ABSTRACT

Steven J. Danielczyk. Meeting the Coast Guard's Need for Radiation Protection while Conducting Inspections of Freight Containers Containing Radioactive Material Through Survey Instrumentation and Safe Work Practices. (Under the direction of Dr. James E. Watson)

United States Coast Guard (USCG) personnel may be exposed to ionizing radiation during inspections of radioactive material (RAM) shipments. This study assesses the potential exposures to USCG inspectors and reviews the requirements for survey instrumentation through a survey of regulatory requirements. It also examines isotopes shipped, quantities shipped, ports involved with RAM, and current work practices.

While the frequency of RAM inspections is low—approximately 150 reported RAM movements in 20 United States ports from 1988-90—the dose rates encountered, up to 200 mrem/hour, are not. This high dose rate situation is further complicated by USCG offices not having standardized portable survey meters, adequate training on RAM, or consistent safe work practices for conducting RAM inspections.

In order to fill the requirements for instrumentation needs, seven portable survey meters were tested using American National Standards Institute (ANSI) procedures. These instruments were tested for System Accuracy, Spectral Dependence, Exposure Rate Limitations, Angular Dependence/Geotropism, Reproducibility, Response/Decay Time, Coefficient of Variance, Temperature Influences/Shock, Battery Lifetime in accordance with ANSI N13.4-1971: American National Standard for the Specification of Portable X- or Gamma Radiation Survey Instruments; N42.17A-1989: American National Standard Performance Specification for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions; N42.3-1969: American National Standard and IEEE Standard Test Procedure for Geiger-Muller Counters; and N323-1978:

American National Standard Radiation Protection Instrumentation Test and Calibration. All survey instruments were exposed to sources of Cesium 137 with an effective energy of 662 KeV, Americium 241 with an effective energy of 60 KeV, and Radium 226 with an effective energy of 830 KeV.

Based on overall instrument response and cost, recommendations for standardized survey instruments for RAM shipment inspections and general contamination monitors were provided. Also recommended were training topics, use of check sources, calibration frequency, and safe work practices.

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Introduction

Silent, odorless and invisible, radiation is virtually impossible to detect without proper equipment. Radiation emissions pass through boxes and standard packaging, travel through the air and penetrate ordinary clothing. Over-exposure to radiation can cause cancer, genetic effects, infertility, skin reddening, clouding of the lens of the eye and other health problems. Radiation over-exposure can be avoided, but proper equipment and appropriate training are needed to succeed.

Throughout the country, men and women of the United States Coast Guard are responsible for port safety, port security and environmental response. They risk radiation exposure while responding to pollution or hazardous material incidents; during vessel boardings; while enforcing "no-entry" areas called safety zones around nuclear facilities; and when monitoring shipments of various radionuclides. They are assigned to Captain of the Port (COTP) offices and are responsible for enforcing the Ports and Waterways Safety Act (33 USC 1503), the National Contingency Plan, the Hazardous Materials Transportation Act (49 USC 1801, et seq) and other regulations delegated through the Department of Transportation.

To protect these men and women and ensure compliance with the regulations, all personnel must be educated about radiation exposure, risks and protective equipment. The only way to guard against over-exposure is to know who is exposed, why they are exposed, to what they are exposed and how much dose has been received. For the Coast Guard, this means knowing what ports handle radioactive material (RAM) shipments, why Coast Guard personnel are involved, what radionuclides are shipped and in what quantities. Only then can a survey instrument appropriate for these emissions, conditions and users be selected.

Department of Transportation/Nuclear Regulatory Commission Regulation Overview

Label and Placard Requirements

Each package containing RAM inside a freight container being offered for transportation must be labeled with two of the appropriate radioactive labels on opposite sides of the package as specified in 49 CFR 172.403 and 173.444. Currently there are three types of labels. *(See Table 1 for radioactive package labeling requirements.)* The proper label is affixed to each package based on the radiation level at the surface of the package, the transport index, or the fissile characteristics of the package as appropriate.

The *Transport Index* is a dimensionless number placed on the package label to designate the degree of control to be exercised during transportation. This number is either a) the maximum radiation level in millirem/hour at 1 meter from the surface of the package or b) the number obtained by dividing 50 by the allowable number of Fissile Class II packages that may be transported together.

Fissile Material consists of one or more of the following radio nuclides: plutonium 238, plutonium 239, enriched uranium 233 and enriched uranium 235.

Fissile Class I packages can be transported together with other packages in unlimited numbers, in any arrangement, without nuclear criticality safety controls.

Fissile Class II packages can be transported in any arrangement but in numbers that do not exceed an aggregate of 50. For criticality control purposes the individual packages can have transport indexes of 0.1 to less than 10. These shipments require no nuclear criticality safety control by the shipper during transportation.

Fissile Class III shipments must be controlled in transportation by specific arrangements between the shipper and the carrier to provide for nuclear criticality safety. These shipments are transported only when assigned to the exclusive use of the shipper and are further reviewed by the Department of Transportation's Director of the Office of Hazardous Materials.

Highway Route Controlled Quantities of Radioactive Material (HWRCQ) are radioactive material shipments containing more than 3,000 times the A1 (materials in special form) or A2 (materials in normal form) values, as appropriate, from table 49 CFR 173.435 *(See Enclosure 1.)* or 30,000 curies whichever is least.

Table 1: Radioactive Package Label Requirements

Label Required	Transport Index (TI)	Radiation Level at Package Surface	Fissile Criteria
White I	n/a	≤ 0.5 mrem/h	Fissile Class I only
Yellow II	≤ 1.0	0.5 to ≤ 50 mrem/h	Fissile Class I or Fissile Class II with a TI ≤ 1.0
Yellow III	> 1.0	> 50 mrem/h	Fissile Class II with TI > 1.0 and all Fissile Class III

NOTE: All Highway Route Controlled Quantities of Radioactive Material must be labeled Radioactive Yellow III.

In all cases the maximum level of radiation for non-exclusive use shipments is limited by 49 CFR 173.441 to 200 mrem/h at any point on the package surface; the transport index must be below 10. (At one meter from the package surface the dose rate must be less than 10 mrem/h.) If the shipment is transported as exclusive use, the provisions of 49 CFR 173.441(b) allow up to 1,000 mrem/h at the package surface.

According to 49 CFR 172.504, each freight container containing any quantity of a Radioactive Yellow III material or uranium hexafloride must be placarded on both sides and ends with the radioactive placard. In addition to the normal radioactive placard, an additional 15-inch special white square background is required for HWRCQ of radioactive materials (49 CFR 172.507).

Packaging Requirements

In addition to meeting the dose rate levels specified above, Titles 10 (Energy) and 49 (Transportation) of the Code of Federal Regulations specify the packaging (type of box or container) for the shipment of radioactive material. These codes specify that design and testing requirements be met before package approval is granted. The general types of packaging required for shipped material is specified as "excepted", "Type A" or "Type B".

In general, *excepted* packages are designed to have external surface radiation levels below 0.5 mrem/h and external surface contamination below 22 disintegrations per minute per square centimeter as determined by wipe testing. These packages may be used only for packages labeled Radioactive White I. These packages must meet the general design requirements of 49 CFR 173.24 and 173.410 including strong tight containment; compatible contents and packaging materials; no significant release of contents; handling/securing ease; lifting attachments with a safety factor of three; surfaces with no protruding features; easily decontaminated pockets; and an ability to withstand the forces that may arise out of normal transportation without deteriorating.

Type A packaging is required to ship radioactive contents above those quantities permitted in excepted packages as specified in 49 CFR 173.421, but is limited to the quantities specified as A1 (materials in special form) or A2 (materials in normal form), as appropriate, in table 49 CFR 173.435. *(See Enclosure 1.)* In addition to the excepted packaging requirements outlined above, Type A packaging must meet the design requirements of 49 CFR 173.412 including positive closing devices, tamper-evident seals, shielding capable of withstanding temperature extremes of -40 ^{o}C (-40 ^{o}F) to 70 ^{o}C

(158 ^{o}F), and containment systems. Testing required prior to use of these packages includes water spray simulating two inches of rain per hour for one hour; a free drop test designed to inflict the maximum damage to the package's safety features, including the package corners or ends; a stacking/compression test with the load in place for at least 24 hours; and a penetration test where a 6-kilogram (13.2 pound), 3.2-centimeter (1.3 inch) diameter rounded end bar is dropped onto the weakest part of the package so that it may hit any containment from a height of one meter (3.3 feet) or more.

Type B packages are required to ship radioactive contents above the A1 and A2 values specified in table 49 CFR 173.435. *(See Enclosure 1.)* In addition to the design requirements of Type A packaging, Type B packaging is designed to meet additional "hypothetical accident condition" requirements of 10 CFR 71.73 and have no escape of radioactive material above one-millionth the A1 value per hour, no increase in external radiation levels, and no reduction in package effectiveness. Included in the hypothetical accident conditions are a free drop of the package from nine meters (30 feet) onto an unyielding surface; a puncture test dropping the package from one meter onto a solid vertical cylindrical mild steel bar; a 30 minute 800 ^{o}C (1475^{o}F) heat flux test; an 0.9 meter (3 feet) eight-hour immersion test for fissile material; and an eight-hour immersion test equal to a water pressure head 15 meters (50 feet). Type B packaging consist of metal inner containers for holding the radioactive material, insulating or filler material, and a steel outer drum. *(See Enclosure 2.)* After reviewing the design and testing requirements of Type B packaging, the amount of attenuating material used in the package construction and the low permitted external dose rates, it can be stated that all alpha and beta particles will be adequately shielded by intact packaging.

Coast Guard Policy and Notification

Coast Guard internal policy, in Marine Safety Manual (COMDTINST 16000.6), Volume 1, Chapter 2, requires that *all* commercial shipping cargo operations involving HWRCQ of radioactive materials, class A or military explosives, oxidizing materials or basting agents requiring a permit be monitored. These listed cargoes are the only activities requiring 100% COTP oversight.

Shippers, marine terminals, port authorities, and local governments are aware of this 100% oversight requirement, so notification is normally given to the local COTP prior to the arrival or departure of any, not just HWRCQ, radioactive shipment pier-side. At the federal government level the COTP often receives a message from the Nuclear Regulatory Commission or the Department of Transportation's Research and Special Program Administration (RSPA) outlining HWRCQ or otherwise controlled, such as Fissile Class III, shipments. *(See Enclosure 3.)* The COTP also might be informed of a radioactive shipment through the shipping regulations contained in 33 CFR 160.203 defining a Highway Route Controlled Quantity or Fissile Class III quantity of radioactive material as a Cargo of Particular Hazard (COPH). Vessels handling radioactive materials designated as COPH also are required to provide the COTP 24-hour notice of arrival and departure. (This requirement is reduced to four hours if the vessel is a barge.) As part of this notice the vessel is required to provide the name and amount of radioactive material, it's stowage location, and other important items.

Coast Guard personnel often are notified when a container of radioactive material enters a port area. Internal policy requires the inspection of all HWRCQ containers. Other non-HWRCQ containers of radioactive materials also may be inspected based on office staffing and the level of training needed. Once the decision is made to inspect a container of radioactive material, the maximum level of surface contamination to be expected is 200 mrem/h at the package surface and 10 mrem/h at a distance of one meter from the package. Except for Fissile Class III shipments, exclusive use shipments are not often found on ships because few shippers have the capability to direct all initial, intermediate, and final loading and unloading steps. Finally and of key importance is the fact that intact package design and surface radiation level requirements eliminate the need to survey for alpha and beta particles. The instrument selected, therefore, should predictably respond to gamma emissions.

Radioactive Material Shipped and Ports Involved

Historical Information

In July 1980 the Coast Guard Ad Hoc Radiological Health Committee was formed after several Coast Guard Marine Safety personnel were exposed to a shipment of an alpha-emitting radioactive monazite ore in leaking packaging. This committee was tasked with studying other radioactive materials and the potential health risks to Coast Guard personnel. The committee published COMDTINST 6470.1, *Radioactive Monitoring Equipment and Training* on November 9, 1982. According to this report, the following Marine Safety Offices or Captain of the Port offices are involved in the transportation of radioactive materials: Norfolk, VA; Baltimore, MD; Savannah, GA; Wilmington, NC; Philadelphia, PA; New Orleans, LA; Portland, ME; Houston, TX; San Francisco, CA; New York, NY; Charleston, SC; Los Angeles/Long Beach, CA. Norfolk, Baltimore, Savannah, and Wilmington were designated primary ports because of the volume of RAM shipments handled. The report also recommended incorporation of radiation safety training in the basic Marine Safety training courses at Yorktown, VA.

Current Department of Commerce Information

In order to determine the COTPs that require radioactive survey instrumentation and training it is important to update the Ad Hoc committee's findings and determine what isotopes have been shipped in and out of the United States in the past few years. Consultations with the Port Safety Division at Coast Guard Headquarters, revealed that few COTPs would have the necessary data to determine the isotopes imported to or exported from their ports or the quantities or activities of these isotopes. Instead of contacting the Captains of the Port for this information, the U.S. Department of Commerce import and export data for all radioactive shipments were reviewed. The data, listed by customs districts that closely parallel COTP boundaries, included all shipments of radioactive elements and isotopes (including fissile or fertile elements and isotopes) and their compounds. The data for calendar year 1991 included uranium 235, plutonium, and thorium-containing compounds as well as spent reactor fuel being returned to the United States, cobalt 60 compounds, and all other isotopes. *(See Table 2 and accompanying graph)* This Department of Commerce data track cobalt 60 and the non-fissile non-cobalt 60 nuclides in units of activity (curies or millicuries). Uranium, plutonium, thorium and spent reactor fuel are tracked in the mass units of kilograms not activity.

The data reveal some interesting facts.

1) New York, Baltimore, Norfolk, Savannah and Portland each lead in the quantity of one isotope being shipped through their port. Of these Baltimore, Norfolk and Savannah were identified as "primary" ports in 1982's COMDTINST 6470.1. According to the 1991 data, no material passed through Wilmington, NC. Other ports handling radioactive material included Buffalo, Philadelphia, Charleston, Houston, Mobile, Los Angeles, San Francisco, Portland, and Seattle.

2) Spent reactor fuel is imported into the United States. According to Kristen Smith, who tracks radioactive shipments throughout the country for the Department of Transportation's Research and Special Programs Administration (RSPA), "Agreements between the United States and other countries to help these other countries develop nuclear power are coming to a close. As part of these agreements, reactor fuels supplied to start power plants must be returned upon exhaustion of that fuel. This spent fuel category has dropped off considerably in the past 5 years and is expected to drop off even more in the future."

3) The 1991 data show that no more than four curies of a non-cobalt 60 or non-fissile material was imported to or exported from a U.S. port. Using the A1 and A2 values in 49 CFR 173.435, it was determined that it is unlikely that there were HWRCQ shipments other than cobalt 60 or a fissile material. RSPA confirmed this, stating that cobalt 60 was the only non-fissile isotope shipped in HWRQ quantities in recent years. They added that cobalt 60 was imported primarily from Argentina. Evaluation of this Department of Commerce data means Coast Guard personnel are only required to inspect containers containing spent reactor fuel, fissile materials or cobalt 60. However it must be mentioned that other containers containing radioactive materials may be opened and inspected during routine operations, including training opportunities, above and beyond the mission performance standards.

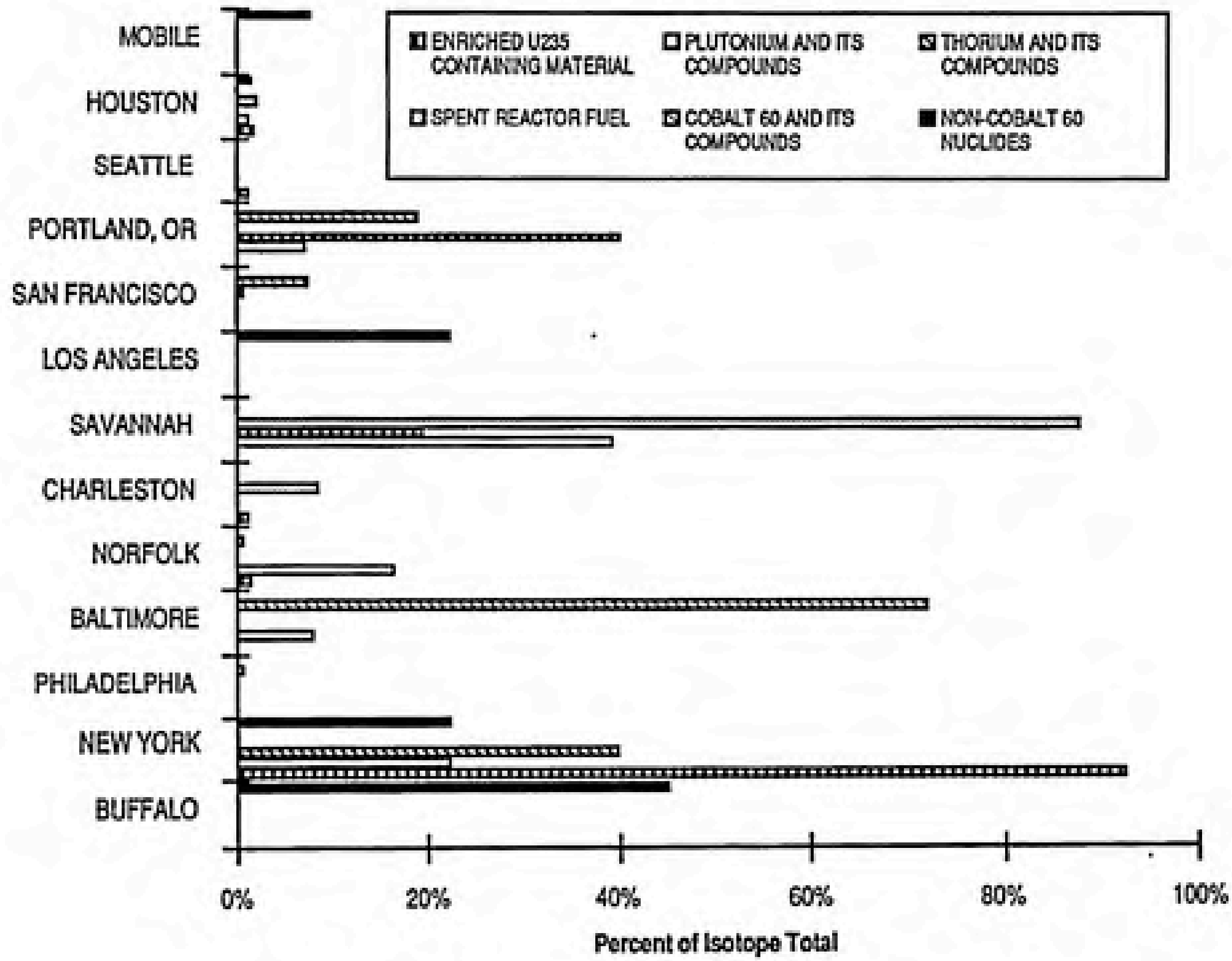
Current Coast Guard Quarterly Activity Report Data

Internally the Coast Guard uses COTP-generated Quarterly Activity Reports (QARs) to review the activities of each port area and determine how many personnel hours each activity entails. These reports track radioactive shipments by the number of shipments reported by the Marine Safety Office (MSO) or COTP and the number of these shipments defined by the Marine Safety Manual as "high priority" shipments. The 1988-1990 QARs (the most recent available) were reviewed to ascertain whether these data paralleled the data provided by the Department of Commerce. *(See Table 2 and accompanying figure.)*

It is clear that there is a correlation between the Department of Commerce data and the QARs. The QARs confirm that New York, Philadelphia, Baltimore, Norfolk, Savannah, Los Angeles, San Francisco, Mobile, and Portland handle radioactive shipments. They

Table 2: 1991 Department of Commerce Radioactive Material Import and Export Data

PORT AREA	ENRICHED U235 CONTAINING MATERIAL (TONS)	PLUTONIUM AND ITS COMPOUNDS (TONS)	THORIUM AND ITS COMPOUNDS (TONS)	SPENT REACTOR FUEL (TONS)	COBALT 60 AND ITS COMPOUNDS (CURIES)	NON-COBAL 60 NUCLIDE (CURIES)
TOTAL	8,697	3,115	165	113	669,810	9.1
BUFFALO						4.1
NEW YORK	8,067	703	66			2.1
PHILADELPHIA					73	
BALTIMORE		260			483,875	
NORFOLK	162	523		0	6,340	
CHARLESTON	145			10		
SAVANNAH		1,236	32	100		
NEW ORLEANS		115				
HOUSTON	177	45		3		0.1
LOS ANGELES					1,311	2.1
SAN FRANCISCO				1	50,681	
PORTLAND, OR		235	67		127,530	
SEATTLE	145					
MOBILE						0.74



also reveal that shipments pass through Honolulu, San Juan, and Juneau. A phone call to USCG Headquarters revealed that shipments through these ports are excluded from Department of Commerce data because they are domestic shipments that are tracked by the U.S. Army Corp of Engineers (ACOE).

A review of the 1988 and 1989 ACOE data complete the shipment data evaluation. Two items of interest appeared.

1) Approximately 50% of Honolulu's annual outbound radioactive shipments were headed for Los Angeles, 20% for Seattle, and 10% for Oakland. According to the QAR data from this time period, none of these shipments were deemed "high priority".

2) There is occasional radioactive material movement on the Mississippi River system as evidenced by a 1,900 ton shipment of RAM (isotope and radioactive quantity unknown) from Beaumont, TX to Huntington, WV in 1988.

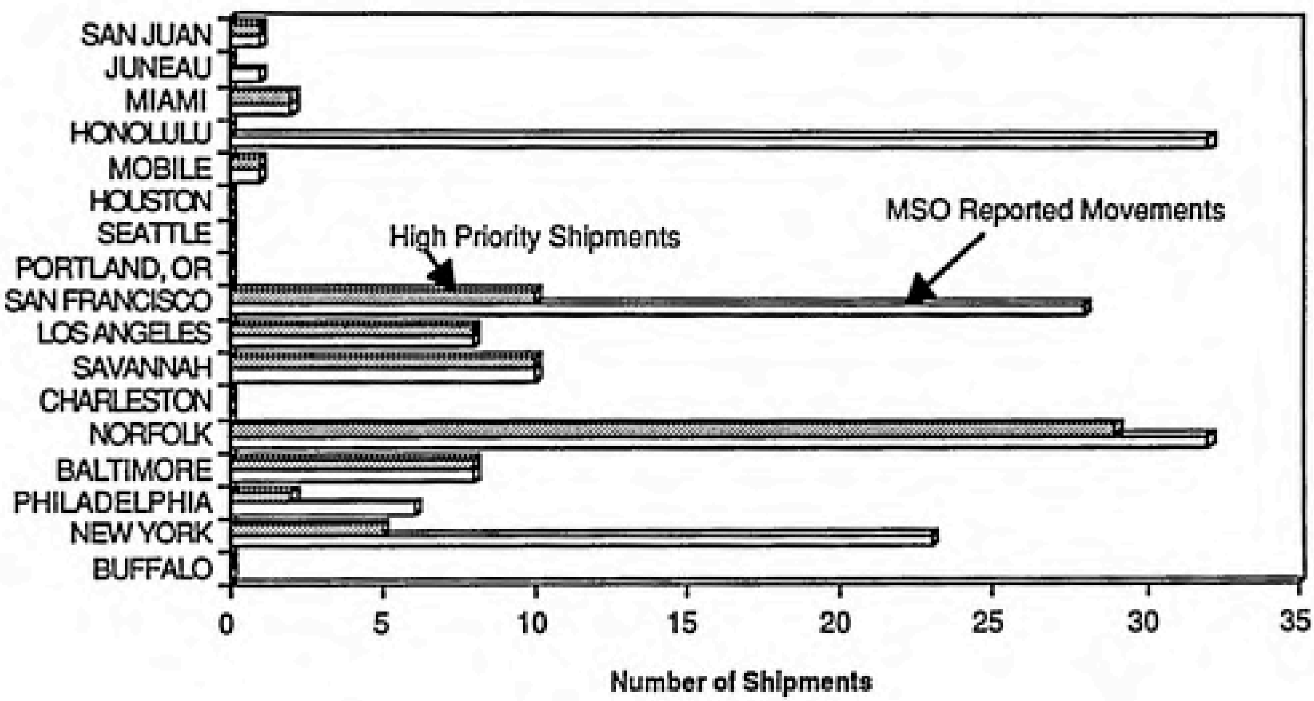
Instrument Summary

The primary purpose of this report is to determine whether there is a portable survey meter that can meet the needs of Coast Guard personnel for hazardous materials shipments. Survey meters were selected based on ease of use, portability, and cost by industrial hygienists at Coast Guard Headquarters. They were purchased by Alan P. Bentz, Ph. D. of the Coast Guard Research and Development Center, Groton, CT, in July and August of 1991. The research was conducted during the summer and fall of 1992 so each instrument was re-calibrated following the manufacturer's recommendations prior to the start of instrument assessment.

The theory of operation of the various meter models including portable Geiger-Mueller counters, ion chambers, and scintillation meters is discussed below.

Table 3: 1988-1990 Reported Radioactive Shipments From USCG QARs

MSO/COTP	REPORTED RADIOACTIVE MOVEMENTS	HIGH PRIORITY SHIPMENTS
BUFFALO	0	0
NEW YORK	23	5
PHILADELPHIA	6	2
BALTIMORE	8	8
NORFOLK	32	29
CHARLESTON	0	0
SAVANNAH	10	10
LOS ANGELES	8	8
SAN FRANCISCO	28	10
PORTLAND, OR	0	0
SEATTLE	0	0
HOUSTON	0	0
MOBILE	1	1
HONOLULU	32	0
MIAMI	2	2
JUNEAU	1	0
SAN JUAN	1	1
TOTALS	152	76



Geiger-Mueller Counters (GM)

Theory of Operation

Geiger-Mueller counters are perhaps the best known type of survey instrument; they provide a fast, reliable indication of the presence of radiation, are simple to operate and inexpensive to construct and purchase. The counters consist of a cylindrical cathode filled with a self-quenching gas. Pulses are formed in the counter probe by the interaction of ionizing radiation with either the sidewall of the tube or the gas within the tube. As these meters operate in the range of 250-1500 volts, any directly ionizing particle that generates even one ion pair in the gas volume will produce a uniform height pulse in the counting circuit. This instrument is therefore seen as a good count-rate instrument. GM tubes are not appropriate for exposure rate or absorbed dose determinations because the complete discharge generates a uniform height pulse that is not directly proportional to the energy absorbed in the sensitive volume. Also GM counters are not useful in determining a radionuclide's absolute activity unless they are calibrated for that nuclide and its effective energy.

Many portable GM counters have either sliding shields or thin mica end windows that permit the detection of lower energy, less penetrating, alpha and beta radiation. Higher energy betas and photons (gamma and x-rays) may not require a "thin end window" for detection. In addition to the typical cylindrical GM tubes, some manufacturers use flat, cylindrical "pancake" style detector tubes to make monitoring alpha and beta radiation easier.

A major drawback of GM tubes is that they have been known to "saturate" in high radiation fields. Saturation occurs when the count rate becomes so high that the count rate circuit fails to function properly resulting in a reading near zero rather than off the scale. Saturation conditions can lead to serious over-exposure of personnel if those conducting the survey believe the instrument is providing a correct reading in a low field rather than a saturated reading in a high exposure rate field.

Ludlum Instrument's Model 44-7 Probe and Model 2 Survey Meter

Manufacturer: Ludlum Measurements, Inc., 501 Oak Street, Sweetwater, TX 79556, (915) 235-5494

Detector Specifics: This instrument is a thin end window GM probe with 6.4 cm^2 mica (1.7 mg/cm^2) end window. Its probe is 1.5 inches wide by 5 inches long with the mica window covered by 74% or 80% (both numbers are mentioned) open stainless steel screen. The meter is 3.5 inches wide by 8.5 inches long by 4.2 inches high and weighs approximately 4 pounds with the probe (not including batteries).

Detection Capabilities: Ludlum states this instrument is capable of detecting alpha, beta and gamma radiation with the following efficiencies: Beta: 10% for C14, 45% for Sr90, Alpha 30%, Gamma 2100 CPM/mR/h for Cs137.

Power Requirements/Average Lifetime: The survey meter operates on two D cell batteries. (No average lifetime for batteries is given.)

Measurement Scales: One 0-10,000 count per minute (CPM) range and three linear exposure rate ranges are provided to provide a maximum reading of 50 mR/h. (Other scales are available.) The 0.1X scale is designed to give 0 to 0.5 mR/h exposure rate readings. The 1.0X scale is designed to give 0 to 5 mR/h exposure rate readings. The 10X is designed to give 0 to 50 mR/h exposure rate readings.

Accuracy: Linearity is stated as +/- 5%.

Temperature Range: not stated

Humidity Range: not stated

Directional Response: not stated

Other Features: The unit has a built-in speaker that clicks at each incoming pulse and adjustable high voltage (400-1500 volts) so it may be used with other Ludlum GM or scintillation probes. The unit has two response time settings, fast and slow. Ludlum states these settings provided 90% of the final reading in four seconds at the fast setting or 22 seconds at the slow setting. The instrument also has a "RESET" button that electronically disconnects the probe to give a zero CPM reading in a field when depressed.

Cost: This meter was purchased under GSA contract for $393.

<u>Dosimeter's Super Mini Radiation Monitor Model 3500</u>

Manufacturer: Dosimeter Corporation, 11286 Groome Road, Cincinnati, OH 45242, (513) 489-0517

Detector Specifics: This unit as supplied has no thin end window. (A separate detachable probe with a thin end mica window is available.) The meter is 3.13 inches wide by 5.17 inches long by 1.43 inches high and weighs about 11 ounces with battery.

Detection Capabilities: Dosimeter states the GM probe is capable of detecting x-ray and gamma radiation. Energy response is stated as +/- 30% from 80 keV to 1.3 MeV. (No efficiencies are mentioned.)

Power Requirements/Average Lifetime: The survey meter operates on one 9-volt battery. This one battery should provide over 100 hours of operation.

Measurement Scales: Four linear exposure rate ranges are provided for a maximum reading of 3 R/h. The 1.0X scale is designed to give 0 to 3 mR/h exposure rate readings. The 10X scale is designed to give 0 to 30 mR/h exposure rate readings. The 100X scale is designed to give 0 to 300 mR/h exposure rate readings. The 1000X scale is designed to give 0 to 3 R/h exposure rate readings.

Accuracy: Linearity is stated as +/- 15% relative to Cs137.

Temperature Range: +14°F to 122°F. Temperature dependence is stated as +/-15%.

Humidity Range: up to 95% non-condensing

Directional Response: +/- 20%

Other Features: The unit has a an optional external probe. A separate switch is provided to light the display.

Cost: This meter was purchased under GSA contract for $405.

<u>S.E. International's Radiation Alert "Digilert"</u>

Manufacturer: S.E. International, 156 Drakes Lane, Summertown, TN 38483, (615) 964-3561

Detector Specifics: This instrument uses a halogen quenched detector with mica end window. Areal density of the window is 1.5-2.0 mg/cm2. The meter is 3.2 inches wide by 5.9 inches long by 1.2 inches high and weighs about 9.5 ounces with battery.

Detection Capabilities: S.E. International states the GM probe is capable of detecting alphas down to 2.5 MeV with a detection efficiency at 3.6 MeV of greater than 80%, betas at 50 keV with 35% efficiency and at 150 keV with 75% efficiency. X-ray and gamma radiation down to 10 keV can be detected though the end window and down to 40 keV through the sidewall.

Power Requirements/Average Lifetime: The survey meter operates on one 9-volt battery. This one battery should provide three to six months of operation at normal background levels.

Measurement Scales: The instrument output is a 0.4 inch high LCD that displays from 0 to 19,999 CPM. Two modes, counts per minute or total counts, are provided.

Accuracy: not stated

Temperature Range: +32°F to 122°F

Humidity Range: not stated

Directional Response: not stated

Other Features: The unit has an internal speaker that can signal each time a count is detected or can be set to alert the user upon reaching a specified count. Two separate plugs are provided: one enables the unit to be powered by AC current with an adapter while the other allows the unit to interface with a computer or data logger.

Cost: This meter was purchased under GSA contract for $290.

<u>Applied Health Physics' Radiation Alert Monitor 4</u>

Manufacturer: S.E. International, 156 Drakes Lane, Summertown, TN 38483, (615) 964-3561 *Sold to the USCG by Applied Health Physics Inc., 2986 Industrial Blvd., Bethel Park PA 15102*

Detector Specifics: This instrument uses a halogen quenched uncompensated GM tube with mica end window. Areal density of the window is 1.5-2.0 mg/cm2. The meter is 2.8 inches wide by 5.7 inches long by 1.5 inches high and weighs about 6.3 ounces without battery.

Detection Capabilities: S.E. International states the GM probe is capable of detecting alphas down to 2.5 MeV with an efficiency at 3.6 MeV of greater than 80%, betas at 50 keV with 35% efficiency and at 150 keV with 75% efficiency. X-ray and gamma radiation down to 10 keV can be detected though the end window and down to 40 keV through the sidewall.

Power Requirements/Average Lifetime: The survey meter operates on one 9-volt battery that should provide up to 2,000 hours of operation at normal background levels.

Measurement Scales: Three linear exposure rate ranges provide a maximum reading of 50 mR/h. The 0.1X scale is designed to give 0 to 0.5 mR/h exposure rate readings. The 1.0X scale is designed to give 0 to 5 mR/h exposure rate readings. The 10X is designed to give 0 to 50 mR/h exposure rate readings.

Accuracy: not stated

Temperature Range: -20°C to 50°C (-4°F to 122°F)

Humidity Range: not stated

Directional Response: not stated

Other Features: The unit has an internal speaker that signals each time a count is detected.

Cost: This meter was purchased under GSA contract for $234.

<u>Xetex's Model 308A Contamination Monitor</u>

Manufacturer: Xetex Inc., 1275 Hammerwood Ave, Sunnyvale, CA 94089, (408) 745-6776

Detector Specifics: This instrument uses a halogen quenched pancake style 1.25-inch diameter GM tube with 1.5 mg/cm^2 mica end window. The meter is 2.8 inches wide by 6.1 inches long by 1.5 inches high and weighs about 10 ounces with battery.

Detection Capabilities: Xetex states the GM probe is capable of detecting alpha, beta, and gamma radiation and x-rays. No efficiency or energy requirements are stated. Xetex lists the response time as 12 seconds for the 0 to 100 CPM scale and three seconds for all other ranges.

Power Requirements/Average Lifetime: The survey meter operates on one 9-volt battery. The instruction manual states the batteries should last over 200 hours.

Measurement Scales: Three ranges are provided to measure reading between 0 and 10,000 CPM. The 1X scale is designed to give CPM readings between 0 and 100 CPM. The 10X scale is designed to give CPM readings between 0 and 1,000 CPM. The 100X is designed to give CPM readings between 0 and 10,000 CPM.

Accuracy: not stated

Temperature Range: 0^oC to 50^oC (32^oF to 122^oF)

Humidity Range: not stated

Directional Response: not stated

Other Features: The unit has an internal speaker and a small light on the unit face that can illuminate each time a count is detected.

Cost: This meter was purchased under GSA contract for $380.

Ionization Chambers

Theory of Operation

Ion chambers, like GM tubes, are gas-filled detectors. They operate at much lower voltages than GM type detectors. They are the only gas-filled detectors that allow the direct determination of absorbed dose. The current measured by an ion chamber is directly proportional to the ionization produced in the sensitive volume and that in turn is directly proportional to the energy deposited in the detector.

Ion chamber designs vary widely so instrumentation should be chosen based on the type and rates of radiation exposures expected. A common design includes a thin aluminized mylar window covering one end of the detector to allow the detection of alpha and low energy beta radiation and walls of plastic or some other organic or low atomic number material to allow photons to interact yet still be penetrated by higher energy betas. The ion chamber wall thickness must exceed the range of the most energetic secondary electrons the photons can produce.

One drawback of the ion chamber is that the radiation field must be uniform over the entire chamber dimension for the reading to be reliable and accurate. This means that exposure rates read near a point source by a large ion chamber may be seriously underestimated when the field does not cover the entire surface of the ion chamber.

Victoreen's Model 450 Ion Chamber Survey Meter

Manufacturer: Victoreen Inc., 6000 Cochran Road, Cleveland, OH 44139-3395, (216) 248-9300

Detector Specifics: The 200 cc volume ionization chamber is made of 200mg/cm^2 impact resistant plastic. The chamber is covered by two 1.7 mg/cm^2 aluminized mylar covers and an additional 200 mg/cm^2 aluminum cover is supplied to protect the mylar window and provide additional shielding. The meter is 4 inches wide by 8 inches long by 6 inches high and weighs about 1 pound 6 ounces with battery.

Detection Capabilities: Victoreen states the ion chamber is capable of detecting alphas above 4 MeV, betas above 100 keV and x-ray and gamma radiation above 7 keV.

Power Requirements/Average Lifetime: This survey meter can operate on either one or two 9-volt batteries. One battery should provide over 100 hours of operation at normal background levels. Two batteries in series should give 200 hours of operation. Two AAA batteries provide the display light source.

Measurement Scales: This unit is auto-ranging and auto-zeroing. Five ranges are provided up to 50 R/h. The 100 segment linear analog bar graph's display is updated according to the following schedule: 0 to 50 R/h scale every 0.05 seconds, 0 to 5 R/h scale every 0.1 seconds, 0 to 500 mR/h scale every 0.1 seconds, 0 to 50 mR/h scale every 0.15 seconds, and the 0 to 5 mR/h scale every 0.25 seconds. Besides the bar graph, the unit also has a digital display that uses either two or three digits. If three digits are used, the third digit is either a zero or one and is considered by Victoreen to be a place-holder. The units of measure also appear on the display. Range units are programmable in R/h or Sv/h.

Accuracy: +/- 10% of reading between 10% and 100% of full scale indication on any range, exclusive of energy response

Temperature Range: -4°F to 122°F

Humidity Range: 0-100% non condensing (A gasket seals the unit from outside moisture and a desiccant pack is provided in the case bottom to absorb any moisture.)

Directional Response: not stated

Other Features: The unit has a warm-up time of less than one minute when at thermal equilibrium with the surrounding environment. Drift is specified as 0.1 mR/h or less after seven minutes of operation. Precision is stated as within 5% of reading. A separate remote communicator allows remote operation. The integrate mode works 30 seconds after the instrument is turned on and integrates exposure up to 999 R.

Cost: This meter was purchased under GSA contract for $1,035.

Scintillation Detectors

Theory of Operation

By utilizing materials in which signal generation occurs more quickly and where a high atomic density results in a high probability of interaction over a short range, scintillation detectors are very efficient at detecting gamma and x-ray radiation.

Scintillation counting depends on the interaction of incident radiation with a suitable florescent material, called the scintillator or phosphor. After absorbing energy from the incident radiation the phosphor is excited to a higher electron energy state, followed by a subsequent return to ground state. This shift from a higher energy to ground state creates an emission of light (electromagnetic radiation) at a wavelength appropriate to the energy level difference. Once detected, the light from the excited scintillator is guided through a suitable optical medium to a photomultiplier. In the photomultiplier each light photon is converted to one or more electrons which are accelerated and hit a dynode causing the emission of two or more secondary electrons. This multiplication of electrons at the dynodes continues until the generated pulse can be further amplified and displayed. In general the magnitude of the output pulse will be proportional to the number of photons reaching the photomultiplier and hence to the energy of the incident radiation. The number of pulses represents the number of separate exciting events in the phosphor and is proportional to the intensity of the incident radiation.

Because of the tremendous multiplication in the number of electrons, portable scintillation detectors are best used to locate weak, just above background, x-ray and gamma fields while other instruments are needed to carry out subsequent identification and measurement.

<u>Bicron's Surveyor M Portable Count Rate Meter and G1 Scintillation Probe</u>

Manufacturer: Bicron Corporation, 12345 Kinsman Road, Newbury, OH 44065, (216) 564-2251

Detector Specifics: The 7.9-inch by 1.37-inch probe houses a 1-inch by 1-inch NaI(Tl) crystal and an 11-stage photomultiplier tube. The probe is made of aluminum with 0.13-inch side and 0.05-inch end thickness. The meter is 4.25 inches wide by 8 inches long by 6.8 inches high and weighs approximately three pounds with the probe (not including batteries).

Detection Capabilities: Bicron states this unit is capable of detecting gamma radiation above 60 keV.

Power Requirements/Average Lifetime: The survey meter operates on one 9-volt battery with an average lifetime of greater than 100 hours. A second battery holder is included to house a spare or double the instrument lifetime if they are wired in series.

Measurement Scales: Four linear ranges of 0 to 1,000 CPM, 0 to 10,000 CPM, 0 to 100,000, and 0 to 1,000,000 are provided.

Accuracy: within 10% of reading 20-100% of full scale at any range

Temperature Range: -4^{o}F to 122^{o}F

Humidity Range: not stated (The manual states there is less than a 5% change from 0-95% RH.)

Directional Response: not stated

Other Features: The unit has a built-in speaker that clicks at each incoming pulse and/or sounds an alarm if the meter goes off-scale on any range. The unit has adjustable high voltage (0 to 1600 volts) so it may be used with other Bicron GM or scintillation probes. This unit has two response time settings, fast and slow. Bicron states these settings provide 90% of the final reading in less than 1 or 20 seconds when used with a GM probe. Bicron recommends the unit's response time should be set on fast, the anti-saturation circuit set on off and the voltage set to reside on the plateau for use with a scintillation probe. No warm-up time is required. Geotropism is listed as less than 2%. For use with GM detectors, the unit has a dead time compensation switch and anti-saturation circuit switch.

Cost: This meter was purchased under GSA contract for $450.

Instrument Testing Standards and Testing Completed

After completing the review of isotopes commonly shipped by water in the United States and the packaging these isotopes require, the next step in this evaluation was to decide how to objectively test the various survey meters purchased by the Coast Guard. After consultation with James Watson, Ph. D., we decided to see if there were any consensus standards for testing portable radioisotope survey instruments. A literature search revealed that the American National Standards Institute (ANSI) had many standards that might be applicable to this project. Of these standards, the tests outlined in ANSI N13.4-1971: American National Standard for the Specification of Portable X- or Gamma Radiation Survey Instruments; N42.17A-1989: American National Standard Performance Specification for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions; N42.3-1969: American National Standard and IEEE Standard Test Procedure for Geiger-Muller Counters; and N323-1978: American National Standard Radiation Protection Instrumentation Test and Calibration were used as a basis for instrument evaluation.

These standards outlined mechanical specifications (weight, controls, dimensions, shock effects, ease of decontamination, etc.), readout specifications (meter scale length, number and heights of digits on digital scales), marking specifications (manufacturer, model and serial number, geometric center of the detector, battery check, scale marking, etc.), radiologic operating specifications and characteristics (operating range, accuracy over entire range, reproducibility, temperature and pressure influences, humidity influences, geotropic influences, response time, warm-up time, response to other radiation including non-ionizing radiation, exposure rate limitations, battery lifetime, etc.).

Quantitative tests in radiation fields were performed to evaluate system accuracy, spectral dependence, exposure rate limitations, angular dependence/geotropism, reproducibility, response/decay time, coefficient of variance, temperature influences/shock and battery lifetime. Specifications such as size, weight, scales, ease of decontamination and displays were judged subjectively. (The data from the quantitative tests are included in Appendices A-G.)

System Accuracy

ANSI N13.4 defines this as "the ability of an instrument to correctly measure exposure rates over its entire range for the standard set exposure conditions". The testing required to meet this specification states "an instrument shall be exposed to photon fluxes with known spectral distributions and exposure rates of approximately one-fifth, one-half and four-fifths of the instrument's indicated range on each scale. From these measurements the associated error shall be determined and the maximum error of each range shall be specified". ANSI N42.17A states that the accuracy of the indicated value should be within 15% of the known value.

In the field test, all instruments were positioned and exposed to the same photon flux to give four data points per instrument scale. For the instruments that had output in units of mR/h, the lowest flux should have provided a reading of approximately 12% of each range's full scale, the second flux was designed to provide a midscale reading between 42% and 51% of full scale, and the highest flux was designed to provide a reading between 75% and 82% of maximum scale. For the CPM-displaying instruments no attempt was made to position the instruments at the one-fifth, one-half and four-fifths of the instrument's indicated range on each scale. The CPM-displaying instruments were positioned and exposed at the same flux positions used and described above for the mR/h displaying instruments.

Spectral Dependence

ANSI N13.4 defines spectral dependence "as the change in response as a function of photon energy...(which) shall be determined over the stated energy range of the instrument. A graphical or tabular presentation should be used (to present the results)". ANSI N13.4 specifies: "for photon energies below about 1.5 MeV, the ratio of indicated to true exposure or exposure rate as a function of energy shall be determined at several effective energies over the operating energy range of the instrument. For energies below 200 KeV the ratio of true exposure/exposure rate should be measured at appropriate increments (less than 25 KeV). . . . For energies between 200 KeV and 1.5 MeV photon energies of 662 KeV (137 Cs) or 1.25 MeV (60Co) should be used. For energies above 1.5 MeV the source and energy of the photon shall be given. . . . Extrapolation shall not be made above the highest energy nor below the lowest energy for which the tests are performed."

As test sources of various energy were limited, each instrument's response was examined through exposure to Am241 with an effective energy of 0.06 MeV, Cs137 with an effective energy of 0.662 MeV, and Ra226 with an effective energy of 0.83 MeV.

Exposure Rate Limitations

ANSI N13.4 describes exposure rate limitations as "the rate above which the instrument fails to give a full scale response." To evaluate exposure rate limitations, ANSI test procedure requires that "response should be checked by placing the instrument in an appropriate radiation flux and increasing the intensity until an effect is noted or a level of 100 times the maximum range of the instrument has been reached. This should be done on all ranges."

In the field test, all instruments were placed at the shield opening, approximately nine centimeters from the Cs137 source. At nine centimeters the exposure rate should be approximately 20 R/h. If the instrument failed to give a appropriate full scale response at the shield opening, also known as "saturation", the instrument was backed away from the source to determine where a full scale reading was observed.

Angular Dependence/Geotropism

ANSI N13.4 defines angular dependence "as the change in response as a function of angle of incidence...(which) shall be determined over the stated energy range of the instrument. A graphical or tabular presentation should be used (to present the results)". Geotropism is defined as "a change in instrument response with a change in instrument orientation as a result of gravitational effects." To complete the angular dependence testing ANSI N13.4 specifies: "the instrument, detector, or source, as applicable, shall be rotated through at least two perpendicular planes using the center of the detector's sensitive volume as the axis about which the rotation will take place. The ratio of the indicated to true exposure rate shall be obtained for at least thirty degree increments and three energies, one in each third of the specified operating energy range of the instrument. For symmetrical instruments, this rotation need not be accomplished over the entire 360° but should represent the response as a whole." ANSI N42.17A states geotropic effects "shall not be greater than 6% of the mean of a set of readings with the instrument in the reference orientation." N42.17A also states that "the mean response of an instrument to a photon radiation incident at any angle not exceeding 45° from the direction of maximum response of the instrument shall be not less than 80% of this maximum response. At an angle of 90° from the direction of maximum response, the mean instrument reading shall be not less than 50% of the maximum response".

In the field test, each instrument was rotated 360° in each instrument's X (vertical rotation), Y (horizontal rotation) and Z (end over end rotation) plane in 45° increments for the entire rotation. In the original position, or reference location, the detector face was perpendicular to and facing the Cs137 photon flux. To ensure that readings reflected only the instrument rotation and not any effect on exposure due to varying distance, each reading was taken with the geometric center of the detector at the same distance from the Cs137 source. For this experiment only one source and one distance were used for each instrument because the ratio of indicated to actual exposure should be approximately the same for any scale and distance. As the Bicron scintillation detector and the Ludlum GM detector both have detachable circular probes and a separate base, there was no need to rotate the probe through a full rotation in the X plane. Instead instrument bases were rotated to achieve the maximum needle deflection due to geotropic effects. These base geotropic effects are listed on the rotation chart for these instruments in place of the X axis rotation.

Reproducibility

ANSI N323 defines the reproducibility (precision) of the instrument as "the degree of agreement of repeated measurements of the same property". This standard goes on to state "to check reproducibility the instrument should be exposed three or more times under identical conditions. The readings obtained should not normally deviate from the mean value by more than ± 10%".

In the field test, instrument response from the angular dependence's reference location (detector facing the source opening) was obtained prior to each axis rotation. As these three reference location readings always started with the same source-to-instrument distance and orientation, they provided the identical conditions needed to complete this requirement.

Response/Decay Time

ANSI N42.17A describes the response time as "the interval for the instrument reading to change from 10% to 90% of the final reading following a step change in the radiation field at the detector." To determine decay time, ANSI N13.4 states, "The instrument shall be removed from a radiation field providing a full scale or decade reading and the time required for the scale or decade reading to return to 10% shall be noted." For response time ANSI N13.4 states "time shall be determined by measuring the time for the entire instrument to reach 90% of a midscale reading when the instrument is exposed to a step change in flux sufficient to provide a midscale or mid-decade reading." ANSI N41.17A further states "instrument's response time for count rate readout should be less than 30 seconds for gas-flow type units and less than 10 seconds for other type units."

In the field test, each instrument was exposed to a Cs137 flux providing a midscale reading on each range. The time to reach 90% of the midscale reading was noted as the response time. After reaching the midscale reading the source was shielded and the time to go from the midscale reading to 10% of that midscale reading was noted as the decay time. This sequence was repeated three times to provide representative sampling.

As the Bicron scintillation detector and the Ludlum GM meter each have "fast" and "slow" response time switches, both switch settings were tested.

Coefficient of Variance

ANSI N42.17A requires that coefficient of variance testing be done on all decades or ranges and that "the coefficient of variance of 20 instrument readings from a single instrument shall be not more than 10% for exposure rate instruments, dose rate instruments, dose equivalent rate instruments and contamination monitors exposed to radiation intensities greater than or equal to 1 mR/h, 1 mrad/h, 10 mrem/h, and 200 DPM." To test this ANSI requires placing the instrument in a field producing 25% to 75% of a full scale response and taking 20 readings. From these 20 readings a mean, standard deviation, and coefficient of variance (standard deviation/mean) are calculated.

In the field test, each instrument was exposed to a unshielded Cs137 field to provide an approximate midscale reading on each range. After taking 20 readings on each scale, the coefficient of variance was calculated in the manner described above.

Temperature Influences/Shock

ANSI N13.4 specifies "mean instrument response shall vary not more than 15% from the mean response at a nominal 22°C (71.6°F) from 0°C (32°F) to 40°C (104°F) and shall vary not more than 20% ... from -10°C (14°F) to 50°C (122°F)." To complete this temperature influence testing ANSI N13.4 requires the temperature be raised and lowered at 10°C increments, the instruments be allowed to reach thermal equilibrium, and measurements taken. For instrument response during a temperature shock scenario, ANSI N42.17A requires instrument response not vary by more than 15% at a midscale reading when the instrument is taken from a nominal environment of 22°C to one of 50°C or -10°C in less than five minutes

Following the ANSI temperature dependence protocol would have required building a chamber around the radioactive source or moving the source to a previously built enclosure. Both of those options were unfeasible so a variation of the temperature shock test was completed. A temperature shock test was designed to reflect the conditions the instruments would face. Since personnel conducting RAM surveys for the Coast Guard likely will come from climate-controlled areas (either onboard ship or from passenger vehicles) to perform the required survey at ambient or internal container temperature, the field test involved leaving the instruments outside overnight to come in equilibrium with an outside temperature of 52^{o}F. They then were brought to the 83^{o}F basement lab. At various intervals, for up to seven hours, instrument readings were taken to see what effect temperature changes had on the instruments and how quickly the instrument readings stabilized. After seven hours in the lab, all instruments were assumed to be in thermal equilibrium. This seven-hour rate is used as the denominator in calculating the percent change in instrument response as a function of time.

Battery Lifetime

ANSI N13.4 describes the battery lifetime "in terms of hours of continuous operation in a field of less than 0.1 mR/h". To complete this test ANSI requires "fresh batteries be installed in the instrument. The instrument shall be turned on in a field 0.1 mR/h and left on continuously. At intervals, the response of the instrument should be tested with a flux providing approximately half-scale reading; the point in time at which the instrument response no longer meets all performance specifications should be used to determine battery lifetime and corresponding end point voltage." According to ANSI 42.17A "non-rechargeable power supply shall operate with a continuous lifetime of at least 100 hours. All functional circuits (alarms and speakers excluded) shall be switched on and remain on during the test. . . . Battery lifetime shall be considered to have been exceeded when the ratio of the mean reading at any time relative to the mean reading taken initially falls outside the interval 0.9 to 1.1."

In the field test, brand new alkaline batteries purchased from Radio Shack were installed in each instrument after having their initial voltages determined. The instruments were placed so that they would give approximately a half scale reading when exposed to a Cs137 field, but not be exposed to a field of greater than 0.1 mR/h with the source shielded. At various intervals (approximately once every 24 hours at the beginning) each instrument was exposed to the midscale Cs137 flux to see if the instrument gave a reliable reading (within 0.9 of 1.1 of the initial reading). The point the instrument gave a "low battery" indication or an unreliable reading was noted. The corresponding voltages for these "low battery" and unreliable readings were noted. ANSI 42.17A specifies elapsed time shall be given in hours. However since one instrument's batteries lasted over seventy days, all elapsed time readings are given in days.

One problem encountered in completing these tests was that the building where this test was conducted, Venable Hall, was locked during weekend and holiday periods. If an instrument was close to providing a "low battery" signal or unreliable reading, it was shut off while the building was locked and restarted when the building was opened. The time each instrument was off was subtracted from the total elapsed time to give battery lifetime.

Except for the coefficient of variance and response/decay time tests, each data point value has a reported mean and standard deviation which is calculated from five readings at each position. The coefficient of variance results are calculated using 20 readings per reported value while the response/decay time test results were calculated from three replicate trials.

Subjective Evaluation

This report includes a subjective evaluation of mechanical specifications (weight, controls, dimensions, shock effects, ease of decontamination, etc.), readout specifications (meter scale length, number and height of digits on digital scales), marking specifications (manufacturer, model and serial number, geometric center of the detector, battery check, scale marking, etc.) and other intangibles (knowledge base of the sales and repair staff, estimated time for calibration turn-around versus actual time for turn-around, and calibration cost).

Isotopes Used and Their Decay Characteristics

The earlier discussion of ANSI survey instrument tests illustrates that many isotopes and/or sophisticated x-ray producing equipment would be needed to complete the battery of outlined tests over all the energies required.

Since it is important to determine how the survey instruments respond to gamma radiation, ANSI standard N323-1978 suggests that the photon emitters presented in Table 4 are suitable for calibration.

TABLE 4: Photon Emitters Suitable for Instrument Calibration

Radionuclide	Effective Energy (KeV)	Half Life	Published Gamma Constant at one meter (R/h Ci)	Mass Attenuation Coefficient in Air (cm^2/g)
241 Am	60	433 years	0.0129	0.188
57 Co	122	270 days	0.097	
51 Cr	320	28 days	0.018	
137 Cs	662	30.1 years	0.323	.077
226 Ra	830	1,600 years	0.825	.070
60 Co	1250	5.27 years	1.30	
24 Na	2000	15 hours	1.84	

Cesium 137, Americium 241 and Radium 226 sources were made available by Bob Wilson, Radiation Safety Officer at the University of North Carolina at Chapel Hill, and

David Jorgenson, Assistant Radiation Safety Officer at Duke University. The physical properties and decay schemes of the three isotopes are listed below.

Cesium 137 $Cs137 \xrightarrow{\beta\gamma(30.1y)} Ba137$

The University of North Carolina at Chapel Hill Health and Safety Office (UNC) has a 990 millicurie (as of May 29,1985) National Bureau of Standards (NBS) traceable source used to calibrate their survey instruments. The Duke University Environmental Safety Office has a 2,630 millicurie source (as of August 28,1992) that also is NBS traceable.

The UNC source had an actual exposure rate of 191±10 mR/h at one meter (equivalent to an actual gamma constant of 0.191 R/h Ci at one meter). This actual gamma constant is significantly lower that the theoretical value published in ANSI N323. Bob Wilson stated this is because this Cs137 source is encapsulated in an unknown metallic material that shields all of the Cs137 beta emissions and attenuates a significant portion of the photons. *(See Enclosure 4 for the exposure rate information on the UNC Cs137 source.)*

The exposure rate of the Duke University Cs137 calibration source was 897.61 mR/h at one meter on June 6, 1992. *(See enclosure 5.)* This is equivalent to an actual gamma constant of 0.340 R/h Ci at one meter, slightly higher than the theoretical value. Dave Jorgenson stated this value being slightly higher than theoretical was probably because his source is not encapsulated and some photons are scattered back into the beam by the lead shield when it is open.

Radium 226

$$Ra226 \xrightarrow{\alpha\gamma(1602y)} Rn222 \xrightarrow{\alpha\gamma(3.82d)} Po218 \xrightarrow{\alpha(3.05m)} Pb214 \xrightarrow{\beta\gamma(26.8m)}$$
$$Bi214 \xrightarrow{\alpha\gamma(19.7m)} Po214 \xrightarrow{\alpha(1.64x10^{-4}s)} Pb210 \xrightarrow{\beta\gamma(22y)} Bi210 \xrightarrow{\beta(5d)}$$
$$Po210 \xrightarrow{\alpha\gamma(138d)} Pb206(stable)$$

The UNC Health and Safety Office accepted their Ra226 source as 5.0 millicuries on

February 5, 1986. By conducting a series of measurements at various distances from the source and a recently calibrated ion chamber, an exposure rate of 5.1 mR/h at one meter was determined. This is equivalent to an actual gamma constant of 1.02 R/h Ci at one meter, slightly higher than the theoretical value. This higher exposure rate constant value is probably due to some photons being scattered back into the beam by the lead shielding when it's open. *(Enclosure 4 outlines the exposure rate data on the UNC Ra226 calibration source.)*

Americium 241

$$Am241 \xrightarrow{\alpha\gamma(458y)} Np327 \xrightarrow{\alpha\gamma(2.14x10^6 y)} Pa233 \xrightarrow{\beta\gamma(27.4d)} U233 \xrightarrow{\alpha\gamma(1.62x105y)}$$

$$Th229 \xrightarrow{\alpha(7300y)} Ra225 \xrightarrow{\beta\gamma(14.8d)} Ac225 \xrightarrow{\alpha\gamma(10.0d)} Fr221 \xrightarrow{\alpha\gamma(4.8m)}$$

$$At217 \xrightarrow{\alpha(0.032s)} Bi213 \xrightarrow{\beta\gamma(47m)} Po213 \xrightarrow{\alpha(4x10^{-6}s)} Pb209 \xrightarrow{\beta(3.3h)} Bi209(stable)$$

The UNC Health and Safety Office obtained their Am241 source as a gift from a factory that used the source to determine whether cigarettes had the proper density prior to being packaged and sold. Because it was a gift there is little documentation of the actual activity or exposure rate of the source. The container housing the source states that the source was 250 millicuries in October 1971. (No specific date was given.) Using this date and activity information and the Health and Safety Office's calibrated ion chamber, Bob Wilson and I obtained an actual gamma constant of 0.0095 mR/h mCi at one meter after accounting for a background exposure rate of 1.85 mR/h. *(Enclosures 6 and 7 provide the data used to obtain the Am241 gamma constant.)*

Bob Wilson and I determined that the high background exposure rate of 1.85 mR/h might be due to table top or floor contamination where the readings were taken. However, since the data appear consistent, this location and these measurements should not provide any unnecessary concern as long as background rates measured by each instrument are subtracted from each instrument's observed reading. Bob also stated he may recalculate the Am241's gamma constant at a later date.

As the decay schemes illustrate, both the radium 226 and Am241 sources are in a dynamic equilibrium with their various decay products. These various decay products emit both alpha and beta emissions as well as the gamma and x-rays we are interested in using. Because alpha particles travel short distances and will not be able to penetrate a detector's end or walls, they should not affect the instrument response data. The beta disintegration can pose a significant threat to instrument photon response unless adequate shielding or sufficient distance is provided to attenuate these emissions.

Obtaining "Expected" Exposure Rates

To evaluate the system accuracy and energy response, data values at approximately one-fifth, one-half, and four-fifths of each range; the inverse square law; isotope half life; the source to instrument separation distance; and the isotope mass attenuation coefficients in air *(See Table 4.)* were used to calculate an "expected" exposure rate. This "expected" exposure rate can be calculated from Equation 1.

Equation 1: Expected Exposure Rate as a Function of Distance From the Source

$$\text{Expected mR / H} = \text{observed } \Gamma \text{ ray constant} \bullet (\text{initial activity} \bullet e^{(-0.693 \,*\, \text{elapsed time / half life})}) * 1{,}000 \div \text{Separtation Distance}^2 * e^{(-\text{mass attenuation coefficient} \bullet \rho_{air} \,*\, \text{Separtation Distance})}$$

Because the rearrangement of Equation 1 to give distance as a function of expected exposure rate is lengthy and complex, a spread sheet program was used to generate graphs *(See Enclosure 8.)* of distance versus expected exposure rate for each calibration isotope used. These graphs were updated weekly to allow the instruments to be placed at a known distance from the source to get an expected exposure rate.

The final data analysis was completed using the actual experiment dates and separation distances in Equation 1 to obtain the "expected" exposure rates in mR/h.

Test Results

The following is a brief discussion of each instrument's strengths and weaknesses based on the quantitative data gathered and other items observed. An evaluation of each instrument's applications for general use as well as its overall fit for the Coast Guard's container inspection and other program areas also is addressed.

Geiger-Mueller Counters (GM)

<u>Ludlum Instrument's Model 44-7 Probe and Model 2 Survey Meter</u>

Appendix A lists the data obtained during the evaluation of this detachable GM probe and survey meter.

Based on the results of the isotope response tests, this instrument is far too sensitive to be used in the RAM container inspection program. On the instruments maximum scale of 50 mR/h scale, the meter's needle went off-scale below 59 mR/h in the Cs137 field, just above 37 mR/h in the Ra226 field, and at 25 mR/h in an Am241 field. *(See Table and Figure A1.)*

With regard to energy dependence, this instrument responded as theory would predict. *(See Figure A1.)* Theory predicts that using a GM tube's exposure rate scale for an isotope other than the one the instrument was calibrated for will cause an over-response when exposed to lower energy photons such as Am241 and an under-response to higher energy photons such as Ra226. This energy response effect arises because exposure rate is proportional to the average energy of the photon multiplied by the disintegration rate. Therefore, when comparing a lower effective energy photon emitter to the instrument's higher energy calibration source, more photons of lower energy need to be detected during the same time period to give identical exposure rates. However, a GM tube over-responds by indicating the increased effective energy of the calibration isotope which is then multiplied by the increased disintegration rate of the lower energy isotope. This expected effect is not striking in analyzing the difference between the cesium and radium sources because their energies do not differ significantly. However, when comparing the response rates of cesium to americium it is evident that the GM tube significantly over-responded to the lower energy americium photon emissions. This over-response effect is most striking when the GM tube's mica window faces the Am241 source. This decrease in mass allows lower energy photons to penetrate and be counted more readily, increasing the response.

Instrument rotation response was as anticipated. *(See Table and Figure A2.)* The instrument response increased with increasing GM tube cross sectional area exposed to the photon flux. Consequently, the lowest readings were obtained when the Cs137 photon flux was parallel with the GM tubes main axis. The window was perpendicular to and facing the source in the reference position; so all side-wall-facing readings were over 100% of the reference value. The lowest readings—52% and 63%—were obtained when the probe was directly opposite the reference location and not facing the Cs137 source. These low readings were anticipated due to two phenomena. First, there was little cross-sectional surface area for photon interaction. Second, at this position many photons are attenuated by the probe/base connector's mass.

This instrument showed no geotropic effect. The values were between 100% and 98% when the base was rotated around the plane of the needle. *(See Table and Figure A2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 2.74% from the average. *(See Table A2.)*

This instrument showed no signs of saturation when exposed to a 20 R/h field.

The average response times on the "fast" response setting were 3.24 and 5.11 seconds; the decay times were 4.64 and 4.12 seconds for the 1X and 10X scales; all were within the

10-second ANSI protocol standards for this type of instrument. On the "slow" response setting the average response times were 22.3 seconds on the 1X scale and 27.9 seconds on the 10X scale; the decay times were 27.9 seconds on the 1X scale and 24.9 seconds on the 10X scale. These were well above the ANSI standard. One should note, however, that this instrument would rarely be used in the slow response mode unless the operator were sure of the field and needed more stable readings.*(See Tables A3 and A4)*

The 3.6% and 2.1% coefficient of variance readings for this instrument on the "fast" response setting were within the 10% standard recommended by ANSI. During the "slow" response setting, the needle movement was dampened and the coefficient of variance readings were improved to 2.0 on the 1X scale and 0.0 on the 10X scale. This 0.0 coefficient of variance is due in part to the reduced width of the 10X scale divisions making interpolation between divisions impracticable.*(See Table A3.)*

The temperature "shock" test showed readings that varied little—100% to 104.8% over the seven hours allotted to reach thermal equilibrium. *(See Table A5 and Figure A3.)* The first four readings, at 0, 10, 20 and 30 minutes, did not include the 100% line at the 95% confidence intervals. However, the count rate values overlapped at the 95% confidence interval bands, so it is safe to state there is no temperature shock effect seen in this instrument.

The battery lifetime of this instrument was over 30 days of continuous operation. *(See Table A6 and Figure A 4.)* A closer examination of the data revealed this instrument also provides an excellent eight-day warning time from the point the "low battery" indication was given until the reading dropped below an acceptable 90% of true value.

The instrument itself was easy to hold and was not cumbersome; the detachable probe allowed survey of cramped areas; the audible clicking feature allowed qualitative searching without looking to see what the meter is displaying. Another nice feature of this instrument is the zero reset button.

The Ludlum servicing and sales personnel I spoke with on the phone seemed very knowledgeable and confident about this instrument. I was told calibration using a Cs137 source would take 10 days and cost $30. I received it back after 11 days.

The switch to a smaller display at the 10X scale made interpolation between scale divisions more difficult.

Overall, this instrument's range, thin end mica window, long battery life and detachable probe make it great for searching and locating contaminated areas.

This instrument does not have the range needed for the Coast Guard's container inspection program. It also would not be appropriate for use in oil spill/hazardous chemical response because the numerous base switches and knobs would make decontamination difficult.

Dosimeter's Super Mini Radiation Monitor Model 3500

Appendix B lists the data obtained during the evaluation of this GM detector.

Based on the results of the isotope response tests, this instrument's range of 3,000 mR/h exceeds the 200 mR/h minimum range needed for the RAM container inspection program. The instrument responded to every isotope exposure rate except for those over 3 R/hour. Exposure rates over 3 R/h were expected to be and were off-scale. *(See Table and Figure B1.)*

With regard to energy dependence, this instrument responded very well, contrary to theory prediction. *(See Figure B1.)* The data show instrument response of ± 20% for almost all readable responses. The exceptions were the Am241 response at 0.9 mR/h, approximately 150% of predicted, and the Ra226 response at 301 mR/h, approximately

75% of predicted. Although the mean instrument response was within ± 20%, the bands indicating confidence levels are very wide.

Instrument rotation response was as anticipated. *(See Table and Figure B2.)* When there was little mass to attenuate the Cs137 gammas before they contacted the GM tube, the readings did not vary more than 5% and were consistently above 95% of the reference location value. Anticipated lower readings were obtained at locations where there was an increased probability of photon surface interaction prior to reaching the GM tube. This occurred at a Z-axis rotation of 315° (64%) and a Z-axis rotation of 45° (89%). At a Z-axis rotation of 90° (32%) the photons were attenuated by the batteries prior to reaching the GM tube. Lower readings were also obtained where the GM tube did not provide adequate cross sectional surface area for interaction. This occurred at a Y-axis rotation of 90° (83%) and 270% (88%)).

This instrument showed no geotropic effect. The values were between 102% and 97% when it was rotated around the X-axis.*(See Figure B2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 3.12% from the average. *(See Table B2.)*

This instrument showed no signs of saturation when exposed to a 20 R/h field.

The average response times were 5.40 and 3.99 seconds; the decay times were 4.13 and 2.83 seconds for the 100X and 1,000X scales. All were within the 10-second ANSI protocol standards for this type of instrument. However the response and decay times of 10.78 and 10.63 for the 10X scale (maximum rate of up to 30 mR/h) were beyond those deemed acceptable by the ANSI protocol. *(See Tables B3 and B4.)*

The 6.0%, 3.8%, and 3.7% coefficient of variance readings for this instrument were within the 10% standard recommended by ANSI. *(See Table B3.)*

The temperature "shock" test showed readings that are not different at the 95% confidence limit. All readings at the 95% confidence interval bands included the 100% value. *(See Table B5 and Figure B3.)*

The battery lifetime of this instrument was between 12 and 13 days of continuous operation. *(See Table B6 and Figure B4.)* A closer examination of the data revealed this instrument provided little warning time from the time the "low battery" indication was given until the reading dropped below an acceptable 90% of true value.

The instrument itself was easy to hold; was not cumbersome and easily fit into a shirt or pants pocket. The display was easy to read and it appeared easy to decontaminate by wiping it down.

I was told the instrument calibration using a Cs137 source would take 10 days and cost $75. I received it back after 23 days, however additional time was needed to replace the instrument's GM tube.

This instrument only detects photons and high energy betas as it does not have a thin end window.

Overall, this instrument's range, accuracy, and quick response rate at higher exposure rates make it great for photon exposure rate survey monitoring. However, the wide confidence interval bands make accurate determination of exposure rates difficult.

This instrument fits the Coast Guard's needs for the container inspection program when packages are intact or are pure gamma emitters. However since this instrument has no thin end window, surveys of lower energy beta emissions are impossible. (A separate GM with a thin end mica window is available to attach to this instrument but it was not tested in this report.)

S.E. International's Radiation Alert "Digilert"

Appendix C lists the data obtained during the evaluation of this GM detector.

Based on the results of the isotope response tests, this instrument is far too sensitive to be used in the RAM container inspection program. Although this instrument yielded excellent straight line "calibration" curves, the instrument was overloaded (19,999 CPM) at approximately 12 mR/h in a Cs137 field and Ra226 field and at 4 mR/h in an Am241 field. *(See Table and Figure C1.)*

With regard to energy dependence, the instrument generally responded as theory would predict. *(See Figure C1.)* The lowest CPM rates were for Ra226; Am241 was off-scale at the same exposure rates. Because the output display is in CPM, the instrument should display more CPM at the same "expected" exposure rates when using a lower effective energy isotope such as Am241, than for the higher energy isotope such as Cs137. For isotopes with higher effective energies such as Ra226, less CPM than the lower energy source such as Cs137, are expected at the same expected exposure rates. (As the effective energies of Cs137 and Ra226 are not significantly different from each other, this effect is not dramatic.)

Instrument rotation response was as anticipated. *(See Table and Figure C2.)* When there was little mass to attenuate the Cs137 gammas before they contacted the GM tube, the values did not vary more than 6% and they were consistently above 90% of the reference location value. Anticipated lower readings were obtained where the probability of photon interaction with detector mass prior to reaching the GM tube was increased or where the GM tube did not provide a adequate cross sectional area for interaction. This occurred at a Y-axis rotation of 90°, when the instrument face and electronics were between the source and the GM tube (79%); a Z-axis rotation of 90°, when the base and electronics, including the battery, were between the source and the detector and there was little photon-GM tube surface interaction area (51%) and at a Z-axis rotation of 270°, when the little cross-sectional end window was facing the source (86%).

This instrument showed no geotropic effect. The values were between 100% and 97% when rotated around the X-axis. *(See Figure C2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 2.96% from the average. *(See Table C2.)*

This instrument also showed no signs of saturation when exposed to a 20 R/h field.

Because this instrument provides a new reading only at one minute intervals there is no way to calculate response and decay times. The user must be cautioned that this instrument will average the count rate during the sampling period. There will be a delay in the observation of the true count rate if users are in a high CPM area.

By obtaining 21 consecutive measurements, I was able to calculate an instrument coefficient of variance of 1.7%. Twenty-one readings were needed as the first one was eliminated ensuring all values were a full minute. *(See Table C3)*

The temperature "shock" test showed readings that varied little—between 100% to 102.8% over the seven hours allotted to reach thermal equilibrium. All count rate values overlap when looking at the 95% confidence interval bands. It is safe to state there is no temperature shock effect seen in this instrument. However, there are three readings at 0, 45 and 60 minutes that do not include the 100% line at the 95% confidence intervals. *(See Table C5 and Figure C3.)*

The battery lifetime of this instrument was between 30 and 35 days of continuous operation. *(See Table 6 and Figure C4.)* A closer examination of the data revealed this instrument also provided a two day warning time from the time the "low battery" indication was given until the reading dropped below an acceptable 90% of true value.

The instrument itself was easy to hold and was not cumbersome; the display was easy to read; it appeared easy to decontaminate by wiping it down; the audible clicking feature allowed a qualitative survey without looking to see what the meter is displaying, and the unit can display either in CPM or total counts mode.

The Digilert servicing and sales personnel I spoke with on the phone seemed very knowledgeable about this instrument. I was told servicing using a pulse rate generator would take 14 days and cost $30. I received it back after 4 days.

The slow display update period is a serious drawback. Having the instrument display at one-minute intervals could lead to overexposures in increasing fields. Also because the display is limited to 19,999 maximum counts, exposure rate situations are severely restricted. Being able to select shorter update periods would greatly expand the range of this instrument.

Overall, this instrument's response rate, update time and ability to give total counts for long periods of time make it great for doing long duration, low level environmental survey monitoring.

The only Coast Guard application for this instrument is background monitoring at hazardous waste sites. Most of these activities are not time critical in nature.

<u>Applied Health Physics' Radiation Alert Monitor 4</u>

Appendix D lists the data obtained during the evaluation of this GM detector.

Based on the results of the isotope response tests, this instrument far too sensitive to be used in the RAM container inspection program. On the 50 mR/h scale, the meter went off-scale below 59 mR/h in a Cs137 field, just above 37 mR/h in a Ra226 field, and at 14 mR/h in an Am241 field. *(See Table and Figure D1.)*

With regard to energy dependence, this instrument responded as theory would predict with over-response to lower energy photons and under-response to higher energy photons when reading the mR/h scales. *(See Figure D1.)* Instrument response especially matched theory in responding to the lower energy Am241 photons as the instrument dramatically over-responded.

Instrument rotation response was as anticipated. *(See Table and Figure D2.)* When there was little mass to attenuate the Cs137 gammas before they contacted the GM tube, readings did not vary more than 5% and were consistently above 95% of the reference location value. Anticipated lower readings were obtained where the GM tube did not provide good cross sectional surface area for interaction or where the probability of photon interaction with detector mass was increased prior to reaching the GM tube. Specific points of interest for decreased cross sectional surface area were at a Z-axis rotation of 90° (53%) and 270° (84%) and when the photons were attenuated prior to reaching the GM tube at a Y-axis rotation of 270% (8%).

This instrument showed no geotropic effect. The values were between 101% and 99% when rotated around the X-axis. *(See Table and Figure D2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 3.70% from the average. *(See Table D2.)*

This instrument showed no signs of saturation when exposed to a 20 R/h field.

The average response times were 6.45 and 8.69 seconds; the decay times were 7.51 and 7.12 seconds for the 10X and 100X scales. All were within the 10-second ANSI protocol standards for this type of instrument. *(See Tables D3 and D4.)*

The 1.9% and 3.3% coefficient of variance readings for this instrument for the 10X and 100X scales were within the 10% standard recommended by ANSI. *(See Table D3)*

The temperature "shock" test showed readings that varied little—102.8% to 98.1% —over the seven hours allotted to reach thermal equilibrium. The second and third values, taken at 10 and 20 minutes, do not include the 100% line at the 95% confidence intervals because the five readings making up this value were identical and therefore have no standard deviation for confidence interval calculation. The count rates all overlapped at the seven-hour 95% confidence interval bands so it is safe to state there is no temperature shock effect seen in this instrument. *(See Table D5 and Figure D3)*

The battery lifetime of this instrument was the best of all instruments tested in this study at between 70 and 80 days of continuous operation. *(See Table D6 and Figure D4.)* A closer examination of the data revealed this instrument provided warning time of over eight days from the time the "low battery" indication was given until the reading dropped below an acceptable 90% of true value.

The instrument itself was easy to hold, was not cumbersome and easily fit into a shirt or pants pocket; the display was easy to read, it appeared easy to decontaminate by wiping it down.

I was told the calibration using a Cs137 source would take two days and cost $60. I received it back after 4 days.

Although within the ANSI specification, the instrument's response time seemed slow at high exposure rates.

Overall, this instrument's range, thin end mica window and long battery life make it great for locating contaminated areas.

This instrument does not have the range needed for the Coast Guard's container inspection program.

Xetex's Model 308A Contamination Monitor

Appendix E lists the data obtained during the evaluation of this pancake-style GM detector.

Based on the results of the isotope response tests, this instrument is far too sensitive to be used in the RAM container inspection program. Although this instrument yielded excellent straight line "calibration" curves, the meter was overloaded on the 1000X scale below 5.9 mR/h in a Cs137 field, just below 4.0 mR/h in a Ra226 field, and just below 2.0 mR/h in an Am241 field. *(See Table and Figure E1.)*

With regard to energy dependence, this instrument did not respond as theory would predict. *(See Figure E1)* Because the output display is in CPM, the instrument should display more CPM at the same expected exposure rates, when using a lower effective energy isotope such as Am241, than for the higher energy isotope such as Cs137. For isotopes with higher effective energies such as Ra226, less CPM than the lower energy source such as Cs137, are expected at the same expected exposure rates. This instrument deviated from this theory by over-responding to Ra226.

Instrument rotation response was as anticipated. *(See Table and Figure E2.)* Lower readings were obtained when the GM tube did not provide good tube cross sectional area for interaction or when there was a greater probability of mass attenuation prior to reaching the GM tube. This instrument's overall instrument rotation response was the lowest (90% to 45% with many readings in the 75% range) of the instruments tested. This low observed rotation response is because pancake probes have only one axis with adequate cross sectional area. In fact one reading of 45% (with the probe face rotated 90° from the source and the probe face facing the ceiling) failed the ANSI requirement that states that "at an angle of 90° from the direction of maximum response, the mean instrument reading shall be not less than 50% of the maximum response"

This instrument showed no geotropic effect. The values were between 102% and 98% when rotated around the X-axis. *(See Table and Figure E2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 6.41% from the average. *(See Table E2.)*

This instrument did saturate when exposed to a field of approximately 20 R/h. At exposure rates of approximately 4.4 R/h this instrument's meter, on any scale, continued to read approximately 100 CPM . An off-scale but "pegged" reading was obtained after the instrument was backed off to a field of just over 4 R/h.

The average response time was 3.79 seconds; the decay time was 4.81 seconds for the 1,000X scale. Both were within the 10-second ANSI protocol standards for this type of instrument. *(See Tables E3 and E4.)*

The 4.9% coefficient of variance readings for this instrument were within the 10% standard recommended by ANSI. *(See Table E3.)*

The temperature "shock" test showed readings that varied considerably—112% to 100%—over the seven hours allotted to reach thermal equilibrium. The exceptionally wide 95% confidence limit bands were due to the meter's erratic needle. Because of these wide confidence bands, these readings are not statistically different from one another. This instrument showed the worst response to temperature shock test of those tested. *(See Table E5 and Figure E3)*

The battery lifetime of this instrument was between seven and eight days of continuous operation. *(See Table E6 and Figure E4.)* A closer examination of the data revealed this instrument did not provide adequate warning time that the battery was low. The "low battery" indication was observed after the instrument was responding below the 95%

level and was close to the acceptable 90% of true value. Batteries in this instrument should be changed prior to the needle nearing the low battery indication.

The instrument itself was easy to hold, was not cumbersome and easily fit into a shirt or pants pocket, it seems easy to decontaminate by wiping it down.

I was told calibration using a Cs137 source would take 14 days and cost $50. I received it back after 27 days.

This instrument's erratic needle jumping made readings hard to obtain.

Overall, this instrument's limited range and angular dependence make it useful for locating grossly contaminated areas or doing environmental surveys. It should not be used in high radiation fields as it is prone to saturation.

This instrument is not appropriate for any Coast Guard programs.

Ion Chamber

<u>Victoreen's Model 450 Ion Chamber Survey Meter</u>

Appendix F lists the data obtained during the evaluation of this ionization chamber.

Based on the results of the isotope response tests, this instrument has more than the 200 mR/h range needed to be used in the RAM container inspection program. This instrument provided on-scale readings for every isotope exposure rate tested. *(See Table 1 and Figures F1(a) and F1(b).)*

For each exposure rate tested there are four separate data points depicted on Figures F1(a) and F1(b). These data points consist of the observed reading with no additional calculations, the observed reading corrected for temperature and pressure, the observed reading corrected for the extra distance to the center of the sensitive volume but not for temperature or pressure, and a reading corrected for distance, temperature and pressure.

The observed readings taken with the cap off ranged from approximately 50% to 115% of the expected exposure rates. *(See Figure F1(a).)* As this range of data was unsatisfactory, I applied the temperature and pressure conversion factor recommended by Victoreen's calibration certificate. The application of this air density correction factor *(See Equation 2.)* is recommended by the manufacturer when conditions differ from those under which the unit was calibrated.

Equation 2:

$$((273.2 + T(^\circ c)) / 295.2) * \left(760 / P_{mmHg}\right)$$

The application of this temperature and pressure correction factor did little to change the range of exposure rates. However, I noted that the expected values agreed fairly well with the observed values farther away from the source at lower expected exposure rates. Also, at close distances with the aluminum cap off, two interesting trends appeared. The first and most striking trend was that both the observed and temperature-corrected bars seemed to increase exponentially at Ra226 exposure rates greater than 12.3 mR/h. *(See Figure F1(a).)* This exponential increase after 12.3 mR/h reading occurred at 64 cm (25.2 inches) due to beta particles reaching and being counted by the ion chamber. When the distances are greater than this 64 cm, the betas are attenuated in air and/or do not possess enough residual energy to pass through the mylar window. This beta effect was confirmed when the aluminum cap was placed over the ion chamber mylar window and no exponential growth was observed. *(See Figure F1(b).)* The second item noted was that the observed/expected ratios became smaller when the distance from the source to the detector became smaller. At first it appeared that this effect might have been caused by having part of the sensitive volume outside the radiation cone, resulting in lower readings proportional to the exposed area over total area. To determine whether this was the problem, I used Duke University's higher activity Cs137 source. This source's larger activity meant that I could increase my source-to-detector separation distance to 50 cm and 60 cm while ensuring the whole detector face was in the photon flux and still get readings comparable to those I obtained close to the UNC source. Results using this

Duke University Cs137 source indicate that although there was some effect of the instrument's sensitive volume not being in the photon cone, there was another, more important, effect to be considered. *(For the Duke University Cs137 source data see Table F1 and Figures F1(a) and Figure F1(b) at 2482 and 3573 mR/h.)* This low observed/expected ratio effect can be explained by noting that the extra distance from the ion chamber face to the electrode was not accounted for when the instrument was first positioned. A phone call to Victoreen's calibration supervisor revealed that the electrode surface is in the center of the sensitive volume, approximately 4.9 cm from the instrument face. The third bar for each exposure rate *(See Figures F1(a) and 1(b))* shows the observed/calculated exposure rates obtained after adding 4.9 cm to the source/instrument separation distance. Finally the fourth line for each calculated exposure rate incudes both the source-to-instrument electrode distance and temperature/pressure effects.

With regard to energy dependence, this instrument responded within 20% of "expected" regardless of photon energy once all distance, temperature and pressure corrections were made. *(See Figure F1(b).)* The manufacturer's response curve for this instrument is fairly flat over a wide range of photon energies. *(See Enclosure 9.)* This flat response is characteristic of ion chambers and therefore makes them well suited as exposure and dose rate instruments.

As this instrument is subjected to higher exposure rates, the energy dependence confidence intervals become smaller making the readings more reliable and easier to interpret. *(See Figure F1(a)and F1(b).)* The widest confidence interval observed, totaling 30% of the expected value, was for an Ra226 exposure rate of 0.6 mR/h. *(See Figure F1(b).)* Above an exposure rate of 125 mR/h, an exposure rate comparable to HWRCQ RAM shipments, the widest confidence interval observed was ± 1.5%.

Instrument rotation response was better than anticipated. This ion chamber had only two values outside the range of 103% to 95% when compared to the reference location value.

These two 93% and 85% values were at 90° and 135° rotation about the Z axis. These lower readings are attributable to the photons being attenuated by either the internal circuitry for the 90° reading or the batteries, located in the handle, for the 135° reading. *(See Table and Figure F2.)*

This instrument showed no geotropic effect. The values were between 102% and 97% when rotated around the X-axis. *(See Table and Figure F2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 1.33% from the average. *(See Table F3 .)*

This instrument showed no signs of saturation when exposed to a 20 R/h field.

The average response times were 4.73 and 2.85 seconds; the decay times were 4.13 and 2.83 seconds for the 10X and 100X scales; all were within the 10-second ANSI protocol standards for this type of instrument. However the response and decay times of 11.78 and 10.62 for the 1X scale are beyond those deemed acceptable by the ANSI protocol. It should be noted that the 1X scale of this instrument ranges from 0 to 5 mR/h and a slower response time at these exposure rates will not put the surveyor at much increased risk. *(See Tables F3 and F4.)*

The 2.9%, 1.5%, and 0.0% coefficient of variance readings for this instrument are within the 10% standard recommended by ANSI. The 0.0% coefficient of variance reading was at higher exposure rates which tends to make these readings more precise. *(See Table F3.)*

The temperature "shock" test showed zero and ten minute readings that do not overlap at the 95% confidence interval. *(The seven-hour upper confidence level is 101.3%, while the lower confidence interval bands for the initial and 10 minute readings were 104.0% and 102.7% respectively.)* As these bands do not overlap, the readings at the 95%

confidence are different and time should be allowed for this instrument to provide indistinguishable readings. After allowing 20 minutes equilibrium time, all 95% confidence interval bands included the 100% value. *(See Table F5 and Figure F3)*

This instrument can function on either one or two batteries. The battery lifetime of this instrument was between 3.5 and 4 days of continuous operation on a single battery and just over eight days on two batteries. *(See Table F6 and Figure F4.)* A closer examination of the data revealed that using either one or two batteries this instrument provided little warning time (about 6 hours) from the time the "low battery" indication was given until the reading dropped below an acceptable value. In all three battery lifetime tests conducted with this instrument, the display dimmed and displayed erratic numbers prior to giving an unacceptable value.

The instrument itself was easy to hold. The handle provided an easy location to attach a carrying strap for climbing. It was not cumbersome. Having the batteries housed in the handle made for easy changing. The displays were easy to read and were updated approximately every two seconds. Its wide scale and auto-ranging feature made it the easiest instrument of those tested to use. Its gasket seals and lack of protruding knobs and switches allowed more thorough decontamination.

I was told the calibration using a Cs137 source would take 14 days and cost $130. I received it back after 21 days.

All of the Victoreen staff seemed very knowledgeable and helpful during the many phone calls I placed to them about temperature and pressure correction, high background readings due to high instrument internal humidity after being locked in a damp refrigerator for a few days, and location of the electrode from the window face.

I had some initial concern about the frailty of the mylar windows. I was worried about the need to return the equipment to Victoreen each time one of these windows was punctured. After taking this instrument apart many times, I can attest that the mylar windows are easy to replace.

This instrument's display can be set for either conventional (R/h) or SI (Sieverts/h) units. The unit integrates exposure rates after the instrument is turned on for one minute to provide dose estimates and can be used as a crude dosimeter in this mode.

There is no mark indicating the electrode/center of the sensitive volume on the instrument housing. The aluminum end cap is not connected to the instrument so it may become easily lost. There is also no audio output from this instrument making an "eyes away" survey impossible.

Overall, this instrument's range, accuracy, and quick response rate at all scales make it great for photon exposure rate survey monitoring. This also was the only instrument that had a thin enough end window to enable detection of the Ra226 betas.

Of the instruments tested this ion chamber best fits the needs of the Coast Guard container inspection program.

Scintillation Detector

Bicron's Surveyor M Portable Count Rate Meter and G1 Scintillation Probe

Appendix G lists the data obtained during the evaluation of this scintillation detector. At present the Coast Guard has approximately 100 of these instruments in use throughout the country.

Based on the results of the isotope response tests, this instrument is far too sensitive to be used in the RAM container inspection program. When the voltage applied to the scintillation probe was set in the middle of the Cs137 plateau (approximately 1,000 volts), the meter's needle went off the 1000X scale at approximately 4 mR/h in a Cs137 field, 6 mR/h in a Ra226 field, and was never on-scale when exposed to a minimum 0.9 mR/h Am241 field. *(See Table and Figure G1.)*

With regard to energy dependence, this instrument responded as theory would predict. The lowest CPM rate was for Ra226 and Am241 was off-scale at the same exposure rate. *(See Figure G1.)* Because the output display is in CPM, the instrument should display more CPM at the same expected exposure rate when using a lower effective energy isotope such as Am241 than for the higher energy isotope such as Cs137. For isotopes with higher effective energies such as Ra226, less CPM than the lower energy source such as Cs137, are expected at the same expected exposure rates.

Instrument rotation response was consistently above 90% of the reference location value. *(See Table and Figure G2.)* I anticipated lower readings at the 135°, 180°, and 235° probe rotation positions as the probe face presented less cross sectional area for the photons to interact and had the entire length of the probe to attenuate the photons prior to the interaction with the NaI crystal. Only at a point with the Z-axis at 135° from the reference location was the response below 90% of the reference location. This 85% minimum value means this instrument is very sensitive, no matter where the source is located in relation to the probe's sensitive volume.

This instrument showed no geotropic effect as its base was rotated around the needle's plane. *(See Table and Figure G2.)*

The precision data were within the 10% specified by the ANSI standard. The three sets of readings had a maximum deviation of 5.71% from the average. *(See Table G2.)*

This instrument showed no signs of saturation when exposed to a 20 R/h field.

Response and decay times of 0.62 to 1.27 seconds were within the 10-second ANSI protocol standards for this type of instrument. There appears to be little difference between the "fast" and "slow" response time settings not attributable to personal response error by the timer. *(See Tables G3 and G4.)*

The 2.2% coefficient of variance readings for this instrument's 1,000 scale also were within the 10% standard published by ANSI. *(See Table G3.)*

The temperature "shock" test values varied little over the seven hours allotted to reach thermal equilibrium. Four points, at 60, 90, 120 and 180 minutes, were suspect. All other temperature effect values overlap when looking at the 95% confidence limits, so it is safe to state there is no temperature shock effect observed in this instrument. *(See Table G5 and Figure G3.)* I attributed the four low readings to the phosphor readjusting to temperature because Bellian notes:

> The temperature response of these detectors should not be overlooked because in many cases it can be quite severe, particularly in the case of the scintillator. . . . In addition to the changing of the sodium iodide phosphor itself, the photomultiplier tube will also show a gain with temperature.[1]

However, after noting that the original seven-hour reading was approximately 83% of the first values and that the data was deteriorating with time, the batteries and photomultiplier tube voltage were checked. The voltage was only 700 volts even though the voltage regulating knob had been set at 1,000 volts. Obviously the batteries had worn down during the test. Once new batteries were installed, the voltage again read 1,000 volts and the 100% seven-hour value was obtained.

The battery lifetime of this instrument was between 4.5 and 5 days of continuous operation. *(See Table G6 and Figure G4.)* Two sets of data for this experiment were needed and are displayed because the instrument initially gave a "low battery" indication after 4.9 days and did not respond when the next reading was taken at 6.1 days. (After a weekend when the building was locked.) A closer examination of the data revealed that

[1] J.G. Bellian, Limitations of Health Physics Instrumentation, Victoreen, p.8

the batteries should be changed when the needle nears the "low battery" display indication because there was not much time between an acceptable reading (110% to 90%) and a dramatic decline in response. *(See Figure G4.)*

The instrument was easy to hold and was not cumbersome; the detachable probe allowed survey of cramped areas; the display was easy to read; the audible clicking feature allowed quicker qualitative searching without looking to see what the meter was displaying. The audible feature also sounds a piercing alarm when the needle goes off-scale for more than two seconds.

Bicron servicing and sales personnel seemed very knowledgeable about this instrument during our phone conversations. I was told the instrument servicing using a pulse rate generator would take 10 days and cost $90. I received it back after 25 days.

The instrument can use either a GM or scintillation probe by varying the probe voltage. The voltage regulating knob is protected by a guard to prevent inadvertent voltage adjustment, but the guard does not adequately protect the knob from the top. A positive acting, fully enclosing cap installed in place of the guard would be a better solution as this would require the operator to physically open the cap to change the voltage rather than just turn a knob.

Overall, this instrument's sensitivity, rapid response rate, lack of directional dependence, and audio alarm make it great for locating photon sources at very low activity and energy levels. It also would make a good contamination monitor to identify contaminated areas (generally thought of as providing levels two times background).

This instrument is appropriate for Coast Guard use in surveying potentially contaminated areas. Its use at hazardous waste sites is questionable since the base's many knobs and buttons make it hard to decontaminate but its quick and sensitive response justify its use.

Conclusions and Recommendations

Instrumentation

The test results revealed that only two instruments, the Victoreen model 450 ion chamber and the Dosimeter Corporation's Super Mini, had the range needed for use in the Coast Guard's RAM container inspection program. Of the two, the Victoreen ion chamber showed better response to the energies tested. It could be used to detect beta emissions through its mylar thin end windows; it showed better response to rotation; and it permitted easier decontamination. Of the instruments tested the Victoreen ion chamber is best suited for the Coast Guard's RAM container inspection program.

Before making my final recommendation, I reviewed various manufacturer catalogues to determine whether there were other survey instruments that could better meet the needs of the Coast Guard than Victoreen's model 450 ion chamber. Based on this survey, I recommend the purchase of the Victoreen 450B Ion Chamber. According to the Victoreen catalogue the 450B has the same predictable flat energy response, range, sensitivity as the 450, but has a sliding beta shield instead of the removable cap used on the 450. This small modification makes the 450B more suited to the rigors of container inspections and should result in a cost saving since the beta shields will not require frequent replacement.

One drawback of this ion chamber is the temperature and pressure adjustments that are needed when working with this instrument under differing pressure and temperature conditions. This drawback is not a major problem, however because inspectors can usually obtain current meteorological conditions from nearby National Weather Service facilities or major airports and easily derive any needed temperature and pressure correction factor.

Check Sources and Calibration

To maintain proper instrument operation, commercially available check sources must be used prior to inspection; instruments must be recalibrated annually; and calibration records maintained for the life of each instrument. These steps help to ensure proper instrument operation and track any problems that might arise over the instrument's lifetime.

The value of periodic equipment checks became clear to me when at calibration time Dosimeter Corporation personnel reported that the instrument's GM tube was defective and needed replacement. (It had a loose electrode wire that could cause intermittent readings.) Had this condition occurred in the field, it is unlikely that the problem would have been noted unless the instrument gave no reading. If a faulty instrument is used in the field, a potentially hazardous situation might not be avoided and personnel might be overexposed .

To ensure instrument reliability, each instrument should be provided with and accompanied by its own check source at all times. ANSI 323 states "a performance check shall be made prior to each use during intermittent use conditions and several times a day during continuous operations." This standard goes on to say "check sources should provide radiation of the same type or types as provided by those sources used in instrument calibration." It is recommended that Cs137 check sources be purchased for all instruments since the facilities that calibrated the instruments under evaluation all used Cs137 as their calibration source. (As the activity of check sources are low, there are no NRC facility permitting or extra storage requirements for the check sources.)

Each instrument's annual recalibration should be timely with a separate check system set up to ensure completion. Upon recalibration, the instrument's calibration certificate should be maintained in a file for the life of the instrument. This calibration function is probably best handled by Commandant (G-KSE-3) as this office currently handles other safety and health related equipment for marine safety personnel. If KSE-3 does not wish to take on this function, either the district Industrial Hygienist should take it on directly or ensure that it is done at the unit level.

Unit Needs

According to the RAM shipment data obtained from the U.S. Department of Commerce, the U.S. Army Corp of Engineers and the Coast Guard's QAR, coupled with the historic data presented in COMDTINST 6470.1, there are more than ten ports involved with RAM shipments. The data indicate that Norfolk, Baltimore, New York, Savannah, San Francisco, Los Angeles and Philadelphia handle the most RAM shipments. Therefore each of these MSOs and a central USCG storage facility [either G-KSE or each District (moh)] should be provided survey instrumentation first. Once additional funding is available, other units will be provided with equipment based on need (i.e. number of total RAM shipments).

Of utmost concern is that each unit needing this instrumentation always have a properly calibrated instrument available. Two methods of ensuring instrument availability are apparent:

1) Two instruments can be provided to each MSO. Providing duplicate instrumentation will enable backup should one instrument fail to operate and leave each unit with an instrument when one is out for calibration. Each unit will then maintain a file of calibration certificates for each instrument.

2) Have the oversight office (anticipating G-KSE-3), the central storage facility for extra instruments, send a newly recalibrated instrument with a copy of its most recent calibration certificate to a MSO whose instrument needs recalibration. When the MSO receives the new instrument it sends the old instrument to the recalibration facility. After recalibration is completed, the newly recalibrated instrument is sent back to KSE-3.

KSE-3 then stores the original new calibration certificate in the instrument's permanent file after making a copy of it. When another MSO's instrument needs recalibration this process is repeated.

Dosimetry Needs

The regulations contained in 10 CFR 20 require that personnel monitoring devices be worn and records kept when workers receive or are liable to receive external radiation doses in excess of 10% of the occupational quarterly dose limit in any calendar quarter (current exposure limits are 1.25 rem/quarter). These regulations and Presidential Recommendations on Radiation Protection Guidance for Federal Agencies for Occupational Exposure further limit the exposure of minors under the age of eighteen to one-tenth that allowed for adults or 12.5 mrem/quarter. The Presidential Recommendations also state that "the dose equivalent to an unborn as a result of occupational exposure of a woman who has declared that she is pregnant should be maintained as low as reasonably achievable and in any case should not exceed 0.5 rem during the entire gestation period."[2]

Ten percent of the occupational quarterly dose limit set in 10 CFR 20 is 125 mR/quarter. This 125 mR could be exceeded by USCG personnel doing HWRCQ RAM inspections depending on how close they get to the RAM, the number of containers they inspect per quarter, the amount of shielding around the RAM and the time each container takes to inspect. Health and Safety Personnel must determine the doses their personnel are absorbing on a regular basis.

Currently only MSO Hampton Roads personnel wear personal dosimeters regularly. MSO Hampton Roads dosimeters have been provided by and are serviced by the Food

[2]Radiation Protection Guidance to Federal Agencies for Occupational Exposures, Federal Register Vol 52, No 17, January 27,1987, page 2832

and Drug Administration (FDA). To date all dosimeters at Hampton Roads have been reported below the FDA's level of detection.

Many other offices have pocket dosimeters and chargers available but are unaware of how or when to use them.

In an effort to track occupational exposures, I recommend the use of the integrating dose feature of the ion chamber. Using the ion chamber as a primary measurement screen should allow some basis in tracking personnel exposure and determining whether there is a need to initiate a separate dosimetry program. As Coast Guard personnel are more familiar with and always have available the transportation regulations contained in 49 CFR, it is recommended that any dosimetry program established use the levels for workers involved with the transportation of radioactive materials specified in 49 CFR 173.405 as guidance. This regulation recommends that periodic assessments of radioactive exposures be made if the dose received is likely to be between 0.5 and 1.5 rem/year. If the dose received is likely to be between 1.5 and 5 rem/year, 49 CFR 173.405(d)(3) recommends individual radiation exposure monitoring programs and special health supervision programs be started.

Assuming that the ion chamber will be held so that the window is closer to the radioactive cargo than to the surveyor, any integrated dose measurement displayed by the ion chamber will be higher than that received by the person doing the survey. Once these screening measurements are made, further evaluation of the need for a personal dosimetry program should be undertaken. This evaluation should include a review of program implementation options, permanent record holding, as well as committed dose rates when employees should be removed from RAM inspection duties.

Employee Training

Once the need to work with radionuclides has been established, it is necessary to provide employee training in the principles and practices of radiation health and safety; radioactive measurements, standardization, and monitoring techniques; instrumentation; radiation calculations; and biological effects. Currently the Coast Guard has no formal training on radioactive materials.

Based on the Ad Hoc Radiological Health Committee's final report (G-CSP memo dated 2 December 1981), COMDTINST 6470.1, dated 9 November 1982, a two day training course at Reserve Training Center Yorktown was implemented. This course was designed for 30 persons from the primary and secondary ports listed in this instruction and taught by a health physicist. The attendees were expected to go back and instruct others from their units on radioactive hazards. This instruction goes on to state "incorporation of this type of training in the basic Marine Safety Courses at Yorktown is also being studied." This is the last mention of Coast Guard training in radioactive materials I uncovered.

Instruction in radioactive material must be provided as long as USCG personnel are required to inspect radioactive shipments. At a minimum, Coast Guard radioactive materials training should cover the health hazards, physics, instrumentation, safe work practices and a review of the pertinent radioactive regulations contained in both 10 and 49 CFR. This minimal training can be provided in several ways.

1) RAM/container inspection training could be offered at the Coast Guard-wide basic marine safety courses for both officer and enlisted personnel (PODC and MSPOC) in Yorktown, VA. Although these courses are now over seven weeks long and the schedules demanding, they offer the most efficient way to reach people prior to or just after starting jobs that may include exposure to RAM.

2) Offer a special RAM/container inspection training course to be attended by both officer and enlisted personnel of those ports involved in any way with the container inspection/RAM inspection program. This specialty training needs to be scheduled at recurring intervals (approximately every two years) and must target those people actively doing the inspections to ensure adequate training is maintained despite transfer vacancies.

3) Have each Coast Guard district Industrial Hygienist schedule and conduct training at their units. The problem with this type of training is that each Industrial Hygienist develops their own areas of emphasis. This knowledge base will readily reflect in the training provided to the various units and may mean that the units actively involved with RAM shipments don't get the depth or breadth of training needed to effectively do their job.

4) Provide radioactive training at the Safety and Occupational Health Coordinator (SOHC) classes and require that this information be passed down to personnel directly involved with RAM inspections. (These SOHC classes are currently held twice a year and are attended by MSO personnel who are responsible for their unit's Health and Safety program maintenance on a daily basis. The class instructors are mainly Industrial Hygiene personnel from district or headquarters staff.) While this seems to be one of the most efficient options, it will most likely involve an intermediary relaying information because few SOHCs actually conduct RAM inspections. Therefore these presentations may be biased as in the Industrial Hygienist training option.

Confined Spaces: Radioactive Container Inspection Ashore *(Draft SWP)*

A. <u>Introduction</u>:

Radioactive container inspections involve both confined-space entry and radiologic hazards. Each of these hazards must be taken into account when doing this type of inspection. Due to the additional hazards associated with container inspection aboard vessels, USCG marine safety personnel will conduct container inspections only on land

and not on vessels. All potential hazards need to be addressed and reasonable procedures developed to ensure the inspection is completed in a safe manner.

B. Hazards Associated with Radioactive Container Inspection

1. Ionizing Radiation: Ionizing Radiation exposure has been linked to four classes of health effects. It is currently believed that there is no completely risk-free level of exposure for two of these classes: cancer and genetic effects. The third class includes radiation sickness, clouding of the lens of the eye, skin erythema (reddening), and temporary impairment of fertility. These effects, it is currently believed, depend on the amount of dose received and have an effective threshold below which these clinical effects are not observed. The fourth and final class of effects includes the risk of severe mental retardation to the unborn exposed while in utero. Although most of the data on radiation effects on people come from studies where those involved have received high doses, estimates of the risks from exposure to low levels of ionizing radiation are fairly well bounded and standards concerning exposure to radiation are considered conservative. The average radiation worker is believed to incur a relatively small risk of harm from radiation exposure when working with radionuclides in activities with a positive net benefit. Currently, the U.S. Nuclear Regulatory Commission (NRC) regulations limit the effective dose equivalent of non-pregnant adult workers to 5 rem/year (1.25 rem/quarter). This 5 rem per year has been adopted by the U.S. Environmental Protection Agency to protect federal employees working with radioactive materials. This recommended dose limit is reduced to 0.5 rem/year for those occupationally exposed under the age of 18 and for women who have declared they are pregnant.

a) Alpha Particles: Upon alpha decay, the alpha particles emitted are heavy and highly charged. Therefore they do not travel great distances and when outside the body, they are stopped without any bodily damage occurring. Once inside the body,, however, alpha particles can cause very concentrated internal damage.

b) Beta Particles: With beta decay, the particles emitted (electrons) travel much farther than alpha particles, but few beta particles can penetrate the skin to cause internal organ damage. Beta particles therefore present little internal organ hazard when they exist outside the body. Internally the damage done by beta particles is not as concentrated as with alpha particles but is also very localized.

c) Gamma rays and x-rays: These "indirectly" ionizing particles have no charge and proceed through a substance until they undergo a chance encounter in the substance and a directly ionizing particle (electron) is released. As gamma and x-rays are not charged and essentially weightless, they can travel long distances before interacting. This possibility of long distance travel makes them a significant external hazard when outside the body. Since the damage is caused only after "chance encounters", any internal damage done will be much less concentrated and more widespread.

2. Low Oxygen Content is another significant hazard associated with confined-space entry. A reduction of 4% in oxygen content could lead to a fatality. There may be a significant oxygen deficient atmosphere in some containers.

3. Toxic Cargoes may be fatal if inhaled or absorbed through the skin.

4. Flammable Cargo Vapors may cause an explosion or fire.

5. Slip, Trip, and Fall Hazards are common in container inspections.

6. Container Doors provide significant structural integrity to a container when closed. Structural collapse of the container is possible when the doors are opened and significant weight is above.

7. Cargo Shifting during transit may create a significant hazard when opening or working in containers.

C. Engineering Controls

1. Radiation Shielding: The most effective engineering control for radioactive emissions is the use of shielding designed for the type of radiation emissions

expected. Paper or some other thin covering is often used to shield all alpha particles as they do not travel great distances and are easily stopped by any blocking substance. Since beta particles travel short, predictable distances, the thickness of required shielding can be easily calculated. As beta particles strike an object, more penetrating x-rays are often produced. Since x-ray production increases with the atomic number of the shielding material, thicker, lower density materials such as plexiglass or aluminum are often used to shield beta particles. Gammas and x-rays interact through chance encounters in the shielding material and some will pass through the shielding unaffected no matter what material is used. Lead, iron or steel is often used to shield high activity gamma and x-ray sources as the probability of gamma or x-ray encounter is higher in these substances.

2. <u>Natural Ventilation:</u> Most individual containers are not equipped with forced air ventilation. For safe entry, boarding personnel must rely on natural ventilation to dilute any toxic materials or increase the oxygen concentration in a potentially oxygen-deficient atmosphere. At a minimum, boarding personnel should open the container doors to allow air exchange before entering. Once sufficient time has elapsed, entry should be done in a cautions manner using an oxygen monitor.

3. <u>Other Controls</u>

a) Time: As with any toxic or hazardous environment, the total dose received from the hazardous substance is proportional to the time in the hazardous environment. Therefore time in a hazardous environment should be limited to the time needed to satisfactorily complete the task. Any training or instruction should be done outside or away from the immediate vicinity of the hazardous environment.

b) Distance: Along with time and shielding, the third keystone of radioactive material safety is distance. As open field conditions involving a point source are assumed for the container inspection program, the dose rate follows the inverse-square law: every time the distance is doubled the expected dose rate falls four-fold. So *in all instances* a person should stay as far away from the radioactive source as possible. When conducting the required surface dose rate survey, the survey instrument should be placed as close as physically practical to the package and the surveyor should keep the survey instrument at arm's length. The measurement should be taken at an external surface of the package that a person could touch

D. <u>Steps To Take Prior to Container Entry</u>

1. Before leaving the office obtain and check the operation of all necessary equipment including oxygen monitor (NEOTOX), Victoreen radiation survey instrument, tape measure, and calculator. Ensure that all instruments have been calibrated within the past year. Ensure that the radiation survey instrument is working by checking it against a known radioactive check source. Log the instrument check source reading on the survey report.

2. Prior to leaving the office obtain properly fit-tested air-purifying respirators fitted with particulate-filtering cartridges. These cartridges should state that they may be used for radionuclides.

3. Consult the facility shipping papers and the vessel cargo manifest/loading plan to become familiar with the cargo and to note any violations of transportation regulations. Review hazard information provided by the facility personnel. Determine the potential hazards and the best methods to control/evaluate these hazards prior to entry. Refer any questionable new information back to the office for further evaluation.

4. Discuss the activity with the person who will watch from a safe location upwind of the container (entry-watch). This discussion should include emergency

communications and procedures needed to get assistance in case of emergency. (Be sure this individual is trained to advise additional personnel prior to attempting any rescue.)

5. The number of persons entering the container containing radioactive material should be limited to the minimum number necessary to conduct the operation, but no less than two persons, a buddy-system approach, if practical.

6. Turn on both the oxygen meter and radiation survey instrument. The Victoreen radiation survey meter will take approximately one minute to warm up and provide accurate readings. During this time the instrument will go through its own internal check cycle. Once the instrument reads less than 0.20 mR/h when away from the container, the instrument is fully operational.

E. Steps To Take During Container Entry

1. Maintain contact with the entry watch discussed in item four above.

2. Before opening the container, conduct a final check of all placards, check the container integrity, check the door for any signs of leakage and do a preliminary radioactive survey on the outside of the container. If measured radiation levels exceed those permitted in the regulations, do not open container doors but complete the survey from outside the container.

3. Open doors carefully. Be sure you are protected from falling cargo, blocking or bracing; released chemicals; or other hazards such as out of control doors that can pin you.

4. Delay entry allowing natural ventilation to dilute potential vapor hazards.

5. Carry a personal oxygen monitor or combination oxygen/flammability/toxicity meter and radiation survey meter when entering a container containing

radioactive material. If more than one person is entering a space only one type of each instrument is required.

6. Ensure blocking and bracing are adequate. Note any visible slip, trip or fall hazards.

7. Immediately leave the space if:

a) your personal oxygen monitor alarms.

b) you feel dizzy or light-headed.

c) you sense any unexpected chemical through smell or dermal sensation. This is a judgment call, however you should depart any time there is a burning sensation in your lungs or you experience a shortness of breath. Any of these situations may indicate a life-threatening situation and you must react properly to avoid possible injury.

8. Conduct radiation rate measurements.

a) First survey the package by placing the detector three feet (approximately 0.97 meters when including the detector face to center of detector sensitive volume distance) from the package surface. Note any locations where the instrument reads over 10 mR/h for packages labeled as Radioactive Yellow III and 1 mR/h for packages labeled Radioactive Yellow II. Allowing a 20% calibration/detector/statistical error factor, if the average of five separate readings is 12.0 mR/h or over, terminate the inspection immediately and call the office to report the results and request guidance including whether or not to continue the inspection.

b) If the survey results at one meter are less than 120% of those permitted by the radiation label affixed to the package, survey the package exterior. Note any "hot spots". At the hottest of these "hot spots" obtain five separate readings with the cap over the mylar window. After removing the cap and uncovering the mylar window, obtain an additional five readings at the same location.

c) Obtain the package width (in inches) from the side where this "hottest spot" reading was taken through to the other side of the package.

d) After completing the inspection, leave the container, shut and seal the door and move a safe distance away to complete your work.

F. <u>Actions To Take After Entry</u>

1. Press the "mode" button on the Victoreen survey instrument until it displays the integrated dose rate, a number ending in either μR, mR, or R (not mR/h or R/h). Note this reading on the inspection form prior to turning the instrument off.

2. Obtain the five-reading average surface dose observed both with the aluminum cap on and off. To obtain this average value, add all the "cap on" numbers together and divide by five. Then do the same calculation for the "cap off" readings. These average numbers give the value of D*observed* to be used in the following equations.

3. Divide the "cap off" average value by the "cap on" average value. If this number is greater than 1.1, there is a possibility that beta particles are not being adequately shielded. Complete the next calculations and call the office for guidance with all the results.

4. Using the average "cap on" figures, calculate the radiation dose at the surface of the package. If the observed rate is below 75 mR/h there is no need to apply any correction factors. If the observed readings are above 75 mR/h, two corrections, for extra detector distance and temperature and pressure effects, might need to be made.

a) The first correction is for the extra distance of the detector. By applying this correction two assumptions are made. First, the inverse square law holds. Second, the radioactive contents are in the center of the package. You may use either Equation 3 below or Figure 1 to get the surface rate.

Equation 3: Exposure Rate at Package Surface $D\mathit{surface} = D\mathit{observed} \times \left(\frac{(d+t)}{d}\right)^2$

where D*surface* is the radiation level at the surface of the package, D*observed* is the average radiation level measured by the detector, d is the side to side width of the package in inches, and t is the diameter of the detector sensitive volume (for the Victoreen ion chamber this is 3.9 inches).

Using this method, remember to apply a 20% calibration detector statistical error factor to the computed D*surface* reading by dividing the calculated D*surface* reading by 1.20 and comparing this to the regulatory level prior to holding the shipment for further evaluation or office clearance.

Figure Method: Using the equation above, Figure 1 is produced for different package widths. The linear distance of the Victoreen ion chamber was assumed to be 3.9 inches from the end cap.

b) If the observed reading is above the "Suggested Hold Value" of Figure 1, the second correction for the difference in temperature and pressure should be applied to the observed reading. Obtain the current local temperature in degrees Celsius and the barometric pressure in millimeters of mercury from a local airport or the National Weather Service. By inserting those temperature and pressure readings into $((273.2 + T(°c) / 295.2 * \left(760 / P_{mmHg}\right)$ the applicable correction factor may be found. When this correction factor is multiplied by the observed reading, Figure 1 should again be consulted to see if the container should be held for further evaluation.

5. Record in your personal log the chemical/radiological hazards to which you were exposed. You also should note the length of time inside the container and the integrated dose. (The number obtained from the ion chamber which has units of either μR, mR, or R.)

6. Immediately after entry and before eating, drinking or smoking, discard used respirator cartridges and wash hands, face, and respiratory protection equipment. Ensure that any clothing that may have radioactive dust on it is washed as soon as practical.

7. In the event of over-exposure, personnel should be evacuated to an appropriate medical facility by the most expeditious means. Medical personnel should be provided the best information on the suspected exposures including concentration, duration and most probable route of exposure. Also provide the medical authority with the phone number to ATDSR.

Safe Work Practice Figure 1: Maximum Average Ion Chamber Readings as a Function of Package Width

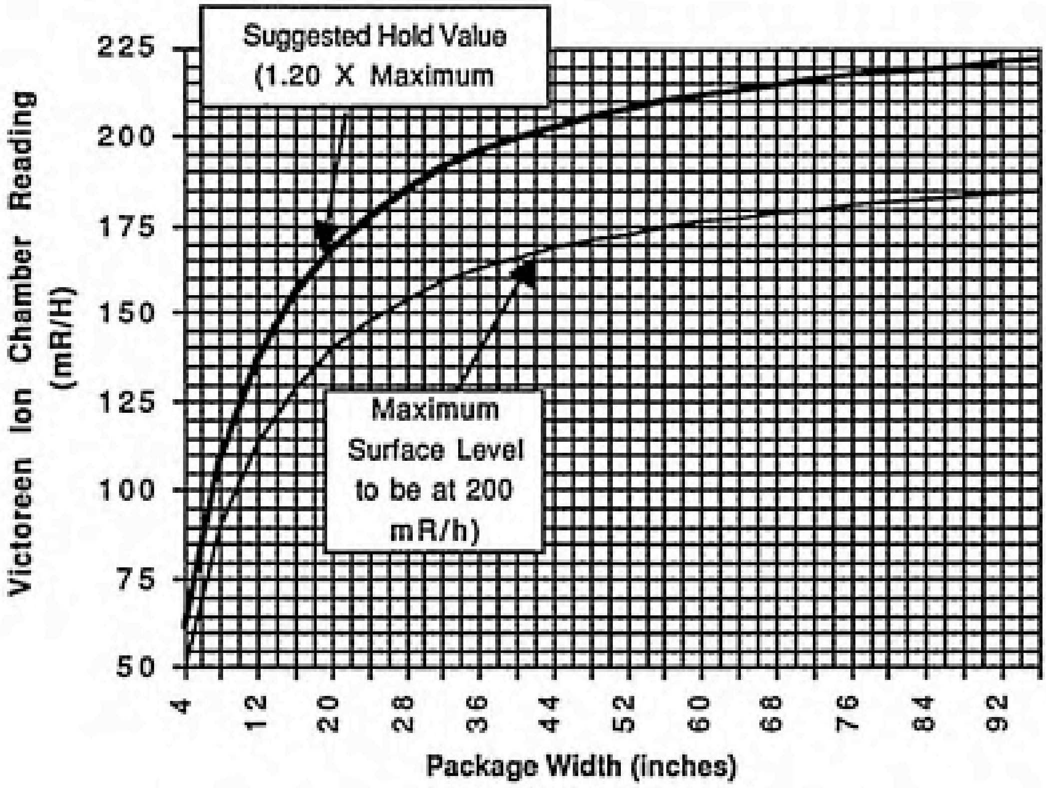


TABLE A1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	GM Tube End Window Facing Mean (mR/h)	GM Tube End Window Facing Standard Deviation	GM Tube Side Facing Mean (mR/h)	GM Tube Side Facing Standard Deviation
Cs 137	2.57	2.9	0.11	3.2	0.09
	3.73	4.1	0.15	4.3	0.13
	5.97	6.4	0.55	8.0	0.02
	12.27	12.0	0.01	14.0	0.01
	25.62	24.4	0.55	28.6	0.55
	37.35	34.5	0.89	39.1	1.10
	59.33	off scale	off scale	off scale	off scale
	124.07	*	*	*	*
	254.71	*	*	*	*
	365.40	*	*	*	*
	589.47	*	*	*	*
	1,231.85	*	*	*	*
	2,557.17	*	*	*	*
	3,625.55	*	*	*	*
Duke University's Source	2,481.70	*	*	*	*
	3,573.00	*	*	*	*
Ra 226	0.61	0.7	0.08	0.8	0.05
	1.25	1.3	0.13	1.5	0.05
	2.56	2.6	0.11	2.9	0.09
	3.81	4.0	0.11	4.1	0.09
	5.96	7.5	0.55	6.9	0.02
	12.35	13.5	0.55	12.9	0.02
	25.01	29.7	0.04	24.9	0.45
	37.03	43.3	0.55	34.3	0.55
	60.32	off scale	off scale	off scale	off scale
	126.92	*	*	*	*
	300.58	*	*	*	*
Am 241	0.89	4.6	0.14	1.6	0.07
	1.79	10.4	0.55	2.9	0.11
	2.72	13.2	0.45	4.2	0.26
	3.71	31.4	0.58	6.9	0.01
	9.10	43.2	0.84	14.2	0.45
	14.25	off scale	off scale	23.2	0.84
	25.40	*	*	36.0	0.02

TABLE A2: INSTRUMENT ROTATION RESPONSE

	Base Spun	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	24.33
45°	99%	115%	110%	Facing Source Maximum Deviation	2.74%
90°	99%	117%	117%		
135°	98%	117%	109%		
180°	99%	52%	63%		
235°	99%	116%	111%		
270°	98%	117%	116%		
315°	98%	112%	111%		

TABLE A3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Speed	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
0.1	N/A	N/A	N/A	N/A	N/A
1	Fast	0>3.24	3.24	0.27	3.6%
1	Slow	0>3.24	22.31	0.63	2.0%
10	Fast	0>30	5.11	0.19	2.1%
10	Slow	0>31	27.85	0.34	0.0%

TABLE A4: DECAY TIME

Scale	Speed	Values	Average Time (seconds)	Standard Deviation (seconds)
0.1	N/A	N/A	N/A	N/A
1	Fast	3.4>0.4	4.64	0.16
1	Slow	3.4>0.4	27.89	0.38
10	Fast	34>4	4.12	0.16
10	Slow	34>4	24.85	0.22

TABLE A5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	104.8%	27.3	0.45
10	103.8%	27.0	0.00
20	104.8%	27.3	0.45
30	103.8%	27.0	0.00
45	102.9%	26.8	0.45
60	101.9%	26.5	0.55
90	101.9%	26.5	0.55
120	101.0%	26.3	0.55
180	100.0%	26.0	0.45
420	100.0%	26.0	0.45

TABLE A6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
	0.0	-	2.54	0.05	3.20
	1.1	0.0%	2.54	0.05	-
	1.9	0.0%	2.54	0.05	-
	4.9	0.8%	2.56	0.05	-
	6.1	0.8%	2.56	0.05	-
	6.9	0.8%	2.52	0.04	-
	8.2	0.8%	2.52	0.04	2.70
	8.9	0.8%	2.52	0.04	-
	8.9	0.8%	2.56	0.05	-
	10.1	1.6%	2.50	0.00	-
	12.1	1.2%	2.57	0.04	-
	13.1	0.0%	2.54	0.05	2.79
	13.4	1.6%	2.58	0.04	-
	14.3	0.8%	2.52	0.04	-
	15.1	0.8%	2.56	0.05	-
	16.3	0.0%	2.54	0.05	-
	24.3	0.8%	2.56	0.05	2.62
	29.2	1.6%	2.58	0.04	2.50
	32.4	1.6%	2.58	0.04	2.30
	33.3	2.4%	2.60	0.00	-
low battery	34.4	1.6%	2.58	0.04	2.20
	35.2	1.6%	2.58	0.04	-
	38.4	4.7%	2.66	0.05	1.95
	41.3	4.7%	2.66	0.05	1.93
	42.0	7.1%	2.36	0.05	1.91
	43.0	11.0%	2.26	0.05	1.55

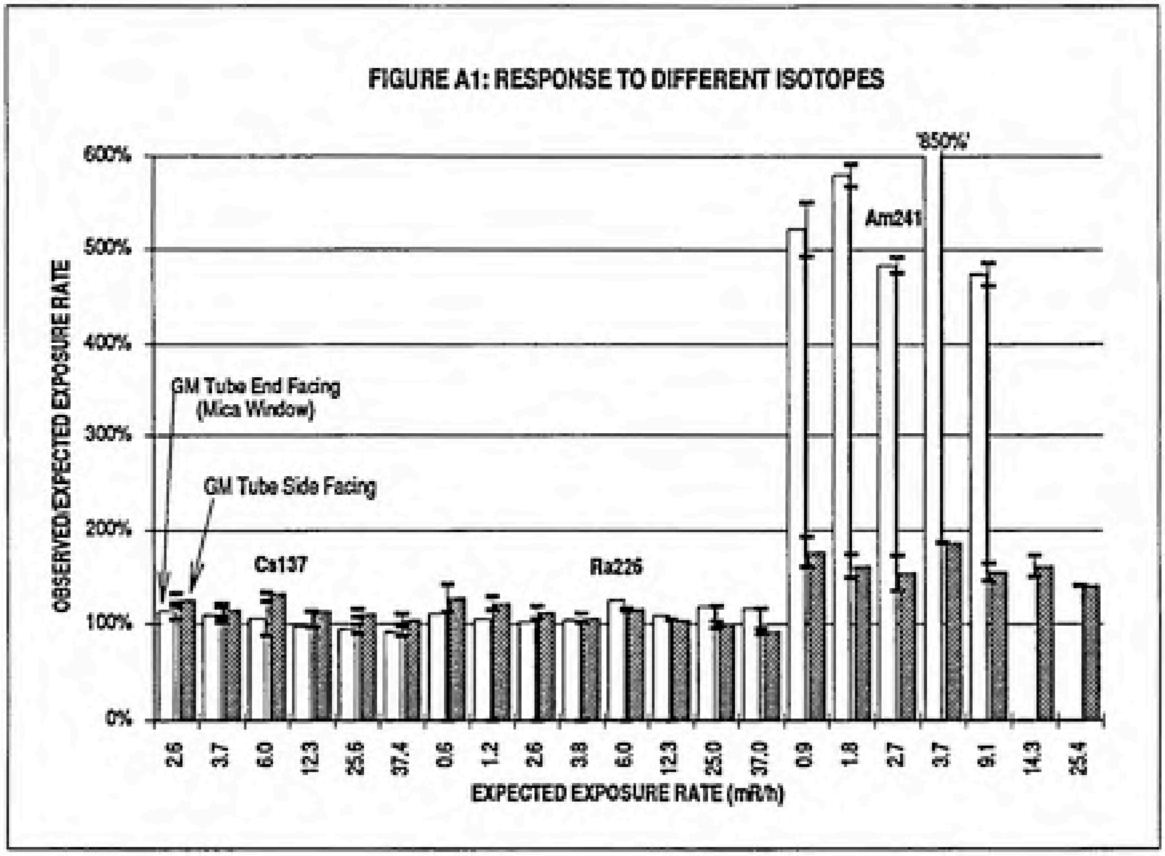
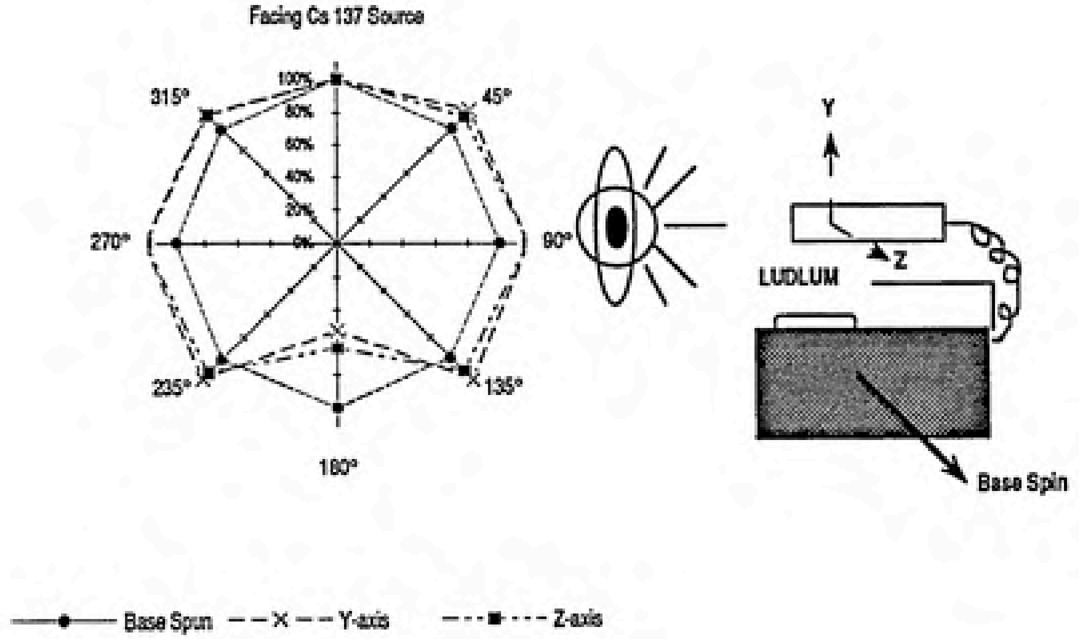


FIGURE A2: RESPONSE VERSUS ANGLE OF ROTATION



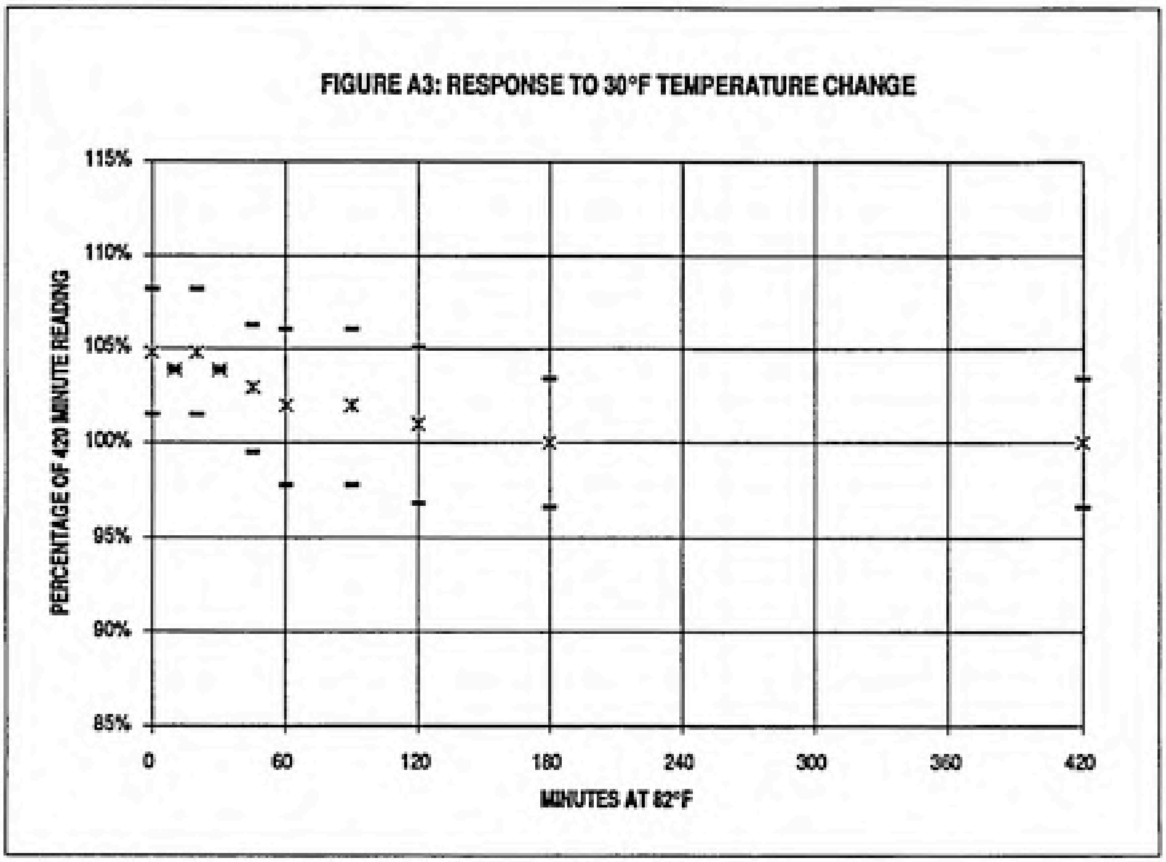


FIGURE A3: RESPONSE TO 30°F TEMPERATURE CHANGE
115%
110%
105%
100%
95%
90%
85%
PERCENTAGE OF 420 MINUTE READING
0
60
120
180
240
300
360
420
MINUTES AT 82°F

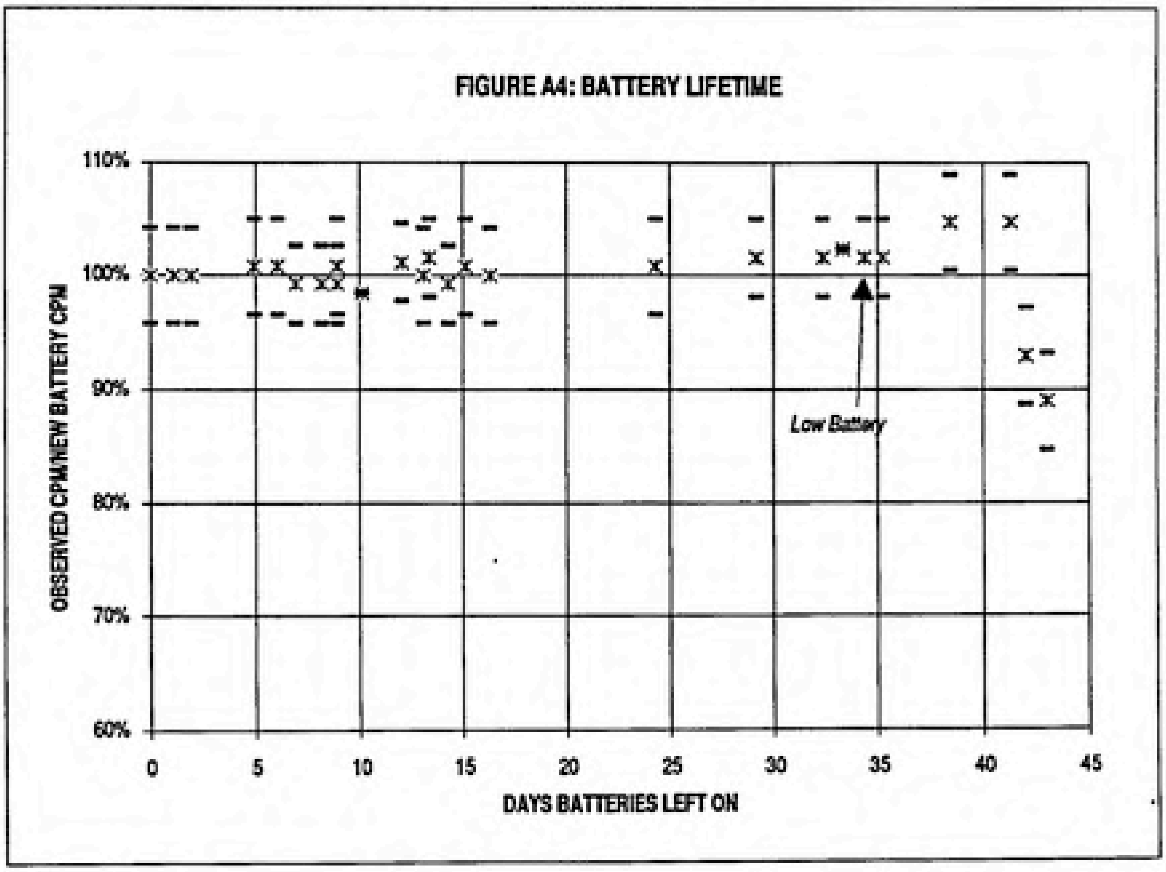


FIGURE A4: BATTERY LIFETIME
110%
100%
90%
80%
70%
60%
OBSERVED CPM/NEW BATTERY CPM
Low Battery
0
5
10
15
20
25
30
35
40
45
DAYS BATTERIES LEFT ON

TABLE B1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	Observed Mean (mR/h)	Observed Standard Deviation
Cs 137	2.57	2.60	0.42
	3.73	3.55	0.55
	5.97	6.05	0.57
	12.27	12.60	1.14
	25.62	24.93	1.00
	37.35	38.93	2.24
	59.33	61.97	2.09
	124.07	125.87	4.18
	254.71	251.76	8.37
	365.40	371.69	43.82
	589.47	609.40	22.36
	1,231.85	1,199.26	0.15
	2,557.17	2,538.52	54.77
	3,625.55	off scale	off scale
Duke University's Source	2,481.70	2,260.00	54.77
	3,573.00	off scale	off scale
Ra 226	0.61	0.54	0.10
	1.25	1.18	0.32
	2.56	2.60	0.24
	3.81	3.52	0.43
	5.96	5.18	0.45
	12.35	11.38	0.55
	25.01	22.02	0.84
	37.03	36.70	2.74
	60.32	49.68	0.04
	126.92	101.74	4.47
	300.58	223.74	5.48
Am 241	0.89	1.30	0.10
	1.79	2.12	0.19
	2.72	2.94	0.09
	3.71	3.50	1.00
	9.10	9.00	1.38
	14.25	14.80	1.30
	25.40	22.60	1.14

TABLE B2: INSTRUMENT ROTATION RESPONSE

	X-axis	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	23.47 mR/h
45°	98%	99%	89%	Facing Source Maximum Deviation	3.12%
90°	100%	83%	32%		
135°	98%	98%	97%		
180°	97%	97%	97%		
235°	98%	97%	98%		
270°	102%	88%	102%		
315°	99%	97%	64%		

TABLE B3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
1	N/A	N/A	N/A	N/A
10	0>2	10.78	0.91	6.0%
100	0>20	5.04	0.30	3.8%
1000	0>200	3.99	0.37	3.7%

TABLE B4: DECAY TIME

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)
1	N/A	N/A	N/A
10	2.2>0.2	10.63	0.40
100	22>2	4.13	0.42
1000	210>21	2.83	0.17

TABLE B5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	102.2%	23.0	0.71
10	102.2%	23.0	0.84
20	101.1%	22.8	0.84
30	98.9%	22.3	0.89
45	100.0%	22.5	0.84
60	103.3%	23.3	0.45
90	100.0%	22.5	0.55
120	103.3%	23.3	0.45
180	100.0%	22.5	0.55
420	100.0%	22.5	0.55

TABLE B6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
	0.0	-	1.96	0.09	9.42
	1.1	3.1%	1.90	0.10	-
	1.9	0.0%	1.96	0.11	-
	4.9	2.0%	1.92	0.13	-
	6.1	2.0%	1.92	0.15	-
	6.9	4.1%	1.88	0.16	-
	8.2	1.0%	1.98	0.16	7.40
	8.9	3.1%	1.90	0.10	-
	8.9	0.0%	1.96	0.11	-
	10.1	6.1%	1.84	0.11	-
	12.1	7.1%	1.82	0.08	6.58
low battery	13.1	15.8%	1.65	0.09	6.05
	13.4	25.5%	1.46	0.05	

FIGURE B1: RESPONSE TO DIFERENT ISOTOPES

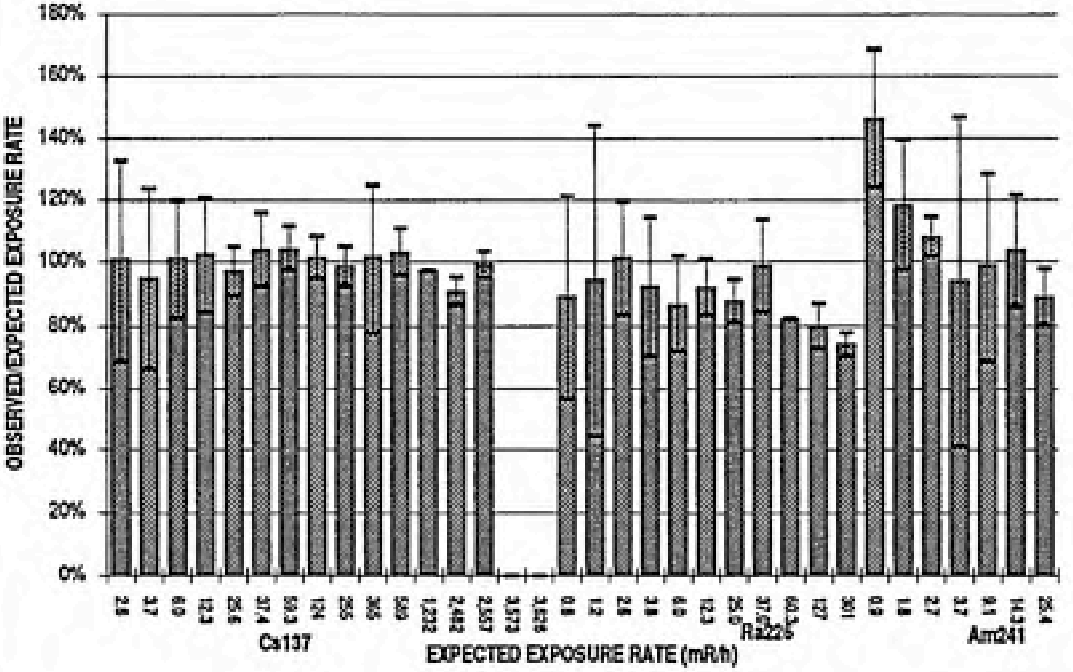
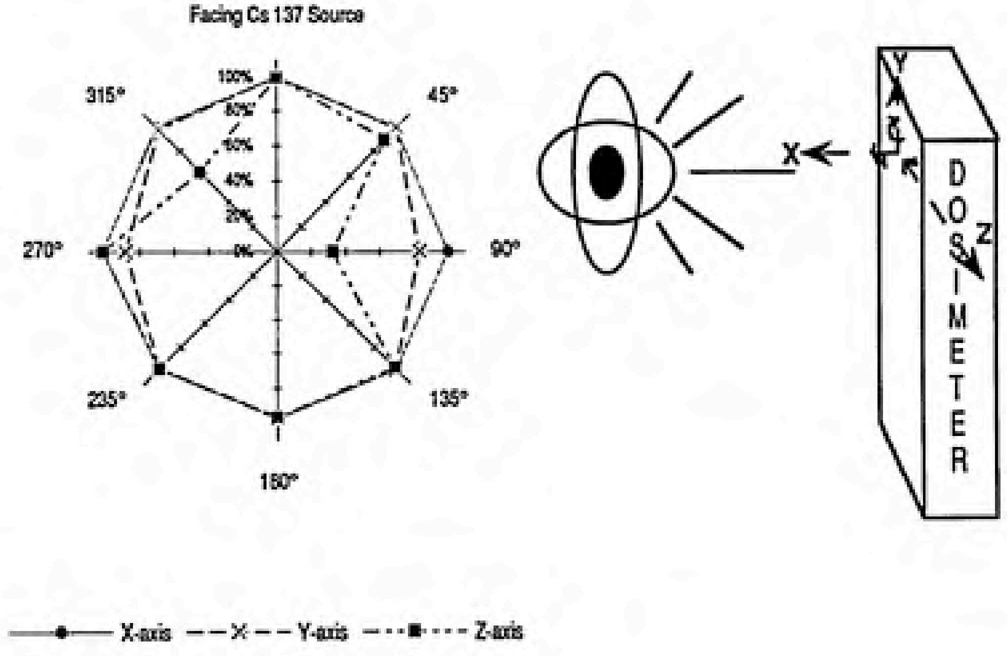


FIGURE B2: RESPONSE VERSUS ANGLE
OF ROTATION



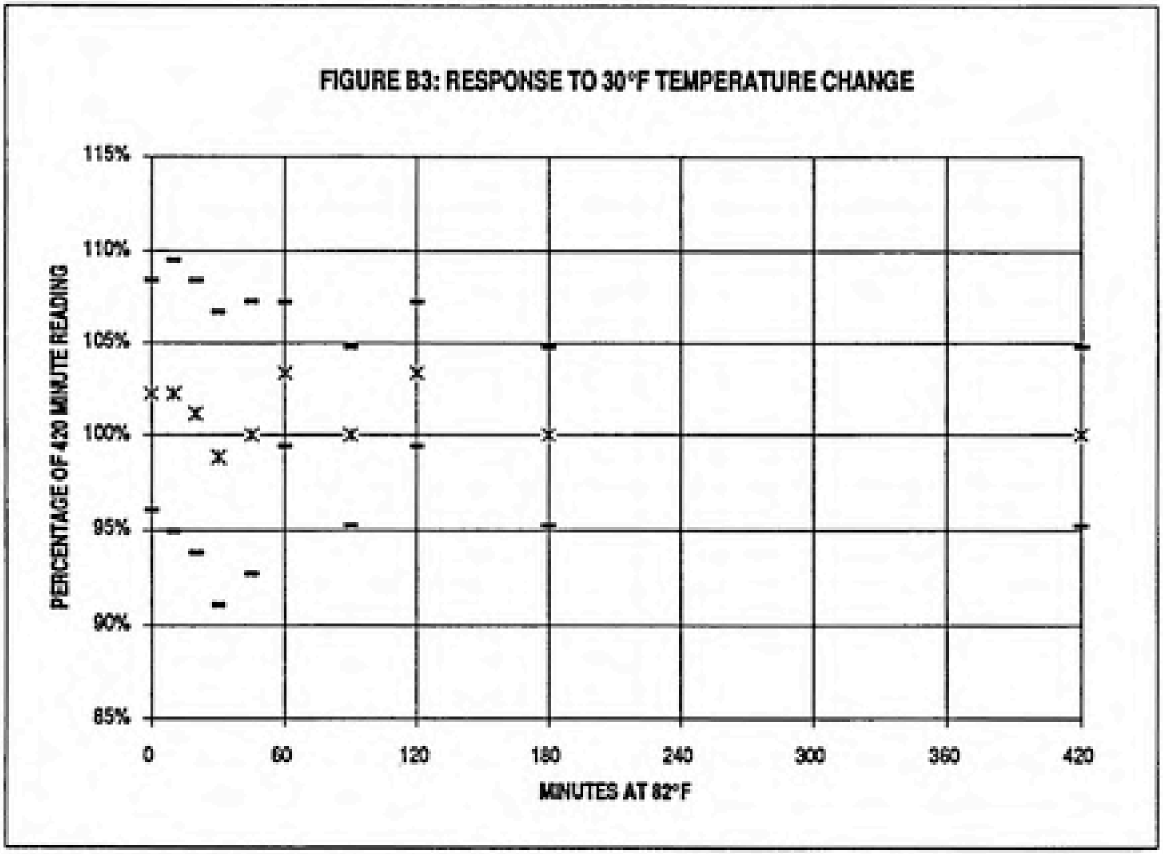


FIGURE B3: RESPONSE TO 30°F TEMPERATURE CHANGE
115%
110%
105%
100%
95%
90%
85%
PERCENTAGE OF 420 MINUTE READING
0
60
120
180
240
300
360
420
MINUTES AT 82°F

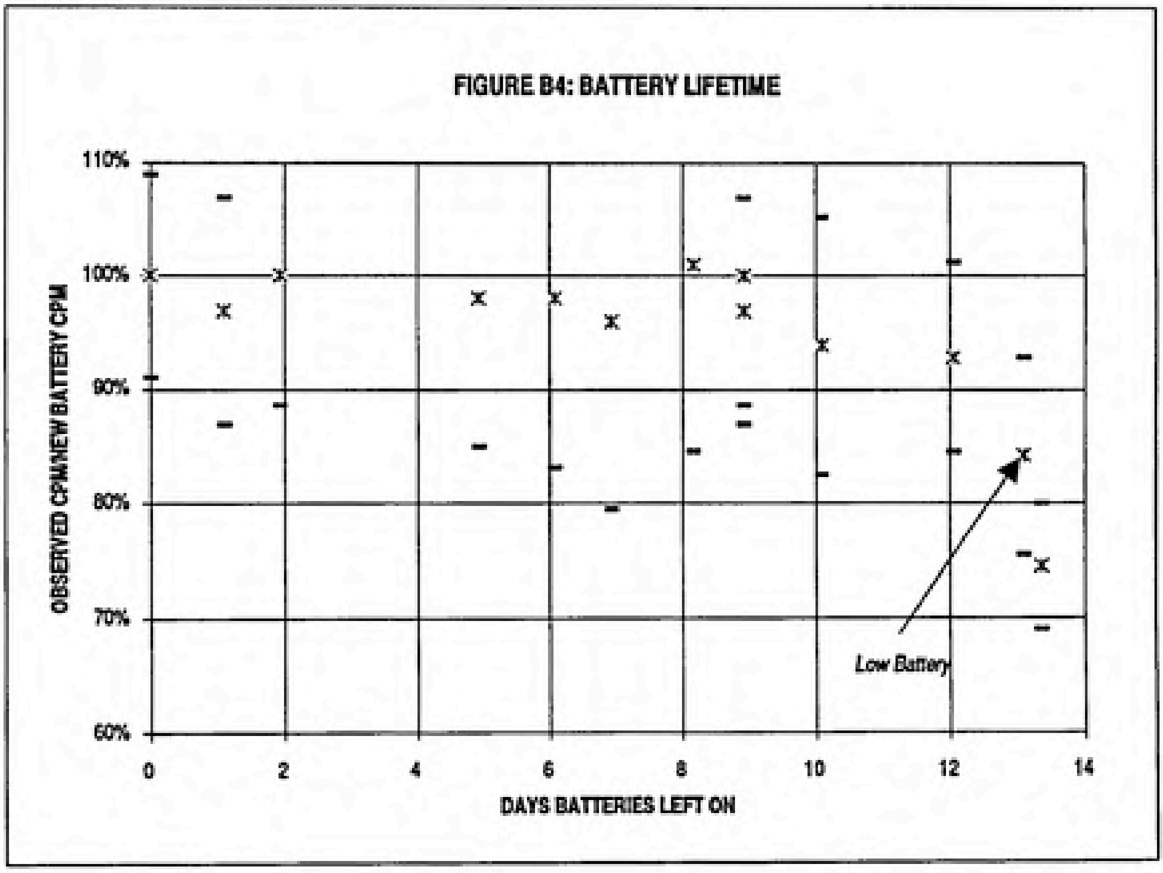


FIGURE B4: BATTERY LIFETIME
110%
100%
90%
80%
70%
60%
OBSERVED CPM/NEW BATTERY CPM
Low Battery
0
2
4
6
8
10
12
14
DAYS BATTERIES LEFT ON

TABLE C1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	Back Facing Mean (CPM)	Back Facing Standard Deviation	End Facing Mean (CPM)	End Facing Standard Deviation
Cs 137	2.57	3,368	84	2,566	14
	3.73	4,749	85	3,282	72
	5.97	6,977	87	5,563	38
	12.27	14,016	132	11,607	103
	25.62	off scale	off scale	off scale	off scale
	37.35	*	*	*	*
	59.33	*	*	*	*
	124.07	*	*	*	*
	254.71	*	*	*	*
	365.40	*	*	*	*
	589.47	*	*	*	*
	1,231.85	*	*	*	*
	2,557.17	*	*	*	*
	3,625.55	*	*	*	*
Duke University's Source	2,481.70	*	*	*	*
	3,573.00	*	*	*	*
Ra 226	0.61	719	11	555	16
	1.25	1,448	37	1,116	18
	2.56	2,959	54	2,269	46
	3.81	4,359	31	3,460	56
	5.96	6,853	64	5,318	83
	12.35	14,368	93	11,032	134
	25.01	off scale	off scale	off scale	off scale
	37.03	*	*	*	*
	60.32	*	*	*	*
	126.92	*	*	*	*
	300.58	*	*	*	*
Am 241	0.89	5,533	101	2,888	158
	1.79	11,084	67	5,638	57
	2.72	16,854	101	9,181	76
	3.71	off scale	off scale	11,472	95
	9.10	*	*	off scale	off scale
	14.25	*	*	*	*
	25.40	*	*	*	*

TABLE C2: INSTRUMENT ROTATION RESPONSE

	X-axis	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	4,036.7 CPM
45°	99%	98%	99%	Facing Source Maximum Deviation	2.96%
90°	99%	79%	51%		
135°	97%	92%	96%		
180°	98%	96%	98%		
235°	97%	95%	94%		
270°	99%	97%	86%		
315°	98%	96%	98%		

TABLE C3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
N/A	N/A	N/A	N/A	1.7%

TABLE C4: DECAY TIME

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)
N/A	N/A	N/A	N/A

TABLE C5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	101.4%	4194.3	13.61
10	102.2%	4227.8	56.75
20	102.8%	4251.3	75.16
30	100.8%	4168.0	34.67
45	102.5%	4239.3	32.19
60	102.6%	4241.8	15.78
90	101.3%	4191.0	60.89
120	101.6%	4203.3	55.18
180	101.1%	4183.8	87.28
420	100.0%	4136.3	63.22

TABLE C6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
	0	-	3,901	49	9.4
	1.1	1.5%	3,961	56	-
	1.9	1.2%	3,950	69	-
	4.9	1.8%	3,973	84	-
	6.1	0.5%	3,882	47	-
	6.9	0.7%	3,927	55	-
	8.2	1.8%	3,973	32	9.2
	8.9	1.4%	3,958	67	-
	8.9	1.1%	3,944	44	-
	10.1	2.2%	3,986	43	-
	12.1	0.9%	3,937	55	-
	13.1	2.1%	3,985	16	-
	13.4	0.2%	3,910	80	-
	14.3	2.7%	4,006	72	8.0
	15.1	2.2%	3,988	111	-
	16.3	1.4%	3,955	86	-
	24.3	2.7%	4,008	46	7.5
	29.2	4.5%	4,075	22	6.6
low battery	32.4	3.7%	4,045	33	6.0
	33.3	3.5%	4,038	38	-
	34.4	0.9%	3,938	72	4.1
	35.2	100.0%	0	0	3.8

FIGURE C1: RESPONSE TO DIFERENT ISOTOPES

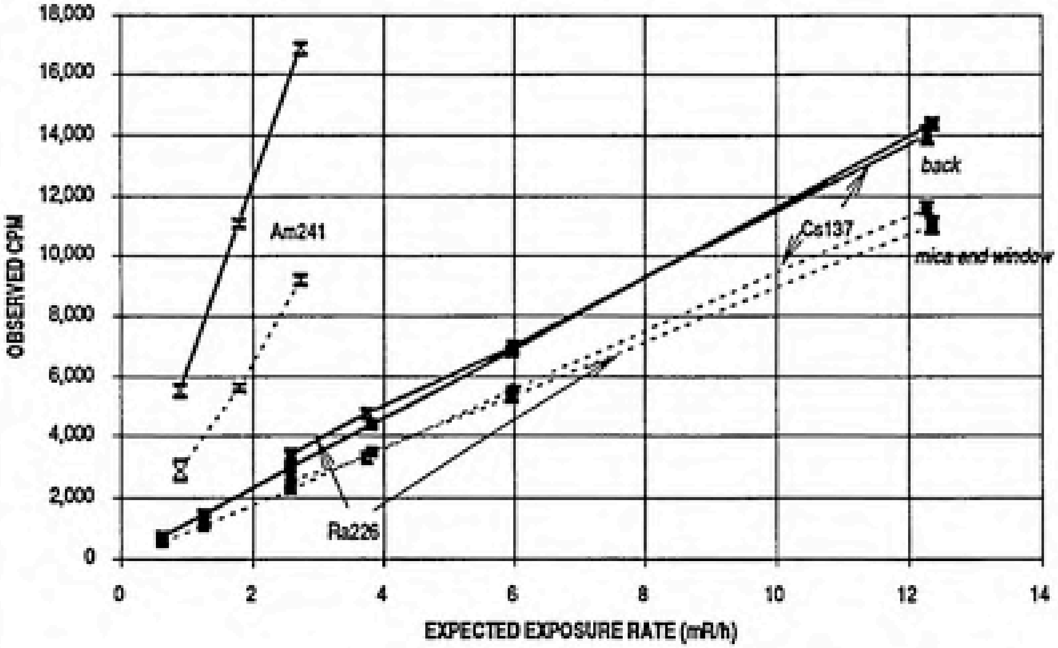
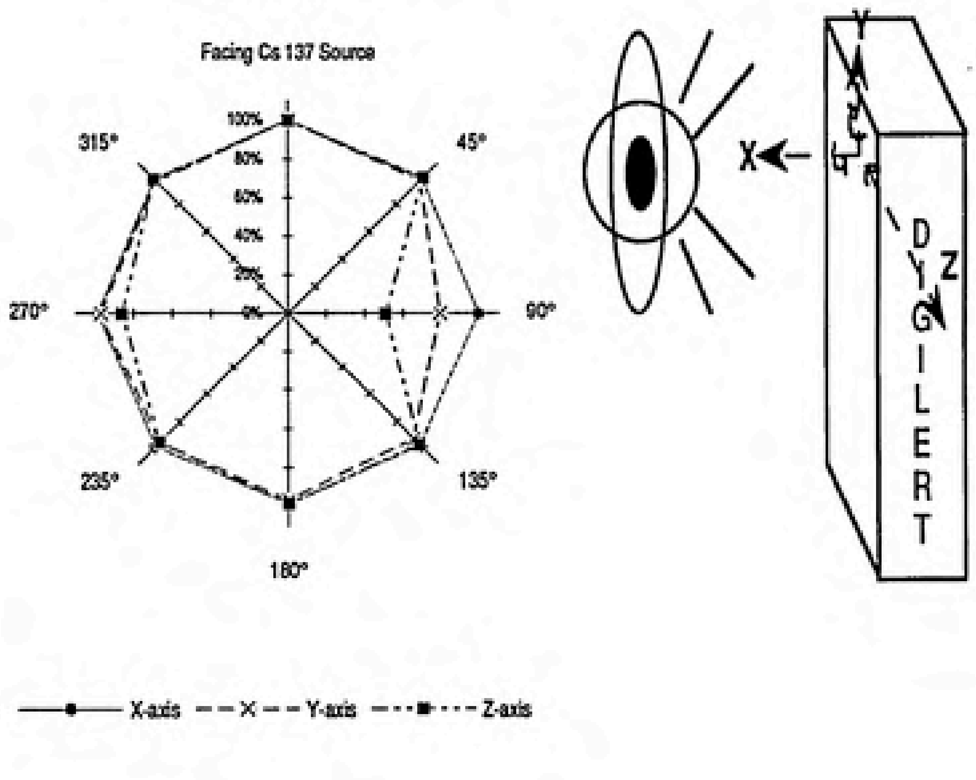


FIGURE 2: RESPONSE VERSUS ANGLE OF ROTATION



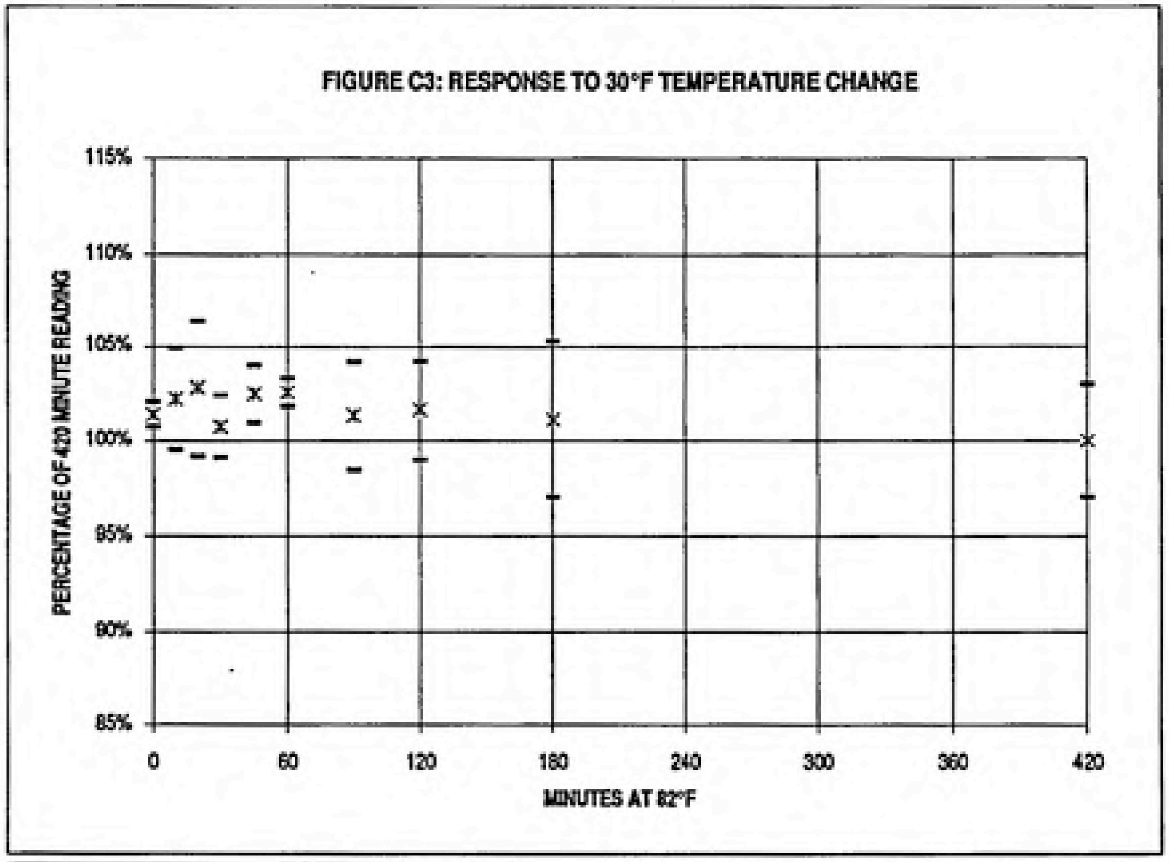


FIGURE C3: RESPONSE TO 30°F TEMPERATURE CHANGE
115%
110%
105%
100%
95%
90%
85%
PERCENTAGE OF 420 MINUTE READING
0
60
120
180
240
300
360
420
MINUTES AT 82°F

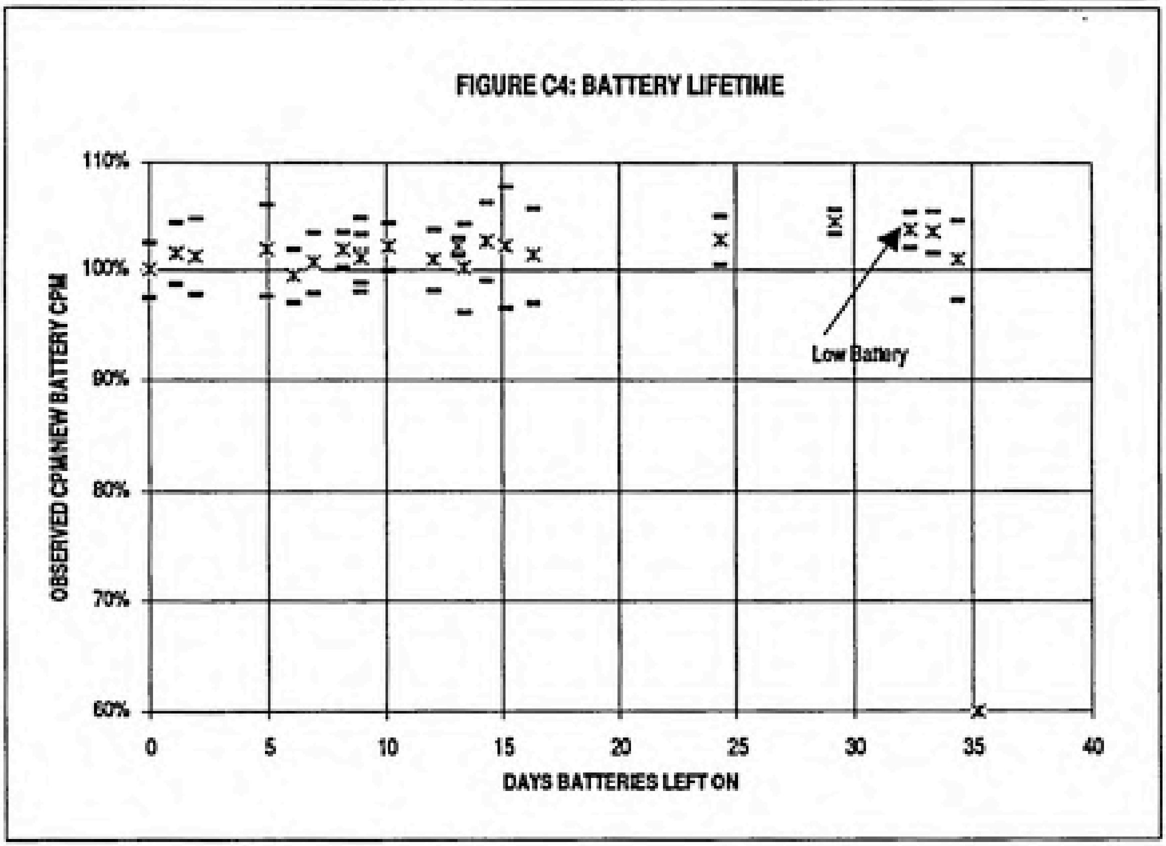


FIGURE C4: BATTERY LIFETIME
110%
100%
90%
80%
70%
60%
OBSERVED CPM/NEW BATTERY CPM
Low Battery
0
5
10
15
20
25
30
35
40
DAYS BATTERIES LEFT ON

TABLE D1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	Back Facing Mean (mR/h)	Back Facing Standard Deviation	Mica Window Facing Mean (mR/h)	Mica Window Facing Standard Deviation
Cs 137	2.57	2.9	0.18	2.5	0.10
	3.73	3.9	0.18	3.3	0.11
	5.97	5.2	0.45	4.8	0.14
	12.27	11.2	0.45	8.8	0.45
	25.62	28.8	0.45	24.2	0.45
	37.35	34.5	0.89	39.2	1.10
	59.33	off scale	off scale	49.6	0.55
	124.07	*	*	off scale	off scale
	254.71	*	*	*	*
	365.40	*	*	*	*
	589.47	*	*	*	*
	1,231.85	*	*	*	*
	2,557.17	*	*	*	*
	3,625.55	*	*	*	*
Duke University's Source	2,481.70	*	*	*	*
	3,573.00	*	*	*	*
Ra 226	0.61	0.5	0.05	0.5	0.05
	1.25	1.2	0.14	1.0	0.01
	2.56	2.8	0.19	2.4	0.11
	3.81	3.9	0.11	3.4	0.06
	5.96	5.5	0.55	4.8	0.11
	12.35	11.2	0.45	8.5	0.55
	25.01	26.4	0.55	22.4	0.90
	37.03	37.5	0.84	32.1	0.90
	60.32	off scale	off scale	off scale	off scale
	126.92	*	*	*	*
	300.58	*	*	*	*
Am 241	0.89	4.8	0.25	3.2	0.11
	1.79	8.6	0.89	4.5	0.17
	2.72	14.0	0.02	6.0	0.02
	3.71	24.0	0.01	8.5	0.58
	9.10	49.6	0.89	30.6	0.89
	14.25	off scale	off scale	off scale	off scale
	25.40	*	*	*	*

TABLE D2: INSTRUMENT ROTATION

	X-axis	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	28 mR/H
45°	101%	96%	99%	Facing Source Maximum Deviation	3.7%
90°	101%	97%	53%		
135°	99%	97%	101%		
180°	101%	101%	101%		
235°	99%	97%	97%		
270°	99%	8%	84%		
315°	99%	99%	95%		

TABLE D3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
1	N/A	N/A	N/A	N/A
10	0>2.8	6.4	0.44	1.9%
100	0>27	8.7	0.36	3.3%

TABLE D4: DECAY TIME

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)
1	N/A	N/A	N/A
10	3.2>0.02	7.5	0.13
100	30>.22	7.1	0.35

TABLE D5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	98.1%	26.25	0.55
10	100.9%	27.00	0.00
20	100.9%	27.00	0.00
30	101.9%	27.25	0.45
45	100.9%	27.00	0.71
60	101.9%	27.25	0.45
90	102.8%	27.50	0.84
120	101.9%	27.25	0.55
180	102.8%	27.50	0.55
420	100.0%	26.75	0.45

TABLE D6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
	0	-	3.4	0.05	9.38
	1.1	0.6%	3.3	0.17	-
	1.9	1.8%	3.4	0.15	-
	4.9	0.6%	3.3	0.15	-
	6.1	3.6%	3.2	0.18	-
	6.9	2.4%	3.3	0.11	-
	8.2	6.5%	3.1	0.09	8.35
	8.9	1.2%	3.3	0.18	-
	8.9	2.4%	3.3	0.11	-
	10.1	1.2%	3.4	0.14	-
	12.1	1.8%	3.3	0.12	-
	13.1	1.2%	3.3	0.08	8.44
	13.4	0.6%	3.3	0.18	-
	14.3	1.2%	3.3	0.11	-
	15.1	1.2%	3.4	0.12	8.3
	16.3	1.2%	3.4	0.12	-
	24.3	1.8%	3.3	0.10	8.1
	29.2	2.4%	3.4	0.09	7.95
	32.4	1.8%	3.3	0.25	7.9
	33.3	1.2%	3.4	0.10	-
	34.4	0.6%	3.3	0.18	7.85
	35.2	4.8%	3.2	0.22	-
	41.4	3.0%	3.3	0.11	7.8
	44.3	1.2%	3.3	0.13	7.75
	48.4	0.0%	3.4	0.17	-
	49.4	2.4%	3.4	0.18	-
	54.3	1.2%	3.3	0.13	7.4
	57.4	1.8%	3.3	0.14	7.3
	61.3	3.0%	3.3	0.13	7.2
	63.3	1.8%	3.3	0.14	7.02
	68.3	3.3%	3.3	0.10	6.8
	72.3	1.8%	3.3	0.14	6.5
low battery	74.3	2.4%	3.3	0.08	6.4
	77.4	5.4%	3.2	0.15	5.8
	80.4	4.8%	3.2	0.12	5.8
	83.8	4.8%	3.2	0.14	5.5
	84.5	100.0%	0.0	0.00	4.6

FIGURE D1: RESPONSE TO DIFERENT ISOTOPES

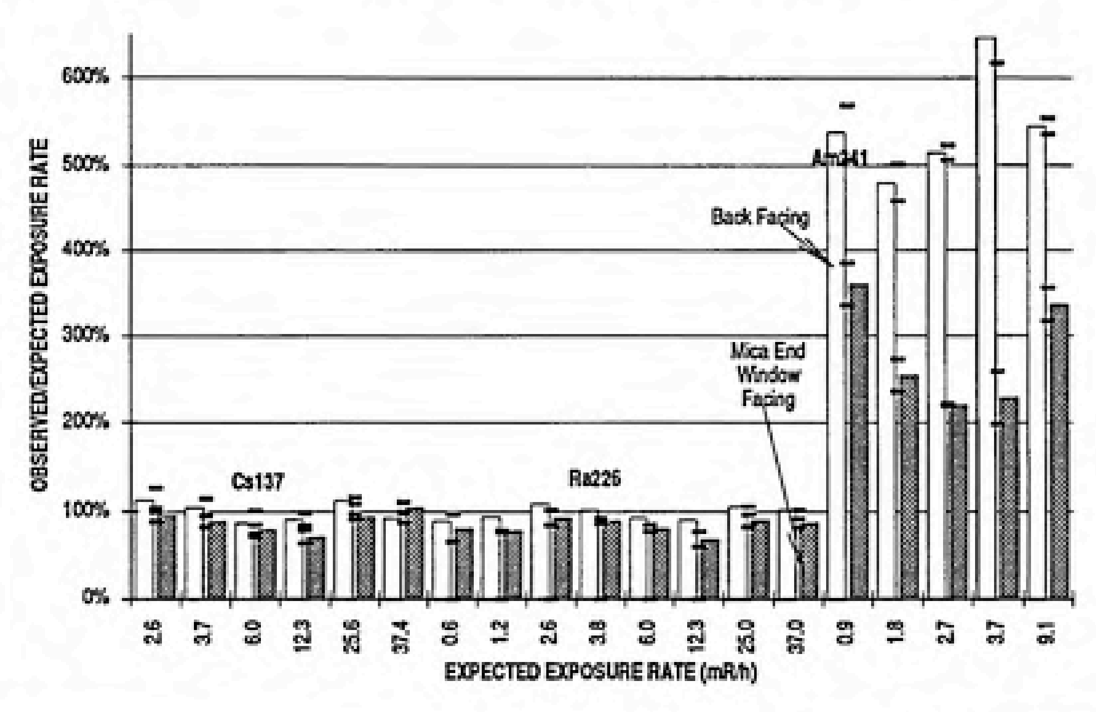
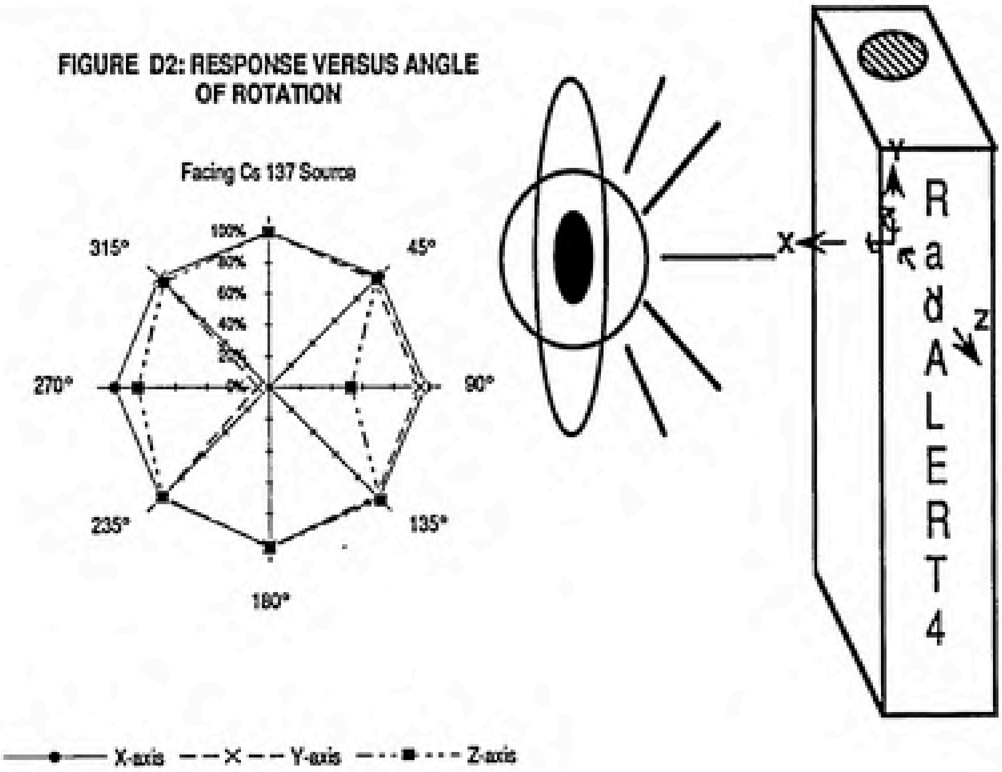


FIGURE D2: RESPONSE VERSUS ANGLE OF ROTATION

Facing Cs 137 Source



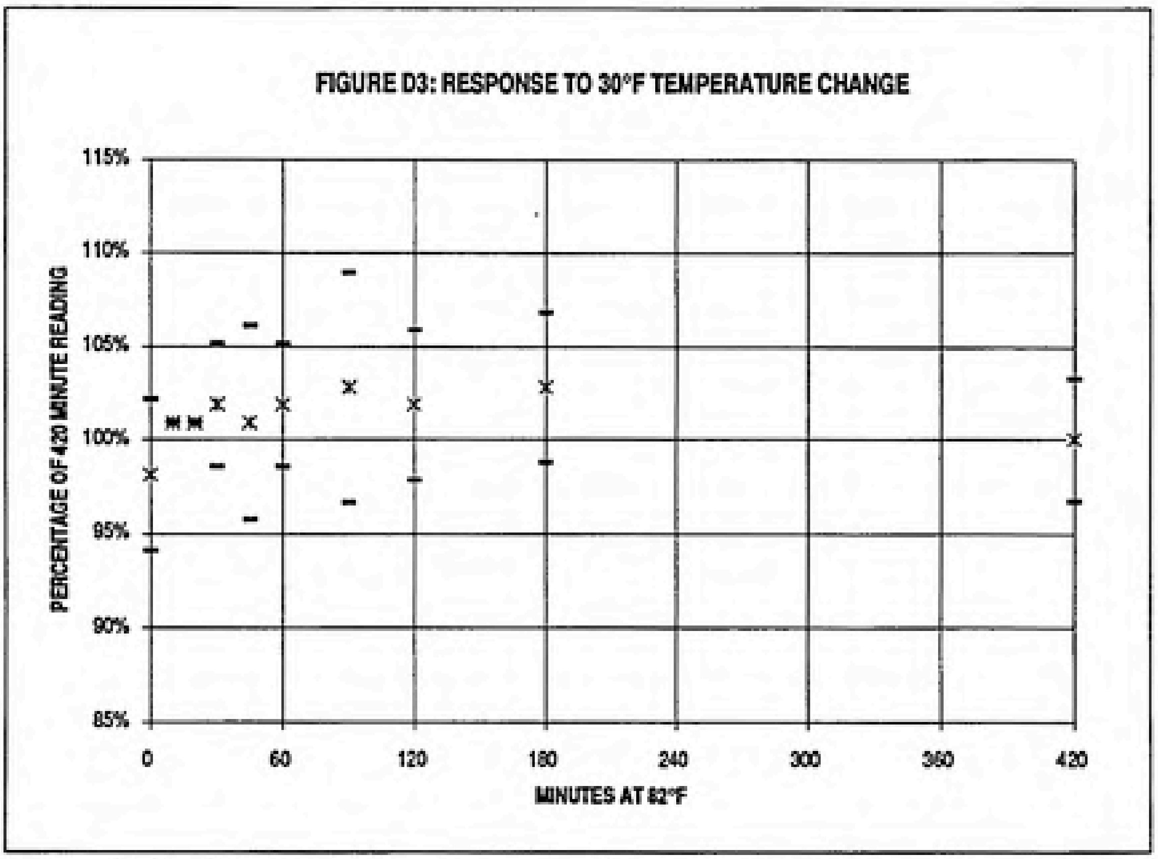


FIGURE D3: RESPONSE TO 30°F TEMPERATURE CHANGE
115%
110%
105%
100%
95%
90%
85%
PERCENTAGE OF 420 MINUTE READING
0
60
120
180
240
300
360
420
MINUTES AT 82°F

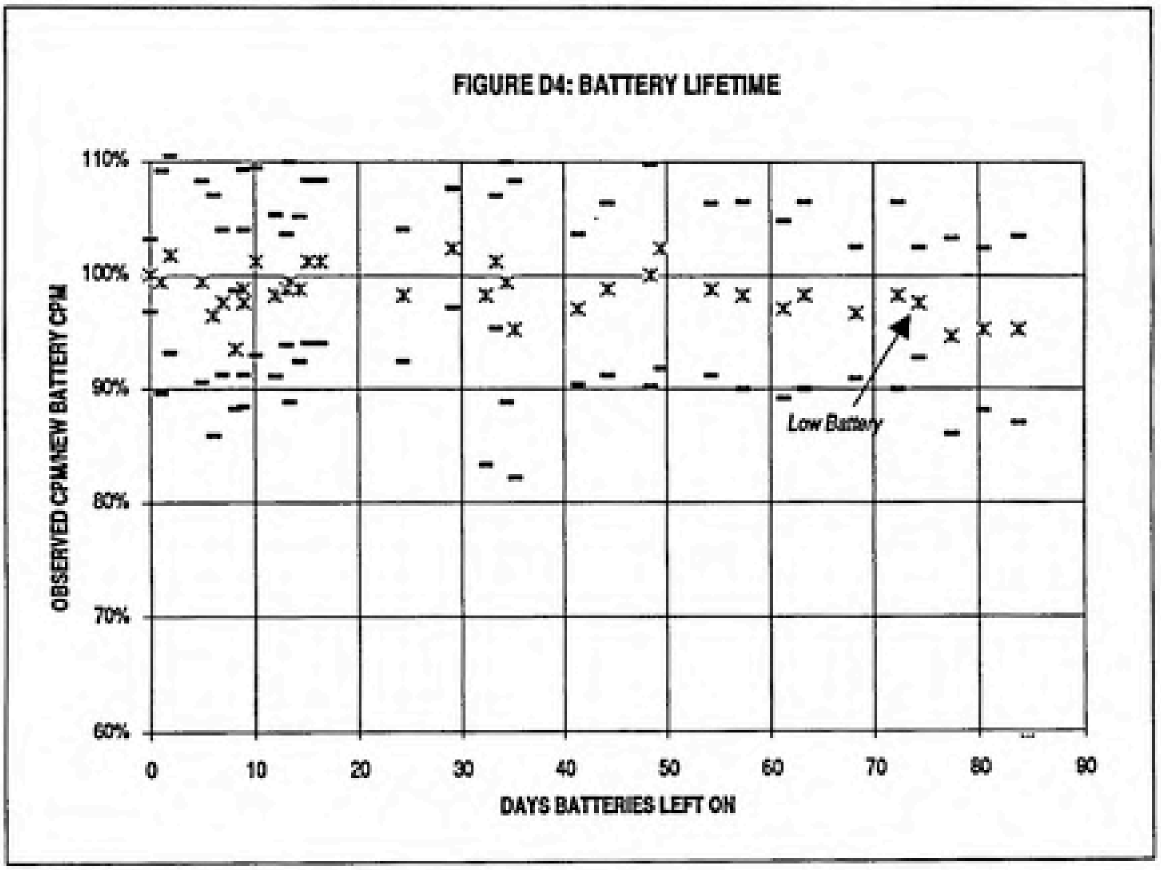


FIGURE D4: BATTERY LIFETIME
110%
100%
90%
80%
70%
60%
OBSERVED CPM/NEW BATTERY CPM
Low Battery
0
10
20
30
40
50
60
70
80
90
DAYS BATTERIES LEFT ON

TABLE E1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	Observed Mean (CPM)	Observed Standard Deviation
Cs 137	2.57	4,365	308
	3.73	5,957	283
	5.97	9,068	304
	12.27	off scale	off scale
	25.62	*	*
	37.35	*	*
	59.33	*	*
	124.07	*	*
	254.71	*	*
	365.40	*	*
	589.47	*	*
	1,231.65	*	*
	2,557.17	*	*
	3,625.55	100	100
Duke University's Source	2,481.70	off scale	off scale
	3,573.00	*	*
Ra 226	0.61	985	91
	1.25	2,309	169
	2.56	5,004	231
	3.81	7,284	265
	5.96	off scale	off scale
	12.35	*	*
	25.01	*	*
	37.03	*	*
	60.32	*	*
	126.92	*	*
	300.58	*	*
Am 241	0.89	4,924	329
	1.79	9,619	196
	2.72	off scale	off scale
	3.71	*	*
	9.10	*	*
	14.25	*	*
	25.40	*	*

TABLE E2: INSTRUMENT ROTATION RESPONSE

	X-axis	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	5,533.3 CPM
45°	100%	87%	89%	Facing Source Maximum Deviation	6.41%
90°	102%	66%	45%		
135°	101%	75%	68%		
180°	99%	81%	76%		
235°	98%	79%	77%		
270°	102%	77%	80%		
315°	101%	85%	92%		

TABLE E3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
1	-	-	-	-
10	-	-	-	-
100	-	-	-	-
1000	0>4500 CPM	3.79	0.03	4.9%

TABLE E4: DECAY TIME

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)
1	-	-	-
10	-	-	-
100	-	-	-
1000	5000>500 CPM	4.81	0.136

TABLE E5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	112.1%	5,800	228
10	112.1%	5,800	261
20	111.1%	5,750	261
30	113.0%	5,850	498
45	107.7%	5,575	200
60	106.3%	5,500	228
90	105.3%	5,450	329
120	100.0%	5,175	245
180	102.4%	5,300	327
420	100.0%	5,175	332

TABLE E6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
	0.0	-	5,460	241	9.3
	1.1	3.7%	5,260	297	-
	1.9	3.7%	5,260	192	-
	4.9	3.3%	5,140	261	-
	6.1	5.9%	5,220	268	-
	6.9	4.4%	5,200	200	-
	8.2	4.8%	4,880	228	6.1
low battery	8.9	10.6%	4,340	195	5.8

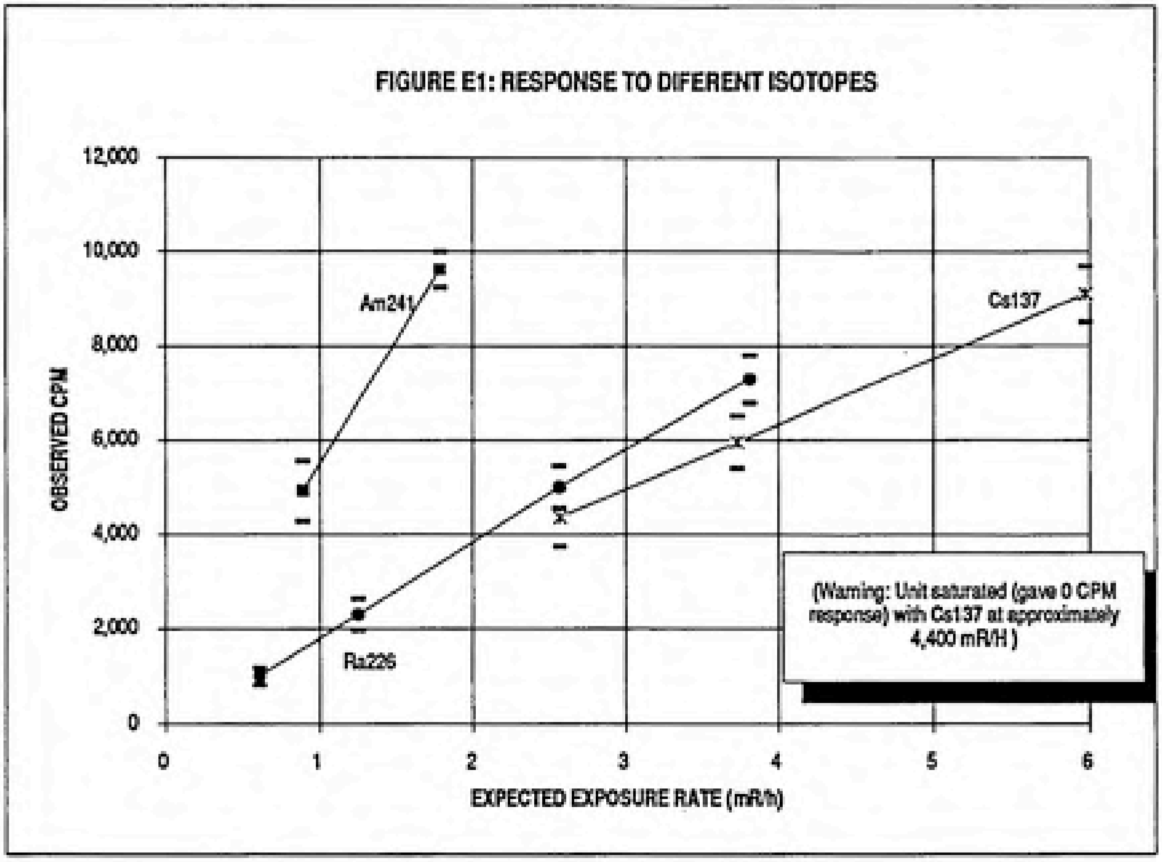
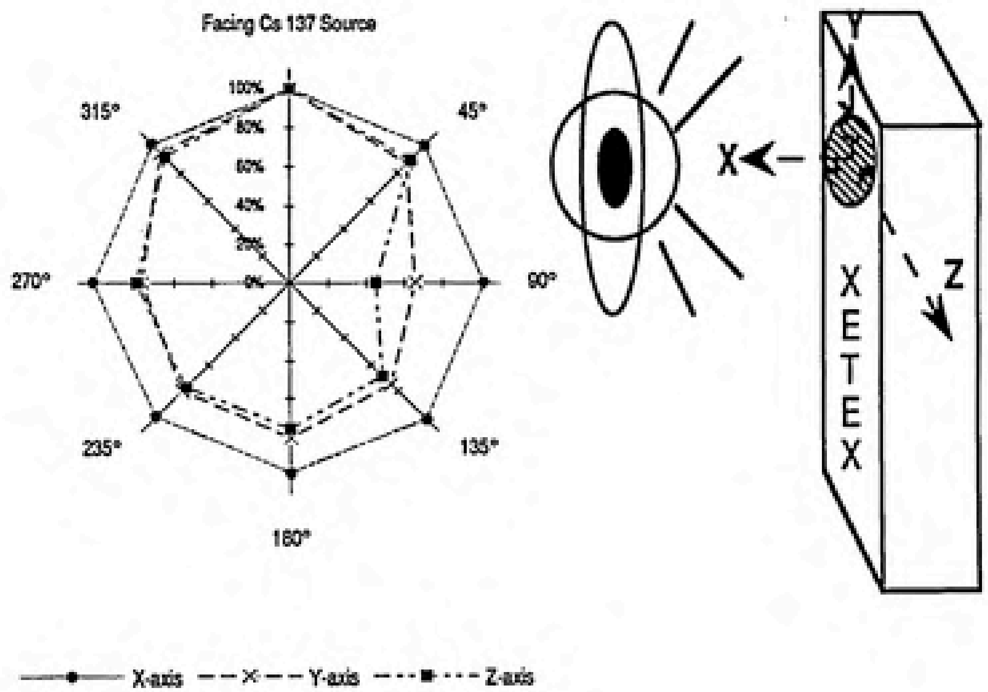


FIGURE E2: RESPONSE VERSUS ANGLE OF ROTATION



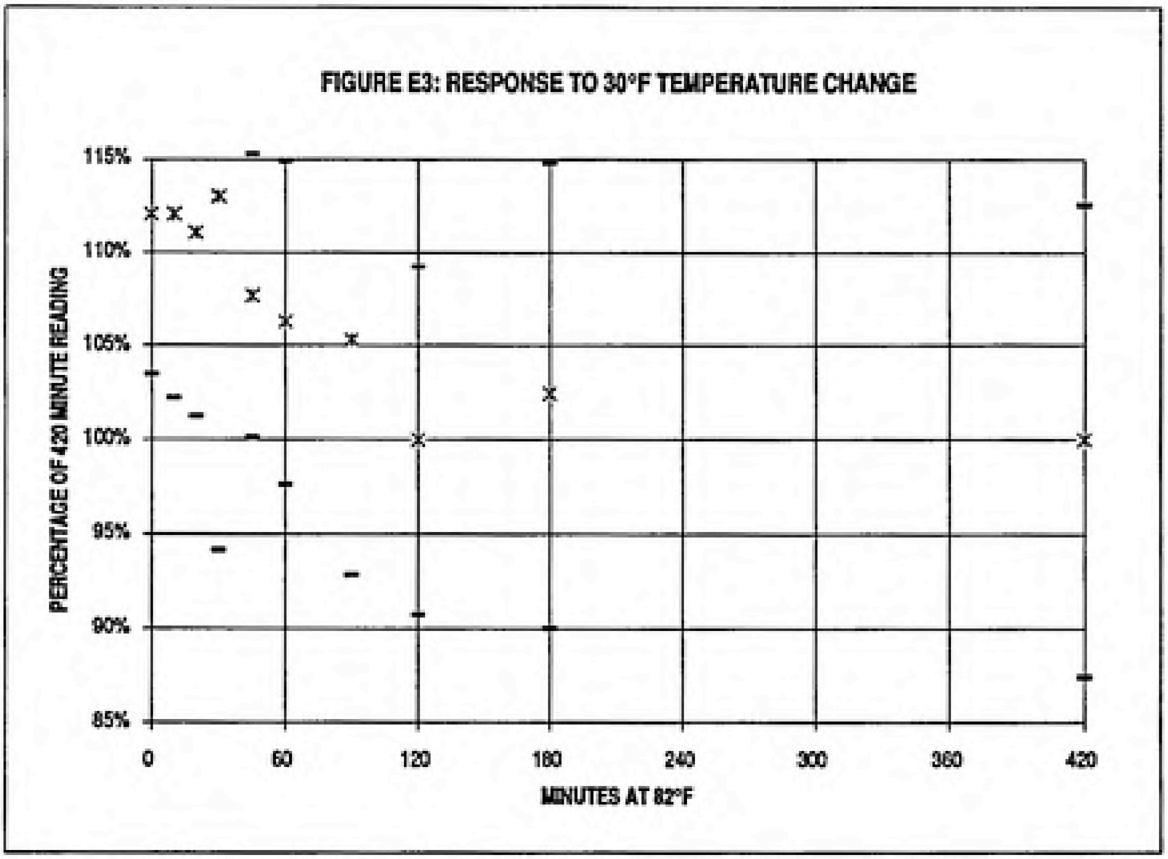


FIGURE E3: RESPONSE TO 30°F TEMPERATURE CHANGE
PERCENTAGE OF 420 MINUTE READING
115%
110%
105%
100%
95%
90%
85%
0
60
120
180
240
300
360
420
MINUTES AT 82°F

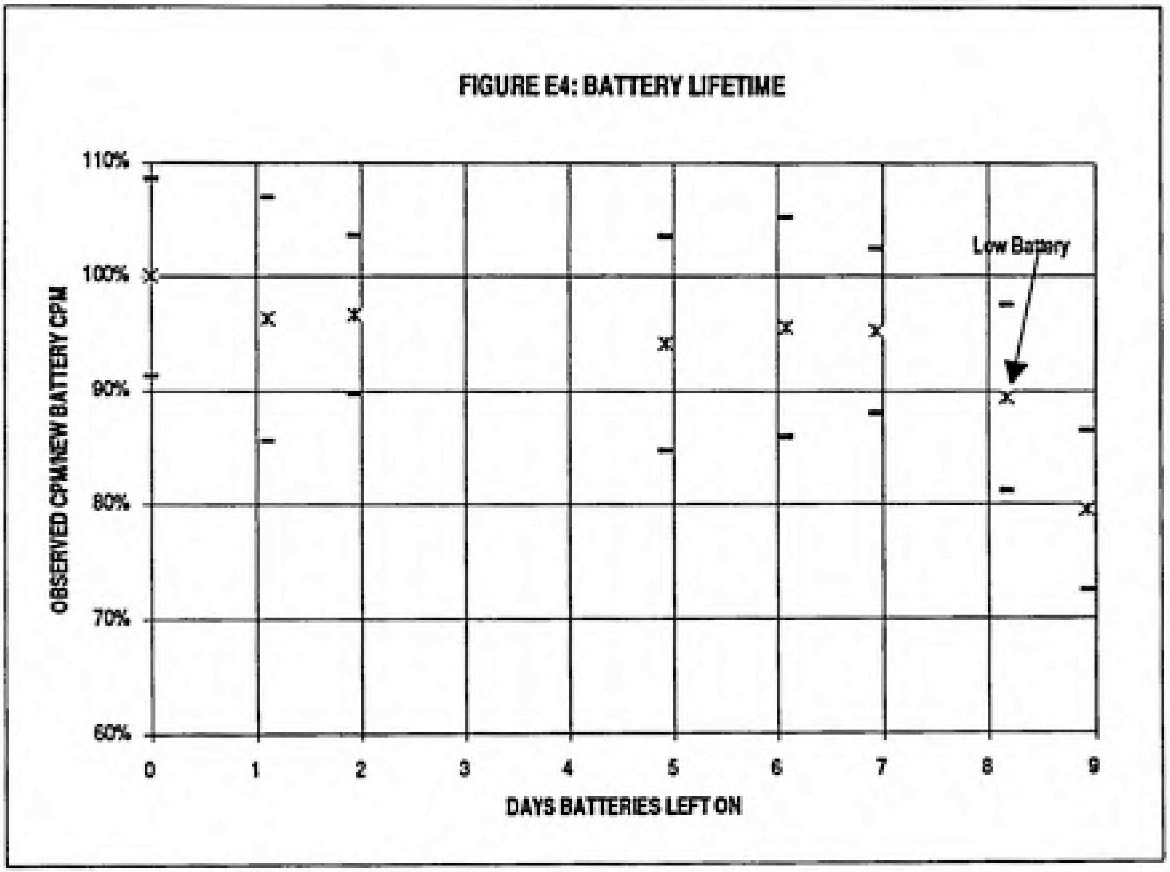


FIGURE E4: BATTERY LIFETIME
OBSERVED CPM/NEW BATTERY CPM
110%
100%
90%
80%
70%
60%
0
1
2
3
4
5
6
7
8
9
DAYS BATTERIES LEFT ON
Low Battery

TABLE F1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	Cap Off Mean (Temperature Corrected) (mR/h)	Cap Off Mean (No Temperature Correction) (mR/h)	Cap Off Standard Deviation	Cap On Mean (Temperature Corrected) (mR/h)	Cap On Mean (No Temperature Correction) (mR/h)	Cap On Standard Deviation
Cs 137	2.57	2.5	2.4	0.06	2.4	2.4	0.06
	3.73	3.6	3.5	0.09	3.4	3.4	0.09
	5.97	5.7	5.5	0.18	5.3	5.3	0.19
	12.27	11.8	11.4	0.21	11.1	11.0	0.18
	25.62	23.0	22.4	0.55	22.2	22.0	0.00
	37.35	33.5	32.6	0.55	32.1	31.8	0.84
	59.33	51.4	50.2	0.84	48.6	48.2	0.84
	124.07	104.7	102.1	0.84	102.9	101.9	0.71
	254.71	205.0	199.9	0.02	194.4	192.7	1.10
	365.40	287.0	279.8	0.05	262.2	259.8	0.05
	589.47	458.6	445.6	5.48	413.3	409.6	0.02
	1,231.85	888.3	863.2	13.42	782.2	775.2	11.40
	2,557.17	1680.4	1633.0	13.42	1484.2	1471.0	8.37
	3,625.55	2159.6	2098.7	0.02			
Duke University's Source	2,481.70				1852.9	1854.0	8.94
	3,573.00				2698.5	2700.0	0.00
Ra 226	0.61	0.6	0.6	0.02	0.6	0.6	0.04
	1.25	1.1	1.1	0.03	1.0	1.0	0.03
	2.56	2.3	2.2	0.11	2.0	2.0	0.05
	3.81	3.4	3.3	0.06	2.9	2.8	0.15
	5.96	5.3	5.2	0.30	4.3	4.2	0.05
	12.35	11.0	10.7	0.19	8.8	8.8	0.13
	25.01	24.9	24.3	0.55	17.4	17.0	0.23
	37.03	37.0	36.1	0.45	24.3	23.7	0.45
	60.32	61.7	60.2	0.55	36.7	35.8	0.02
	126.92	146.1	142.7	1.22	80.8	78.9	0.45
	300.58	331.7	324.0	5.48	154.8	151.2	0.84
Am 241	0.89	0.7	0.7	0.02	0.7	0.7	0.02
	1.79	1.6	1.6	0.05	1.7	1.6	0.09
	2.72	2.1	2.1	0.06	2.1	2.1	0.06
	3.71	3.2	3.1	0.06	3.2	3.1	0.06
	9.10	7.2	7.0	0.09	7.1	7.0	0.23
	14.25	12.3	12.2	0.10	12.3	12.2	0.11
	25.40	19.2	19.0	0.16	19.1	19.0	0.12

TABLE F2: INSTRUMENT ROTATION RESPONSE

	X-axis	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	22.29 mR/H
45°	99%	101%	101%	Source Maximum Deviation	1.33%
90°	99%	103%	93%		
135°	99%	99%	85%		
180°	99%	94%	96%		
235°	98%	101%	101%		
270°	98%	103%	106%		
315°	98%	97%	103%		

TABLE F3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
1	0>2.6	11.76	0.59	2.9%
10	0>25	4.73	0.41	1.5%
100	0>189	2.85	0.10	0.0%

TABLE F4: DECAY TIME

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)
1	2.2>0.2	10.62	0.40
10	22>2	4.13	0.42
100	230>20	2.83	0.17

TABLE F5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	104.0%	200	0.0
10	104.0%	200	1.3
20	102.1%	196	1.6
30	101.4%	195	0.8
45	100.4%	193	1.5
60	100.5%	193	2.4
90	98.8%	190	1.7
120	99.6%	192	2.2
180	99.3%	191	1.2
420	100.0%	192	1.3

TABLE F6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change of Mean from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
Two Batteries	0.0	-	3.0	0.1	9.4
	1.1	0.7%	3.1	0.1	-
	1.9	0.7%	3.1	0.0	-
	4.9	1.3%	3.0	0.1	-
	6.1	1.3%	3.1	0.1	-
	6.9	0.7%	3.0	0.1	-
low battery	8.2	0.0%	3.1	0.1	4.8
	8.9	2.0%	0.0	0.0	3.0
One Battery					
Trial 1	0.0	-	2.98	0.1	9.3
	2.9	2.7%	3.06	0.1	6.6
low battery	3.9	8.1%	3.22	0.4	6.4
	4.0	7.4%	3.20	0.3	4.6
	4.2	100.0%	0.00	0.0	4.1
Trial 2	0.0	-	25.40	0.5	9.2
	0.7	0.8%	25.20	0.4	8.0
	1.7	0.0%	25.40	0.5	7.6
	2.8	1.6%	25.80	0.4	6.8
	2.9	0.0%	25.40	0.5	6.7
	3.0	0.0%	25.40	0.5	6.4
	3.1	0.0%	25.40	0.5	6.3
	3.2	0.0%	25.40	0.5	6.1
	3.4	0.0%	25.40	0.5	5.8
low battery	3.7	1.6%	25.80	0.4	5.4
	3.8	0.8%	25.60	0.5	5.4
	3.9	1.6%	25.00	0.0	5.4
	4.1	100.0%	0.00	0.0	4.4

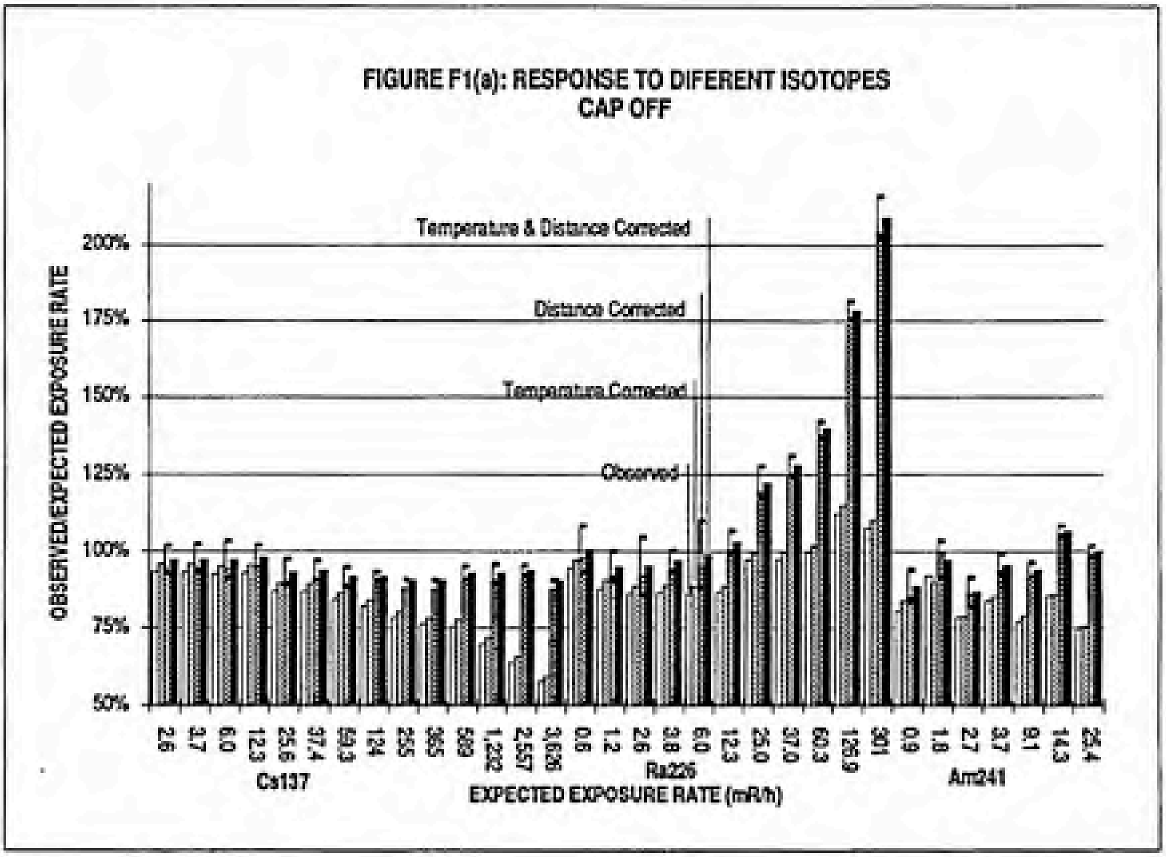


FIGURE F1(a): RESPONSE TO DIFERENT ISOTOPES
CAP OFF
Temperature & Distance Corrected
Distance Corrected
Temperature Corrected
Observed
OBSERVED/EXPECTED EXPOSURE RATE
200%
175%
150%
125%
100%
75%
50%
2.6
3.7
6.0
12.3
25.6
37.4
59.3
124
255
365
589
1,232
2,557
3,626
0.6
1.2
2.6
3.8
6.0
12.3
25.0
37.0
60.3
126.9
301
0.9
1.8
2.7
3.7
9.1
14.3
25.4
Cs137
Ra226
Am241
EXPECTED EXPOSURE RATE (mR/h)

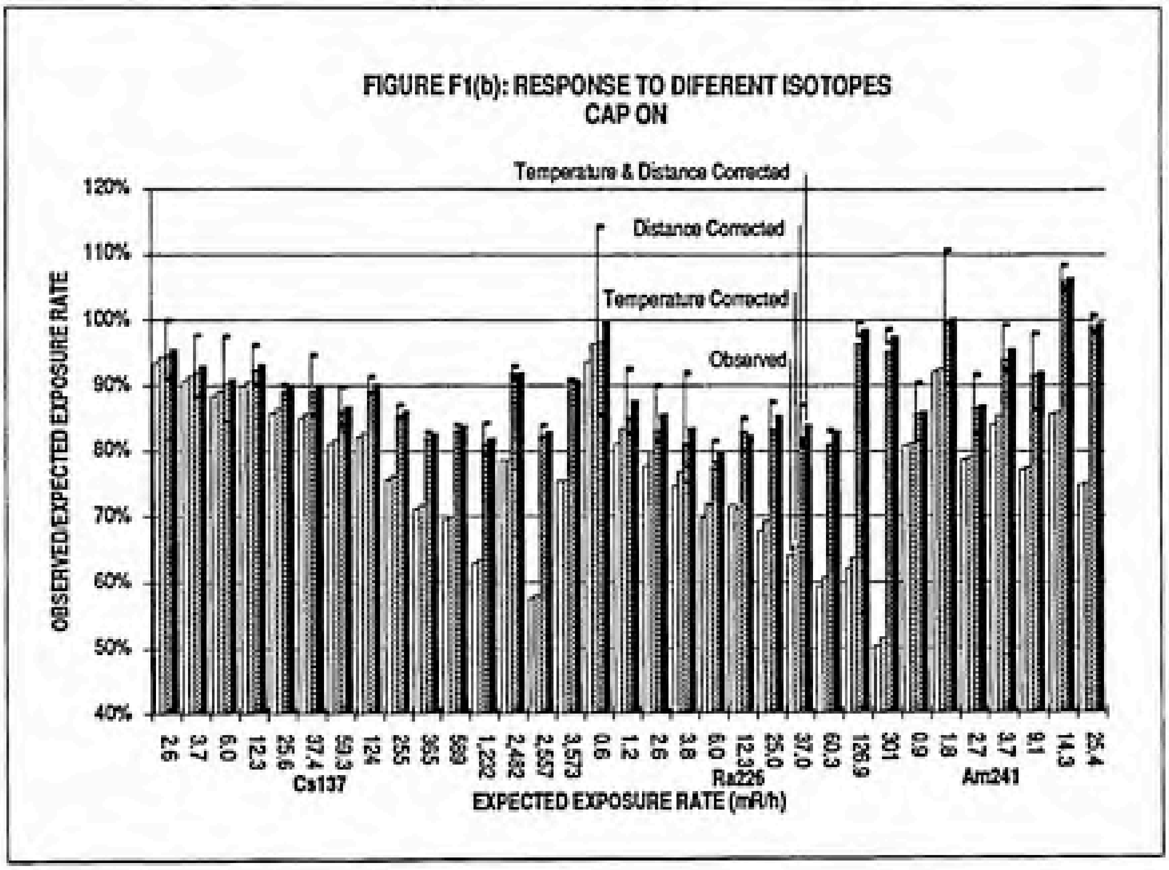
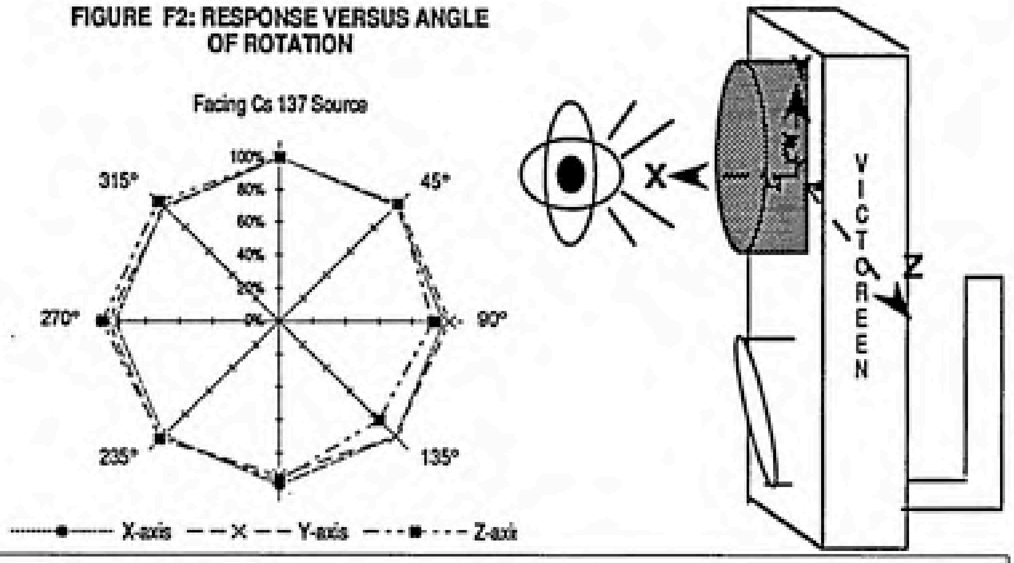
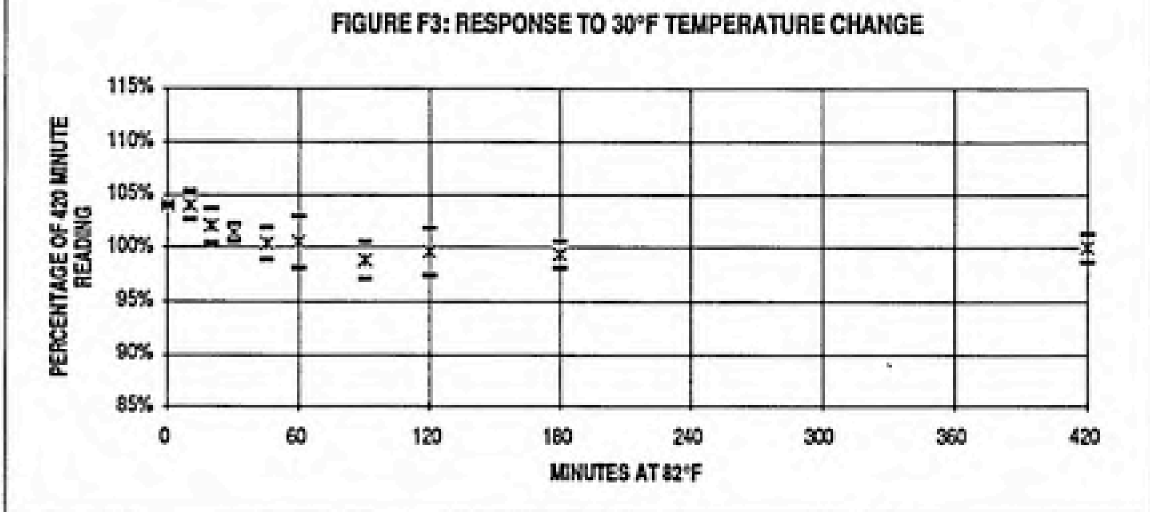


FIGURE F1(b): RESPONSE TO DIFERENT ISOTOPES
CAP ON
Temperature & Distance Corrected
Distance Corrected
Temperature Corrected
Observed
OBSERVED/EXPECTED EXPOSURE RATE
120%
110%
100%
90%
80%
70%
60%
50%
40%
2.6
3.7
6.0
12.3
25.6
37.4
59.3
124
255
365
589
1,232
2,482
2,557
3,573
0.6
1.2
2.6
3.8
6.0
12.3
25.0
37.0
60.3
126.9
301
0.9
1.8
2.7
3.7
9.1
14.3
25.4
Cs137
Ra226
Am241
EXPECTED EXPOSURE RATE (mR/h)

FIGURE F2: RESPONSE VERSUS ANGLE OF ROTATION





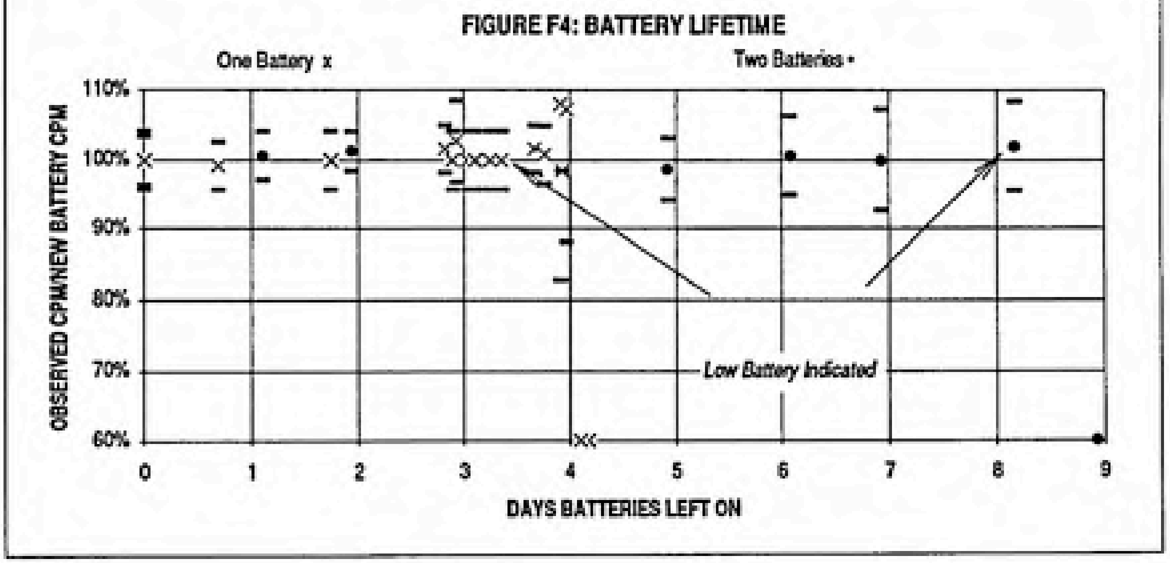


TABLE G1: INSTRUMENT RESPONSE TO ISOTOPES

Isotope	"Expected" Exposure Rate (mR/h)	Observed Mean (CPM)	Observed Standard Deviation
Cs 137	2.57	582,760	10,003
	3.73	780,240	19,497
	5.97	off scale	off scale
	12.27	*	*
	25.62	*	*
	37.35	*	*
	59.33	*	*
	124.07	*	*
	254.71	*	*
	365.40	*	*
	589.47	*	*
	1,231.85	*	*
	2,557.17	*	*
	3,625.55	*	*
Duke University's Source	2,481.70	*	*
	3,573.00	*	*
Ra 226	0.61	90,120	1,521
	1.25	191,600	4,561
	2.56	327,800	13,046
	3.81	493,600	8,385
	5.96	727,600	17,344
	12.35	off scale	off scale
	25.01	*	*
	37.03	*	*
	60.32	*	*
	126.92	*	*
	300.58	*	*
Am 241	0.89	off scale	off scale
	1.79	*	*
	2.72	*	*
	3.71	*	*
	9.10	*	*
	14.25	*	*
	25.40	*	*

TABLE G2: INSTRUMENT ROTATION

	Base Spun	Y-axis	Z-axis	Precision	
Facing Cs 137 Source	100%	100%	100%	Facing Source Average	700,000 CPM
45°	99%	101%	101%	Facing Source Maximum Deviation	5.71%
90°	99%	103%	93%		
135°	99%	99%	85%		
180°	99%	94%	96%		
235°	98%	101%	101%		
270°	99%	103%	106%		
315°	98%	97%	103%		

TABLE G3: RESPONSE TIME / COEFFICENT OF VARIANCE

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)	Coefficent of Variance
1000	FAST	0.62	0.13	2.2%
(0> 5,500 CPM)	SLOW	1.27	0.03	-

TABLE G4: DECAY TIME

Scale	Values	Average Time (seconds)	Standard Deviation (seconds)
1000	FAST	0.95	0.13
(5,600>500 CPM)	SLOW	0.68	0.04

TABLE G5: TEMPERATURE SHOCK RESPONSE

Time from Cold (Minutes)	% of 420 Minute Reading	Instrument Response Mean	Standard Deviation
0	102.1%	715.00	10.95
10	101.4%	710.00	10.95
20	100.4%	702.50	13.42
30	101.1%	707.50	10.95
45	100.4%	702.50	11.40
60	97.9%	685.00	8.94
90	97.5%	682.50	5.48
120	96.1%	672.50	8.37
180	92.5%	647.50	8.37
420	100.0%	700.00	15.17

TABLE G6: BATTERY LIFE

	Days After New Batteries Installed	Percent Change from New Batteries	Instrument Response Mean	Standard Deviation	Voltage
Trial 1	0	-	650,000	10,000	9.29
	1.1	0.3%	648,000	8,367	-
	1.9	0.6%	646,000	11,402	-
low battery	4.9	14.8%	554,000	5,477	4.95
Trial 2	0.0	-	626,000	13,416	9.3
	1.2	1.3%	618,000	8,367	-
	3.1	1.9%	614,000	8,944	-
	4.2	2.9%	608,000	8,367	6.8
	4.4	2.2%	612,000	8,367	6.1
low battery	5.4	32.9%	420,000	7,071	4.1

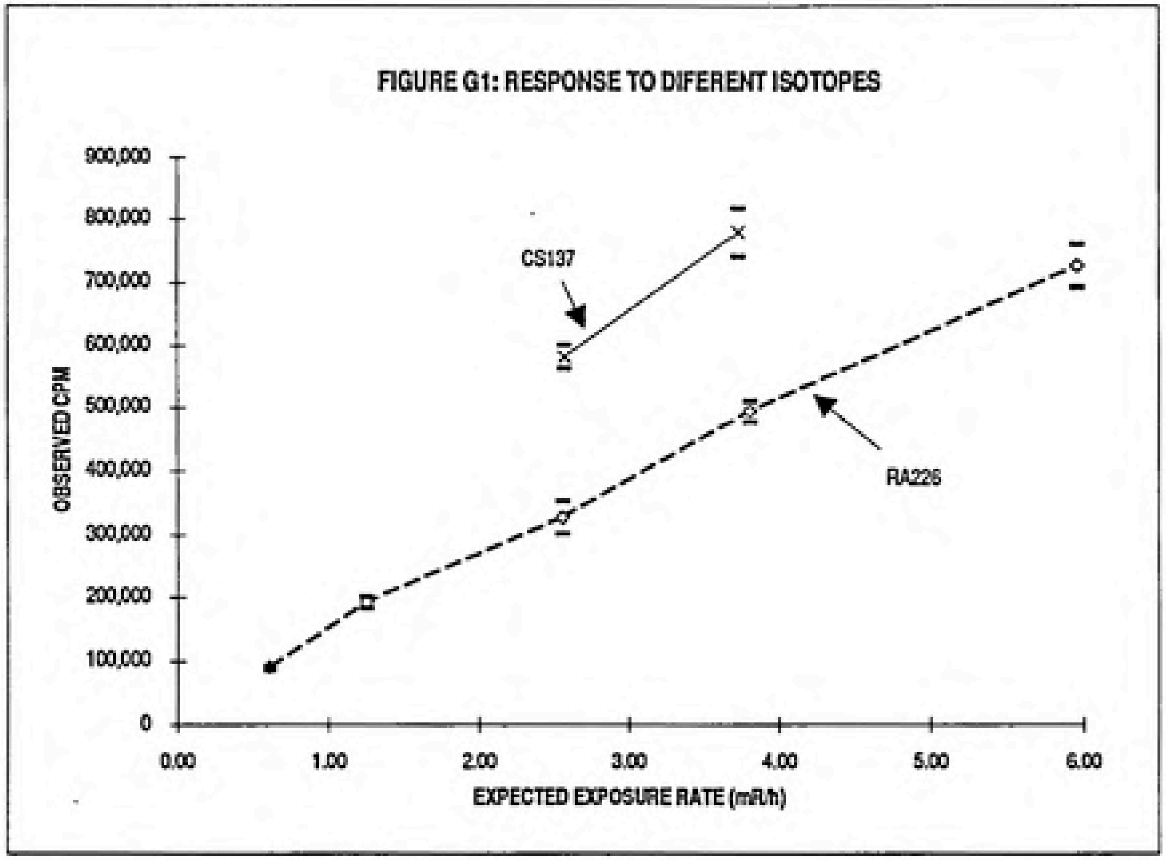
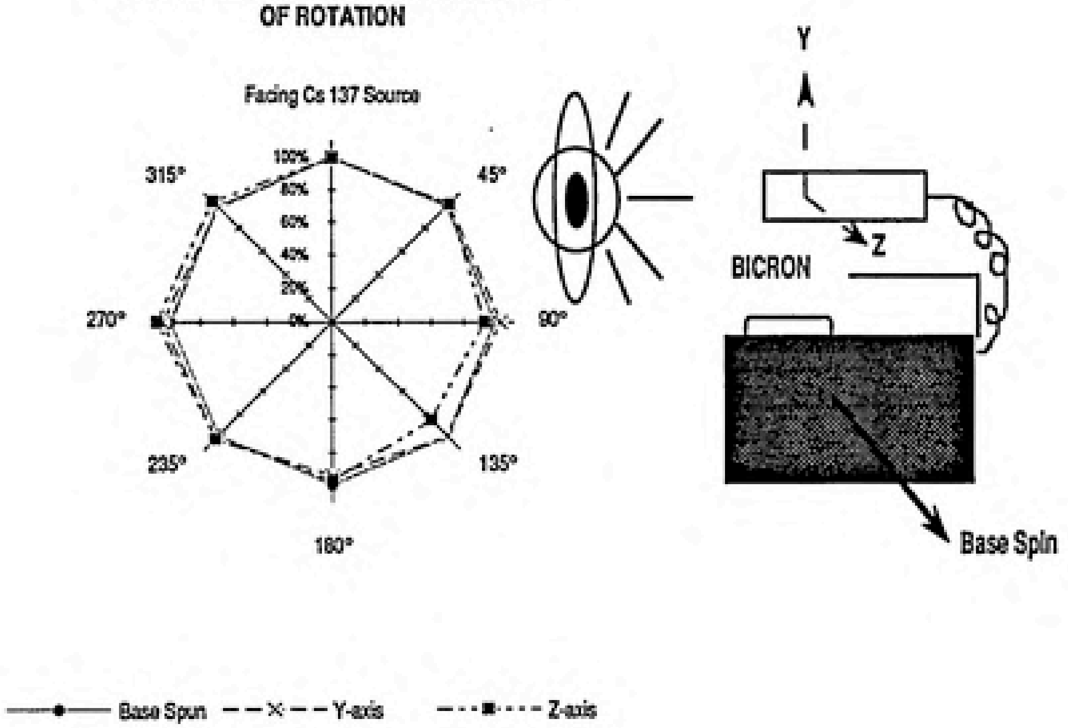


FIGURE G2: RESPONSE VERSUS ANGLE OF ROTATION



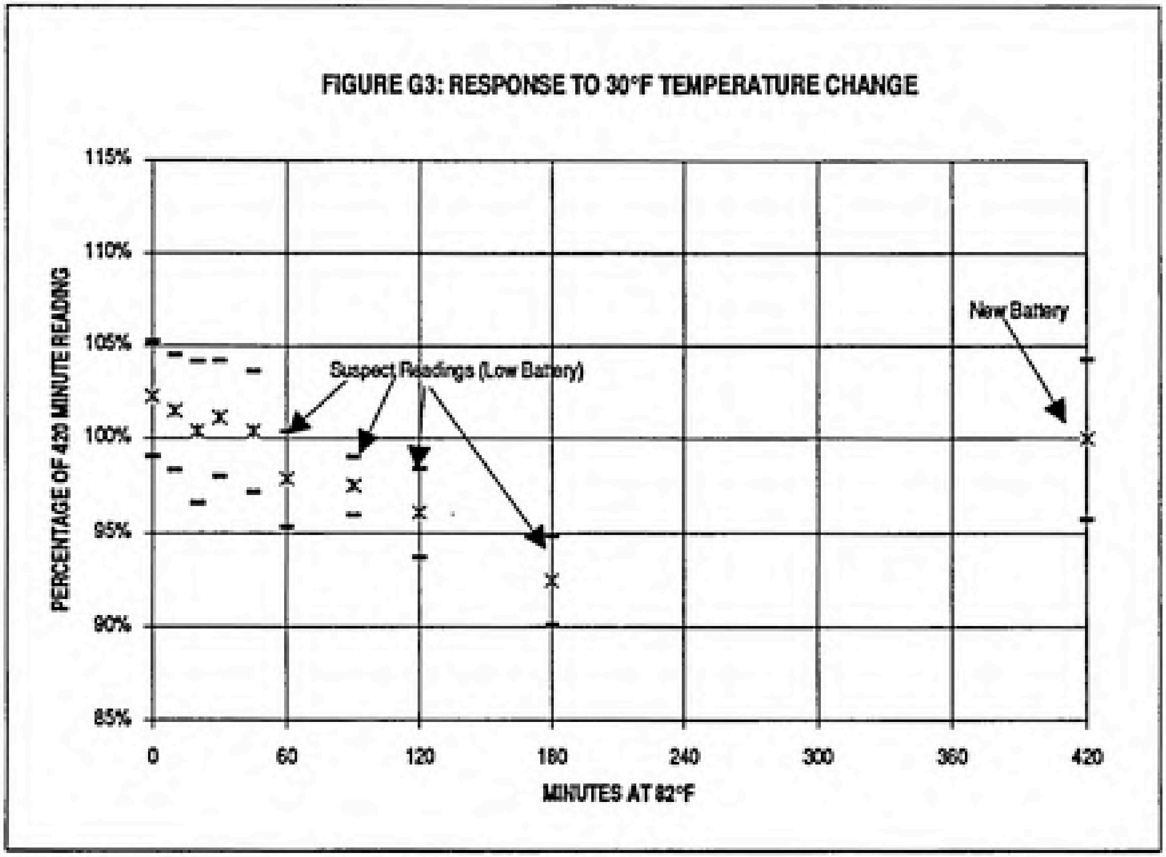


FIGURE G3: RESPONSE TO 30°F TEMPERATURE CHANGE
PERCENTAGE OF 420 MINUTE READING
115%
110%
105%
100%
95%
90%
85%
New Battery
Suspect Readings (Low Battery)
0
60
120
180
240
300
360
420
MINUTES AT 82°F

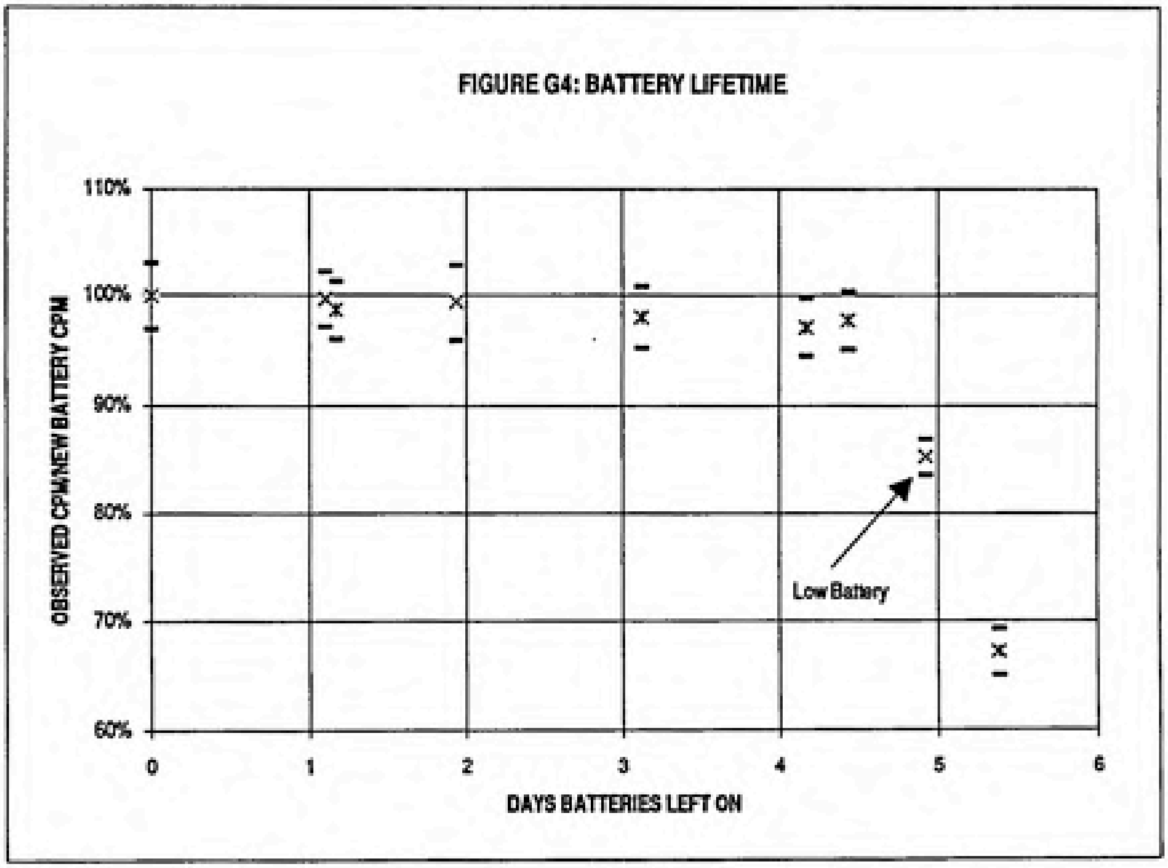


FIGURE G4: BATTERY LIFETIME
OBSERVED CPM/NEW BATTERY CPM
110%
100%
90%
80%
70%
60%
Low Battery
0
1
2
3
4
5
6
DAYS BATTERIES LEFT ON

of A_1 or A_2 as appropriate. All the radionuclides whose individual activities are not known, [illegible] whose total activity is known) [illegible] be classed in a single group and the most restrictive value of A_1 or A_2 applicable to any one of them shall be used as the value of A_1 and A_2 in the denominator of the fraction.

(5) When the identity of each radionuclide is known but the individual activity of the radionuclides is not known, the most restrictive value of A_1 or A_2 applicable to any one of the radionuclides present is the applicable value.

(6) When the identity of the radionuclides is not known, the value of A_1 is 2 curies and the value of A_2 is 0.002 curies. However, if alpha emitters are known to be absent, the value of A_2 is 0.4 curies.

[Amdt. 173-162, 48 FR 10226, Mar. 10, 1983; 48 FR 13432, Mar. 31, 1983, as amended at 48 FR 31218, July 7, 1983; Amdt. 173-185, 50 FR 11055, Mar. 19, 1985]

§ 173.434 Activity-mass relationships for uranium and natural thorium.[1]

Radioactive material	Curies per gram	Grams per curie
Uranium—(Wt% 235 U present):		
0.45	5.0×10^{-7}	2.0×10^{6}
0.72 (natural)	7.06×10^{-7}	1.42×10^{6}
1.0	7.6×10^{-7}	1.3×10^{6}
1.5	1.0×10^{-6}	1.0×10^{6}
5.0	2.7×10^{-6}	3.7×10^{5}
10.0	4.8×10^{-6}	2.1×10^{5}
20.0	1.0×10^{-5}	1.0×10^{5}
35.0	2.0×10^{-5}	5.0×10^{4}
50.0	2.5×10^{-5}	4.0×10^{4}
90.0	5.8×10^{-5}	1.7×10^{4}
93.0	7.0×10^{-5}	1.4×10^{4}
95.0	9.1×10^{-5}	1.1×10^{4}
Natural thorium	2.2×10^{-7}	4.8×10^{6}

[1] The figures for uranium include representative values for the activity of uranium-234 which is concentrated during the enrichment process. The activity for thorium includes the equilibrium concentration of thorium-228.

§ 173.435 Table of A_1 and A_2 values for radionuclides.

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
227_{Ac}	Actinium (89).	1000	0.003
228_{Ac}		10	4
105_{Ag}	Silver (47)	40	40
$110m_{Ag}$		7	7
111_{Ag}		100	20
241_{Am}	Americium (95)[1].	8	0.008
243_{Am}		8	0.008
37_{Ar} (compressed or uncompressed)	Argon (18)	1000	1000
41_{Ar} (uncompressed)		20	20
41_{Ar} (compressed)		1	1
73_{As}	Arsenic (33)	1000	400
74_{As}		20	20
76_{As}		10	10
77_{As}		300	20
211_{At}	Astatine (85).	200	7
193_{Au}	Gold (79)	200	200
196_{Au}		30	30
198_{Au}		40	20
199_{Au}		200	25
131_{Ba}	Barium (56)	40	40
133_{Ba}		40	10
140_{Ba}		20	20
7_{Be}	Beryllium (4).	300	300
206_{Bi}	Bismuth (83).	5	5
207_{Bi}		10	10
210_{Bi} (RaE)		100	4
212_{Bi}		6	6
249_{Bk}	Berkelium (97).	1000	1
77_{Br}	Bromine (35).	70	25
82_{Br}		6	6
11_{C}	Carbon (6)	20	20
14_{C}		1000	60
45_{Ca}	Calcium (20).	1000	25
47_{Ca}		20	20
109_{Cd}	Cadmium (48).	1000	70
$115m_{Cd}$		30	30
115_{Cd}		80	20
139_{Ce}	Cerium (58)	100	100
141_{Ce}		300	25
143_{Ce}		60	20
144_{Ce}		10	7
249_{Cf}	Californium (98).	2	0.002
250_{Cf}		7	0.007
252_{Cf}		2	0.009
36_{Cl}	Chlorine (17).	300	10
38_{Cl}		10	10
242_{Cm}	Curium (96)	200	0.2
243_{Cm}		9	0.009
244_{Cm}		10	0.01
245_{Cm}		6	0.006
246_{Cm}		6	0.006
56_{Co}	Cobalt (27)	5	5
57_{Co}		90	90
$58m_{Co}$		1000	1000
58_{Co}		20	20
60_{Co}		7	7
51_{Cr}	Chromium (24).	600	600
129_{Cs}	Cesium (55)	40	40
131_{Cs}		1000	1000
$134m_{Cs}$		1000	10
134_{Cs}		10	10
135_{Cs}		1000	25
136_{Cs}		7	7
137_{Cs}		30	10
64_{Cu}	Copper (29)	80	25
67_{Cu}		200	25
165_{Dy}	Dysprosium (66).	100	20
166_{Dy}		1000	200
169_{Er}	Erbium (68)	1000	25
171_{Er}		50	20
$152m_{Eu}$	Europium (63).	30	30
152_{Eu}		20	10
154_{Eu}		10	5
155_{Eu}		400	60
18_{F}	Flourine (9)	20	20
52_{Fe}	Iron (26)	5	5
55_{Fe}		1000	1000
59_{Fe}		10	10
67_{Ga}	Gallium (31)	100	100
68_{Ga}		20	20
72_{Ga}		7	7
153_{Gd}	Gadolinium (64).	200	100
159_{Gd}		300	20
68_{Ge}	Germanium (32).	20	10
71_{Ge}		1000	1000
3_{H}	Hydrogen (1) See T-Tritium.		
181_{Hf}	Hafnium (72).	30	25
$197m_{Hg}$	Mercury (80).	200	200
197_{Hg}		200	200
203_{Hg}		80	25
166_{Ho}	Holmium (67).	30	30
123_{I}	Iodine (53)	50	50
125_{I}		1000	70
126_{I}		40	10
129_{I}		1000	2
131_{I}		40	10
132_{I}		7	7
133_{I}		30	10
134_{I}		8	8
135_{I}		10	10
111_{In}	Indium (49)	30	25
$113m_{In}$		60	60
$114m_{In}$		30	20
$115m_{In}$		100	20
190_{Ir}	Iridium (77)	10	10
192_{Ir}		20	10
194_{Ir}		[illegible]	10
42_{K}	Potassium (19)	[illegible]	10
43_{K}		20	10
$85m_{Kr}$ (uncompressed).	Krypton (36)	100	100
$85m_{Kr}$ (compressed).		3	3
85_{Kr} (uncompressed).		1000	1000
85_{Kr} (compressed).		5	5
87_{Kr} (uncompressed).		20	20
87_{Kr} (compressed).		0.6	0.6
140_{La}	Lanthanum (57)	30	30
LSA	Low specific activity material—see § 173.403		
177_{Lu}	Lutetium (71).	300	25
MFP	Mixed fission products.	10	0.4
28_{Mg}	Magnesium (12).	6	6
52_{Mn}	Manganese (25).	5	5
54_{Mn}		20	20
56_{Mn}		5	5
99_{Mo}	Molybdenum (42).	100	20
13_{N}	Nitrogen (7)	20	10
22_{Na}	Sodium (11)	8	8
24_{Na}		5	5
$93m_{Nb}$	Niobium (41).	1000	200
95_{Nb}		20	20
97_{Nb}		20	20
147_{Nd}	Neodymium (60)	100	20
149_{Nd}		30	20
59_{Ni}	Nickel (28)	1000	900
63_{Ni}		1000	100
65_{Ni}		10	10
237_{Np}	Neptunium (93).	5	0.005
239_{Np}		200	25
185_{Os}	Osmium (76).	20	20
191_{Os}		600	200
$191m_{Os}$		200	200
193_{Os}		100	20
32_{P}	Phosphorus (15).	30	30
230_{Pa}	Protactinium (91).	20	0.8
231_{Pa}		2	0.002
233_{Pa}		100	100
201_{Pb}	Lead (82)	20	20
210_{Pb}		100	0.2

Enclosure 1

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
212Pb		6	5
103Pd	Palladium (46)	1000	700
109Pd		100	20
147Pm	Promethium (61)	1000	25
149Pm		100	20
210Po	Polonium (84)	200	0.2
142Pr	Praseodymium (59)	10	10
143Pr		200	20
191Pt	Platinum (78)	100	100
193mPt		200	200
197mPt		300	20
197Pt		300	20
238Pu	Plutonium (94)[1]	3	0.003
239Pu		2	0.002
240Pu		2	0.002
241Pu		1000	0.1
242Pu		3	0.003
223Ra	Radium (88)	50	0.2
224Ra		6	0.5
226Ra		10	0.05
228Ra		10	0.05
81Rb	Rubidium (37)	30	25
86Rb		30	30
87Rb		Unlimited	Unlimited
Rb (natural)		Unlimited	Unlimited
186Re	Rhenium (75)	100	20
187Re		Unlimited	Unlimited
188Re		10	10
Re (natural)		Unlimited	Unlimited
103mRh	Rhodium (45)	1000	1000
105Rh		200	25
222Rn	Radon (86)	10	2
97Ru	Ruthenium (44)	80	80
103Ru		30	25
105Ru		20	20
106Ru		10	7
35S	Sulphur (16)	1000	60
122Sb	Antimony (51)	30	30
124Sb		5	5
125Sb		40	25
46Sc	Scandium (21)	8	8
47Sc		200	20
48Sc		5	5
75Se	Selenium (34)	40	40
31Si	Silicon (14)	100	20
147Sm	Samarium (62)	Unlimited	Unlimited
151Sm		1000	90
153Sm		300	20
113Sn	Tin (50)	60	60
119mSn		100	100
125Sn		10	10
85mSr	Strontium (38)	80	80
85Sr		30	30
87mSr		50	50
89Sr		100	10
90Sr		10	0.4
91Sr		10	10
92Sr		10	10
T (uncompressed)	Tritium (1)	1000	1000
T (compressed)		1000	1000
T (activated luminous paint)		1000	1000
T (adsorbed on solid carrier)		1000	1000
T (tritiated water)		1000	1000
T (other forms)		20	20
182Ta	Tantalum (73)	20	20
160Tb	Terbium (65)	20	10
96mTc	Technetium (43)	1000	1000
96Tc		6	6
97mTc		1000	200
97Tc		1000	400
99mTc		100	100
99Tc		1000	25
125mTe	Tellurium (52)	1000	100
127mTe		300	20
127Te		300	20
129mTe		30	10
129Te		100	20
131mTe		10	10
132Te		7	7
227Th	Thorium (90)	200	0.2
228Th		6	0.005
230Th		3	0.003
231Th		1000	25
232Th		Unlimited	Unlimited
234Th		10	10
Th (natural)		Unlimited	Unlimited
Th (irradiated)[2]			
200Tl	Thallium (81)	20	20
201Tl		200	200
202Tl		40	40
204Tl		300	10
170Tm	Thulium (69)	300	10
171Tm		1000	100
230U	Uranium (92)	100	0.1
232U		30	0.03
233U		100	0.1
234U		100	0.1
235U		100	0.2
236U		200	0.2
238U		Unlimited	Unlimited
U (natural)		Unlimited	Unlimited
U (enriched)			

Symbol of radionuclide	Element and atomic number	A_1(Ci) special form	A_2(Ci) normal form
<20%		Unlimited	Unlimited
20% or greater.		100	0.1
U (depleted).		Unlimited	Unlimited
U (irradiated)[3].			
48V	Vanadium (23).	6	6
181W	Tungsten (74).	200	100
185W		1000	25
187W		40	20
127Xe (uncompressed).	Xenon (54)	70	70
127Xe (compressed).		5	5
131mXe (compressed).		10	10
131mXe (uncompressed).		100	100
133Xe (uncompressed).		1000	1000
133Xe (compressed).		5	5
135Xe (uncompressed).		70	70
135Xe (compressed).		2	2
87Y	Yttrium (39)	20	20
90Y		10	10
91mY		30	30
91Y		30	30
92Y		10	10
93Y		10	10
169Yb	Ytterbium (70).	80	80
175Yb		400	25
65Zn	Zinc (30)	30	30
69mZn		40	20
69Zn		300	20
93Zr	Zirconium (40)	1000	200
95Zr		20	20
97Zr		20	20

[1] For shipments solely within the United States the A_1 value is 20 curies for americium and plutonium contained in Am-Be or Pu-Be neutron sources or in nuclear-powered pacemakers.

[2] The values of A_1 and A_2 must be calculated in accordance with the procedure specified in § 173.433 of this subchapter, taking into account the activity of the fission products and of the uranium-233 in addition to that of the thorium.

[3] The values of A_1 and A_2 must be calculated in accordance with the procedure specified in § 173.433 of this subchapter, taking into account the activity of the fission products and plutonium isotopes in addition to that of the uranium.

[Amdt. 173-162, 48 FR 10226, Mar. 10, 1983; 48 FR 13432, Mar. 31, 1983, as amended at 48 FR 31219, July 7, 1983; Amdt. 173-207, 53 FR 38274, Sept. 29, 1988]

§ 173.441 Radiation level limitations.

(a) Except as provided in paragraph (b) of this section, each package of radioactive materials offered for transportation shall be designed and prepared for shipment so that under conditions normally incident to transportation the radiation level does not exceed 200 millirem per hour at any point on the external surface of the package, and the transport index does not exceed 10.

(b) A package which exceeds the radiation level limits specified in paragraph (a) of this section shall be transported by exclusive use shipment only and the radiation levels for such shipment must not exceed the following during transportation:

(1) 200 millirem per hour (2 millisievert per hour) on the exterr ... rface of the package unless the ... owing conditions are met, in whic ... e the limit is 1000 millirem per ... r (10 millisievert per hour).

(i) The shipment is made ... losed transport vehicle;

(ii) The package is secu ... ithin the vehicle so that its positi ... mains fixed during transportation;

(iii) There are no loading ... loading operations between the ... nning and end of the transportati...

(2) 200 millirem per hour ... millisievert per hour) at any point on the outer surfaces of the vehicle, including the top and underside of the vehicle, or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load (or enclosure is used), and on the lower external surface of the vehicle;

(3) 10 millirem per hour (0.1 millisievert per hour) at any point 2 meters (6.6 feet) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) fr... e vertical planes projected by ... outer edges of the vehicle (exclud... e top and underside of the vehicle ...

(4) 2 millirem per hour (0. ... llisie... vert per hour) in any norm... occu... pied space, except that thi... isio...

Enclosure 1

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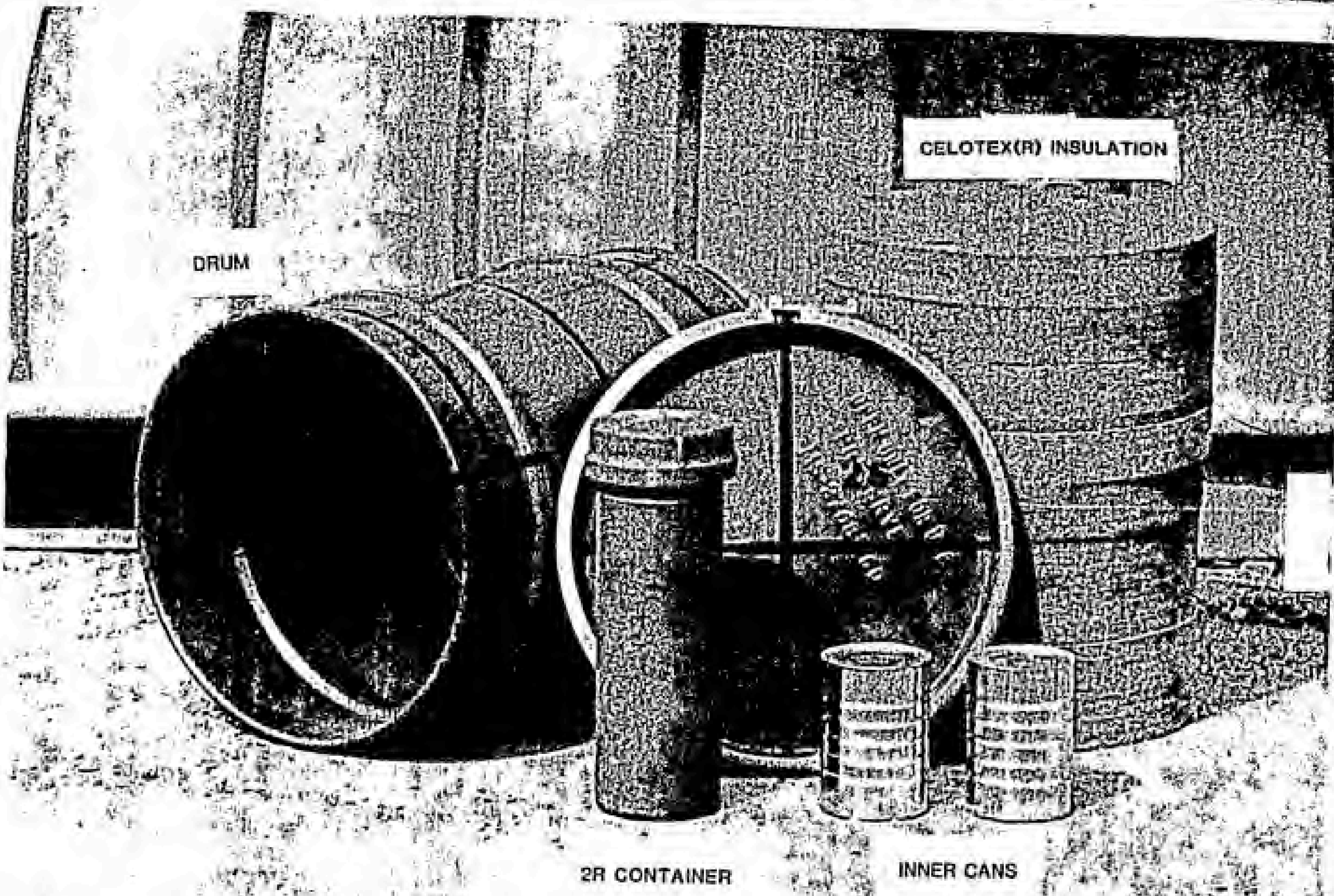

Enclosure 2

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P DE DO
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R 151805Z OCT 91 ZUI ASN-D00288000218 G-MTH/G-MPS/G-TGC/SUPR
FM EASYLINK
TO EZP/EASYLINK PRINTER
ACCT CG-W2GARC
BT
UNCLAS
EASYLINK MBX.4360147A001 15OCT91 12:51/13:02 EST
VIA: 892427
TO: 62806908
COASTGUARD WSH
23458CNEASC AR
TLX:345 15 10 1991 OP:LAB.-
U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION.
THIS IS NOTIFICATION THAT THE ATOMIC ENERGY COMMISSION
OF ARGENTINA IS SENDING APPROXIMATELY 372.000 CURIES OF
COBALT-60 IN CONTEINERS TYPE F-231 SERIAL 10 (TEN) WITH
CERTIFICATE CDN/2047/B (U).
THE SHIPMENT IS SCHEDULED ON [redacted] DEPARTING
BUENOS AIRES NOVEMBER 1 AND ARRIVING IN BATILMORE NOVEMBER 23.
THE PROPOSED INLAND ROUTING IS:
BROENING HIGHWAY, I-95, I-695, I-70, STATE 85, STATE 28, MT
EPHRAIM ROAD.
SALUDOS
ING. JUAN C.KIEFER
JEFE DPTO. TEC.ADM.
GCIA. RAD. Y RAD.
CNEA - ARGENTINA
PRESIATOM BAIRES
COASTGUARD WSH
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MMM
OCT 15 1991 1251
BT
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*   UNCLASSIFIED   *
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THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
CHAPEL HILL, NORTH CAROLINA 27514

From: Bob Wilson, RSO Bob Wilson
Health and Safety Office
B-5 Venable Hall 045A
Campus

To: Calibration File
Radiation Safety Section
UNC-CH Health and Safety Office
Campus

Staple or Tape

DATE: February 10, 1986

SUBJECT: Calibration of ICN Model CCsD-1m Cs-137 (990 ± 30 mCi, May 29, 1985) Instrument Calibration Source, Daniel Bourland and Bob Wilson

A 3M Model 6D6C-CA Cs-137 source, Serial No. 996 (65.6 mCi, ± < 5%, 11 January 1984, NBS Traceable), was used to calibrate the NCMH MDH Industries, Inc. Model 1015, Serial No. 2115, x-ray monitor. The large volume, low range ion chamber was calibrated.

The decay corrected activity of 3M source 996 was 62.5 mCi as of 5 February 1986. The calculated exposure rate from the source on this date was 20.5 milliroentgen per hour at one meter.[1]

A series of measurements was made, providing the following mean exposure rate.

Chamber	Distance (m)	Calculated mR/hr	Measured mR/hr	Correction Factor
Large	1.0	20.5 ± 1.0	21.5 ± 1.5	0.953

Correction Factor (C.F.) for Cs-137 Measurements with the MDH, Large Chamber: 0.953

The 5.0 milligram Ra-226 source, HSO ID No. 13, was used to calibrate the NCMH MDH, Serial No. 2115, x-ray monitor using yhe large chamber.

The activity of the Ra-226 source was accepted as 5.0 millicuries, 5 February 1986. The calculated exposure rate from the source on this date was 5.1 milliroentgen per hour at one meter.[1]

A series of measurements was made, providing the following mean exposure rate.

Chamber	Distance (m)	Calculated mR/hr	Measured mR/hr	Correction Factor
Large	1.0	5.1 $\pm$ 0.3	5.1 $\pm$ 0.4	1.000

Correction Factor (C.F.) for Ra-226 Measurements with the MDH, Large Chamber: 1.000

The MDH, calibrated on 5 February 1986 with an NBS traceable Cs-137 source, was used with its large chamber to measure the exposure rate from the ICN Model CCsD-1m Cs-137 Instrument Calibration Source on 5 February 1986.

The activity of the ICN source, corrected for decay to 5 February 1986, was 975 millicuries. An unknown thickness of metal remained in the radiation beam port. Therefore, no calculated exposure rate was attempted.

A series of measurements was made, providing the following mean exposure rate.

Chamber	Distance (m)	Measured mR/hr	Corrected mR/hr
Large	1.0	200.0 $\pm$ 3.6	190.6 $\pm$ 10.3

The exposure rate at 1 meter, center beam, from the ICN Cs-137 Calibration Source, as measured by an NBS traceable system, is found to be 190.6 + 10.3 mR/hr as of 4:00 p.m. EDT, February 5, 1986.

Reference:

1. NCRP Report No. 41, Specification of Gamma-Ray Brachytherapy Sources, April 1, 1974.

OUTPUTS 6 JUNE, 1992

CM	RSO UNATTENUATED mR/Hr	X-2 mR/Hr	X-4 mR/Hr	X-10 mR/Hr	X-100 mR/Hr	X-100+1 mR/Hr
10	89761	44217	21734	9254	976.7	71.3
20	22440.25	11054.25	5433.5	2313.5	244.17	17.82
30	9973.44	4913	2414.89	1028.5	108.52	7.92
40	5610.06	2763.56	1358.37	578.37	61.04	4.46
45	4432.6					
50	3590.44	1768.68	869.36	370.16	39.07	2.85
60	2493.36	1228.25	603.72	257.06	27.13	1.98
70	1831.86	902.39	443.55	188.86	19.93	1.46
80	1402.52	690.89	339.59	144.59	15.26	1.11
90	1108.16	545.89	268.32	114.25	12.06	0.88
100	897.61	442.17	217.34	92.54	9.77	0.71
110	741.83	356.43	179.62	76.48	8.07	0.59
120	623.34	307.06	150.93	64.26	6.78	0.5
130	531.34	261.64	128.6	54.76	5.78	0.42
140	457.96	225.6	110.89	47.21	4.98	0.36
150	398.94	196.52	96.6	41.13	4.34	0.32
160	350.63	172.72	84.9	36.15	3.82	0.28
170	310.59	153	75.2	32.02	3.38	0.25
180	277.04	136.47	67.08	28.56	3.01	0.22
190	248.65	122.48	60.2	25.63	2.71	0.2
200	224.4	110.54	54.33	23.13	2.44	0.18
210	203.54	100.27	49.28	20.98	2.21	0.16
220	185.46	91.36	44.9	19.12	2.02	0.15
230	169.68	83.59	41.09	17.49	1.85	0.13
240	155.84	76.77	37.73	16.07	1.7	0.12
250	143.62	70.75	34.77	14.81	1.56	0.11
260	132.78	65.41	32.15	13.69	1.44	0.11
270	123.13	60.65	29.81	12.69	1.34	0.1
280	114.49	56.4	27.72	11.8	1.25	0.09
290	106.73	52.58	25.84	11	1.16	0.08
300	99.73	49.13	24.15	10.28	1.09	0.08
310	93.4	46.01	22.62	9.63	1.02	0.07
320	87.66	43.18	21.22	9.04	0.95	0.07
330	82.43	40.6	19.96	8.5	0.9	0.07
340	77.65	38.25	18.8	8.01	0.84	0.06
350	73.27	36.1	17.74	7.55	0.8	0.06
360	69.26	34.12	16.77	7.14	0.75	0.06
370	65.57	32.3	15.88	6.76	0.71	0.05
380	62.16	30.62	15.05	6.41	0.68	0.05
390	59.01	29.07	14.29	6.08	0.64	0.05
400	56.1	27.64	13.58	5.78	0.61	0.04

404 Sharon Rd.
Chapel Hill, NC 27514
(919) 932-1734
22 July 1992

Bob Wilson
Radiation Safety Officer
Health and Safety Office
212 Finley Rd, CB#1650
Chapel Hill, NC 27514

Dear Bob,

On July 20, 1992 I borrowed your MDH model 10X5-180 ion chamber (serial number 5896) and model number 1015C pancake probe (serial number 2115) in an effort to determine an acceptable gamma constant from your 250 mCi Americium source.

The data I obtained in B34 Venable Hall is enclosed. All measurements were taken for 5 minutes in the exposure mode. These readings were then multiplied by 12 to obtain an exposure rate per hour.

As the exposure rates I encountered were so low, I decided to measure and then subtract out any effect from background radiation. I obtained an average background exposure rate of 1.85 mR/H. Completing the calculations I obtained an acceptable gamma constant of 0.095 $R \cdot cm^2/hr \cdot mCi$ (the published value is 0.129 $R \cdot cm^2/hr \cdot mCi$ or 0.0129 $R/hr \cdot Ci$ at one meter).

The data you obtained in a similar fashion on July 16, 1992 also yields an acceptable gamma constant once this background exposure rate is taken into account.

As I mentioned earlier, I will be out of town until August 10th. Upon my return I'd like to go over any questions you may have about the enclosed data, talk to you about why the background exposure rate is so high, and determine if the basement lab is an acceptable place to do my calibration with ^{241}Am because of this background rate.

If you can meet with me on August 10th, please leave a message on my answering machine at the above number.

Steve Danielczyk

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7/20/92 Steve Danielczyk's Am241 Gamma Constant Data

source and detector approx 1 m from floor

Separation distance (cm)	91		112		158		50	
	in field mR/h	background mR/h	in field mR/h	background mR/h	in field mR/h	background mR/h	in field mR/h	background mR/h
	4.368	*1.968*	*3.600*	*1.824*	*2.664*	*1.848*	*10.728*	*1.944*
	4.440	*1.872*	*3.552*	*1.920*	*2.688*	*1.872*	*10.776*	*1.920*
	4.464	*1.944*	*3.648*	*1.800*	*2.760*	*1.728*	*10.776*	
mean	4.424	1.928	3.600	1.848	2.704	1.816	10.760	1.932
stdev	0.050	0.050	0.048	0.063	0.050	0.077	0.028	0.017
net mean		2.496		1.752		0.888		8.828
net std dev		0.071		0.080		0.092		0.032
gamma constant		**0.087**		**0.093**		**0.095**		**0.092**

Enclosure 6

7/20/92 Background Exposure Rate

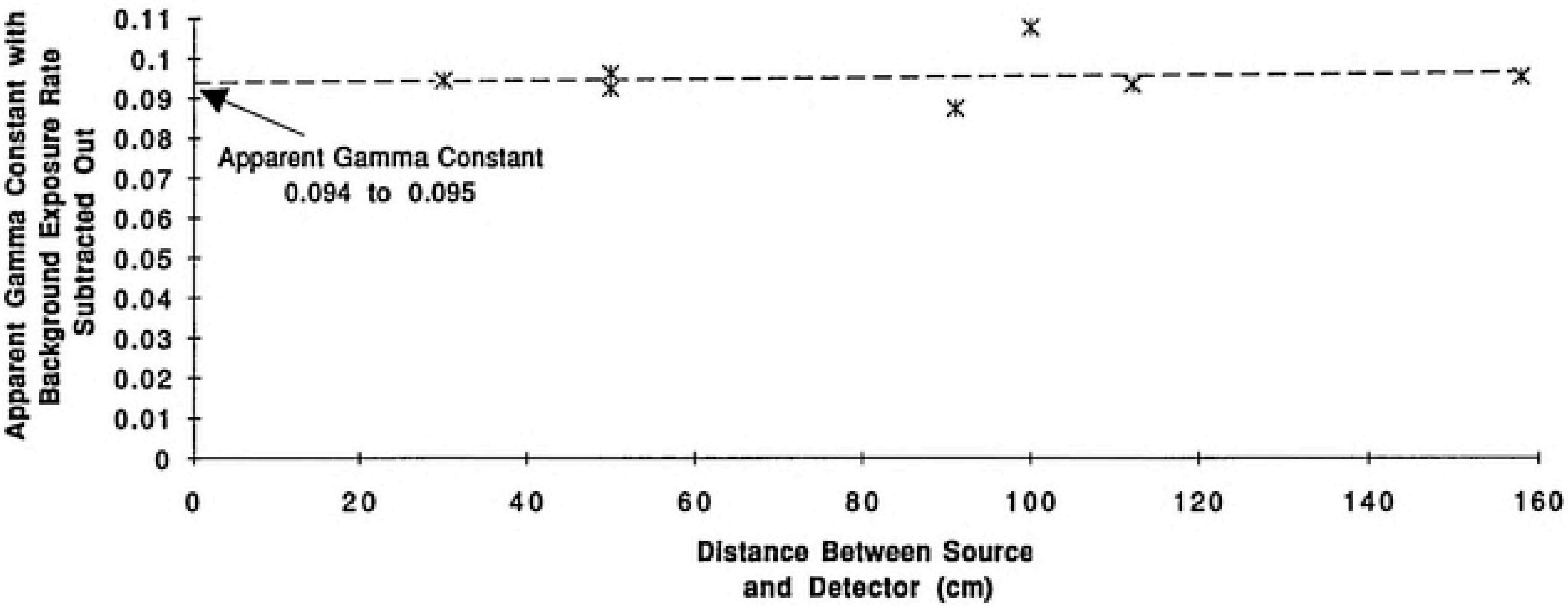
average	1.852
std dev	0.072

7/16/92 Bob Wilson's Am2421 Gamma Constant Data

source and detector approx 1 m from floor on lab bench

Separation distance (cm)	50		30		100	
	in field mR/h	background from 7/20/92 mR/h	in field mR/h	background from 7/20/92 mR/h	in field mR/h	background from 7/20/92 mR/h
	10.968		*27.240*		*4.296*	
	11.112		*26.880*		*4.488*	
	11.064					
mean	11.048	1.852	27.060	1.852	4.392	1.852
stdev	0.073		0.255		0.136	
net mean		9.196		25.208		2.540
gamma constant		**0.096**		**0.095**		**0.108**

Am241 Gamma Constant Determination Data



Bob Nolan, RSO
16 July 92

15 July 92 Am-241 Calibration Source Output

Measurements made with MDH Model 1015C, SN 2115
and Model 10X5-180 Ion Chamber, SN 5-896
System calibrated by MDH, July 10, 1990,
with 150 kVp x-ray with 10 mm Al filtration
Chamber correction factor: 1.00.

I. Measurements at base distance of 0.5 m:

10.968 mR/hr (taken in integrate mode
11.112 " for 5 min periods)
11.064 "
11.048 mR/hr, mean ± 0.14, 2 SD

.095

II Measurements at 0.3 m:

27.24 mR/hr (taken in integrate mode for
26.88 " 5 min. periods)
27.06 mR/hr, mean ± 0.51, 2 SD

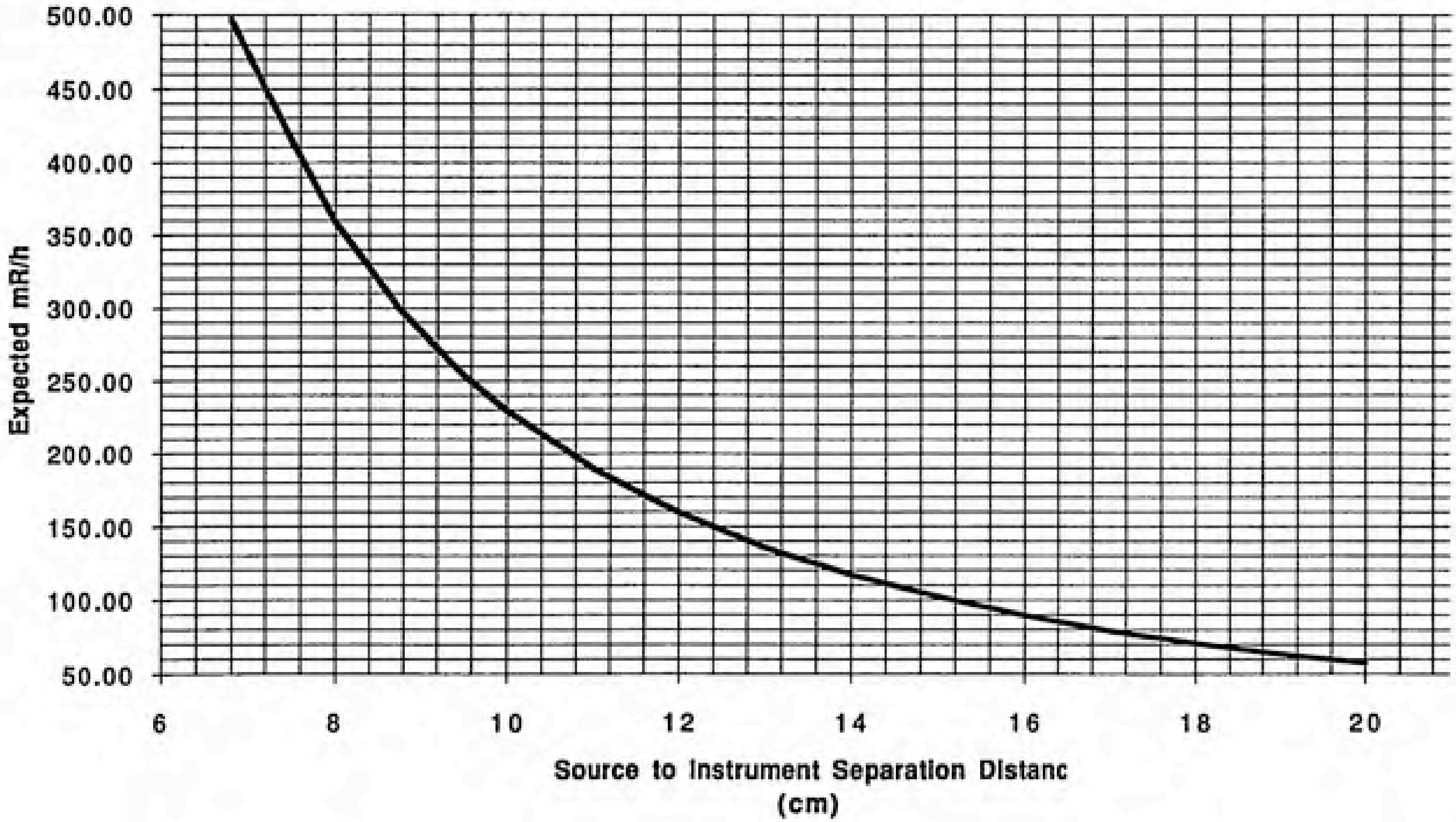
.094

III Measurements @ 1.0 m:

4.296 mR/hr (taken in integrate mode for
4.488 5 min. periods)
4.392 mR/hr, mean ± 0.27, 2 SD.

.106

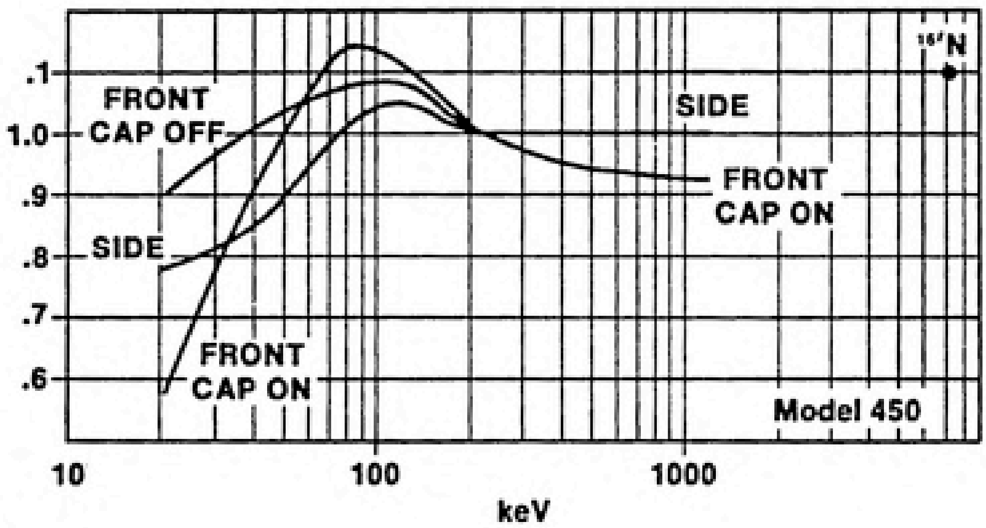
Am241:
Expected Exposure Rate as Function of Distan



Enclosure 8

Enclosure 9

Victoreen's Model 450 Ion Chamber Energy Response Data



REFERENCES

1. ANSI N13.2-1969, USA Standard - Guide for Administrative Practices in Radiation Monitoring, American National Standards Institute, New York, 1969

2. ANSI N13.4-1971, American National Standard for the Specification of Portable X- or Gamma Radiation Survey Instruments, American National Standards Institute, New York, 1971

3. ANSI N14.5-1987, American National Standard for Radioactive Materials - Leakage Tests on Packages for Shipment, American National Standards Institute, New York, 1987

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