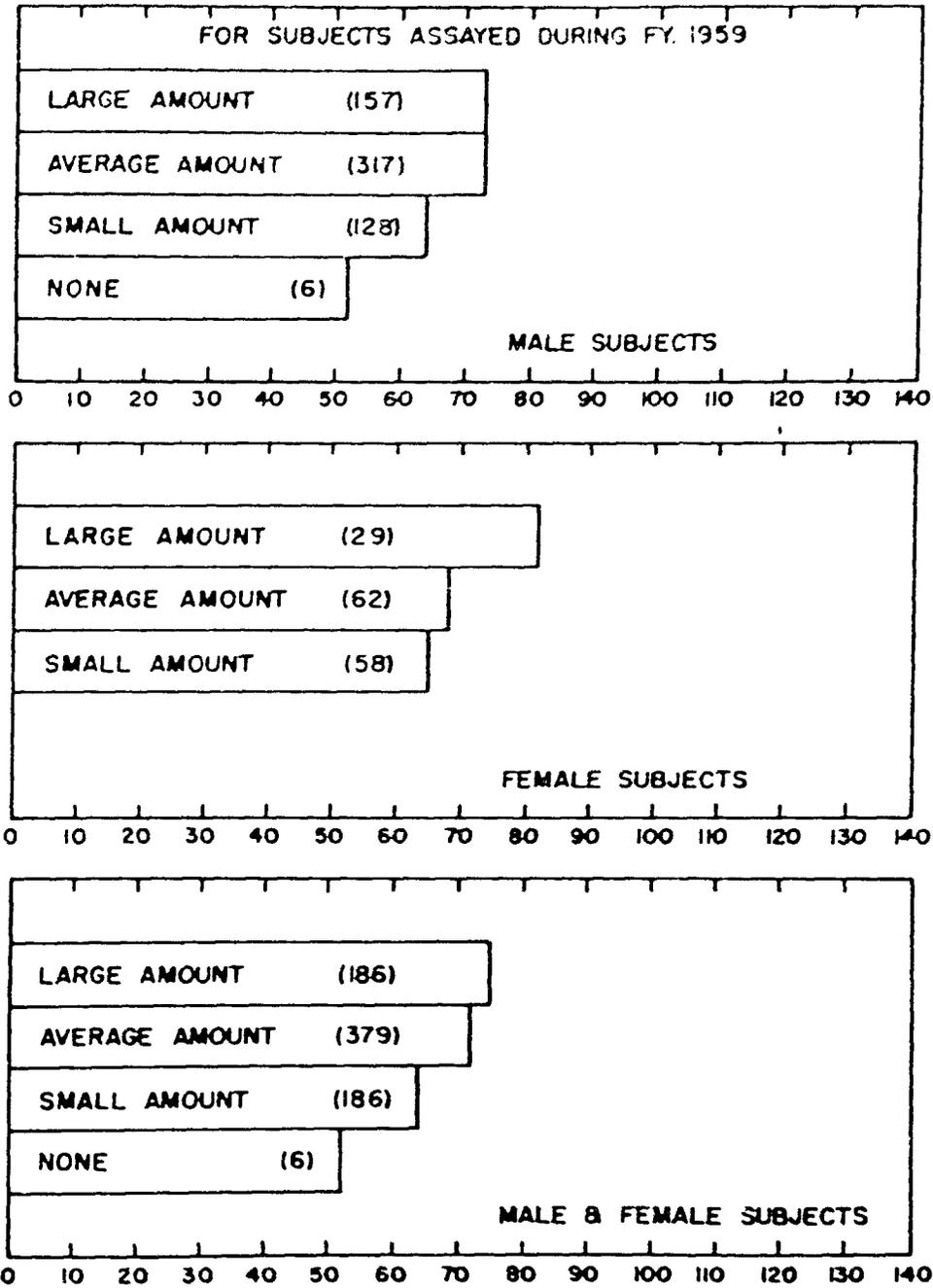


Figure 45

CONSUMPTION OF DAIRY PRODUCTS



$\mu\text{C Cs}^{137}/\text{gm K}$

Figure 46

contribution from dairy products to the total Cs-137 body burden would be about 23/52 or 43 per cent. For other dietary foodstuffs, no differences in Cs-137 body burden were noted (Figure 47).

10.3 World-Wide Cesium-137 Levels

Body Cs-137 levels were measured in military personnel returning from overseas assignments and in foreign subjects visiting the United States. Average values for France and Germany during 1958 - 1960 are shown graphically in Figure 48. Similarly, temporal variations for Japan and Korea are illustrated in Figure 49. By averaging reported values (Table 6) from all major geographic areas since 1956, world-wide population changes in cesium-137 were obtained.

The French-German values in Figure 48 clearly show elevations coincident with high intensity fallout during the summer of 1959. Estimates for Europe are primarily derived from English, French, and German levels and the highest value occurs in 1959. Europe is consistently the area of highest cesium-137 body burden and exceeds the United States by about 15 to 20 per cent. Since the 1959 summer peak, French-German levels have decreased monotonically about 25 per cent, similar to Washington, D. C.

Quarterly results for Japan - Korea show peak levels in the fall of 1958 and summer of 1959. Using all data the Cs-137 body burden in the Far East was identical to the European population in 1958. The 1958 level is also the maximum obtained in the Far East. In 1959 the Cs-137 burden decreased by about 25 per cent. No significant change is evident over the past 9 months.

FOOD CONSUMPTION FOR SUBJECTS ASSAYED DURING FY. 1959

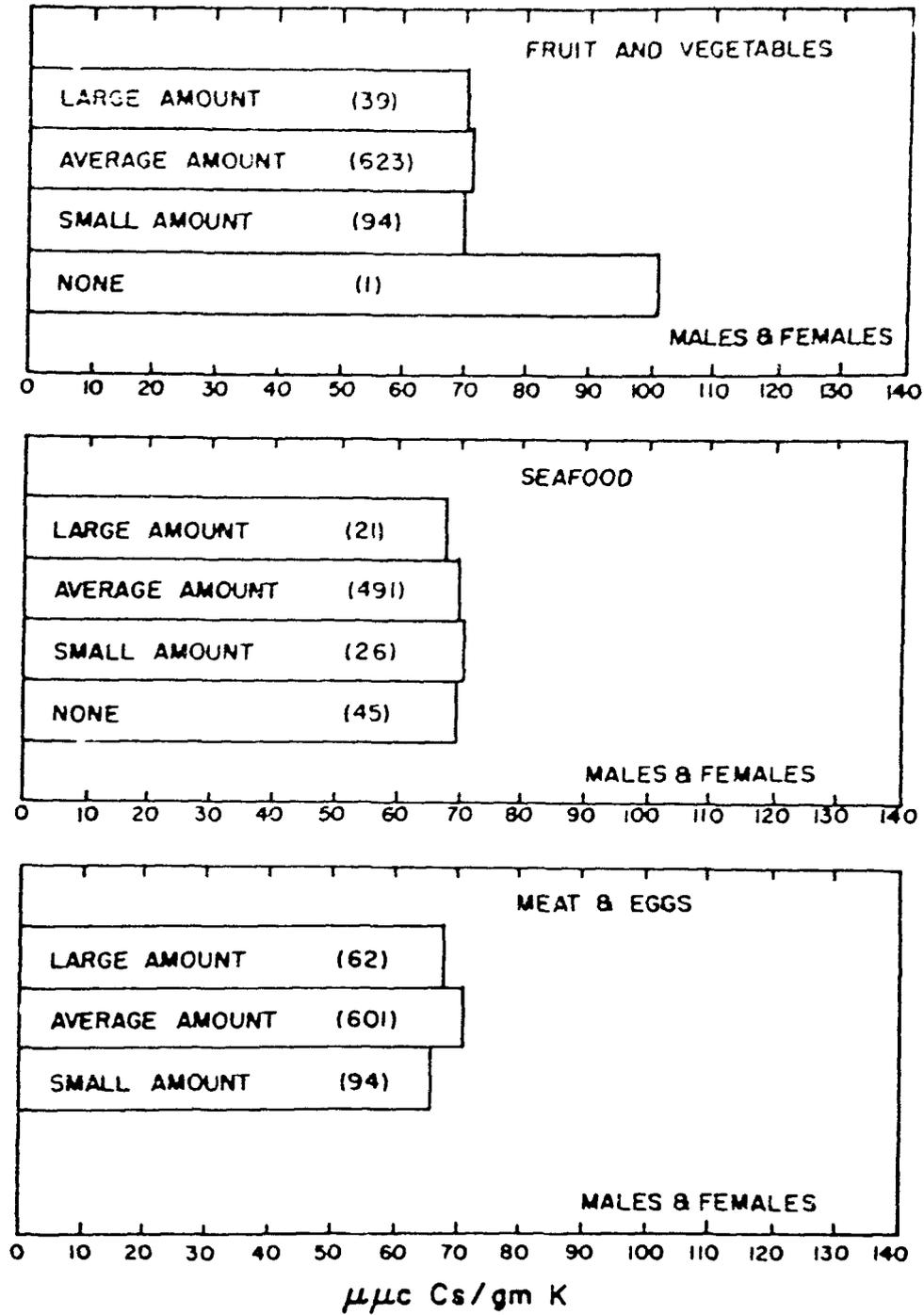


Figure 47

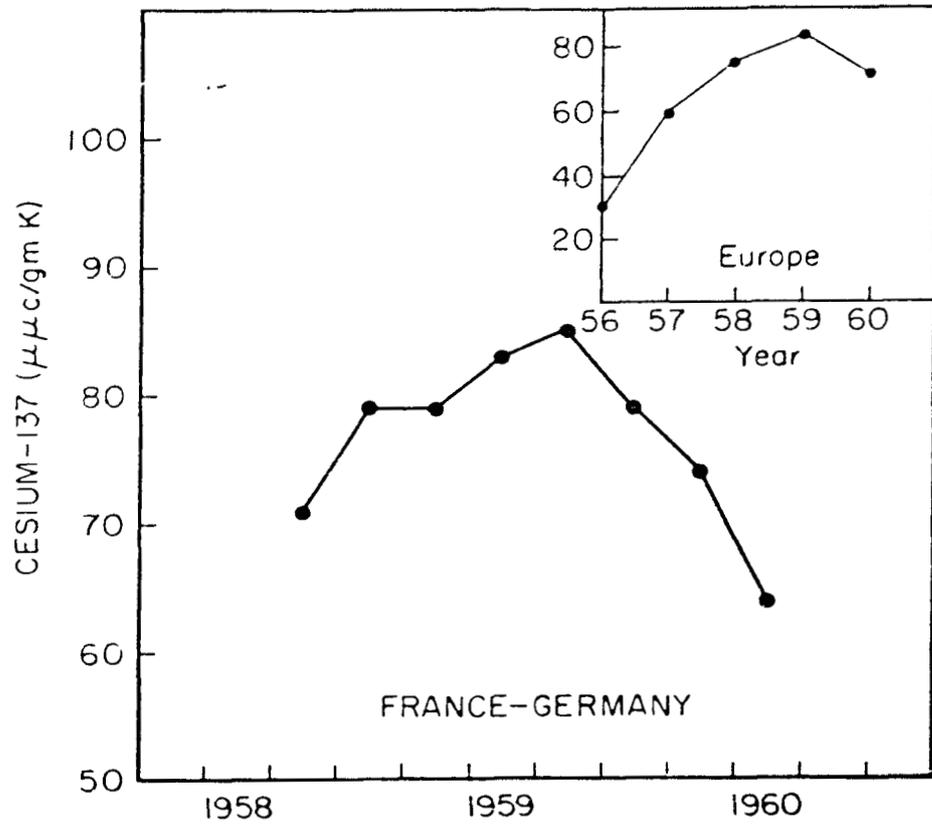


Figure 48

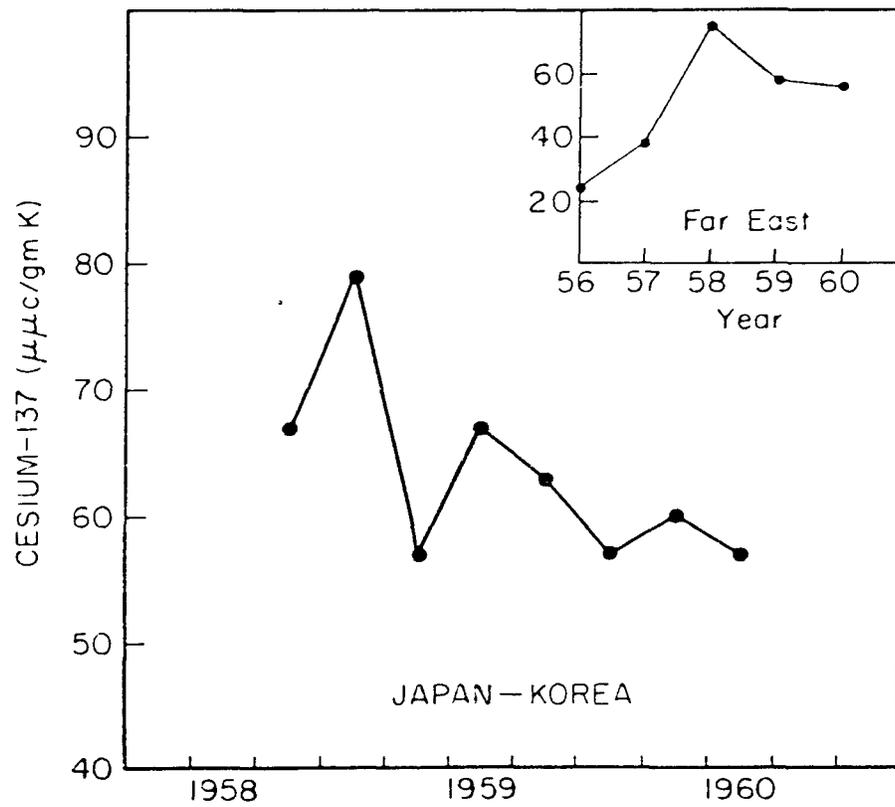


Figure 42

Table 6

Variations In Mean Calcium-137 Body Burden
For Various Populations Since 1954

REGION	T I M E				
	1956	1957	1958	1959	1960
North America*	41(204)	44(328)	63(1369)	67(822)	61(333)
Central America and Caribbean	-	8(1)	70(6)	53(13)	-
South America	-	16(10)	15(4)	40(13)	-
Europe	31(8)	59(15)	75(46)	83(131)	71(69)
Near East	-	-	60(2)	54(1)	43(3)
Africa	-	-	-	58(3)	-
Asia	16(4)	42(3)	46(1)	58(14)	51(2)
Far East	24(1)	38(1)	75(16)	58(81)	56(40)
Australia and New Zealand	-	50(1)	-	48(3)	51(2)
Oceania	-	-	52(1)	47(5)	31(1)

* Average of 11 values in U. S. (Ill.) for 1955 was 21 $\mu\text{C/gm K}$.

10.4 Discussion

Since 1952 approximately 11 million curies of cesium-137 have been injected into the stratosphere from high yield nuclear weapons tests (Table 7). Over this period the rate of injection has been roughly 1.8 megacuries of Cs-137 per year. The 1959 stratospheric inventory of Sr-90 is estimated to be about 1 megacurie (12, 13) and the Cs-137 inventory would be about 1.8 megacuries. With approximately 34 per cent of the total fallout deposited, the cumulative Sr-90 fallout for New York City was reported to be 75 millicuries per square mile in mid-1959 (14). For Cs-137 the amount would be 135 mc/mile².

Martel and Drevinsky (11) have shown that after the injection of fission debris into the stratospheric reservoir, regardless of the latitude of detonation, the appearance of fallout occurs within several months. Also there is considerable evidence that there is little disturbance in the fission product ratios, particularly Cs-137 to Sr-90, from the time of production to ground deposition (12, 15, 16, 17). According to Wellford and Collins (18) however, Cs-137 is somewhat less soluble than Sr-90. From New York City ground deposits they obtained about 70 per cent solubility for cesium-137 activity and 96 per cent for strontium-90. Consequently the accessibility of Cs-137 and Sr-90 to the human could be within a few months of production and the production ratio reduced to about 1.3 due to differences in solubility. Since the Cs-137 body burden may vary in accordance with the rate of fallout on foliage, the stratospheric residence time is particularly important. For debris injected in polar latitudes the residency time may vary from 4 to 9 months, and 9 to 15 months for U. S. and U. K. equatorial detonations (13).

Table 7*

Approximate Stratospheric Injections^(a) of Cesium-137 from
Nuclear Detonations

<u>Date</u>	<u>Test</u>	<u>Location</u>	<u>Fission Yield (Megatons)</u>	<u>Cs¹³⁷ Production^(b) (Megacuries)</u>
1952(Nov)	U. S. (Ivy)	11°N	1.4	0.25
1954(Spring)	U. S. (Castle)	11°N	20.0	3.60
1954(Fall)	U. S. S. R.	52°N	-	-
1955(Fall)	U. S. S. R.	52°N	1.8	0.32
1956(Spring)	U. S. (Red Wing)	11°N	6.7	1.21
1956(Fall)	U. S. S. R.	52°N	2.7	0.48
1957(Spring)	U. S. S. R.	52°N	2.7	0.48
1957(Spring)	U. K.	2°N		
1957(Fall)	U. S. S. R.	52°N	4.5	0.81
1958(Early)	U. S. S. R.	52°&73°N	3.3	0.59
1958(Spring)	U. S. (Hardtack)	11°N	4.0	0.72
1958(Oct)	U. S. S. R.	73°N	<u>12.5-15.0</u>	<u>2.25-2.70</u>
			60.0-62.0	10.7-11.1

* Summary of Major Nuclear Test Series by Martell (33) using inventory data furnished by Libby.

(a) Stratospheric Injections are 20% of fission yield for surface coral shots, 80% for surface seawater shots, and 100% for air shots.

(b) Using 0.18 megacuries of cesium-137 produced per megaton of fission energy.

During the twenty months since the cessation of weapons tests no consistent pattern is evident from the three major population samples as to the amount or the time at which decreases in Cs-137 body burden might occur. If quarterly levels for Japan - Korea are used, the change in body burden between the fall of 1958 and winter quarter of 1959 was 79 to 57 $\mu\mu\text{c}$ per gram or about 29 per cent in three months. The resultant half-time for elimination would be about 7 months, indeed similar to the stratospheric clearance of polar debris. For Washington, D. C., the decrease occurs considerably later than in the Far East and with a half-time of about 14 months during the first two quarters of 1960. The peak activity level in France - Germany occurred in the summer of 1959. A decrease of about 25 per cent then occurred over the past 9 months. Here the half-time would be 25 months which is somewhat longer than the residency time estimated for fission debris from equatorial detonations. The longer elimination time for Europeans is not in keeping with the fact that 1958-1959 fallout, derived primarily from polar detonations, resulted in the highest world-wide cesium-137 burdens in this population.

Apparently a direct relationship between cesium-137 in people and fallout is initially limited by the complexity and variability of stratospheric injections and subsequent clearance. Differences in dietary habits and methods of processing and holding foodstuffs would also be expected to influence the Cs-137 burden.

It is particularly important at this time to continue surveying domestic and foreign subjects since the fraction of cesium-137 obtained from accumulated soil deposition may be of about the same order as obtained from direct fallout on plant life.

11.0 Clinical Studies Using Whole Body Counters

The use of whole body counters for clinical and metabolic research has been emphasized repeatedly (19, 20). Four pi detectors are particularly applicable to whole body retention and excretion studies where minimum dosage and rapid counting times are important. The crystal spectrometer is reserved for studies requiring localization of radio-deposits or accurate energy discrimination of multiple radio-nuclides used simultaneously.

11.1 Methods

Prior to the administration of a radio-element or compound the natural gamma activity of the subject is measured. If the presence of other gamma activity* is suspected, the subject is examined by crystal spectrometry.

After administration of the radioactivity the subject is counted at short intervals until a maximum rate is obtained. This varies from minutes after intravenous injection to four hours or so after ingestion. The count rate of the subject and excreta are then determined at various intervals depending on the objectives of the investigation.

The count rates of the subject and of excretory collections are compared to those of known standards, and the relationships shown in Figure 50 are used to obtain fractional retention and excretion values at any time. A 2500 ml and a 250 ml plastic bottle standard is used containing distilled water and an aliquot of the administered radio-nuclide. The counting geometry for

*It is not an infrequent occurrence to detect gamma activity, particularly Cr-51 and I-131, from previous diagnostic studies.

CALCULATION OF PERCENT RETENTION

$$\frac{\text{Subject (c/s)} = R_1 \text{ (day 1)}}{\text{Standard (c/s)}} \quad R_1 \times 100 = 100\% \text{ Retention}$$

$$\frac{\text{Subject (c/s)} = R_x \text{ (day x)}}{\text{Standard (c/s)}} \quad R_x \times 100 = \text{Percent retention on day x}$$

PERCENT EXCRETION

$$\frac{\text{Urine or Feeces (c/s)}}{\text{Standard (c/s)}} \times 100 = \text{Percent excretion}$$

Figure 50

urine and stool samples compares with that of the two respective standards. Calibration of the 4" detector for absolute quantities is not required for most whole body retention studies. Retention values are obtained by comparing the count rate of the subject with the 2500 ml standard. For studies using Iron-59 and Iodine-131 the accountability of total radio-nuclide from either retention or excretion values is about 95 per cent.

11.2 Metabolic Studies Using Iodine-131

11.2.1 Iodine-131

The retention and excretion of orally administered Iodine-131 has been measured in several euthyroid subjects. Typical results are shown in Figure 51 using a single 6.0 μ c dose. Within two to four hours the I-131 is absorbed and distributed systemically (maximum count rate). At 24 hours the retention value is 24 per cent. After 48 hours all of the unbound iodine is excreted and the fraction retained is about 18 per cent (thyroidal). The retention curve has no significant slope (14 day observation) in agreement with a very long half-time for thyroidal release of iodine in the euthyroid subject.

11.2.2 Iodine-131 Serum Albumin

Radio-iodinated serum albumin has been used to estimate protein catabolism in disease states and the effect of diet on protein turnover. The test requires, however, a relatively large dose of Iodine-131 since the conventional method of estimating the catabolic rate is directly from small serum samples or indirectly from fractional urine analyses (used to obtain retention values).

RETENTION AND EXCRETION OF ORALLY ADMINISTERED I¹³¹

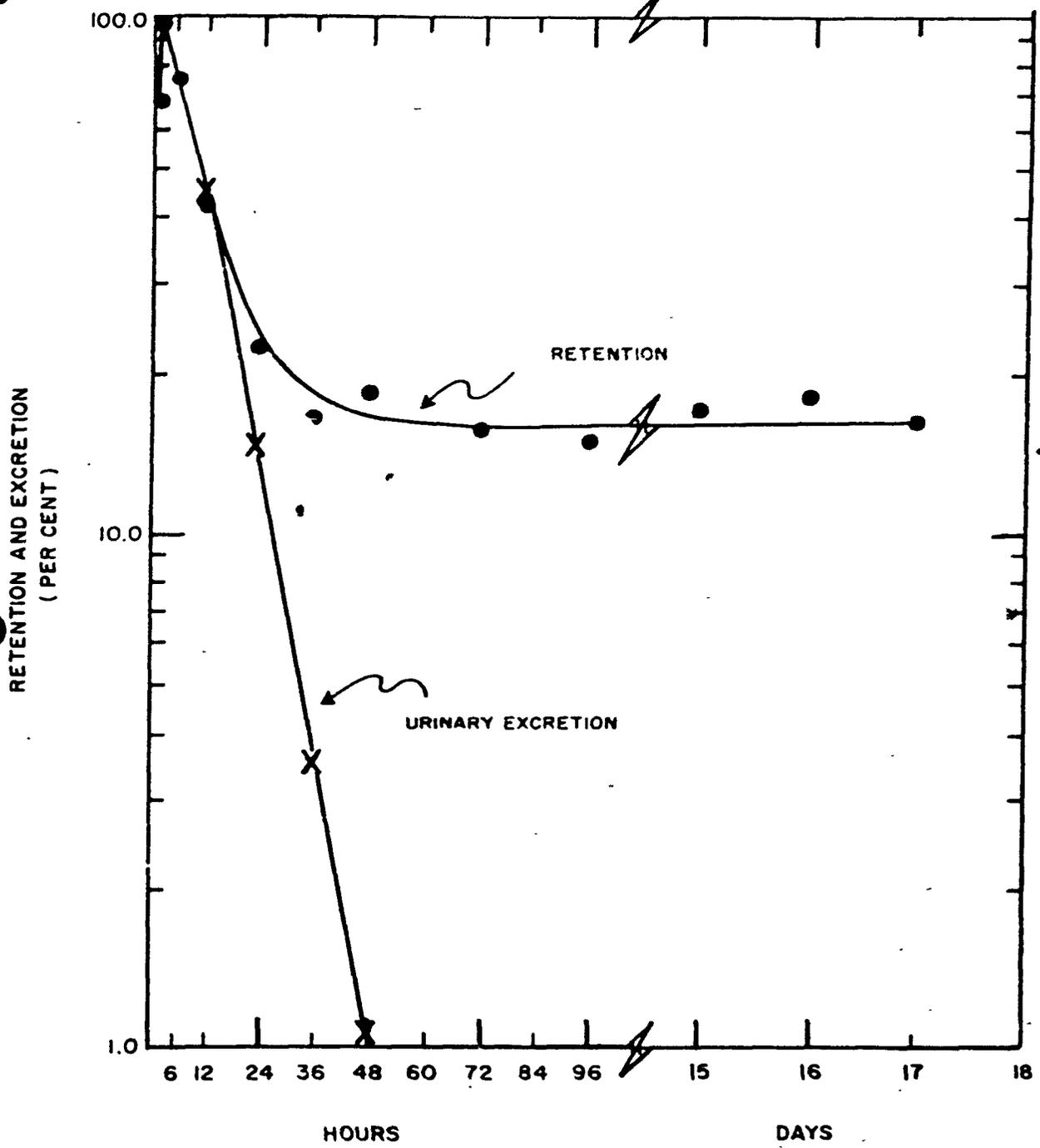


Figure 51

Figure 52 shows the results obtained directly by whole body counting. The retention values show a single exponential catabolic rate process for 34 days. The urinary excretion curve shows two rate processes. Initially, about five per cent of the urinary iodine-131 is excreted rapidly (due to unbound iodine-131 in the albumin which varies from lot to lot) following which the urinary curve parallels the measured retention curve. At about 20 days the retention values (open circles) estimated from the sum of the individual urine values is noted to deviate significantly from the true retention. This variance is due to the large decay constants applied to the low urinary count rates obtained at late times.

11.3 Iron-59

The absorption of iron has been measured in 13 normal subjects (12 males, one female). After fasting, the subject ingests one microcurie of Fe-59 (as citrate) with one mgm of elemental iron as FeSO_4 . Less than ten per cent of the dose is retained in the normal subject. As noted in Figure 53 individuals with iron deficiency show 3 to 8 fold increases over normal in retention values. The iron-59 retention curve for the normal subject shows no evidence of iron loss in sixty days or so. A decrease in retention ten days or so after administration is evidence of blood loss. Occult gastro-intestinal bleeding is readily quantitated by whole body counting, and fecal iron-59 assays can be used to verify this.

11.4 Strontium-85

Strontium-85 retention and excretion in the normal adult male is shown in Figure 54. After a single oral dose body retention may be expressed

RETENTION AND EXCRETION OF INTRAVENOUSLY ADMINISTERED
RADIO-IODINATED HUMAN SERUM ALBUMIN

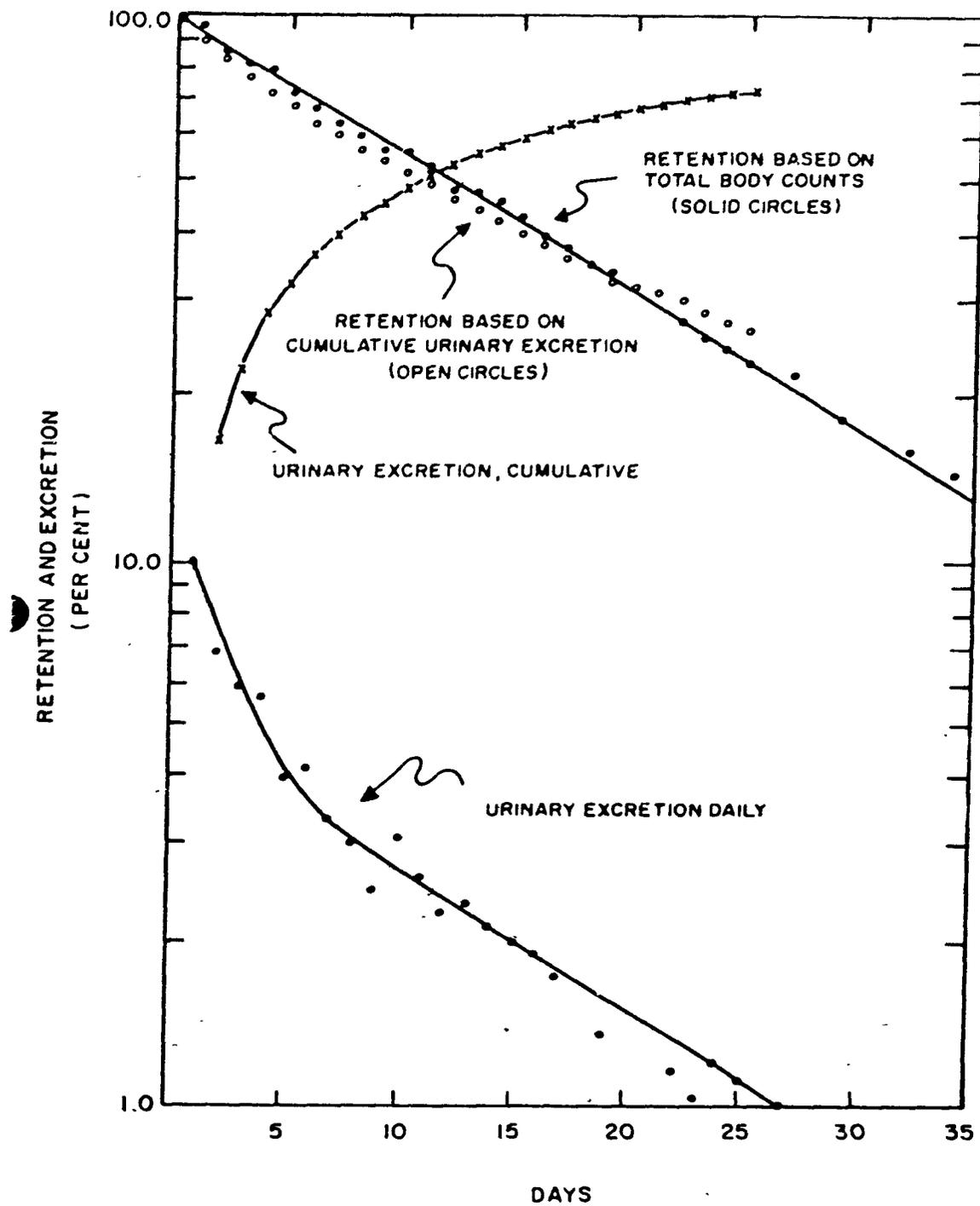


Figure 52

11-6

ORAL Fe^{59} ABSORPTION

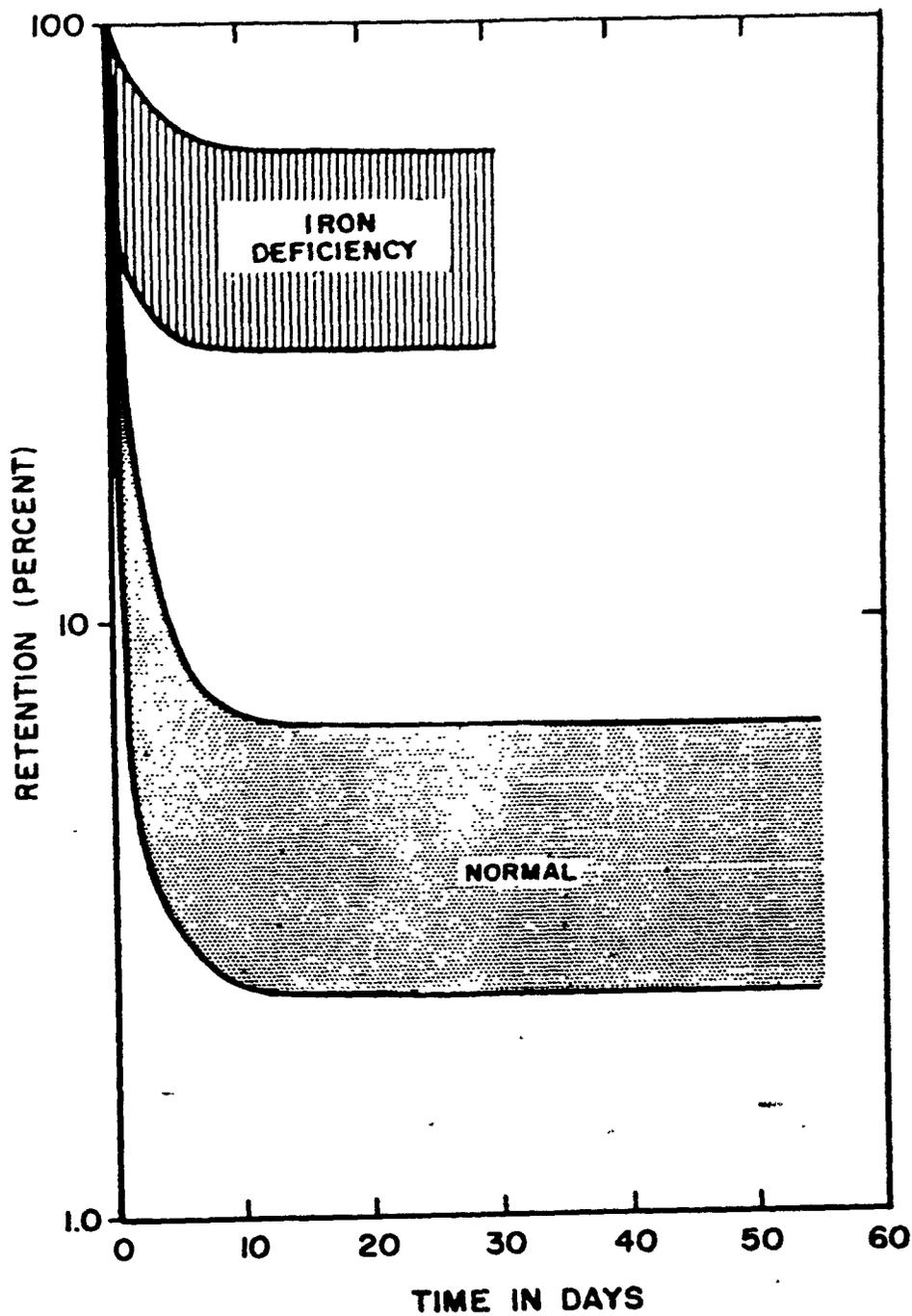
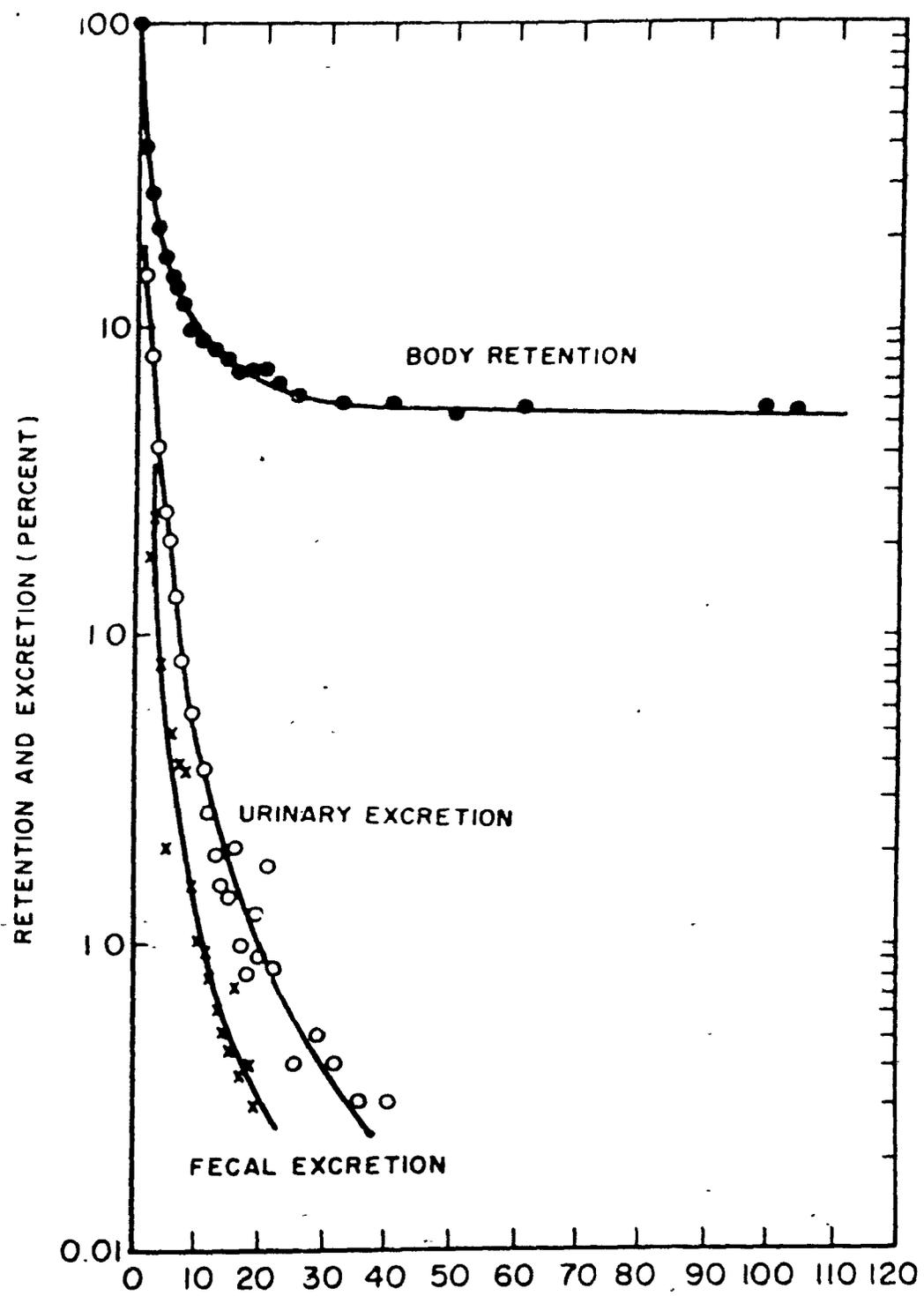


Figure 53

RETENTION AND EXCRETION OF Sr⁸⁵
AFTER A SINGLE ORAL DOSE



TIME IN DAYS
Figure 54

by a three component exponential function:

$$R = 83.6e^{-0.693t} + 11e^{-0.099t} + 5.4e^{-0.0006t}$$

and the component half-times are 1, 7, and 1150 days. Excretion curves are essentially parallel to the retention curve over the limited time samples were obtained. The ratio of urinary to fecal excretion is about 3.5 excluding the initial forty-eight hours for gastro-intestinal transit of unabsorbed Sr-85.

In patients with bone disease and disturbances in calcium metabolism significant differences in Sr-85 retention are shown in Figure 55. This radio-element may be extremely useful in differentiating malfunctions in calcium metabolism and in evaluating the effects of treatment.

11.5 Total Body Potassium

The isotopic dilution of K-42 has been used to measure total body potassium, however, a minimum of about 24 hours is required for mixing with the exchangeable potassium pool. Whole body counting provides an immediate and precise measure of total body K-40 gamma activity for timely application. Also body potassium values can be ascertained in large population samples for correlation studies.

Body potassium values obtained from chemical balance data and from K-40 gamma activity measurements are shown in Figure 56. Potassium loss was induced in a normal male subject by restricting the dietary intake of potassium and sodium. Potassium intake was restricted to 5 - 10 meq per day with sodium intake limited to 5 - 7.5 meq per day. The discrepancy in the results of the two methods increases with time and approaches 12%.

RETENTION OF A SINGLE ORAL DOSE OF STRONTIUM-85

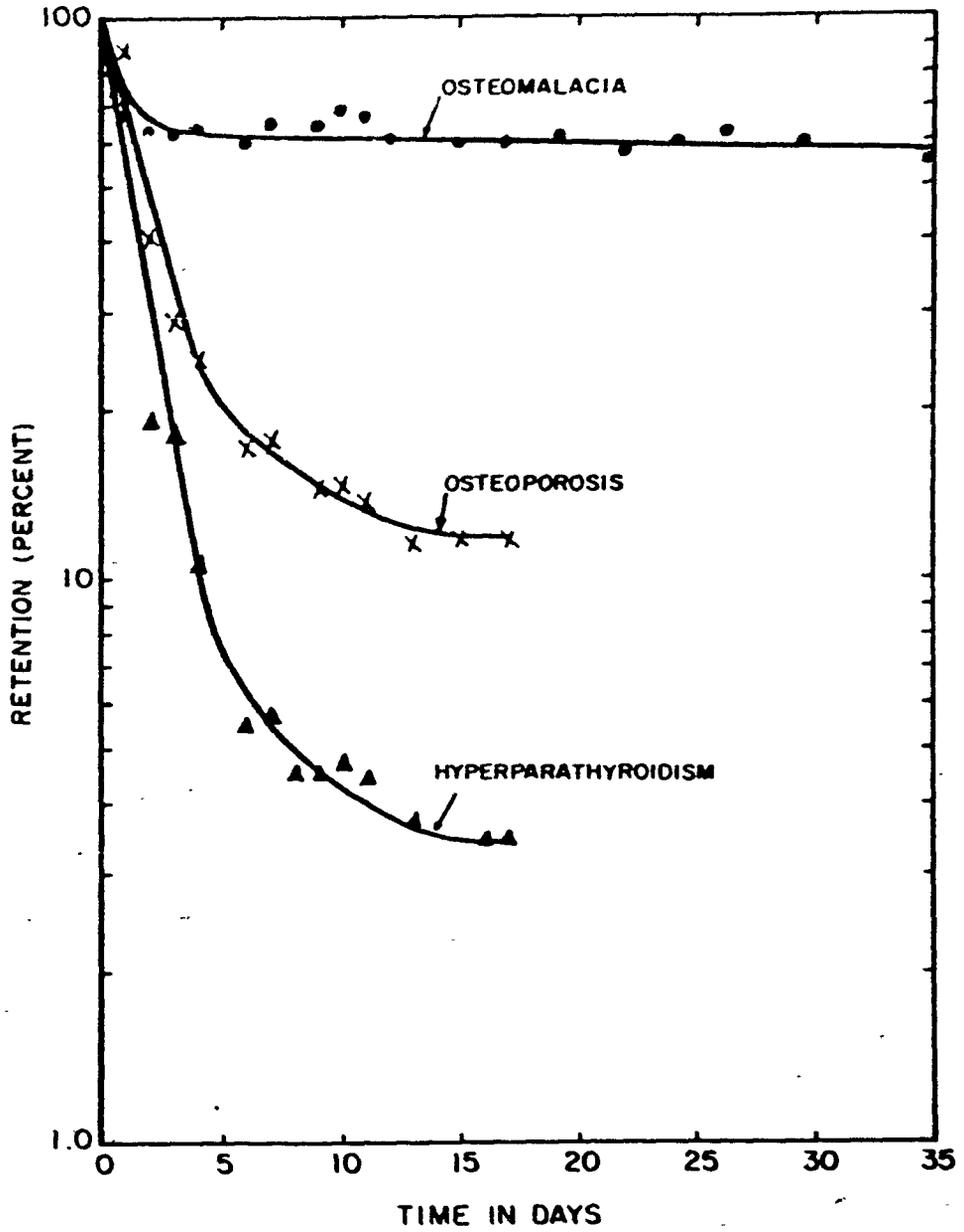


Figure 55

POTASSIUM DEPLETION AND REPLETION

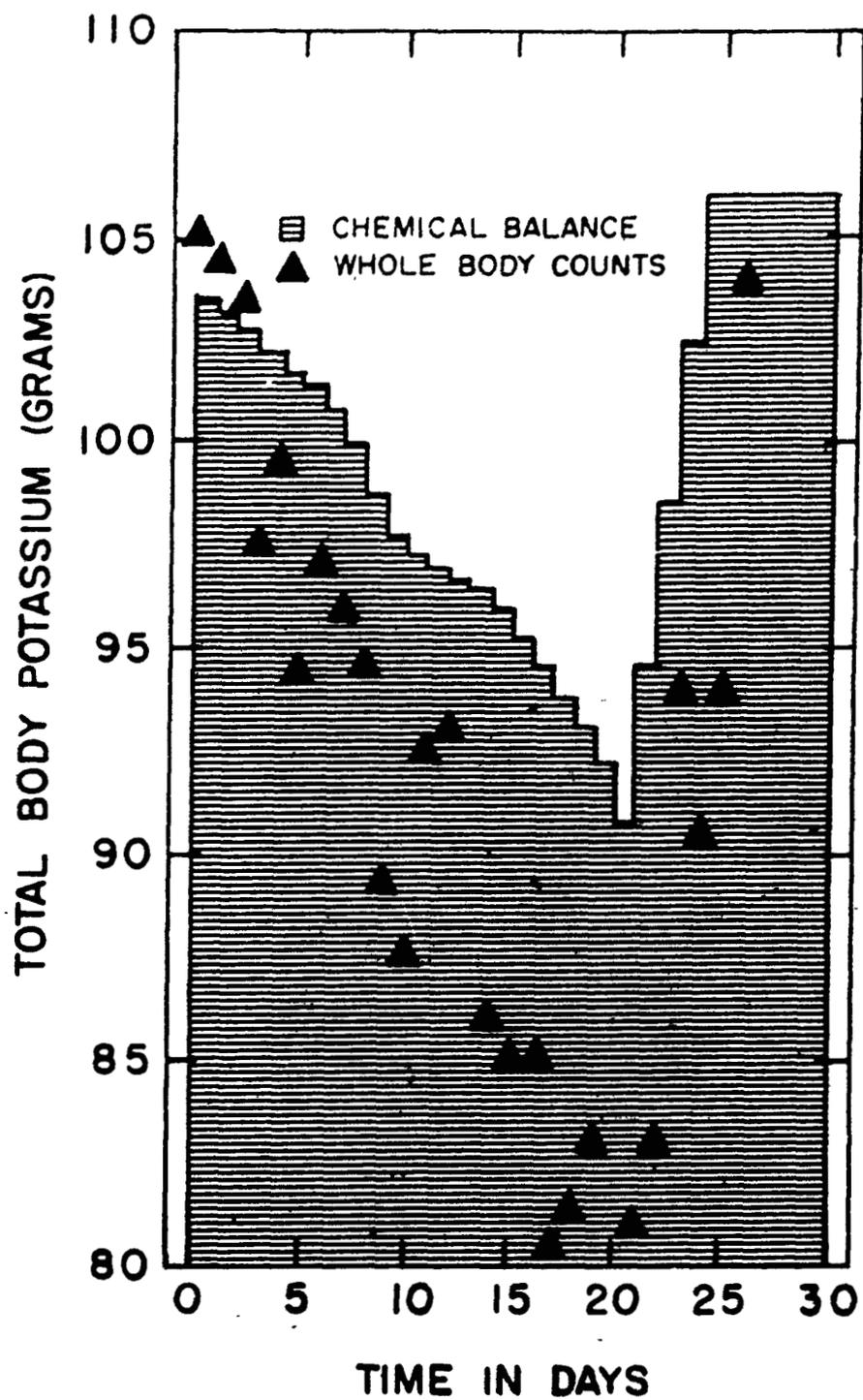


Figure 56

This is attributed to a small error in the chemical determinations which is cumulative. Potassium-40 gamma activity measurements at 18 days reveal a 23 gram deficit in body potassium. The average rate of decrease is then 1.22 per cent of body stores per day, and the half-time for potassium elimination would be 57 days.

As previously noted (Figure 42) the average body content of elemental potassium is 1.88 grams per kilogram of body weight. The standard deviation for this population is 15 per cent. Tables 8 and 9 list average potassium values obtained in normal male and female subjects for various ages. As reported previously (21) the potassium value reaches a maximum at 17 years in males and thereafter declines monotonically with age. No corresponding peak for females is noted, however, the loss of potassium with age closely parallels the results for males. A least squares fit of the potassium data from age 20 and above is:

$$\text{Male} \quad K(\text{gm/K.g}) = 2.19 - 0.009Y \text{ (years)}$$

$$\text{Female} \quad K(\text{gm/K.g}) = 1.75 - 0.008Y$$

The rate of body potassium loss with increasing age suggests its use as an index of physiological aging. Body potassium measurements in large population studies may be the most important use of large volume counters with humans. In the case of the Hiroshima and Nagasaki populations exposed to ionizing radiation, an accelerated aging effect might be expected. The application of body potassium measurements to assess the physiological age of this population is an exciting possibility.

Table 8

BODY POTASSIUM MEASUREMENTS FOR NORMAL MALESUBJECTS AT VARIOUS AGES

<u>Age</u>	<u>Weight</u>	<u>gm K./Kg</u>	<u>No. of Subjects</u>
8	25.5	1.86	4
9	32.7	1.74	5
11	38.7	1.82	7
12	41.7	1.84	6
13	44.0	1.95	4
15	60.6	2.07	5
16	73.6	2.11	8
17	72.0	2.14	12
18	71.0	2.05	41
19	70.5	2.04	61
20	74.3	1.98	58
21	72.5	2.05	58
22	73.2	2.05	53
23	73.9	1.99	162
24	74.8	1.95	147
25	74.0	1.94	58
26	73.1	1.90	42
27	73.3	1.93	55
28	72.6	1.94	43
29	72.5	1.95	50
30	72.1	1.92	50
31	74.9	1.83	51
32	72.7	1.93	34
33	74.8	1.82	42
34	73.7	1.84	31
35	78.2	1.84	43
36	75.5	1.84	32
37	78.9	1.86	34
38	78.9	1.80	41
39	77.4	1.79	30
40	75.6	1.79	26
41	79.0	1.88	20

Table 8 (Continued)

<u>Age</u>	<u>Weight</u>	<u>gm K/Kg</u>	<u>No. of Subjects</u>
42	79.1	1.80	23
43	77.3	1.81	14
44	77.9	1.84	20
45	78.8	1.75	16
46	77.8	1.70	13
47	77.0	1.76	12
48	84.6	1.70	9
49	77.2	1.82	9
50	69.7	1.72	13
51	75.7	1.74	7
52	84.3	1.60	13
53	70.9	1.66	8
54	81.8	1.63	2
55	64.3	1.64	4
56	79.3	1.69	8
57	86.9	1.61	3
58	73.0	1.68	6
59	73.8	1.59	2
60	70.2	1.58	2
61	70.4	1.73	4
62	72.7	1.59	4
63	68.5	1.74	8
64	68.5	1.57	6
66	70.5	1.45	2
67	69.2	1.69	3
68	75.0	1.49	2
69	66.8	1.70	3
70	81.7	1.90	1
72	70.9	1.59	4
74	62.8	1.60	3
75	74.9	1.39	5
76	73.9	1.54	2
77	75.9	1.35	2
86	75.9	1.48	2

Table 9

BODY POTASSIUM MEASUREMENTS FOR NORMAL FEMALESUBJECTS AT VARIOUS AGES

<u>Age</u>	<u>Weight</u>	<u>gm K./Kg</u>	<u>No. of Subjects</u>
4	15.4	1.95	1
7	19.9	2.17	1
10	39.9	1.58	7
12	37.8	1.63	2
13	52.5	1.56	10
14	49.4	1.63	6
15	57.1	1.76	2
16	55.2	1.55	8
17	53.6	1.65	7
18	59.8	1.54	22
19	59.1	1.64	13
20	60.0	1.55	14
21	59.3	1.47	11
22	62.8	1.52	5
23	58.8	1.70	6
24	60.5	1.52	11
25	55.4	1.63	8
26	62.5	1.44	14
27	54.3	1.68	4
28	53.7	1.61	2
29	54.5	1.51	6
30	59.2	1.56	10
31	57.7	1.43	3
32	58.5	1.49	11
33	54.1	1.45	6
34	57.7	1.54	8
35	62.5	1.40	5
36	65.1	1.43	8
37	63.0	1.45	4
38	57.8	1.36	10
39	57.8	1.57	4

Table 9 (Continued)

<u>Age</u>	<u>Weight</u>	<u>gm K/Kg</u>	<u>No. of Subjects</u>
40	63.2	1.41	6
41	61.6	1.42	8
42	55.0	1.45	10
43	60.8	1.52	10
44	61.8	1.46	7
45	66.4	1.43	9
46	63.5	1.43	2
47	60.5	1.54	5
48	73.1	1.34	4
49	56.6	1.21	1
50	69.1	1.32	8
51	63.7	1.37	2
52	71.3	1.34	3
53	90.9	1.16	2
54	58.5	1.38	2
55	70.3	1.13	1
57	63.5	1.63	1
58	72.3	1.17	2
59	66.2	1.40	2
62	77.6	1.11	1
63	67.5	1.15	1
65	66.4	1.33	5
66	63.0	1.06	1
68	72.1	1.23	1
69	61.7	1.36	1
71	64.4	1.29	1

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APPENDIX A

Specifications for Reflective Coating (Epon Resin Formulation KA-200, Shell Chemical Corp., pigmented with anatase TiO_2 , Zopague SD, Glidden Co.) of Liquid Scintillation Detector Tank.*

1.0 Cleaning The Detector Tank

- 1.1 Shot blast the tank with small steel shot to provide a fine granular surface within the detector tank.
- 1.2 Solvent degrease the entire inner surface with trichlorethylene.
- 1.3 Bake the detector tank at 600°F for eight hours. Look for grease in crevices, overlays, etc. Depending on appearance and persistence of grease or oils, the detector tank may require up to 24 hours of baking at 600°F to thoroughly degrease.

2.0 Paint Formulation (Also See: Shell Chemical Corp., Technical Bulletin SC: 55-10)

2.1 Epon No. 1001 - 200 grams

Solvent (50% toluene, 45% methyl isobutyl ketone, 5% butyl cellosolve) - 300 grams.

Dissolve, let set for 2 weeks and decant. Remake to 500 grams with solvent.

Add Zopague SD - 250 grams

Grind overnight in ball mill with glass balls.

Add "Beetle" plasticizer - 6 grams

- 2.2 Twenty minutes before spraying, add 20 grams of accelerator and mix thoroughly. The accelerator is 50% diethylene triamine and 50% solvent (a 1:1 mixture of butanol and toluene).

*Kindly furnished by the Los Alamos Scientific Laboratory of the University of California.

3.0 Spraying The Detector Tank

3.1 Spray on - moderately heavy and bake detector tank at 150°F for one hour (at temperature). Minimum of two coats and bake at 150°F for one hour (at temperature) after each coat.

APPENDIX B

Bonding Windowed Sleeves for Multiplier Phototubes

Unfilled Epon resin (Shell Chemical Corp., No. VI) was used to bond the recessed glass windows to the seamless steel sleeves (See Section 2.1). Diethylene triamine, 8 parts per 100 of resin, was used as the activator with vigorous mixing for a minimum of 5 minutes. Although the pot time of the activated resin is short, i. e., about 30 minutes, the resin is easy to apply using a syringe and large bore needle. For good curing of the resin the sleeve to window bond must be baked at 150°F for 12 hours. The desired bond takes on a glass-like appearance.

APPENDIX C

Neoprene Gaskets for Liquid Scintillation Counter

Neoprene gaskets (See Section 2.1) require refluxing in hot toluene for several hours until all coloring matter is dissolved. If allowed to contaminate the scintillation solution this yellow-green color would seriously quench light output.

APPENDIX D

MAJOR GEOGRAPHIC AREAS

<u>AREA</u>	<u>CODE</u>
United States	A
Canada	B
Central America	C
South America	D
Caribbean	E
Africa	F
Europe	G
Asia	H
Near East	I
Far East	J
Indonesia	K
Australia	L
Pacific Islands	M
Iceland - Greenland	N
Antartica	O

GEOGRAPHIC AREAS

UNITED STATES

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Alabama	ALAB A
Alaska	ALAS A
Arizona	ARIZ A
Arkansas	ARK. A
California	CAL A
Colorado	COLO A
Connecticut	CONN A
Delaware	DEL A
District of Columbia	DC A
Florida	FLA A
Georgia	GA A
Hawaii	HAWI A
Idaho	IDA A
Illinois	ILL A
Indiana	IND A
Iowa	IOWA A
Kansas	KANS A
Kentucky	KY A
Louisiana	LA A
Maine	ME A
Maryland	MD A
Massachusetts	MASS A
Michigan	MICH A

GEOGRAPHIC AREAS

UNITED STATES

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Minnesota	MINN A
Mississippi	MISS A
Missouri	MO A
Montana	MONT A
Nebraska	NEBR A
Nevada	NEV A
New Hampshire	NH A
New Jersey	NJ A
New Mexico	NMEX A
New York	NY A
North Carolina	NC A
North Dakota	NDAK A
Ohio	OHIO A
Oklahoma	OKLA A
Oregon	OREG A
Pennsylvania	PA A
Rhode Island	RI A
South Carolina	SC A
South Dakota	SDAK A
Tennessee	TENN A
Texas	TEX A
Utah	UTAH A
Vermont	VT A

GEOGRAPHIC AREAS

UNITED STATES

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Virginia	VA A
Washington	WASH A
West Virginia	WVA A
Wisconsin	WIS A
Wyoming	WYO A

GEOGRAPHIC AREAS

CANADA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Alberta	ALTA B
British Columbia	BC B
Manitoba	MAN B
New Brunswick	NB B
Newfoundland	NEWF B
Nova Scotia	NS B
Northwest Territories	NWT B
Ontario	ONT B
Quebec	QUE B
Saskatchewan	SASK B
Yukon	YUK B

GEOGRAPHIC AREAS

CENTRAL AMERICA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
British Guiana	EGUI C
British Honduras	BHON C
Colombia	COLM C
Costa Rica	CORI C
Ecuador	ECUA C
El Salvador	SALV C
French Guiana	FGUI C
Guatemala	GUAT C
Honduras	HON C
Mexico	MEX C
Nicaragua	NIC C
Panama	PAN C
Surinam	SURI C
Venezuela	VEN C
Miscellaneous	MISC C

GEOGRAPHIC AREAS

SOUTH AMERICA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Argentina	ARG D
Bolivia	BOL D
Brazil	ERAZ D
Chile	CHIL D
Falkland Islands	FALK D
Paraguay	PARA D
Peru	PERU D
Uruguay	URUG D
Miscellaneous	MISC D

GEOGRAPHIC AREAS

CARIBBEAN

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Bahamas	BAH E
Cuba	CUBA E
Dominican Republic	DREP E
Haiti	HAIT E
Jamaica	JAM E
Lesser Antilles	ANT E
Puerto Rico	PURE E
Virgin Islands	VIRG E
Miscellaneous	MISC E

GEOGRAPHIC AREAS

AFRICA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Angola	ANGO F
Bechuanaland Protectorate	BECH F
Belgian Congo	BCON F
Egypt	EGYP F
Ethopia	ETH F
Federation of Rhodesia & Nyasaland	RHNY F
French Equatorial Africa	FEAF F
French West Africa	FWAF F
Gambia	GAMB F
Ghana	GHAN F
Kenya	KENY F
Liberia	LIBE F
Libya	LIBY F
Madagascar	MADA F
Morocco	MOR F
Mozambique	MOZA F
Nigeria	NIGE F
Port Guinea	GUIN F
Sierra Leone	SILE F
Somaliland	SOMA F
Somaliland Protectorate	SOMP F

GEOGRAPHIC AREAS

AFRICA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Southwest Africa	SAF F
Spanish West Africa	SWAF F
Sudan	SUD F
Tanganyika Territory	TANG F
Union of South Africa	USAF F
Miscellaneous	MISC F

GEOGRAPHIC AREAS

EUROPE

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Albania	ALBA G
Austria	AUST G
Bulgaria	BULG G
Corsica	CORS G
Crete	CRET G
Czechoslovakia	CZEC G
Denmark	DENM G
England	ENGL G
Finland	FINL G
France	FRAN G
Germany	GERM G
Greece	GREE G
Hungary	HUNG G
Ireland	IREL G
Italy	ITAL G
Liechtenstein	LIEC G
Luxembourg	LUXE G
Netherlands	NETH G
Norway	NORW G
Poland	POLA G
Portugal	PORT G
Rumania	RUMA G

GEOGRAPHIC AREAS

EUROPE

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Russia	RUSS G
Sardinia	SARD G
Scotland	SCOT G
Sicily	SICI G
Spain	SPAI G
Sweden	SWED G
Switzerland	SWIT G
Yugoslavia	YUGO G
Miscellaneous	MISC G

GEOGRAPHIC AREAS

ASIA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Afghanistan	AFGH H
Assam	ASSA H
Bhutan	BHUT H
Burma	BURM H
Cambodia	CAMB H
Ceylon	CEYL H
China	CHIN H
India	INDI H
Kashmir	KASH H
Laos	LAOS H
Malayan Federation	MALA H
Nepal	NEPA H
Pakistan	PAKI H
Siberia	SIBE H
Sikkim	SIKK H
Thailand	THAI H
Viet Nam	VIET H
Miscellaneous	MISC H

GEOGRAPHIC AREAS

NEAR EAST

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Aden Protectorate	ADEN I
Iran	IRAN I
Iraq	IRAQ I
Israel	ISRA I
Jordan	JORD I
Lebanon	LEBA I
Oman	OMAN I
Saudi Arabia	SAUD I
Syria	SYRI I
Turkey	TURK I
Yemen	YEME I
Miscellaneous	MISC I

GEOGRAPHIC AREAS

FAR EAST

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Formosa	FORM J
Japan	JAPA J
Korea	KORE J
Okinawa	OKIN J
Philippines	PHIL J
Miscellaneous	MISC J

GEOGRAPHIC AREAS

INDONESIA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Java	JAVA K
Kallimantan	KALI K
Netherlands New Guinea (Irian)	IRIA K
North Borneo	BORN K
Papua Territory	PAPU K
Sarawak	SARA K
Sumatra	SUMA K
Territory of New Guinea	NGUI K
Miscellaneous	MISC K

GEOGRAPHIC AREAS

AUSTRALIA

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
New South Wales	WALE L
New Zealand	ZEAL L
Northern Australia	NAUS L
Queensland	QUEE L
Southern Australia	SAUS L
Victoria	VICT L
Western Australia	WAUS L
Miscellaneous	MISC L

GEOGRAPHIC AREAS

PACIFIC ISLANDS

<u>COUNTRY OR PROVINCE</u>	<u>CODE</u>
Carollna's	CARO M
Fiji's	FIJI M
Gilbert's	GILE M
Marlana's	MARI M
Marshall's	MARS M
New Hebrides'	HEBR M
Solomon's	SOLO M
Miscellaneous	MISC M

GEOGRAPHIC AREAS

COUNTRY OR PROVINCE

CODE

Greenland	GREM N
Iceland	ICEL N

GEOGRAPHIC AREAS

COUNTRY OR PROVINCE

CODE

Antarctica ANTA O

Table E-1

Cesium¹³⁷ Levels (µmc/gm F) In Subjects From The United States

State	Jul- Sep 1958	Oct- Dec 1958	Jan- Mar 1959	Apr- Jun 1959	Jul- Sep 1959	Oct- Dec 1959	Jan- Mar 1960	Apr- Jun 1960
Alabama	89 (4)	67 (2)	73 (2)	76 (1)	83 (2)	59 (2)	63 (2)	69 (1)
Alaska	57 (2)	92 (1)	56 (2)	84 (1)	56 (5)	58 (1)	57 (3)	35 (1)
Arizona	69 (1)	-	46 (1)	-	52 (3)	-	61 (1)	-
Arkansas	79 (2)	-	-	-	77 (4)	61 (2)	82 (1)	-
California	57(16)	88 (2)	52(13)	59 (7)	43(10)	38 (3)	46(13)	41 (7)
Colorado	83 (3)	68 (3)	66 (4)	68 (3)	69 (3)	53 (5)	40 (1)	62 (3)
Connecticut	102 (3)	-	56 (1)	95 (1)	67 (5)	55 (1)	69 (3)	56 (1)
Delaware	77 (2)	-	-	-	60 (2)	-	-	-
District of Columbia	66(271)	69(37)	66(68)	70 (42)	70(77)	70(26)	60(39)	50(51)
Florida	80 (2)	37 (1)	74 (4)	78 (1)	-	100 (2)	105 (7)	44 (1)
Georgia	63 (6)	-	61 (2)	82 (1)	71(14)	76 (1)	72 (6)	46 (3)
Hawaii	49 (4)	74 (2)	71 (2)	67 (5)	64 (6)	57 (1)	44 (2)	78 (1)
Idaho	-	-	-	-	46 (1)	36 (1)	-	-
Illinois	75 (5)	73 (4)	70 (4)	94 (2)	59(11)	58 (5)	66 (7)	46 (4)
Indiana	-	-	67 (3)	74 (4)	51 (1)	36 (2)	-	45 (4)
Iowa	74 (4)	-	-	-	61 (4)	36 (1)	-	55 (2)
Kansas	64 (2)	-	63 (3)	77 (1)	46 (2)	-	68 (1)	37 (2)
Kentucky	55 (1)	89 (1)	64 (2)	70 (1)	69 (8)	56 (1)	45 (4)	50 (3)
Louisiana	82 (2)	-	69 (3)	-	94 (2)	50 (1)	80 (1)	56 (1)
Maine	-	-	-	-	71 (1)	65 (1)	137 (2)	46 (1)
Maryland	-	-	67 (8)	74 (2)	75 (3)	64 (3)	65 (4)	54 (2)
Massachusetts	80 (3)	85 (7)	70 (2)	87 (7)	80 (8)	62 (2)	53 (3)	55 (3)
Michigan	59 (6)	-	-	80 (4)	62 (6)	46 (6)	49 (7)	45 (3)
Minnesota	70 (2)	68 (3)	70 (3)	74 (1)	62 (2)	84 (1)	-	78 (1)
Mississippi	99 (3)	-	-	-	57 (3)	56 (3)	-	44 (1)
Missouri	87 (1)	56 (1)	60 (1)	79 (2)	61 (2)	57 (3)	21 (1)	-
Montana	68 (3)	-	-	-	-	-	-	-
Nebraska	-	78 (1)	-	-	58 (2)	-	-	-
Nevada	-	-	63 (1)	-	-	-	-	-
New Hampshire	62 (1)	52 (2)	-	136 (1)	-	-	-	-
New Jersey	66(14)	79 (7)	72 (4)	80 (5)	74 (6)	76 (3)	44 (4)	55 (5)
New Mexico	-	-	51 (3)	-	-	-	46 (1)	-

Table E-1 (Continued)

State	Jul- Sep 1958	Oct- Dec 1958	Jan- Mar 1959	Apr- Jun 1959	Jul- Sep 1959	Oct- Dec 1959	Jan- Mar 1960	Apr- Jun 1960
New York	75(30)	81(13)	68(14)	73(12)	73(14)	58(12)	64(13)	49(13)
North Carolina	71(2)	75 (3)	71 (7)	71 (3)	72 (7)	40 (1)	56 (2)	65 (3)
Ohio	69 (8)	80 (6)	58 (3)	74(14)	75(10)	59 (6)	51 (9)	42 (5)
Oklahoma	108 (1)	-	50 (2)	-	53 (4)	72 (2)	60 (4)	-
Oregon	85 (2)	67 (1)	-	64 (1)	-	50 (1)	-	68 (1)
Pennsylvania	82(17)	74 (5)	67 (9)	80(11)	70(17)	64(10)	60(13)	55(14)
Rhode Island	69 (1)	-	-	84 (2)	89 (1)	15 (1)	55 (3)	-
South Carolina	72 (3)	83 (2)	70 (2)	84 (1)	55 (3)	47 (1)	50 (4)	-
Tennessee	35 (1)	105 (3)	-	75 (2)	-	59 (4)	42 (4)	-
Texas	77 (8)	68 (5)	52 (9)	62 (4)	63(13)	56 (6)	47 (9)	38 (2)
Utah	-	41 (1)	-	-	74 (3)	-	46 (1)	-
Vermont	75 (1)	-	-	-	104 (1)	78 (1)	-	-
Virginia	78 (9)	59 (3)	62 (8)	60 (3)	77(14)	69 (3)	59 (5)	60 (5)
Washington	56 (4)	-	74 (4)	70 (4)	75(12)	72 (2)	38 (1)	40 (2)
West Virginia	72 (4)	70 (2)	75 (2)	-	71 (2)	49 (3)	49 (4)	49 (2)
Wisconsin	63 (1)	-	68 (3)	-	71 (1)	62 (1)	-	64 (1)
Wyoming	70 (1)	-	-	-	-	-	-	-

Table B-2

137
 Gestural Levels (unc/unk) In Subjects From Various Countries

Major Area or Country	Jul- Sep 1958	Oct- Dec 1958	Jan- Mar 1959	Apr- Jun 1959	Jul- Sep 1959	Oct- Dec 1959	Jan- Mar 1960	Apr- Jun 1960
Canada								
Alberta	-	-	68 (1)	-	-	-	-	-
British Columbia	-	-	106 (1)	-	-	-	-	-
Newfoundland	-	-	70 (2)	-	-	-	-	-
Nova Scotia	-	-	79 (1)	-	-	-	-	-
Quebec	-	-	72 (1)	70 (1)	96 (1)	-	-	-
Central America								
Colombia	-	116 (1)	-	-	53 (1)	-	-	-
Ecuador	-	-	77 (1)	-	-	-	-	-
Guatemala	-	-	50 (1)	-	-	-	-	-
Mexico	-	-	-	-	41 (1)	-	-	-
Panama	-	78 (1)	60 (2)	-	53 (2)	41 (3)	48 (1)	-
Venezuela	-	-	64 (1)	-	-	-	-	-
South America								
Brazil	-	15 (1)	-	-	-	32 (1)	-	-
Paraguay	-	-	-	-	-	21 (1)	-	-
Caribbean								
Bahamas	-	-	-	-	65 (1)	-	-	-
Cuba	-	-	57 (1)	-	-	-	-	-
Dominican Republic	75 (1)	-	-	-	-	-	-	-
Lesser Antilles	-	-	-	-	57 (1)	-	-	-
Puerto Rico	-	56 (2)	62 (1)	142 (1)	70 (1)	-	45 (1)	-
Africa								
Ethiopia	-	-	-	54 (1)	-	-	-	-
Tanganyika Territory	-	-	-	-	36 (1)	-	-	-
Europe								
England	-	-	-	-	102 (1)	-	46 (1)	-
France	76 (3)	87 (9)	92 (5)	95 (7)	73 (7)	82 (2)	61 (4)	62(10)
Germany	69(13)	73(15)	76(25)	77(14)	86(44)	79(10)	76(29)	65(20)
Greece	-	-	-	-	-	-	-	42 (1)
Italy	104 (1)	70 (3)	53 (1)	94 (2)	62 (1)	-	63 (1)	-
Netherlands	74 (1)	88 (1)	-	-	111 (2)	-	-	-
Norway	-	-	-	-	104 (1)	-	-	-

Table E-2 (Continued)

Major Area or Country	Jul- Sep 1958	Oct- Dec 1958	Jan- Mar 1959	Apr- Jun 1959	Jul- Sep 1959	Oct- Dec 1959	Jan- Mar 1960	Apr- Jun 1960	(1)
Europe (Continued)									
Rumania	-	-	-	-	-	-	-	47 (1)	
Scotland	-	84 (1)	-	-	-	-	-	-	
Asia									
Afghanistan	-	-	-	-	39 (1)	-	-	-	
Ceylon	-	-	-	-	54 (1)	-	-	-	
Malayan Federation	-	-	-	66 (1)	-	-	-	-	
Nepal	-	-	-	-	-	61 (1)	-	-	
Pakistan	-	-	79 (2)	-	86 (1)	-	-	-	
Thailand	-	-	46 (1)	-	24 (1)	-	-	-	
Near East									
Iran	38 (1)	-	-	-	-	-	32 (2)	-	
Iraq	82 (1)	-	-	-	-	-	-	-	
Turkey	-	-	54 (1)	-	-	-	-	-	
Far East									
Formosa	-	-	67 (1)	-	-	-	-	-	
Japan	67 (4)	79 (8)	60 (6)	66 (4)	65 (9)	59 (1)	39 (1)	60 (2)	
Korea	-	72 (2)	54(12)	67 (8)	55(19)	51(11)	55(21)	51(10)	
Okinawa	81 (1)	-	58 (1)	-	56 (1)	61 (2)	55 (2)	62 (4)	
Phillipines	82 (1)	-	51 (1)	89 (1)	53 (3)	-	-	-	
Australia									
New South Wales	-	-	-	-	-	-	34 (1)	-	
New Zealand	-	-	-	-	68 (1)	-	-	-	
Victoria	-	-	-	-	47 (2)	-	-	-	
Pacific Islands									
Carolina's	-	-	-	-	-	46 (1)	-	-	
Mariana's	-	52 (2)	-	-	-	-	-	-	
Marshall's	-	-	-	-	53 (1)	40 (1)	31 (1)	-	
Miscellaneous	-	-	53 (1)	-	-	-	51 (1)	-	
Miscellaneous Areas									
Antarctic	-	-	-	-	88 (2)	-	-	-	
Greenland	-	-	-	-	-	-	-	62 (1)	
Iceland	-	-	-	82 (3)	94 (1)	-	-	-	

Table E-3

Chronological List of Cesium-137 Levels in People
Reported From Various Laboratories

<u>Date</u>	<u>Location</u>	<u>Number of Subjects</u>	<u>Cs-137 μuc/gm K</u>	<u>Reference</u>
NORTH AMERICA				
1955(Apr)	USA(III)	3	10	(22)
1955(Dec)	USA(III)	8	26	(22)
1956	USA	196	41	(23)
1956(June)	USA(III)	8	35	(22)
1957	USA	311	44	(10)
1957(June)	USA(III)	13	35	(22)
1957	Canada	3	82	(24)
1957	Cuba	1	20	(22)
1957-1958 (Nov-Apr)	USA(Utah)	42	66	(25)
1958	USA	793	56	(26)
1958	USA(III)	13	52	(27)
1958(July)	Canada	2	63	(26)
1958(Dec)	Canada	30	51	(28)
1959(to Apr)	USA	63	53	(29)
1959	Canada	4	94	(30)
1959	Cuba	1	80	(31)
1959	Puerto Rico	1	119	(30)
CENTRAL AMERICA				
1957	El Salvador	1	8	(22)
SOUTH AMERICA				
1957	Argentina	2	7	(22)
1957	Bolivia	1	13	(22)
1957	Brazil	2	14	(22)
1957	Chile	1	22	(22)
1957	Colombia	1	21	(22)
1957	Ecuador	1	13	(22)
1957	Peru	1	35	(24)
1957	Uruguay	1	11	(22)
1959	Chile	7	46	(30)
1959	Colombia	4	35	(30)
EUROPE				
1956	Belgium	1	26	(22)
1956	England	2	34	(22)
1956	England	3	30	(32)
1956	France	1	33	(22)

Table E-3 (Continued)

<u>Date</u>	<u>Location</u>	<u>Number of Subjects</u>	<u>Cs-137 μCi/gm K</u>	<u>Reference</u>
1956	Sweden	1	32	(22)
1957	England	3	69	(24)
1957	England	7	43	(32)
1957	France	1	78	(24)
1957	Germany	1	106	(24)
1957	Sweden	3	64	(24)
1958	England	1	56	(32)
1959	Belgium	2	60	(30)
1959	England	5	83	(30)
1959	Germany	1	96	(30)
1959	Sweden	1	125	(30)
1959	Switzerland	1	100	(30)
1960	England	1	100	(31)
1960	France	1	120	(31)
1960	Switzerland	1	135	(31)
NEAR EAST & AFRICA				
1959	Africa	1	77	(31)
1959	Liberia	1	62	(30)
1960	Jordan	1	65	(31)
ASIA				
1956	India	2	20	(22)
1956	Indonesia	2	11	(22)
1957	Thailand	3	42	(24)
1959	Thailand	3	42	(30)
1960	India	2	51	(31)
FAR EAST				
1956	Japan	1	24	(22)
1957	Japan	1	38	(24)
1959	Japan	2	63	(30)
1960	Japan	1	109	(31)
AUSTRALIA & NEW ZEALAND				
1957	Australia	1	50	(22)
1959	Australia	2	103	(30)
1960	New Zealand	1	68	(31)

APPENDIX

On 1 July 1960, the absolute calibration of the liquid scintillation counter for cesium-137 and potassium-40 was changed, employing a new set of bottle phantoms (Tables 1 and 2, #2 and 4) and a new geometry (Figure 17b). The new technique was adopted because the efficiencies for potassium-40, obtained by this method of calibration, most closely approximated the efficiencies obtained in the K-42 human and manikin studies (Sections 4.1.2 and 4.1.3).

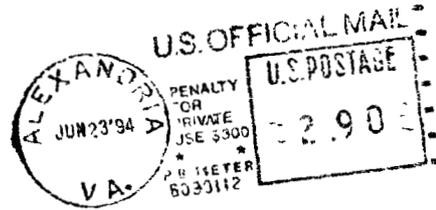
During a one month period, daily calibrations have been performed with both standards (Tables 1 and 2, #2 and 4) in their respective geometries. 68 normal subjects and 12 control subjects were assayed in this same period, the results, based on both calibration methods, have been compared. This reveals that, after 1 July 1960, the reported results will average 14% higher for potassium. Assuming no change in body burden, cesium-137 results would be 11% higher and the cesium-potassium ratio 6% lower.

Further duplicate calibration is required to confirm these initial results and is currently in progress.

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