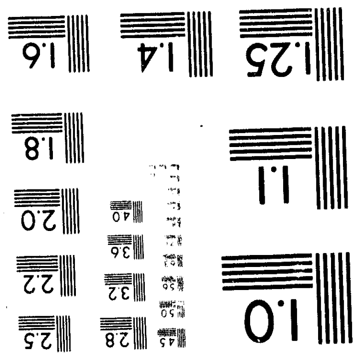

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Technical Basis For External Dosimetry At The Waste Isolation Pilot Plant (WIPP)

Prepared for
The U.S. Department of Energy

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TECHNICAL BASIS FOR EXTERNAL DOSIMETRY
AT THE WASTE ISOLATION PILOT PLANT (WIPP)

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**TECHNICAL BASIS FOR EXTERNAL DOSIMETRY
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List of Acronyms

ALARA - As Low As Reasonably Achievable
CH - Contact Handled
DOE - Department of Energy
DOELAP - DOE Laboratory Accreditation Program
DRD - Direct Reading Dosimeter
ECC - Element Correction Coefficient
ES&H - Environmental, Safety & Health
GET - General Employee Training
HQ - Headquarters
LLD - Lower Limit of Detection
MMES - Martin Marietta Energy Systems
M&O - Management and Operating
OHP - Operational Health Physics
PC - Personal Computer
PDIS - Personnel Dosimetry Intercomparison Study
PMT - Photomultiplier Tube
PNL - Pacific Northwest Laboratory
PSO - Program Secretarial Officers
QC - Quality Control
RadCon - Radiological Control
RCF - Reader Calibration Factor
RH - Remote Handled
RMA - Radioactive Materials Area
RWP - Radiological Work Permit
SWB - Standard Waste Box
TLD - Thermoluminescent Dosimeter
TLDREMS - TLD Radiation Evaluation and Management System
TRU - Transuranic
TTP - Time Temperature Profile
WAC - Waste Acceptance Criteria
WHB - Waste Handling Building
WIPP - Waste Isolation Pilot Plant

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1.0 INTRODUCTION

1.1 SCOPE

The WIPP External Dosimetry Program, administered by Westinghouse Electric Corporation, Waste Isolation Division, for the U.S. Department of Energy (DOE), provides external dosimetry support services for operations at the Waste Isolation Pilot Plant (WIPP) Site. These operations include the receipt, experimentation with, storage, and disposal of transuranic (TRU) wastes.

This document describes the technical basis for the WIPP External Radiation Dosimetry Program. The purposes of this document are to:

- provide assurance that the WIPP External Radiation Dosimetry Program is in compliance with all regulatory requirements
- provide assurance that the WIPP External Radiation Dosimetry Program is derived from a sound technical base
- serve as a technical reference for radiation protection personnel
- aid in identifying and planning for future needs

The external radiation exposure fields are those that are documented in the WIPP Final Safety Analysis Report (reference 8.9).

1.2 OBJECTIVES

The WIPP External Dosimetry Program is part of the overall site radiation protection organization. The External Dosimetry Program is administered by the Dosimetry and Analytical Technology Section. Radiation protection also includes Operational Health Physics (OHP) and Radiological Engineering, which are responsible for monitoring personnel for external radiation exposure on a daily basis using direct-reading dosimeters, area radiation monitors, air radioactivity monitors, area radiation surveys, radioactive contamination control, and airborne radiation respiratory protection. The ALARA program is administered by Safety Analysis Review.

The year-to-date accountability of personnel radiation exposures is accomplished through the use of the thermoluminescent dosimeter (TLD) readings, prior and concurrent occupational radiation exposures obtained off the WIPP site, and the subsequent daily accumulation of direct-reading dosimeter readings. The direct-reading dosimeter program is implemented by OHP. The TLD program compliments the direct-reading dosimeter program by measuring the exposure monthly and/or quarterly. The results of the TLD program are entered into the individual's radiation exposure history records.

Through this comprehensive program, the adequacy of radiological control measures are validated, thus ensuring that the WIPP Administrative Dose Control Levels are not exceeded.

1.3 EXTERNAL DOSIMETRY REQUIREMENTS

1.3.1 DOE/EH-0256T Radiological Control Manual

1.3.1.1 Chapter 5, Part 1 External Dosimetry, Article 511 Requirements

1. "Personnel dosimetry shall be required for personnel who are expected to receive an annual external whole body dose greater than 100 mrem or an annual dose to the extremities, lens of the eye or skin greater than 10 percent of the corresponding limits specified in Table 1.1. Neutron dosimetry shall be provided when a person is likely to exceed 100 mrem annually from neutrons."

Table 1.1

SUMMARY OF DOSE LIMITS	
Type of Exposure	Annual Limit
Radiological Worker: Whole Body (internal + external)	5 rem
Radiological Worker: Lens of Eye	15 rem
Radiological Worker: Extremity (hands and arms below the elbow; feet and legs below the knees)	50 rem
Radiological Worker: Any organ or tissue (other than lens of eye) and skin	50 rem
Declared Pregnant Worker: Embryo/Fetus	0.5 rem in 9 months
Minors and Students: (under age of 18) Whole Body (internal + external)	0.1 rem
Visitors and Public: Whole Body (internal + external)	0.1 rem

2. Dosimeters shall be issued only to personnel formally instructed in their use and shall be worn only by those to whom the dosimeters were issued.

3. To minimize the number of personnel in the dosimetry program, the issuance of dosimeter is discouraged to other than personnel entering Radiation Areas, High Radiation Areas or Radiological Buffer Areas where there is a potential for external exposure. Although issuing dosimeters to personnel who are not occupationally exposed to radiation can appear as a conservative practice, it creates the impression that the wearers are occupationally exposed to radiation.

4. Personnel shall return dosimeters for processing as scheduled or upon request, and should be restricted by line management from continued radiological work until dosimeters are returned.

5. Personnel shall wear their primary dosimeters on the chest area, on or between the waist and the neck, in the manner prescribed by dosimetry personnel.

6. Film dosimeters shall not be worn or taken off-site unless specifically authorized by the Radiological Control Manager.

7. The practice at some facilities of taking thermoluminescent dosimeters (TLDs) off-site is discouraged and shall not be implemented where not in place.

8. Personnel shall not wear dosimeters issued by their resident facilities while being monitored by dosimeter at another site. Personnel shall not expose their dosimeters to security x-ray devices, excessive heat, or medical sources of radiation.

9. A person whose dosimeter is lost, damaged, or contaminated should place work in a safe condition, immediately exit the area and report the occurrence to the Radiological Control Organization. Reentry of the person into Radiological Buffer Areas should not be made until a review has been conducted and management has approved reentry.

1.3.1.2 Chapter 5, Part 1 External Dosimetry, Article 512 Technical Requirements for External Dosimetry

1. DOE 5480.15 specifies the requirements for accreditation of personnel external dosimetry monitoring programs by the DOE Laboratory Accreditation Program (DOELAP). A technical basis document shall be developed for the external dosimetry program. Personnel external dosimeters include but are not limited to TLDs, track etch dosimeters and neutron sensitive film.

2. The technical basis document shall also address dosimeters monitoring radiation outside the scope of DOELAP, such as dosimetry associated with high-energy accelerators and extremity dosimeters.

3. Facilities should participate in intercomparison studies for external dosimetry programs.

4. Personnel exposures to the skin, lens of the eye and extremities shall be reported separately when monitored.

5. Multiple dosimeters should be issued to personnel to assess whole body exposure in non-uniform radiation fields or as required on Radiological Work Permits. Non-uniform radiation fields exist when the dose to a portion of the whole body will exceed the dose to the primary dosimeter by more than 50 percent and the anticipated whole body dose is greater than 100 mrem. The technical basis document should describe the methodology used in determining the dose of record when multiple dosimeters are used.

6. A dose assessment shall be performed for each instance of a lost, damaged or contaminated personnel dosimeter.

1.3.2 DOE Order 5480.11 Radiation Protection for Occupational Workers

1.3.2.1 9.g.(1)

Personnel dosimetry programs shall be adequate to demonstrate compliance with the radiation protection standards provided in paragraph 9b. Personnel dosimeters shall be routinely calibrated and maintained and shall meet the requirements of the DOE Laboratory Accreditation Program for Personnel Dosimetry as specified in DOE Order 5480.15. Personnel dosimetry shall be provided to radiation workers who have the potential to exceed in a year any one of the following from external sources:

(a) One hundred mrem (0.001 sievert) annual effective dose equivalent to the whole body.

(b) Five rem (0.05 sievert) annual dose equivalent to the skin.

(c) Five rem (0.05 sievert) annual dose equivalent to any extremity.

(d) One and a half rem (0.015 sievert) annual dose equivalent to the lens of the eye.

1.3.3 DOE Order 5480.15 Department of Energy Laboratory Accreditation Program for Personnel Dosimetry

Heads of DOE and DOE Contractor Personnel Dosimetry Programs or their designated representatives shall:

(1) Complete and submit an initial application for a DOE Laboratory Accreditation Program performance evaluation through the Head of the appropriate Field Element who must concur on the application. Applications are contained in DOE/EH-0026.

(2) Submit dosimeters for testing upon request of the Performance Evaluation Program Administrator. Each test requires three separate submissions of dosimeters at intervals of approximately one month.

(3) Evaluate irradiated dosimeters in terms of the units specified by DOE/EH-0027 and report the values to the Performance Evaluation Program Administrator.

(4) Allow site assessors to examine all aspects of the program, including facilities, equipment, dosimeters, procedures, notebooks, records, reports, position descriptions, personnel qualifications, and training documentation.

(5) Respond in writing within 45 days of receipt of the site assessment report to any recommendations. Responses should be sent to the Performance Evaluation Program Administrator, with the concurrence of the Head of the appropriate Field Element. The response shall include corrective action (as appropriate) and completion dates.

(6) Within 60 days, identify and implement plans to make appropriate changes in equipment, procedures, and/or personnel to achieve a program capable of receiving accreditation in the event that accreditation is denied. Plans shall have the concurrence of the Head of the appropriate Field Element.

(7) Apply and complete testing procedures and on site assessment for re-accreditation before each 2-year anniversary of the initial accreditation.

1.3.4 DOE/EH-0026 Handbook for the Department of Energy Laboratory Accreditation Program for Personnel Dosimetry Systems

1.3.4.1 Scope of Accreditation Program

The DOELAP for personnel dosimetry systems applies to the technical aspects of personnel dosimetry systems at DOE/DOE contractor facilities and to the documentation of those aspects. During the accreditation:

1. A performance testing laboratory evaluates the technical performance of dosimetry systems

2. An on site assessment studies the quality assurance, documentation, and technical adequacy of such systems

Dosimeter types or models used to determine whole-body and skin dose for personnel are included in the scope of the Accreditation Program. Accreditation currently does not apply to extremity dosimeters, pocket ionization chambers, thermal neutron dosimetry, and high-energy neutron dosimetry.

The DOELAP test standard scope is limited. Approximate energy intervals covered are: 15 keV to 2 MeV for photons; above 0.3 MeV for beta particles; and 1 keV to 2 MeV for neutrons.

Every two years, each DOE contractor must maintain its accreditation by demonstrating compliance with DOELAP criteria.

1.3.4.2 Accreditation Process

To obtain accreditation, a DOE contractor must first submit an application through the field office. The contractor must then satisfy both the performance testing and the on site assessment requirements. The Performance Evaluation Program Administrator prepares an administrative report documenting the test results and recommendations for accreditation. The Oversight Board evaluates the report and the recommendation and, if approved, sends them to the HQ (DOE Headquarters) DOELAP Administrator. The HQ DOELAP Administrator makes the final decisions on accreditation and issues the Certificates of Accreditation. A Certificate of Accreditation specifies the model(s) or type(s) of dosimeters accredited for specific radiation categories.

1.3.5 DOE/EH-0027 Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems

1.3.5.1 Test Procedures

The applicant shall certify that the dosimeters submitted for each test are representative of those supplied routinely to its users.

The dosimeters shall be submitted to the testing laboratory in three shipments.

The applicant shall report the evaluations to the testing laboratory within 45 days of receiving the dosimeters.

The testing laboratory shall report all test results to the applicant after the test is completed. An estimate of the uncertainty of the assigned values of the delivered dose equivalent (or absorbed dose) shall be included in the report. The applicant shall not be permitted to change or void the reported values after receiving the test results from the testing laboratory.

1.3.5.2 Performance Standards

Performance standards for the DOELAP irradiation categories are listed in Table 1.2.

Table 1.2

DOELAP IRRADIATION CATEGORIES				
CATEGORY	DESCRIPTION	TEST RANGE (rem/rad)	TOLERANCE LEVEL Deep	Shallow
I *	Low-Energy Photons (X-Ray) NBS Filtered Technique - M150[a] 70 keV[b]	10 - 500	0.3	n/a
II	High-Energy Photons (^{137}Cs[a]) 662 keV	10 - 500	0.3	n/a
IIIA	Low-Energy Photons (X-Ray) General NBS Filtered Techniques M30[a] - 20 keV[b] S60[a] - 36 keV[b] M150[a] - 70 keV[c] H150 - 120 keV[c]	0.03 - 10	0.3	0.3
IIIB *	Low-Energy Photons (X-Ray) Plutonium Environments monoenergetic - 15 to 20 keV monoenergetic - 55 to 65 keV ^{241}Am[d] - 59 keV	0.03 - 5	0.3	0.3
IV *	High-Energy Photons (^{137}Cs[a]) 662 keV	0.03 - 10	0.3	0.3
VA *	Beta Particles - General Point Geometry ^{204}Tl[a] - 0.76 MeV[f] ^{90}Sr/^{90}Y (filtered)[a] - 2.3 MeV[f]	0.15 - 10	n/a	0.3
VB	Beta Particles - Special Slab Geometry Uranium - 2.3 MeV[f]	0.15 - 5	n/a	0.3
VC	Beta Particles - Special Point Geometry ^{204}Tl[a] - 0.76 MeV[f] ^{90}Sr/^{90}Y - 2.3 MeV[f]	0.15 - 10	n/a	0.3
VI	Neutrons ^{252}Cf (moderated)[g] * ^{252}Cf (unmoderated)	0.20 - 5	0.3	n/a
VII *	Mixtures III + IV[a] III + V IV + V[a] III + VI[h] IV + VI[a]	0.05 - 5 0.20 - 5 0.20 - 5 0.30 - 5 0.30 - 5	0.4 0.4 0.4 0.4 0.4	0.4 0.4 0.4 n/a n/a

* Categories applicable to WIPP.
n/a not applicable
a This category or a subset of this category is also specified in ANSI N13.11-1983.
b Average
c Effective
d The ^{241}Am source is optional. At the option of the testing laboratory, it may be used in lieu of the 55 to 65 keV monoenergetic source.
e A modified performance algorithm is recommended.
f Maximum
g Moderated by 15 cm of D_2O.
h For work environments containing plutonium, use the monoenergetic or ^{241}Am sources.

For each dosimeter design submitted for testing and for each type of radiation in Categories III through VI for which performance is tested, a study of dosimeter performance when the incident radiation is non-perpendicular shall be carried out once. The study need not be a part of a test series or performed by the testing laboratory. No performance criteria shall be applied to the results of this study.

For each dosimeter design submitted for testing and for at least one source in Categories III through VI for which performance is tested, a study to determine the lower limit of detectability shall be conducted once and reported to the testing laboratory. The study need not be part of a test series or performed by the testing laboratory. No performance criteria shall be applied to the results of this study.

1.3.6 DOE N 5480.6 Radiological Control Notice

Each PSO (Program Secretarial Officers) shall act to apply the provisions of the RadCon Manual (DOE/EH-0256T) to each site, facility or program under his/her responsibility, including those sites, facilities or programs managed by a management and operating (M&O) contractor or another contractor, subcontractor or supplier, to the extent the site, facility or program involves an activity that may potentially result in radiation exposure to workers, the public, or the environment.

Each DOE site, facility, or program shall have an implementation plan that sets forth the resources, actions, and schedule for implementing the RadCon Manual to the fullest extent practicable while using reasonable judgment to minimize unnecessary cost. An implementation plan shall specify any additional costs for implementing the RadCon Manual beyond those currently being spent for radiological control and the basis for the incremental costs.

To the extent there is a conflict between a provision of the RadCon Manual and a provision of DOE 5480.11, "Radiation Protection for Occupational Workers," or any other DOE Order listed on page R-2 of the RadCon Manual, the provision of the RadCon Manual shall supersede the provision of the DOE Order.

1.3.7 WIPP Radiological Control Manual, Chapter 5 Part 1, External Dosimetry, 511 Requirements

1. The frequency for processing TLDs shall be monthly for Radiation Worker II personnel and quarterly for all other personnel. Non-routine processing may be required by Operational Health Physics (OHP) or the Dosimetry section. The Dosimetry section shall ensure that neutron dosimeters used at the WIPP meet the requirements of ANSI N319-1976.

2. The thermoluminescent dosimeter (TLD) is the primary dosimeter used at the WIPP for measuring personnel radiation exposure for permanent record purposes. The TLD measures beta and gamma exposure and distinguishes between penetrating and non-penetrating radiations. The self reading pocket dosimeter and the digital alarming dosimeter are the supplemental dosimeters used at the WIPP for providing real-time indication of gamma radiation exposure. The Dosimetry section is responsible for issuing and controlling primary dosimetry. OHP is responsible for issuing and controlling supplemental dosimetry. Any deviation from this method of issuing personnel dosimetry will be decided and authorized by the Dosimetry section and/or OHP, as applicable.

3. Each individual entering the security area (the area entered through the security gate) will be advised of personnel monitoring requirements according to work assignment and will be provided with the required dosimetry devices. Dosimetry requirements for group tours will be determined on a case-by-case-basis.

4. When not being worn, TLDs shall be stored in racks located in the Guardhouse in accordance with WP 12-3, WIPP Dosimetry Program Manual, Section 1.4.1.

5. All employees shall ensure that their TLDs are routinely exchanged for processing upon the Dosimetry section's request. Personnel failing to make a TLD available for exchange during the designated exchange period shall be restricted from work in a radiological area until the dosimeter is returned to the Dosimetry section or a dose estimate has been completed and a new TLD assigned.

6. Personnel shall not wear dosimeters issued by the WIPP while being monitored by a dosimeter at another site. TRU waste truck drivers are excluded from this policy per WP 12-3, WIPP Dosimetry Program Manual, Section 1.4.1.Personnel shall not expose their dosimeters to security x-ray devices, or medical sources of radiation. If a primary dosimeter has been subjected to any of the above conditions, the Dosimetry section shall be notified immediately. If it is a supplemental dosimeter, OHP shall be notified immediately. Deliberate abuse of any dosimeter is a basis for disciplinary action.

7. Every reasonable effort shall be made to avoid radioactive contamination of dosimeters to prevent possible erroneous measurements.

512 Technical Requirements for External Dosimetry

1. The expected radiation fields at the WIPP are all within the scope of DOELAP. Although it is not anticipated that there will be a need for extremity dosimeters, this will be verified during the preparation of a Radiological Work Permit (RWP).

2. Need for extremity monitoring shall be determined by the Operational Health Physics (OHP) Manager and the Dosimetry Manager on an individual job basis.

3. All dose indicated by a damaged or contaminated dosimeter shall be assumed to have been received by the individual unless it can be clearly demonstrated otherwise.

4. Radiation Safety or the Dosimetry section shall be immediately notified whenever there is a question concerning the ability of a dosimeter to perform properly.

5. All employees, visitors and contractor personnel working at the WIPP shall, upon request, provide a history of prior work with sources and with a release allowing the WIPP to have a complete record of exposure received while performing such work.

6. The Dosimetry section shall prepare and retain exposure records in accordance with Chapter 7, Radiological Records and WP 12-3, WIPP Dosimetry Program Manual.

2.0 RADIATION EXPOSURE SOURCE TERMS

TRU waste is radioactive waste that, without regard to source or form, is contaminated with alpha-emitting TRU radionuclides with half lives greater than 20 years in concentrations greater than 100 nCi/g. Heads of DOE Field Organizations can determine that other alpha-contaminated waste, peculiar to a specific site, must be managed as TRU waste (see reference 8.9, paragraph 3.1.1).

The criteria by which TRU waste will be accepted for emplacement at the WIPP facility and a description of the basis upon which these criteria were established are presented in WIPP-DOE-069 (Waste Acceptance Criteria for the Waste Isolation Pilot Plant) (see reference 8.9, paragraph 3.1.1).

TRU waste that will be accepted at WIPP is divided into two classifications; contact handled TRU waste (CH TRU) and remote handled TRU waste (RH TRU).

The sources of radiation exposure at the WIPP facility, during normal operations, are limited to the CH TRU and RH TRU waste that will be handled at the facility. Radiation exposure for workers can be in the form of either direct exposure or inhalation of contaminated particulate (reference 8.9, Chapters 1A.2.2 and 6.1.2.1). Other sources of radiation may include in-plant generated solid or liquid radioactive waste having radiation levels that are much lower than those of the CH TRU waste (reference 8.9, Chapter 1A.2.3.1 and 6.1.2.1). Areas within the facility where this exposure could occur include the Waste Handling Building (WHB) and the Underground Storage Areas. The source terms described for direct radiation analysis use maximum expected values and conservative assumptions (reference 8.9, Chapters 1A.2.3.1 and 6.1.2.1).

Alpha and beta particles within the waste containers are essentially shielded by the waste containers themselves and do not contribute to the external dose (reference 8.9, Chapters 1A.2.3.1 and 6.1.2.1). Beta-generated bremsstrahlung contribution to the gamma spectrum is not significant and thus was not considered (reference 8.9, Chapter 6.1.2.1).

2.1 CONTACT HANDLED TRANSURANIC WASTE

CH TRU waste refers to TRU waste materials that are packaged in such a way that the dose rate at the surface of the waste package is not greater than 200 mrem/hr (reference 8.9, Chapter 3.1.1.1).

The waste exists in a wide variety of physical forms. These forms range from unprocessed general trash and concrete stabilized sludge to decommissioned machine tools and glove boxes. For acceptance at the WIPP facility, the waste must be stabilized or packaged to eliminate it as a propagational fire source. Free liquids are minimized. The density of CH TRU waste is assumed to be a maximum of 2.2 g/cm^3 and is expected to be about 1.0 g/cm^3 on the average (reference 8.9, Chapter 3.1.1.1).

The radionuclide composition of CH TRU waste varies widely among the DOE facilities that generate the waste. To simplify radiological analyses, the mean activity of a 55-gallon drum, for each generator, has been normalized (weighted) based on the estimated number of containers contributed by each facility to the WIPP. Taking the product of this weighted activity with the individual radionuclide distributions for each generator and combining them represents the radionuclide breakdown of an average drum shipped to the WIPP facility. The representative radionuclide distribution for CH TRU wastes are shown in Tables 2.1 and 2.2 (reference 8.9, Chapter 3.1.1.1.2).

Table 2.1

REPRESENTATIVE RADIONUCLIDE CONTENT OF CH TRU WASTE DRUM		
RADIONUCLIDE	MASS PERCENT (grams/container)	ACTIVITY (Ci/container)
Th-232	6.0 E + 00	6.6 E - 07
U-233	1.7 E + 00	1.7 E - 02
U-235	4.0 E - 01	8.8 E - 07
U-238	1.0 E + 01	3.5 E - 06
Np-237	3.1 E - 02	2.2 E - 05
Pu-238	6.2 E - 01	1.1 E + 01
Pu-239	1.4 E + 01	8.5 E - 01
Pu-240	8.5 E - 01	1.9 E - 01
Pu-241	6.6 E - 02	6.8 E + 00
Pu-242	7.8 E - 03	3.1 E - 05
Am-241	4.9 E - 01	1.7 E + 00
Cm-244	4.2 E - 04	3.4 E - 02
Cf-252	1.0 E - 05	5.4 E - 03
Total	3.4 E1	20.6

Table 2.2

REPRESENTATIVE RADIONUCLIDE CONTENT OF CH TRU WASTE STANDARD WASTE BOX		
RADIONUCLIDE	MASS PERCENT (grams/container)	ACTIVITY (Ci/container)
Th-232	1.2 E + 01	1.3 E - 06
U-233	6.7 E + 00	6.5 E - 02
U-235	9.6 E - 01	2.1 E - 06
U-238	2.5 E + 01	8.3 E - 06
Np-237	4.4 E - 04	3.1 E - 07
Pu-238	4.2 E - 02	7.2 E - 01
Pu-239	7.9 E + 01	4.9 E + 00
Pu-240	6.5 E + 00	1.5 E + 00
Pu-241	6.7 E - 01	6.9 E + 01
Pu-242	7.5 E - 02	2.9 E - 04
Am-241	2.1 E - 01	7.3 E - 01
Cm-244	8.6 E - 05	7.0 E - 03
Cf-252	2.1 E - 06	1.1 E - 03
Total	1.3 E2	77.0

According to the Waste Acceptance Criteria (WAC), the fissile material content in equivalent grams of ^{239}Pu is a maximum of 200 grams for a 55-gallon drum and 5 g/cm^3 up to 350 grams for boxes. These limits have been evaluated to show that they pose no criticality concern at the WIPP facility. The average content is approximately 17 grams for a 55-gallon drum and 90 grams for the most common box used to store waste (4 feet by 4 feet by 7 feet) (reference 8.9, Chapter 3.1.1.1.2).

By definition, the surface dose rate on CH TRU waste containers is not greater than 200 mrem/hr. In practice, very few of the containers would have surface dose rates approaching the maximum. Present information suggests that the mean surface dose rate for drums to be shipped from all generators to the WIPP facility will be less than 14 mrem/hr. This average is based on the Integrated Data Base, which is frequently updated by the DOE. Whenever such updates occur, the average will be re-evaluated and impacts of changes assessed. For this report the average surface dose rate on a 55-gallon drum or box of CH TRU waste is assumed to be 14 mrem/hr. This is a conservative estimate that provides an adequate margin should there be an increase in surface dose rate due to radionuclide concentration in waste processing, ingrowth of ^{241}Am, or a change in the internal shielding configuration. The WAC requires that packages with neutron surface dose rates greater than 20 mrem/hr have these rates noted separately in the data package (reference 8.9, Chapter 3.1.1.1.3).

The average dose rate for a CH TRU waste 55-gallon drum is 14.0 mrem/hr at four inches from the surface and for a standard waste box (SWB) is estimated to be 5 mrem/hr (reference 8.9, Chapter 1A.2.4.1).

2.2 REMOTE HANDLED TRANSURANIC WASTE

A fraction of the TRU waste generated exceeds the CH TRU surface dose rate of 200 mrem/hr. This waste is designated as RH TRU waste (reference 8.9, Chapter 3.1.1.2).

The Oak Ridge National Laboratory is projected to be the predominant source of RH TRU waste. The existing RH TRU waste contains a wide range of radionuclides. For use in analyzing postulated accidents, an average reference waste has been derived. This reference waste consists of a normalized actinide inventory based on the current data base and an assumed distribution of mixed activation and fission products. Table 2.3 characterizes the radionuclide content of RH TRU waste. Concentrations of all radionuclides will not exceed 23 Ci/l (reference 8.9, Chapter 3.1.1.2.2).

Table 2.3

REPRESENTATIVE RADIONUCLIDE CONTENT OF RH TRU WASTE		
RADIONUCLIDE[a]	Ci/canister	Ci/l
Co-60	1.7 E - 01	2.0 E - 04
Sr-90	5.1 E + 00	6.0 E - 03
Ru-106	3.5 E - 02	4.2 E - 05
Sb-125	1.1 E - 03	1.2 E - 06
Cs-137	4.3 E + 00	5.0 E - 03
Ce-144	3.4 E - 01	4.0 E - 04
Eu-155	1.7 E - 03	2.0 E - 06
U-233	5.5 E - 03	6.5 E - 06
U-235	3.0 E - 03	3.6 E - 06
U-238	1.5 E - 03	1.7 E - 06
Pu-238	5.7 E + 00	6.7 E - 03
Pu-239	6.8 E + 00	8.0 E - 03
Pu-240	2.2 E + 00	2.5 E - 03
Pu-241	1.2 E + 01	1.4 E - 02
Pu-242	3.8 E - 04	4.5 E - 07
Am-241	2.1 E - 01	2.5 E - 04
Cm-244	1.6 E - 01	1.9 E - 04
Cf-252	2.8 E - 01	3.3 E - 04
Total	3.7 E + 01	4.3 E - 02

a daughter products are not included

An upper limit of 1000 rem/hr is defined as the maximum dose rate at the surface of a RH TRU waste canister. However, no more than 5 percent of the total allowed volume of 250,000 cubic feet will exceed 100 rem/hr surface dose rate. Neutron contributions are limited to 270 mrem/hr. On an exception basis with prior approval, RH TRU waste canisters with a dose rate in excess of 100 rem/hr, but less than 1000 rem/hr, may be shipped to the WIPP facility (reference 8.9, Chapter 3.1.1.2.3).

The average dose rate for RH TRU waste transport casks and RH TRU facility cask is estimated to be 2.0 mrem/hr at four inches from the cask surfaces (reference 8.9, Chapter 1A.2.4.1).

2.3 EXTERNAL DOSE ESTIMATES

Radiological impacts during normal operations have been estimated for the primary occupationally exposed groups involved in waste handling operations at the WIPP facility. The results are representative values, determined by estimating dose rates based on shielding analyses, the characterizations of the waste forms, time and motion/manpower studies for the handling of the waste, and the estimated quantities of waste received. The time and motion/manpower information used is based on the current concept of staffing levels and the organization planned for WIPP facility operations (reference 8.9, Chapter 1A.2.4.1).

In unshielded areas, estimated exposure rates are based on the dose rates from waste containers and the expected range of distances between radiation sources and personnel. For shielded areas, e.g., immediately outside the hot cell, the exposure rate is conservatively estimated from shielding analyses that consider effectiveness using experimental waste as the design source (reference 8.9, Chapter 1A.2.4.1).

Although the CH TRU waste contains alpha- and beta-emitting nuclides, the primary radiation of interest in shielding calculations is gamma rays. Alpha and beta particles are essentially shielded by the waste containers and do not significantly contribute to the external dose with the possible exception of a beta-generated bremsstrahlung contribution to the gamma spectrum. For shielding design calculations, a spectrum representing typical waste containing TRU nuclides and fission products was derived. The gamma spectrum selected as being representative of the CH TRU waste gamma radiation is characterized by an RH TRU radionuclide distribution with a reduced photon source. The selection of this spectrum is believed to yield conservative results since the photon energies are greatly skewed to the higher energies. Photon energies for TRU radionuclides are typically much lower (reference 8.9, Chapter 6.1.2.1).

The average and maximum gamma source strengths used in the CH TRU waste shielding calculations are based on a design average CH TRU waste surface exposure rate of 10 mrem/hr and the maximum CH TRU waste surface exposure rate of 200 mrem/hr.

Photons of up to 2 MeV are expected from either CH or RH wastes. These energies are covered by DOELAP performance testing indicating adequate performance of the WIPP Dosimetry system for the expected sources.

A few neutron sources have been identified for CH TRU waste, but the neutron component of the total dose rate for these few identified waste forms is typically quite small (reference 8.9, Chapter 6.1.2.1).

The estimated annual exposure during normal CH TRU waste handling to various categories of workers is as follows (reference 8.9, Chapters 1A.2.4.1 and 6.1.4.2):

- Waste Handlers 0.70 rem/yr
- Radiation Control 0.60 rem/yr
- Average Individual 0.68 rem/yr

The estimated annual exposure during normal RH TRU waste handling to various categories of workers is as follows (reference 8.9, Chapters 1A.2.4.1 and 6.1.4.2):

- Waste Handlers 0.09 rem/yr
- Radiation Control 0.25 rem/yr
- Average Individual 0.12 rem/yr

The estimated annual exposure during normal handling of all TRU waste to various categories of workers is as follows (reference 8.9, Chapter 6.1.4.2):

- Waste Handlers 0.79 rem/yr
- Radiation Control 0.87 rem/yr
- Average Individual 0.81 rem/yr

Abnormal operations include tasks such as cask and waste container decontamination and repair. It is conservatively assumed for purposes of assessing radiological impacts that 1 percent of RH shipping casks require external decontamination and 1 percent of the CH TRU containers are damaged or contaminated to the extent that decontamination or over-packing is required. External radiation dose to personnel for each abnormal operational activity is estimated to be 0.11 person-rem/yr for CH TRU waste handling and 0.03 person-rem/yr for RH TRU cask decontamination (reference 8.9, Chapter 1A.3).

3.0 WIPP EXTERNAL PERSONNEL DOSIMETRY

To implement the personnel external radiation monitoring requirements of DOE Order 5480.11 at the WIPP site, all site personnel (Westinghouse employees, WPSO staff, SNL personnel, subcontractors, and visitors) will be classified as belonging to one of the following exposure group classifications (reference 8.12, Section 1.4.1):

Group I — Personnel whose job description gives them the potential to work (on the average) more than 10 hours per week or in the proximity of radioactive materials in a RMA (radioactive material area).

Group II — Personnel who work (on the average) less than 10 hours per week with or in the proximity of radioactive materials in RMA(s).

Group III — Personnel who do not routinely perform work with or in the proximity of radioactive materials in RMA(s).

Upon waste receipt, external radiation monitoring at the WIPP site shall be performed according to the sampling rationale and scheduled frequency shown in Table 3.1 (reference 8.12, Section 1.4.1). The WIPP may elect to perform all or part of the monitoring program prior to waste receipt. The purposes of conducting external dosimetry monitoring prior to waste receipt may include (but not limited to) maintenance of DOELAP accreditation, training and qualification of dosimetry personnel, monitoring of selected workers with recorded exposure from previous jobs, and training of site personnel on the use and care of dosimeters.

Table 3.1

WIPP ROUTINE EXTERNAL MONITORING SCHEDULE				
EXPOSURE GROUP	PORTION OF GROUP SAMPLED	METHOD OF MONITORING	FREQUENCY OF MONITORING	FREQUENCY OF READING
I, II	All	DRD[a] TLD	Continuous while in RMA[b] Continuous while on WIPP site	Each entrance and exit Quarterly[c]
III	All	TLD	Continuous while on WIPP site	Quarterly[c]
Visitors	All	TLD	Continuous while on WIPP site	Upon completion of visit

a Direct-Reading Dosimeter
b Radioactive Materials Area
c Monthly if exposure is expected to approach 1 rem annually.

Upon receipt of TRU waste, all individuals shall be issued a TLD. Brief verbal and written instructions will be provided on the proper use and care of the TLD. Monitored individuals are instructed to leave the dosimeter at the site entry/exit when leaving the site and to pick up their assigned TLD upon returning to the site. An exception to this policy is for the TRU waste truck drivers, who will wear their dosimeters during transport of the TRU waste (reference 8.12, Section 1.4.1).

TLDs will be exchanged quarterly for most individuals. Individuals with projected exposures approaching 1 rem annually will have their TLDs exchanged monthly. In addition, TLDs will be exchanged more frequently if the daily recording of the direct-reading dosimeter results approach an Administrative Control Level, or other conditions exist that require immediate dosimetry results. Conditions that would require immediate dosimetry results include (reference 8.12, Section 1.4.1):

- potential overexposure
- potential or expected pregnancy
- lost or damaged dosimeter
  potential or expected internal exposure
- other conditions or situations as determined by the ES&H Manager or the Dosimetry Manager

The current WIPP External Dosimetry Program policy is to provide TLDs to all individuals entering the WIPP Site upon the receipt of TRU waste. This is a conservative policy that ensures that any individual with the potential to receive an annual external whole body dose greater than 100 mrem per year will be provided personnel dosimetry (reference 8.6, Article 511). This policy is justified for the following reasons:

- Obtaining initial DOELAP accreditation requires significant lead time and operational experience

- DOELAP re-accreditation requires the continued demonstration of proficiency

- The initial training and experience of individuals in the proper wearing, use, and care of the TLD will ensure continued good practices in personnel dosimetry upon the arrival of TRU waste at the WIPP site

This policy will be re-evaluated when sufficient operational experience and information is obtained such that continued compliance with Article 511 of the DOE Radiological Control Manual may be demonstrated while providing personnel dosimetry to fewer individuals.

3.1 THERMOLUMINESCENT DOSIMETER (TLD)

The TLD utilized at the WIPP site is the Harshaw[1] 8805. This dosimeter is composed of a four element TLD card placed in a TLD card holder. The TLD card holder has various radiation filters over the TLD card elements to determine radiation type and quality. The quantity of radiation is determined by reading the TLD card in a TLD card reader and processing the TLD card element readings through a dose calculation algorithm which reports the deep, shallow, and neutron radiation dose in units of rem (reference 8.8).

3.1.1 TLD Card

The Harshaw model 8801 (7776-1141) TLD card is composed of four thermoluminescent (TL) elements encapsulated between two thin sheets of teflon and sandwiched between aluminum jackets. The jackets have four holes for the TL elements such that the TL elements can be heated by the hot N_2 gas and the resulting TL signal recorded by the photomultiplier tubes of the reader (reference 8.8).

[1]Harshaw was the original name of the company that developed the TLD card and TLD card reader system. The name has changed from Harshaw, to Harshaw/Filtrol Partnership, to Engelhard Corporation, to Solon Technologies Inc. (STI), and now to Bicron. The TLD cards and TLD card reader products are now in the Harshaw/Bicron Radiation Measurement Products product line of Bicron. For simplicity, this report will continue to use the word Harshaw.

The physical attributes of the 8801 TLD card TL elements are listed in Table 3.2.

Table 3.2

TLD CARD PHYSICAL ATTRIBUTES			
POSITION	MATERIAL	SIZE (inches)	THICKNESS (inches)
1	TLD-700	1/8" x 1/8"	0.015"
2	TLD-700	1/8" x 1/8"	0.015"
3	TLD-700	1/8" x 1/8"	0.0036"
4	TLD-600	1/8" x 1/8"	0.015"

A barcode is positioned in the center portion of the card to uniquely identify each card.

The Lithium Fluoride (LiF) (TLD-700) material has a characteristic glow curve. The attributes are listed in Table 3.3 (Harshaw training manual, 1990).

Table 3.3

TLD-700 GLOW CURVE CHARACTERISTICS		
GLOW CURVE PEAK	TEMPERATURE (^{o}C)	FADE (half life)
1	59	20 seconds - 5 minutes
2	120	10 hours
3	137	0.5 years
4	170	7 years
5	195	80 years

The TLD-700 chip is LiF enriched with approximately 99.93% ^{7}Li and the TLD-600 chip is LiF enriched with approximately 95.62% ^{6}Li. The TLD-600 chip is the neutron sensitive element.

3.1.2 TLD Card Holder

The Harshaw 8805 TLD card holder is configured with various radiation filters. The filters are listed in Table 3.4.

Table 3.4

TLD CARD HOLDER CHARACTERISTICS	
POSITION	MATERIAL (mg/cm^2)
1	ABS/Teflon (1000)
2	ABS (242) Cu (91)
3	Mylar (17)
4	ABS (300)

3.1.3 Thermoluminescent Dosimeter

The WIPP External Dosimetry Program utilizes the Harshaw model 8805 TLD card holder. A Harshaw model 8801 TLD card is placed inside the card holder. The entire package consisting of one TLD card in a TLD card holder is referred to as the WIPP personnel dosimeter.

3.1.4 Harshaw TLD System 8800C Card Reader

The Harshaw 8800C TLD Card Reader system consists of two major components, the TLD card reader and the TLD Radiation Evaluation and Management System (TLDREMS[2]) software resident on a personal computer (PC).

The Harshaw TLD System 8800C Card Reader is a fully automated instrument for TLD measurement. It combines high capacity and throughput capabilities with non-contact heating. A precisely temperature-controlled stream of hot nitrogen gas is used to heat the TL elements, with the benefits of increased number of re-uses, extended card durability, and dramatic improvement in the reproducibility of glow curves. Up to 1400 cards may be loaded into the TLD card reader for automatic operation.

A transport mechanism in the TLD card reader moves one card at a time to the read station. Here, the barcode identification number is read and the card elements are heated causing them to give off light in proportion to the radiation they have received. The elements are heated by a microprocessor-based, hot gas system capable of generating a precisely controlled time-temperature profile that can be applied simultaneously to the four TL elements of the card without physical contact between the heater and the TL element. Photomultiplier tubes (PMTs) convert the emitted light to electrical signals that are transmitted to a microprocessor based data acquisition system.

As data is generated by the TLD card reader, it is transmitted to the TLDREMS software where it can be monitored as it is received, and stored for future reference and reporting. TLDREMS software also stores information used by the

[2]TLDREMS (TLD Radiation Evaluation and Management System) is a software program developed by Harshaw.

TLD card reader in its operations, such as time temperature profiles[3] (TTPs), Reader Calibration Factors[4] (RCFs), and Element Correction Coefficients[5] (ECCs), requiring that the two components of the system be interactive during all card read operations. It is also used to set the TLD card reader operating parameters and to perform a variety of calibration and Quality Control (QC) operations. The various QC checks include continued TLD card reader operational limits on PMT Noise readings, Reference Light readings, and QC card readings.

3.1.5 TLD Calibration and Controls

Calibration and control programs, policies and procedures are in place to ensure the continued quality of the TLD measurement results. The following activities are included:

- acceptance testing of TLD cards, TLD card holders and TLD card readers
- daily calibration of TLD card reader
- scheduled routine maintenance of the TLD card reader, additional maintenance as needed by QC trending and operational controls
- QC trending of TLD card reader operational parameters (reader calibration factors)
- calibration of field TLD cards (element correction coefficients) on an annual basis
- QC trending of TLD card element correction coefficients

[3]No preheat (50 °C for 0 seconds), temperature ramp of 25 °C per second up to a maximum of 300 °C, 13 1/3 seconds acquire time, and no anneal (300 °C for 0 seconds). No explicit anneal is necessary since an implicit annealing is performed. The 300 °C maximum temperature specified will be reached in approximately 11 seconds; the remaining 2 1/3 seconds are held at the 300 °C maximum temperature, thereby giving the same effect as an explicit 2 1/3 second anneal at 300 °C. The calibration region contains all 200 channels, encompassing peaks 1-5 in the LiF glow curve.

[4]The RCFs (nC/gU) serve three main purposes. First, they are used to convert from units of electrical charge (nC) (the output of the photomultiplier tube that measures the light output of a TLD chip) to generic radiation units (gU). Second, they monitor and adjust for a specific TLD reader system's sensitivity variations over time. Lastly, they are also used to adjust for sensitivity variations between two or more TLD readers. An RCF is related to the efficiency of a particular TLD reader channel under a specific time-temperature profile.

[5]An ECC is used to improve the precision of the TLD system by adjusting for differences between TLD cards. It normalizes the response of each field card to the mean response of all calibration cards. An ECC is similar to the element correction factor (ECF) concept proposed by Plato and Miklos, with two exceptions. First, ECCs are multiplicative correction factors, whereas ECFs are used as divisors. Secondly, the ECC method uses only a single exposure, whereas multiple exposures are usually used to generate ECFs. The excellent precision of the non-contact, hot-gas heating system in the Harshaw model 8800 TLD system makes multiple exposures unnecessary. There is one ECC for each chip in the 8801 (7776-1141) TLD card.

- operational QC controls during reading of TLD field cards (QC cards, PMT noise QC limits, reference light QC limits, high TLD card reading alarms)
- storage, handling, and cleaning controls on TLD cards
- assignment, issue, and return verification of TLD card assignments to individuals
- return inspection of TLDs
- background monitoring performed monthly and quarterly
- TLD lab contamination surveys (will be performed monthly after the delivery of the first shipment of TRU waste)
- Quarterly Blind Testing program
- DOELAP Accreditation and scheduled re-accreditation

The quarterly blind testing program is controlled by procedure (reference 8.12) and implemented by the dosimetry Cognizant QA Engineer. The dosimetry Cognizant QA Engineer selects a subset of the DOELAP irradiation categories applicable to the WIPP site each quarter for testing. The selection is arranged such that all DOELAP irradiation categories applicable to the WIPP site are tested each year. Five TLDs are used for each DOELAP irradiation category tested and the irradiations are performed at the Pacific Northwest Laboratory (PNL). The dosimetry Cognizant QA Engineer then evaluates the reported doses against the known values from the PNL using the method described in DOE/EH-0027 (reference 8.5). A tolerance level of 0.5 is used rather than values listed in DOE/EH-0027 due to the smaller number of TLDs tested for each DOELAP irradiation category.

3.2 DIRECT-READING DOSIMETER

The direct-reading dosimeter (self reading pocket dosimeter and the digital alarming dosimeter) are the supplemental dosimeters that provide real-time indication of exposure to radiation and assist in maintaining personnel doses less than Administrative Control Levels. These dosimeters may be worn by radiation workers, other WIPP personnel, and visitors in order to provide a qualitative check of external radiation exposures on a daily (or per visit) basis (reference 8.13, Section 513).

The TLD will be exchanged immediately if the daily recording of the direct-reading dosimeter readings approach an Administrative Control Level, or other conditions exist that require immediate dosimetry results.

Pocket and electronic dosimeters are calibrated at least semi-annually (per procedures WP 12-528, Calibration Check and Operation of the Xetex Digital Dosimeter Model 415b and WP 12-529, Self Reading, Pocket-Type Dosimeter). Direct-reading dosimeters bear a label or tag with the date of the calibration and the date the calibration is due.

4.0 PERSONNEL DOSE ASSESSMENT METHODOLOGIES

4.1 ROUTINE DOSE ASSESSMENT

The TLD is the primary dosimeter used at the WIPP for measuring personnel radiation exposure for permanent record purposes. The TLD measures beta, gamma, and neutron exposure and distinguishes between penetrating and non-penetrating radiations. The direct-reading dosimeter (self reading pocket dosimeter and the digital alarming dosimeter) are the supplemental dosimeters used at the WIPP for providing real-time indication of gamma radiation exposure. The Dosimetry section is responsible for issuing and controlling primary dosimetry (TLDs). Operational Health Physics (OHP) is responsible for issuing and controlling supplemental dosimetry (reference 8.13, Section 511).

4.1.1 Daily External Dose Assessment

Direct-reading dosimeters (DRDs) shall be issued by OHP to personnel prior to entry into a Radiation Area, when a person could exceed 10 percent of an Administrative Control Level from external radiation in 1 work day, or when required by a Radiological Work Permit (RWP). The specifications for the number and type of DRDs is recorded on the RWP. These dosimeters shall be worn simultaneously with the primary dosimeter. They shall be read before entering areas requiring them, periodically while in use (approximately every 15 minutes), when exiting the controlled area, and should not be allowed to exceed 75 percent of full scale. Daily assessment of external radiation exposure is performed by reading and recording the accumulated radiation dose measured by the DRDs upon each exit of the RMA. Daily measurements are accumulated and tracked to ensure that no individual approaches or exceeds the WIPP Administrative Control Levels (reference 8.13, Section 513).

If the TLD results exceed 100 mrem and the DRDs daily accumulation reading results differ from the TLD results by more than 50%, a dosimetry investigation is performed to resolve the discrepancy. Any changes to the TLD results are documented (reference 8.13, Section 513).

Individuals with off-scale or higher than expected DRD readings shall promptly report the readings to Radiation Safety. Radiation Safety shall investigate and document the cause of the readings. Their TLD shall be exchanged and processed to asses their external radiation exposure. The individual shall be restricted from radiological work until their compliance with dose limits is verified (reference 8.13, Section 513).

4.1.2 TLD External Dose Assessment

TLDs are normally exchanged for all WIPP site personnel on a quarterly exchange schedule. TLDs for individuals whose external radiation exposure is expected to approach 1 rem annually are exchanged monthly. Individual TLDs may be exchanged immediately if their direct-reading dosimeter daily accumulated readings approach or exceed the WIPP Administrative Control Levels. Visitor TLDs are returned upon completion of their visit (reference 8.12, Section 1.4.1).

Exchanged TLDs are taken to the TLD Processing Center where they are received, inspected, and disassembled. The bar code number on the TLD card is verified against the number of the TLD card that was issued to the individual. Any discrepancies in the assignment, issue, and return of the TLD card/TLD are investigated.

The TLD cards are read in the Harshaw 8800C TLD card reader and the readings recorded. The TLD card readings are processed through the Harshaw dose calculation algorithm (reference 8.8) to calculate deep, shallow, and neutron dose (rem). If neutron exposure is expected, the WIPP External Dosimetry Program specifies the use of an unmoderated neutron dose conversion factor in the dose calculation algorithm which will result in a conservative estimation of neutron dose at the WIPP site. The data processing software and the dose algorithm performs various QC checks. The final external dose assessment results are held in suspense until all QC check failures are resolved, documented, and approved by the Dosimetry Manager. Final external dose assessment results are recorded in the individual's dose history file.

4.1.3 Non-Uniform Exposure of the Skin

Non-uniform exposures of the skin from x-rays, beta radiation and radioactive materials on the skin, including hot particles, shall be assessed and recorded as specified in Table 4.1 (reference 8.13, Appendix 2C).

Table 4.1

NON-UNIFORM SKIN EXPOSURE DOSE ASSESSMENT	
AREA OF SKIN IRRADIATED	METHOD OF AVERAGING, ADDING TO OTHER DOSES RECEIVED, AND RECORDING NON-UNIFORM SKIN DOSE
$\geq$ 100 cm^2	Averaged over the 100 cm^2 of skin receiving the maximum dose. Added to any uniform dose equivalent also received by the skin. Recorded as the annual extremity or skin (shallow) dose equivalent (H).
< 100 cm^2	Averaged over the 1 cm^2 of skin receiving the maximum dose (D), reduced by the fraction (f) which is the irradiated area in cm^2 divided by 100 cm^2 (i.e. H=fD). Added to any uniform dose equivalent also received by the skin. Recorded as the annual extremity or skin (shallow) dose equivalent.
< 10 cm^2	Averaged over the 1 cm^2 of skin receiving the maximum dose. Not added to any other dose equivalent, extremity or shallow dose equivalent (skin) recorded for the annual dose equivalent. Recorded in the individual's radiation dose history record as a special entry.

Non-uniform skin exposure will utilize all available health physics information which may include, but not be limited to the following:

- radiation detection survey instrumentation readings
- radioactive contamination swipe radiochemical analysis
- hot particle radiochemical analysis
- pre- and post-decontamination radiation detection survey instrumentation readings
- time motion studies
- VARSKIN computer code assessments (or other appropriate calculational model)

4.2 RADIATION WORK RESTRICTIONS

Radiation work restrictions may be imposed on an individual to prevent additional radiation exposure when the current radiation exposure history of the individual is in question. Restrictions can be initiated by either the Dosimetry and Analytical Technology Manager or the Radiation Safety Manager. Reasons for initiating a radiation work restriction include (reference 8.12, Section 1.4.3):

- incomplete occupational radiation exposure history
- exposures near or above Administrative Control Levels
- uncertain exposure status

- suspected or positive internal exposure
- physical or medical impairment
- fertile female policy
- nuclear medicine procedure involving radioisotopes
- repeated violation of radiological safety rules or procedures
- other circumstances as determined by the ES&H Manager

The radiation work restriction can be removed upon resolution of the issues that led to the radiation work restriction.

4.3 NON-ROUTINE DOSE ASSESSMENT

Non-routine external radiation dose assessments are performed for the following conditions (reference 8.12, Section 1 and reference 8.13, Sections 511 and 513):

- lost or damaged TLD
- contaminated TLD
- QC check failures during TLD card processing
- QC check failures during dose algorithm processing
- TLD card element readings with element response ratios outside expected ranges and for abnormal glow curves
- estimated individual dose greater than 50 mrem
- TLD results exceeding 100 mrem and the direct-reading dosimeter daily accumulation reading results differ from the TLD results by more than 50%
- upon request of the Dosimetry and Analytical Technologies Manager or the Radiation Safety Programs Manager
- upon request of the ES&H Manager

Non-routine external radiation dose assessments are performed under the supervision of the Dosimetry and Analytical Technologies Manager and/or the Radiation Safety Programs Manager. All available health physics and dosimetry data should be made available for the assessment and all results shall be documented, reviewed, and approved by the appropriate Department Manager. The dose assessment results will then be incorporated in the individual's occupational radiation dose history file.

5.0 LOWER LIMITS OF DETECTION

The lower limit of detectability (LLD) study for the WIPP TLD was performed and a report issued in 1989 (Appendix A). Based on the LLD study, reporting limits of 10 mrem for deep dose and 35 mrem for shallow dose for each read cycle were established. A summary of the LLD results is provided in Table 5.1.

Table 5.1

WIPP TLD LLD RESULTS (rem)

DOELAP CATEGORY	QUARTERLY[a]		MONTHLY[b]		TRANSIT[c]	
	Shallow	Deep	Shallow	Deep	Shallow	Deep
I	n/a	0.010	n/a	0.007	n/a	0.010
II	n/a	0.010	n/a	0.007	n/a	0.010
IIIB	0.038	0.013	0.029	0.009	0.024	0.012
IV	0.034	0.011	0.026	0.007	0.022	0.010
VA	0.034	n/a	0.026	n/a	0.022	n/a
VI	n/a	0.010	n/a	0.007	n/a	0.010
IIIB+IV	0.036	0.012	0.027	0.008	0.023	0.011
IIIB+VA	0.037	0.012	0.028	0.008	0.024	0.011
IV+VA	0.036	0.011	0.027	0.008	0.023	0.010
IIIB+VI	n/a	0.010	n/a	0.007	n/a	0.010
IV+VI	n/a	0.010	n/a	0.007	n/a	0.010

a 109 day period
b 58 day period
c 51 to 65 day period
The transit results are from the pooled transit dosimeter data from the three rounds of WIPP 1989 DOELAP performance testing.
n/a not applicable

See Table 1.1 for an explanation of the DOELAP irradiation categories.

6.0 ANGULAR DEPENDENCE

The angular dependence study for the WIPP TLD was performed and a report issued in 1989 (Appendix B). The transmittal from A. M. Nazarali with angular dependence plots is provided in Appendix C. A summary of the angular dependence results is provided in Tables 6.1 through 6.5. The values in the tables were normalized by dividing the dose calculation algorithm results at each angle by the delivered dose at normal incidence (zero angle).

Table 6.1

WIPP TLD ANGULAR DEPENDENCE
^{137}Cs IRRADIATION

ANGLE	HORIZONTAL ROTATION		VERTICAL ROTATION	
	Deep	Shallow	Deep	Shallow
-90	0.926	0.926	0.881	0.836
-85	0.983	0.983	0.908	0.891
-75	1.015	1.015	0.936	0.915
-60	1.025	1.025	0.966	0.966
-45	0.977	0.959	0.974	0.968
-30	0.970	0.959	0.985	0.945
-15	0.964	0.953	0.994	0.956
0	0.951	0.942	0.990	0.946
15	0.946	0.925	0.992	0.959
30	0.993	0.941	0.993	0.993
45	0.965	0.961	0.970	0.970
60	0.960	0.935	0.987	0.987
75	0.968	0.964	1.011	1.011
85	0.933	0.815	0.982	0.982
90	0.728	0.592	0.952	0.952

Table 6.2

WIPP TLD ANGULAR DEPENDENCE K-17 IRRADIATION				
ANGLE	HORIZONTAL ROTATION		VERTICAL ROTATION	
	Deep	Shallow	Deep	Shallow
-90	0.078	0.043	0.079	0.069
-85	0.187	0.274	0.244	0.117
-75	0.646	1.835	0.618	0.719
-60	0.786	1.376	0.882	0.879
-45	0.992	1.126	0.975	1.128
-30	1.051	0.988	1.071	0.979
-15	1.079	0.896	1.059	0.856
0	1.041	0.868	1.020	0.833
15	1.058	0.901	1.046	0.919
30	1.039	0.925	0.983	0.991
45	1.063	0.994	0.942	0.998
60	0.930	1.232	0.803	1.225
75	0.745	1.631	0.493	1.383
85	0.169	0.200	0.061	0.577
90	0.088	0.077	0.035	0.284

Table 6.3

WIPP TLD ANGULAR DEPENDENCE $^{90}Sr/^{90}Y$ IRRADIATION				
ANGLE	HORIZONTAL ROTATION		VERTICAL ROTATION	
	Deep	Shallow	Deep	Shallow
-90	-	0.030	-	0.025
-85	-	0.027	-	0.052
-75	-	0.083	-	0.122
-60	-	0.351	-	0.354
-45	-	0.758	-	0.839
-30	-	0.947	-	1.079
-15	-	0.999	-	1.056
0	-	1.011	-	1.005
15	-	1.056	-	0.967
30	-	1.053	-	0.983
45	-	0.907	-	0.734
60	-	0.396	-	0.387
75	-	0.140	-	0.117
85	-	0.071	-	0.052
90	-	0.032	-	0.041

Table 6.4

WIPP TLD ANGULAR DEPENDENCE MODERATED ^{252}Cf IRRADIATION				
ANGLE	HORIZONTAL ROTATION		VERTICAL ROTATION	
	Deep	Shallow	Deep	Shallow
-90	0.300	0.158	0.275	0.164
-85	0.357	0.219	0.330	0.215
-75	0.503	0.346	0.495	0.363
-60	0.729	0.571	0.709	0.569
-45	0.929	0.766	0.859	0.727
-30	1.015	0.865	0.954	0.833
-15	1.091	0.939	1.017	0.899
0	1.104	0.955	1.061	0.912
15	1.132	0.980	1.046	0.902
30	1.050	0.923	1.036	0.890
45	0.925	0.801	0.931	0.747
60	0.770	0.630	0.876	0.610
75	0.553	0.420	0.538	0.396
85	0.366	0.255	0.376	0.250
90	0.273	0.178	0.307	0.181

Table 6.5

WIPP TLD ANGULAR DEPENDENCE ^{241}Am IRRADIATION				
ANGLE	HORIZONTAL ROTATION		VERTICAL ROTATION	
	Deep	Shallow	Deep	Shallow
-90	0.536	0.248	0.303	0.464
-85	0.774	0.451	0.395	0.680
-75	1.029	1.077	0.605	0.797
-60	1.165	1.219	1.066	1.221
-45	1.217	1.274	1.092	1.217
-30	1.228	1.292	1.146	1.351
-15	1.194	1.326	1.151	1.303
0	1.220	1.317	1.165	1.369
15	1.174	1.364	1.172	1.318
30	1.144	1.384	1.156	1.290
45	0.929	1.147	1.158	1.264
60	0.858	1.022	1.137	1.190
75	0.728	0.808	0.847	0.887
85	0.622	0.810	0.861	0.901
90	0.325	0.504	0.703	0.861

The TLD angular dependence data was obtained from the Martin Marietta Energy Systems (MMES) Oak Ridge National Laboratory External Dosimetry Program through an information exchange. The data is applicable to the WIPP TLD because the dosimeters, processing equipment, and TLDREMS software at MMES and WIPP are identical (Appendix B and C).

7.0 CONCLUSIONS

The WIPP External Dosimetry Program is DOELAP accredited. DOELAP accreditation has been awarded January 31 1990 and March 15, 1993. The WIPP External Dosimetry Program will participate in the DOELAP re-accreditation process in accordance with the DOELAP re-accreditation schedule.

Accreditation is granted to the WIPP for the following dosimetry system:

Dosimeter Identification: A Harshaw 8801 (7776-1141) TLD card insert inside an 8805 TLD card holder.

Reader System: Harshaw 8800C Automated Reader System

DOELAP Categories:

I Low-energy photons, high dose levels
II High-energy photons, high dose levels
IIIB Low-energy photons, plutonium environments
IV High-energy photons
VA Beta particles, general, point geometry
VI Neutrons, moderated ^{252}Cf
VII Mixture categories:
IIIB + IV
IIIB + VA
IV + VA
IIIB + VI
IV + VI

The expected radiation fields at the WIPP are all within the scope of DOELAP as described in WP 12-341 (reference 8.15).

The lower limit of detection of the WIPP TLD has been measured and the results are provided in Section 5.0 and Appendix A of this report. An individual who works in a low radiation area and is on the quarterly TLD exchange period could potentially receive a whole body exposure of 40 mrem (deep dose equivalent) per year without recording a positive dose on his/her TLD. This "missed dose" is well below the requirement in the DOE Radiological Control Manual (reference 8.6, Article 511) to provide dosimetry to individuals with the potential to exceed 100 mrem per year.

The angular dependence of the WIPP TLD has been measured and the results are provided in Section 6.0, Appendix B and Appendix C of this report.

Although it is not anticipated that there will be a need for extremity dosimeters, this will be verified during the preparation of a Radiological Work Permit (RWP) (reference 8.13, Section 512). If extremity dosimetry is required, the WIPP personnel TLD will be used. Finger ring dosimetry will not be required based on low dose rates and geometry conditions of CH TRU waste.

Average annual external radiation exposures are estimated to range from 90 to 870 mrem per year. Upon receipt of TRU waste, all individuals at the WIPP facility will be provided continuous TLD coverage. Individuals are required to wear the TLDs at all times while at the WIPP facility and are required not to remove the TLD from the WIPP facility.

A few neutron sources have been identified for CH TRU wastes, but the neutron component of the total dose rate for these few identified waste forms is typically quite small (reference 8.9, Chapter 6.1.2.1). The neutron component of the total external radiation exposure for RH TRU is expected to be a small percentage of the total gamma exposure. If one looks at the ratio of the maximum neutron dose rate to the maximum total allowed dose rate (270 mrem per hour/1,000,000 mrem per hour), the expected neutron dose rate is only 0.027 percent of the total estimated dose (reference 8.9, Chapter 6.1.2.1). The average annual external neutron radiation exposure is estimated to range from 0.02 to 0.23 mrem per year. Although average annual external neutron radiation exposures are well below 100 mrem per year, the WIPP TLD provided neutron dosimetry to all individuals at the WIPP facility. Additional information on the potential neutron exposures at the WIPP facility and possible future improvements in personnel neutron exposure monitoring to the WIPP External Dosimetry Program is provided in Appendix D.

The WIPP External Dosimetry Program routinely participates in the Personnel Dosimetry Intercomparison Study (PDIS) program administered by the Oak Ridge National Laboratory. The PDIS is performed annually and irradiates dosimeters with irradiation sources and geometries different from the DOELAP performance testing (performed every two years or as scheduled) and the WIPP External Dosimetry Program quarterly blind testing program. Participation began in 1990. The PDIS-17 (1992) irradiations included D_2O moderated ^{252}Cf, bare ^{252}Cf, polyethylene moderated ^{252}Cf, unmoderated $^{238}Pu/Be$, $^{90}Sr/^{90}Y$ beta, and ^{137}Cs sources. Participation in PDIS-18 is currently in progress. The PDIS results are used to evaluate the performance of the WIPP External Dosimetry Program.

Dose assessments are performed for each instance of a lost, damaged, or contaminated WIPP TLD per WP 12-340 (reference 8.14).

8.0 REFERENCES

8.1 Department of Energy, *Environmental Protection, Safety and Health Protection Standards*, DOE Order 5480.4, May 15, 1984

8.2 Department of Energy, *Radiation Protection for Occupational Workers*, DOE Order 5480.11, December 21, 1988

8.3 Department of Energy, *DOE Laboratory Accreditation Program for Personnel Dosimetry*, DOE Order 5480.15, December 14, 1987

8.4 Department of Energy, *Handbook for DOE Laboratory Accreditation Program in Personnel Dosimetry*, DOE/EH-0026, Washington, D.C, December 1986

8.5 Department of Energy, *DOE Standard for Performance Testing of Personnel Dosimetry Systems*, DOE/EH-0027, Washington, D.C, December 1986

8.6 Department of Energy, *U.S. DOE Radiological Control Manual*, DOE/EH-0256T, June 1992

8.7 Plato, P. and Miklos, J., *Production of Element Correction Factors for Thermoluminescent Dosimeters*, Health Phys. 49, pp. 873-881 (1985)

8.8 T. A. Rhea, et. al., *Documentation of the WIPP Dosimetry Algorithm for the Harshaw 8800C/8805 TLD System (Software Versions S-23755.005 and S-23755.005A)*, WIPP, December 1989

8.9 WP 02-9, Final Safety Analysis Report

8.10 WP 12-1, WIPP Safety Manual

8.11 WP 12-2, WIPP ALARA and Chemical Exposure Manual

8.12 WP 12-3, WIPP Dosimetry Program Manual

8.13 WP 12-5, WIPP Radiological Control Manual

8.14 WP 12-340, Results Validation on the Harshaw 8800C TLD System and External Dose Estimates

8.15 WP 12-341, External Dosimetry Program Accreditation Application and Intercomparison Studies

8.16 WP 12-528, Calibration Check and Operation of the Xetex Digital Dosimeter Model 415b

8.17 WP 12-529, Self Reading, Pocket-Type Dosimeter

8.18 WP 12-568, Radiological Protection Instrumentation Control and Calibration Program

APPENDIX A

LOWER LIMIT OF DETECTABILITY (LLD)
FOR THE HARSHAW 8800C/8805 TLD SYSTEM

Lower Limit of Detectability (LLD) for the Harshaw 8800C/8805 TLD System

at the

Waste Isolation Pilot Plant (WIPP)

Westinghouse Electric Corporation
Waste Isolation Division
P.O. Box 2078
Carlsbad, NM 88220

Prepared by — Date: 11/28/89

Reviewed by — Date: 11/28/89

Dosimetry Manager — Date: 11/29/89

Quality Assurance — Date: 12/4/89

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1.0 Introduction

This report is intended to address the following requirement from the *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems*, DOE/EH-0027, p. 14 (December, 1986):

> "For each dosimeter design submitted for testing and for at least one source in Categories III through VI for which performance is tested, a study to determine the lower limit of detectability shall be conducted once and reported to the testing laboratory."

This study is required by the Department of Energy Laboratory Accreditation Program (DOELAP) for external personnel dosimetry systems. At this time, no performance criteria are applied to the results of this study. A summary of this study's results is presented in Section 2.0 of this report.

Three lower limit of detectability (LLD) studies were carried out using standard Harshaw model 8805 TLD badges and the Harshaw model 8800C TLD reader ("reader number 1") using the alternate method prescribed in DOE/EH-0027. The bias (B) and standard deviation (S) results from the WIPP 1989 DOELAP performance testing during session nine were used as part of this study. The study was performed within six months of DOELAP performance testing, as required by DOE/EH-0027. The original Harshaw algorithm, software module S-23755.005, was used for all calculations. The unexposed dosimeter readings came from field dosimeters assigned to personnel at the WIPP site, since essentially no radioactive material was present during these periods. The dosimeters were processed as "blanks" with no background subtraction, but with normal fading corrections applied. The algorithm options used are shown in the attached pages. No attempt was made to force the unexposed dosimeter readings through each "branch" of the algorithm; the algorithm chose the most appropriate branch based on the observed element ratios.

The quarterly LLD values presented in Section 3.0 were computed from 508 quarterly exchange ("green dot") dosimeters from non-radiation workers. This sample represents a large fraction of the total WIPP non-radiation worker population. Five dosimeter results were rejected as outliers because their results were outside of the 99.9% confidence interval. An t value of 1.648 was used for the specified 0.95 p value. These dosimeters were annealed on June 29, 1989 and read on October 16-17. Therefore, they were in use for 109-110 days. A 109-day period was assumed for fading calculations.

The monthly LLD values in Section 4.0 were computed from 54 monthly exchange dosimeters from November, 1989. The t statistic used was 1.674. It is believed that none of these workers were occupationally exposed to dosimetrically significant amounts of radioactive materials. Since these dosimeters were annealed on September 19-21, 1989 and read on November 16. Due to this delay in processing, these dosimeters were in use for approximately 58 days.

The transit LLD values in Section 5.0 were computed from the three rounds of 1989 DOELAP performance testing (session nine). The data from all three rounds were pooled, even though it is probable that they did not all receive exactly the same amount of background radiation exposure during shipment to the performance testing laboratory. The t statistic used was 1.714. Each testing round had a different fading period and fading correction factors, as shown in that section of this report. The transit LLD results bear little relation to actual field conditions for WIPP personnel; they are included here merely for information purposes. These dosimeters were in use for periods of 51 to 65 days; each round was individually fade-corrected.

As can be seen from the enclosed results, the LLD of the Harshaw 8800C/8805 TLD system at WIPP for both monthly and quarterly issue periods is approximately 10 mrem for the deep dose equivalent and 35 mrem for the shallow dose equivalent.

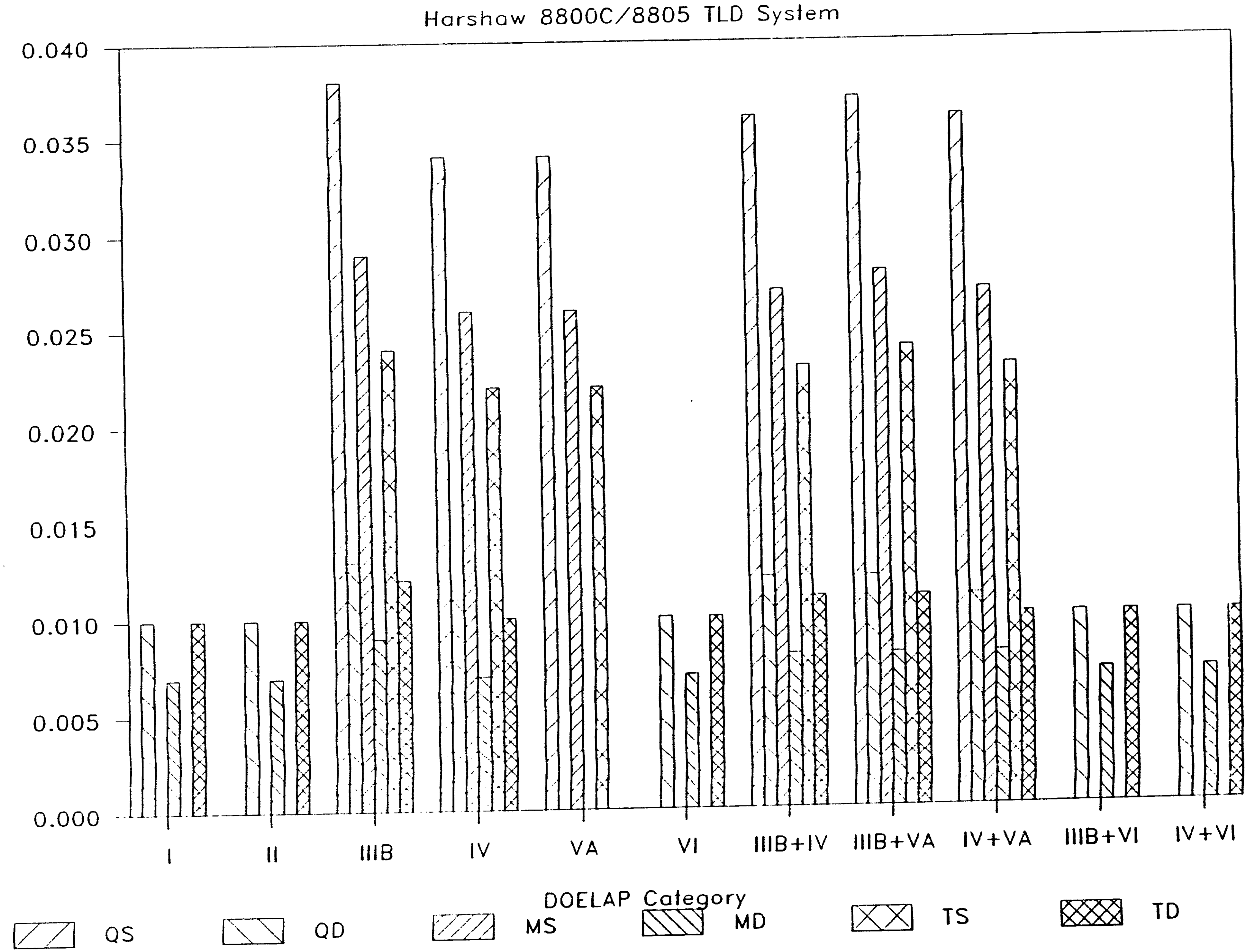
2.0 Summary of LLD Results

Summary of 1989 WIPP LLD Results

DOELAP Category	LLD, rem					
	Quarterly(*)		Monthly		1989 DOELAP Transit	
	Shallow	Deep	Shallow	Deep	Shallow	Deep
I	NA	0.010	NA	0.007	NA	0.010
II	NA	0.010	NA	0.007	NA	0.010
IIIB	0.038	0.013	0.029	0.009	0.024	0.012
IV	0.034	0.011	0.026	0.007	0.022	0.010
VA	0.034	NA	0.026	NA	0.022	NA
VI	NA	0.010	NA	0.007	NA	0.010
IIIB+IV	0.036	0.012	0.027	0.008	0.023	0.011
IIIB+VA	0.037	0.012	0.028	0.008	0.024	0.011
IV+VA	0.036	0.011	0.027	0.008	0.023	0.010
IIIB+VI	NA	0.010	NA	0.007	NA	0.010
IV+VI	NA	0.010	NA	0.007	NA	0.010

(*) The quarterly results are for a period of 109 days. The monthly results are for a period of 58 days. The transit results are from the pooled transit dosimeter data from the WIPP 1989 DOELAP performance testing results from session nine; the issue period for the three performance test rounds varied from 51 to 65 days.

WIPP Lower Limit of Detection



3.0 Quarterly LLD Results

WIPP LLD - Quarterly Background Results (Q3, 1989)

Green Dot (non-radiation worker) dosimeters from Qtr 3, 1989
Cards were annealed in 8906292 and read in 8910162
Some additional Q3 cards are in #8910172, but are not included here.
Algorithm version used: S-23755.005
Five cards' results were deleted as outliers (see below).

SETUP	Holder: 8805; HEPH model field(s): Cs-137
	Beta model field(s): Tl-204+Sr-90/Y-90 ; Neutrons: none
FADE	Fbg = 0.857 Fn = 0.857
BCKGND	[0.00, 0.00, 0.00, 0.00] gU
CAL FACTORS	[1272.00, 1199.00] gU/rem
REL RESPONSE	[1310.00, 1254.00, 1235.00, 1474.00] gU/R

WIPP Quarterly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
5220	0.057	0.016
6763	0.013	0.010
5016	0.045	0.017
4856	0.053	0.018
4857	0.036	0.016
4907	0.063	0.015
4872	0.043	0.016
4895	0.037	0.017
4892	0.034	0.018
4859	0.048	0.015
5508	0.053	0.019
5227	0.038	0.016
5516	0.062	0.017
5502	0.048	0.017
5504	0.037	0.017
5237	0.035	0.017
5512	0.032	0.018
5213	0.038	0.017
4891	0.044	0.016
4896	0.034	0.016
4897	0.043	0.015
4899	0.036	0.026
4898	0.043	0.016
4905	0.036	0.018
5235	0.035	0.015
4884	0.034	0.027
4885	0.033	0.024
4881	0.035	0.019

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem	
	Shallow	Deep
5501	0.031	0.019
5300	0.033	0.017
5314	0.050	0.019
5338	0.038	0.016
5339	0.035	0.015
5337	0.034	0.024
5305	0.060	0.019
5135	0.061	0.019
5180	0.038	0.017
5147	0.045	0.016
5155	0.072	0.016
5054	0.042	0.018
5053	0.049	0.017
5174	0.033	0.018
5149	0.043	0.023
5141	0.049	0.016
5148	0.036	0.020
5157	0.032	0.015
5173	0.063	0.017
5165	0.038	0.017
5132	0.035	0.016
5144	0.044	0.018
5168	0.052	0.016
5160	0.059	0.020
5126	0.068	0.018
5176	0.052	0.018
5136	0.037	0.026
5151	0.042	0.016
5020	0.047	0.017
5143	0.059	0.017
5258	0.033	0.025
5262	0.049	0.016
5068	0.061	0.016
5091	0.042	0.017
5085	0.039	0.020
5057	0.042	0.015
5049	0.045	0.016
5065	0.042	0.017
5094	0.055	0.016
5093	0.035	0.016
5080	0.049	0.017
5072	0.042	0.017
5047	0.029	0.015
5077	0.056	0.016

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
5408	0.045	0.018
4929	0.040	0.015
5272	0.037	0.017
5270	0.031	0.017
5276	0.031	0.016
5278	0.051	0.016
5280	0.033	0.018
5299	0.050	0.019
5315	0.021	0.016
5319	0.031	0.026
5321	0.029	0.020
5509	0.039	0.019
5506	0.043	0.018
4919	0.047	0.019
4916	0.075	0.020
4918	0.030	0.016
4908	0.039	0.016
4925	0.039	0.015
5242	0.045	0.016
5335	0.043	0.016
5252	0.051	0.014
5217	0.039	0.015
5209	0.037	0.015
5556	0.043	0.016
5225	0.030	0.016
5261	0.030	0.015
5263	0.032	0.016
5259	0.037	0.016
5236	0.031	0.021
5311	0.035	0.014
5416	0.039	0.015
5368	0.034	0.014
5398	0.034	0.015
5370	0.030	0.015
5414	0.033	0.022
5406	0.041	0.016
5381	0.046	0.016
5365	0.034	0.016
5364	0.030	0.014
5404	0.044	0.017
5371	0.038	0.015
5417	0.035	0.015
5185	0.071	0.016
5188	0.048	0.015

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
4917	0.052	0.018
5510	0.023	0.018
5193	0.033	0.017
5189	0.037	0.015
5389	0.033	0.017
5520	0.037	0.018
5560	0.035	0.019
4202	0.033	0.016
5534	0.042	0.019
5543	0.049	0.017
5542	0.042	0.017
5535	0.049	0.017
5558	0.053	0.016
5566	0.049	0.016
4877	0.047	0.015
4871	0.034	0.016
4867	0.029	0.016
4879	0.038	0.016
4880	0.031	0.016
5549	0.034	0.015
5550	0.053	0.017
5564	0.049	0.017
5569	0.060	0.018
4599	0.027	0.019
5583	0.055	0.021
5030	0.040	0.016
5642	0.030	0.015
5647	0.030	0.016
5518	0.032	0.025
5671	0.039	0.017
5156	0.040	0.018
5555	0.038	0.016
5083	0.038	0.017
4299	0.036	0.018
5678	0.023	0.017
5590	0.039	0.025
5689	0.033	0.016
5133	0.031	0.023
5377	0.036	0.017
5688	0.023	0.016
5140	0.040	0.015
5123	0.054	0.017
4153	0.041	0.016
5693	0.022	0.016

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem Shallow	Deep
5134	0.036	0.016
5112	0.031	0.019
5111	0.032	0.017
5572	0.042	0.017
4791	0.032	0.016
4420	0.036	0.015
4813	0.030	0.025
5450	0.029	0.016
4825	0.038	0.024
5638	0.032	0.018
5289	0.044	0.016
5255	0.034	0.016
4851	0.021	0.016
4854	0.036	0.016
4862	0.047	0.015
4865	0.036	0.015
4893	0.046	0.016
4983	0.043	0.016
4984	0.054	0.017
4986	0.032	0.024
4987	0.032	0.016
4988	0.034	0.025
4989	0.030	0.016
4990	0.029	0.016
4996	0.031	0.022
5003	0.044	0.015
5008	0.028	0.016
5011	0.037	0.015
5012	0.035	0.017
5019	0.054	0.016
5028	0.044	0.016
5033	0.036	0.016
4003	0.022	0.015
4028	0.031	0.017
4029	0.021	0.015
4054	0.038	0.017
4056	0.034	0.018
4058	0.028	0.022
4071	0.029	0.016
4110	0.030	0.024
4113	0.029	0.016
4117	0.023	0.016
4133	0.025	0.018
4190	0.039	0.017

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem Shallow	Dose Equivalent, rem Deep
5202	0.066	0.015
4192	0.030	0.014
4203	0.034	0.017
4250	0.046	0.015
4222	0.028	0.014
4224	0.043	0.014
4228	0.026	0.015
4231	0.031	0.023
4233	0.038	0.016
4236	0.036	0.014
4241	0.030	0.023
4258	0.029	0.016
4277	0.031	0.016
4279	0.029	0.017
4281	0.030	0.022
4289	0.020	0.016
4311	0.020	0.014
4321	0.027	0.020
4346	0.033	0.015
4361	0.043	0.015
6558	0.030	0.021
6552	0.041	0.014
6548	0.031	0.015
6539	0.031	0.016
6543	0.039	0.014
6506	0.033	0.014
6498	0.038	0.014
6494	0.037	0.015
6443	0.031	0.013
6438	0.036	0.013
6426	0.029	0.015
6425	0.038	0.015
6367	0.032	0.022
6354	0.032	0.014
6353	0.020	0.013
6753	0.022	0.015
6340	0.031	0.024
6339	0.031	0.020
6338	0.021	0.016
6332	0.050	0.015
6328	0.031	0.024
6327	0.043	0.015
6326	0.022	0.017
6325	0.033	0.015

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem	
	Shallow	Deep
6324	0.021	0.016
6322	0.034	0.017
6315	0.073	0.023
6313	0.021	0.017
6311	0.032	0.016
6304	0.033	0.024
6300	0.031	0.025
6299	0.028	0.015
6298	0.033	0.017
6270	0.033	0.015
6264	0.046	0.016
6262	0.038	0.016
6247	0.031	0.024
6251	0.021	0.014
6249	0.036	0.024
6246	0.034	0.015
6245	0.033	0.015
6244	0.035	0.016
6243	0.037	0.016
6242	0.019	0.013
6237	0.030	0.015
6231	0.041	0.016
6222	0.046	0.016
6217	0.047	0.016
6200	0.031	0.023
6199	0.051	0.016
6191	0.034	0.015
6190	0.021	0.015
6189	0.031	0.022
6188	0.036	0.020
6182	0.029	0.022
6177	0.021	0.016
6168	0.037	0.021
6635	0.026	0.011
6162	0.030	0.015
6152	0.029	0.021
6144	0.019	0.013
6143	0.020	0.014
6142	0.020	0.015
6141	0.039	0.015
6140	0.020	0.015
6076	0.028	0.018
6139	0.020	0.014
6183	0.031	0.024

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
6128	0.041	0.016
6127	0.021	0.015
6120	0.044	0.017
6119	0.032	0.016
6118	0.034	0.017
6116	0.021	0.016
6114	0.029	0.018
6111	0.021	0.015
6109	0.030	0.016
6108	0.031	0.017
6103	0.031	0.016
6099	0.033	0.015
6098	0.028	0.016
6095	0.021	0.018
6093	0.021	0.015
6092	0.030	0.016
6086	0.020	0.015
6085	0.032	0.017
6084	0.031	0.017
6083	0.034	0.016
6080	0.021	0.016
6074	0.020	0.016
6070	0.029	0.016
6068	0.032	0.016
6063	0.022	0.015
6054	0.021	0.018
6052	0.027	0.016
6050	0.030	0.015
6047	0.031	0.024
6040	0.028	0.015
6039	0.030	0.016
6138	0.019	0.014
6137	0.019	0.013
6035	0.020	0.015
6023	0.030	0.016
6013	0.028	0.015
6006	0.030	0.023
6005	0.033	0.015
6003	0.032	0.016
6002	0.033	0.016
6001	0.034	0.015
6000	0.037	0.016
5995	0.028	0.025
5992	0.032	0.015

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
5987	0.028	0.015
5956	0.031	0.015
5947	0.034	0.029
5946	0.030	0.023
5935	0.020	0.014
5933	0.038	0.023
5931	0.031	0.021
5930	0.030	0.017
5929	0.020	0.014
5927	0.023	0.020
5918	0.033	0.025
5915	0.021	0.015
5912	0.032	0.023
5907	0.021	0.017
5906	0.034	0.022
5904	0.030	0.018
5903	0.020	0.014
5901	0.031	0.015
5898	0.028	0.023
5896	0.032	0.016
5895	0.021	0.015
5893	0.034	0.017
5890	0.022	0.017
5888	0.021	0.017
5886	0.022	0.016
5885	0.030	0.023
5884	0.030	0.014
5883	0.040	0.016
5878	0.032	0.023
5877	0.030	0.022
5876	0.021	0.015
5874	0.027	0.014
5198	0.059	0.015
5872	0.045	0.017
5869	0.021	0.017
5866	0.030	0.022
5864	0.029	0.014
5700	0.032	0.023
5701	0.022	0.017
5702	0.035	0.017
5703	0.021	0.015
5706	0.020	0.014
5707	0.024	0.019
5708	0.029	0.016

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem Shallow	Deep
5709	0.031	0.015
5711	0.020	0.015
5713	0.031	0.022
5714	0.033	0.015
5716	0.029	0.015
5719	0.030	0.016
5720	0.033	0.017
5723	0.035	0.016
5724	0.036	0.023
5732	0.036	0.015
5736	0.032	0.016
5744	0.030	0.015
5745	0.027	0.020
5748	0.030	0.017
5749	0.033	0.025
5750	0.020	0.015
5753	0.033	0.016
5754	0.021	0.017
5756	0.021	0.016
5757	0.021	0.015
5758	0.038	0.024
5759	0.021	0.014
5760	0.037	0.016
5761	0.022	0.018
5762	0.020	0.014
5764	0.034	0.014
5769	0.028	0.020
5775	0.029	0.021
5776	0.037	0.016
5778	0.033	0.016
5788	0.021	0.016
5792	0.030	0.015
5832	0.029	0.015
5834	0.020	0.014
5842	0.029	0.022
5847	0.041	0.016
5848	0.045	0.015
5850	0.034	0.016
5856	0.030	0.015
5859	0.037	0.020
5862	0.021	0.016
5863	0.036	0.014
6796	0.030	0.015
6749	0.031	0.014

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem Shallow	Deep
5796	0.040	0.015
6745	0.020	0.015
6721	0.032	0.014
6704	0.027	0.020
6700	0.031	0.020
6689	0.029	0.014
6672	0.040	0.016
6638	0.031	0.022
6631	0.031	0.020
6628	0.029	0.015
6594	0.028	0.021
6581	0.039	0.016
6565	0.021	0.014
6559	0.031	0.016
5127	0.030	0.014
5125	0.051	0.016
5115	0.048	0.015
5110	0.053	0.016
5109	0.041	0.019
5108	0.039	0.014
5107	0.045	0.017
5106	0.041	0.016
5104	0.042	0.015
5101	0.033	0.020
5100	0.045	0.018
5088	0.040	0.016
5081	0.058	0.015
5079	0.051	0.015
5075	0.044	0.014
5074	0.038	0.014
5059	0.036	0.015
5203	0.044	0.019
4383	0.028	0.014
5186	0.051	0.016
5179	0.051	0.015
5178	0.032	0.014
5172	0.039	0.015
4417	0.065	0.016
4387	0.019	0.013
4391	0.027	0.021
4401	0.029	0.015
4402	0.041	0.015
4411	0.020	0.014
4416	0.027	0.016

WIPP Quarterly LLD Data

Card #	Dose Equivalent, rem Shallow	Deep
4419	0.043	0.015
4424	0.026	0.015
4425	0.020	0.015
4429	0.031	0.016
4430	0.043	0.015
4441	0.027	0.012
6684	0.028	0.018
6033	0.029	0.021
6022	0.026	0.012
6471	0.030	0.012
4596	0.031	0.021
4622	0.030	0.017
4445	0.041	0.022
4621	0.027	0.014
4616	0.038	0.011
4606	0.023	0.011
4601	0.025	0.015
4600	0.026	0.017
4548	0.031	0.018
4559	0.028	0.015
4549	0.024	0.015
4558	0.017	0.017
4569	0.029	0.013
6014	0.027	0.012
4583	0.024	0.021
4595	0.032	0.019
6485	0.027	0.009
4886	0.039	0.017
5538	0.037	0.015
5218	0.032	0.012
5412	0.048	0.015
5182	0.034	0.015
5593	0.030	0.015
5575	0.030	0.023
5640	0.035	0.017
5698	0.032	0.023
4798	0.019	0.015
4992	0.041	0.014
4991	0.033	0.015
4993	0.065	0.015

WIPP LLD - Quarterly Background Results (Q3, 1989)

WIPP Quarterly LLD Data

Dose Equivalent, rem

	Shallow	Deep
Ho'	0.035	0.017
So	0.010	0.003

Number of cards: 508
t(507,0.95) = 1.648

LLD = LOWER LIMIT OF DETECTION
- = Level which must be present in order to obtain 95% confidence of positive detection a priori
- = 2(t*So + (Factor**2)*Ho')/(1 - Factor**2)
  where "Factor" = 1.75*S/(1+B). See DOE/EH-0027, pp. 14-15. Values for S and B are from 1989 WIPP DOELAP performance testing (session nine).

Ho' = average of the unirradiated dosimeter values (rem) with no background subtraction. See page 15 of DOE/EH-0027.

So = standard deviation of the unirradiated dosimeter values (rem). See equation (16) in DOE/EH-0027.

NOTE: Five dosimeter results were excluded as outliers since their results were outside of the 99.9% confidence interval (3.216 * S).

WIPP LLD - Quarterly Background Results (Q3, 1989)

	I Deep	II Deep	IIIB Shallow	IIIB Deep	IV Shallow	IV Deep
S	0.054	0.046	0.123	0.157	0.035	0.068
B	-0.010	-0.032	0.079	0.027	-0.045	-0.068
1.75*S/(1+B)	0.095	0.083	0.199	0.268	0.064	0.128
LLD, rem	0.010	0.010	0.038	0.013	0.034	0.011

WIPP LLD - Quarterly Background Results (Q3, 1989)

	VA Shallow	VI Deep	IIIB+IV Shallow	IIIB+IV Deep	IIIB+VA Shallow	IIIB+VA Deep
S	0.030	0.059	0.088	0.129	0.113	0.145
B	-0.099	-0.076	0.084	0.103	0.072	0.180
1.75*S/(1+B)	0.058	0.112	0.142	0.205	0.184	0.215
LLD, rem	0.034	0.010	0.036	0.012	0.037	0.012

WIPP LLD - Quarterly Background Results (Q3, 1989)

	IV+VA Shallow	IV+VA Deep	IIIB+VI Deep	IV+VI Deep
S	0.080	0.088	0.068	0.047
B	-0.026	-0.035	0.021	-0.103
1.75*S/(1+B)	0.144	0.160	0.117	0.092
LLD, rem	0.036	0.011	0.010	0.010

WIPP LLD - Quarterly Background Results (Q3, 1989)

SUMMARY OF WIPP QUARTERLY LLDs

Category	LLD, rem Shallow	LLD, rem Deep
I	NA	0.010
II	NA	0.010
IIIB	0.038	0.013
IV	0.034	0.011
VA	0.034	NA
VI	NA	0.010
IIIB+IV	0.036	0.012
IIIB+VA	0.037	0.012
IV+VA	0.036	0.011
IIIB+VI	NA	0.010
IV+VI	NA	0.010

4.0 Monthly LLD Results

WIPP LLD - Monthly Background Results (October, 1989)

Monthly exchange dosimeters from October, 1989
Cards were annealed in 8909192, 8909202, and 8909212 and read in 8911162
For fading purposes, assume they were all annealed on 9/20/89.
Algorithm version used: S-23755.005
Approximately 58 days elapsed between annealing and readout, so actual monthly LLDs will likely be somewhat lower than these values.

SETUP Holder: 8805; HEPH model field(s): Cs-137
Beta model field(s): Tl-204+Sr-90/Y-90 ; Neutrons: none
FADE Fbg = 0.933 Fn = 0.933
BCKGND [0.00, 0.00, 0.00, 0.00] gU
CAL FACTORS [1272.00, 1199.00] gU/rem
REL RESPONSE [1310.00, 1254.00, 1235.00, 1474.00] gU/R

WIPP Monthly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
5355	0.049	0.020
6077	0.022	0.009
6048	0.024	0.010
4388	0.017	0.009
5823	0.029	0.009
6305	0.021	0.009
6648	0.015	0.008
6510	0.018	0.008
6654	0.014	0.008
5822	0.020	0.008
6540	0.017	0.009
4848	0.022	0.012
5458	0.027	0.010
5482	0.022	0.009
4947	0.031	0.010
5722	0.021	0.012
5478	0.018	0.014
5376	0.025	0.008
5990	0.031	0.013
5919	0.028	0.012
6314	0.017	0.012
5916	0.019	0.010
5816	0.030	0.013
6474	0.019	0.009
5860	0.032	0.009
6275	0.019	0.008
6194	0.023	0.012

WIPP Monthly LLD Data

	Dose Equivalent, rem	
Card #	Shallow	Deep
6541	0.023	0.009
6634	0.018	0.009
6747	0.019	0.013
6236	0.026	0.009
6501	0.017	0.009
4128	0.024	0.009
5405	0.027	0.008
4182	0.025	0.009
5603	0.044	0.010
5998	0.016	0.010
6301	0.022	0.009
6352	0.020	0.010
6349	0.023	0.011
6187	0.017	0.008
6537	0.026	0.009
6220	0.027	0.009
5652	0.015	0.010
5383	0.022	0.008
6508	0.016	0.009
5459	0.041	0.009
6600	0.017	0.009
6277	0.022	0.010
6699	0.024	0.009
6706	0.020	0.008
6344	0.023	0.010
5429	0.044	0.011
5600	0.040	0.013

WIPP LLD - Monthly Background Results (October, 1989)

WIPP Monthly LLD Data

Dose Equivalent, rem

	Shallow	Deep
Ho'	0.024	0.010
So	0.008	0.002

Number of cards: 54
t(53,0.95) = 1.674

LLD = LOWER LIMIT OF DETECTION
- Level which must be present in order to obtain 95% confidence of positive detection a priori
- 2(t*So + (Factor**2)*Ho')/(1 - Factor**2)
  where "Factor" = 1.75*S/(1+B). See DOE/EH-0027, pp. 14-15.
  Values for S and B are from 1989 WIPP DOELAP performance testing (session nine).

ho' = average of the unirradiated dosimeter values (rem) with no background subtraction. See page 15 of DOE/EH-0027.

So = standard deviation of the unirradiated dosimeter values (rem). See equation (16) in DOE/EH-0027.

WIPP LLD - Monthly Background Results (October, 1989)

	I Deep	II Deep	IIIB Shallow	IIIB Deep	IV Shallow	IV Deep
S	0.054	0.046	0.123	0.157	0.035	0.068
B	-0.010	-0.032	0.079	0.027	-0.045	-0.068
1.75*S/(1+B)	0.095	0.083	0.199	0.268	0.064	0.128
LLD, rem	0.007	0.007	0.029	0.009	0.026	0.007

WIPP LLD - Monthly Background Results (October, 1989)

	VA Shallow	VI Deep	IIIB+IV Shallow	IIIB+IV Deep	IIIB+VA Shallow	IIIB+VA Deep
S	0.030	0.059	0.088	0.129	0.113	0.145
B	-0.099	-0.076	0.084	0.103	0.072	0.180
1.75*S/(1+B)	0.058	0.112	0.142	0.205	0.184	0.215
LLD, rem	0.026	0.007	0.027	0.008	0.028	0.008

WIPP LLD - Monthly Background Results (October, 1989)

	IV+VA Shallow	IV+VA Deep	IIIB+VI Deep	IV+VI Deep
S	0.080	0.088	0.068	0.047
B	-0.026	-0.035	0.021	-0.103
1.75*S/(1+B)	0.144	0.160	0.117	0.092
LLD, rem	0.027	0.008	0.007	0.007

SUMMARY OF WIPP MONTHLY LLDs

	LLD, rem	
Category	Shallow	Deep
I	NA	0.007
II	NA	0.007
IIIB	0.029	0.009
IV	0.026	0.007
VA	0.026	NA
VI	NA	0.007
IIIB+IV	0.027	0.008
IIIB+VA	0.028	0.008
IV+VA	0.027	0.008
IIIB+VI	NA	0.007
IV+VI	NA	0.007

5.0 Transit LLD Results

WIPP LLD - 1989 DOELAP Session Nine Transit Results

Transit dosimeters from 1989 WIPP DOELAP Performance Testing
Algorithm version used: S-23755.005
All three rounds' data are pooled; specific fading info is shown below.

Round	Group Number: Anneal	Read	# Days	Fbg	Fn
1	8904122	8906132	62	0.927	0.927
2	8905232	8907272	65	0.922	0.922
3	8907012	8910102	51	0.944	0.944

SETUP Holder: 8805; HEPH model field(s): Cs-137
Beta model field(s): Tl-204+Sr-90/Y-90 ; Neutrons: none
FADE (see above)
BCKGND [0.00, 0.00, 0.00, 0.00] gU
CAL FACTORS [1272.00, 1199.00] gU/rem
REL RESPONSE [1310.00, 1254.00, 1235.00, 1474.00] gU/R

WIPP Transit LLD Data

Card #	Dose Equivalent, rem: Shallow	Deep	Round
6401	0.021	0.015	1
6573	0.013	0.010	1
6411	0.017	0.012	1
6402	0.014	0.009	1
6151	0.013	0.010	1
6465	0.013	0.009	1
6732	0.014	0.010	1
6475	0.014	0.009	1
4131	0.019	0.017	2
4635	0.016	0.014	2
4576	0.017	0.015	2
4592	0.017	0.016	2
4097	0.015	0.012	2
4587	0.017	0.016	2
4689	0.016	0.012	2
4122	0.015	0.014	2
6408	0.032	0.020	3
4105	0.021	0.015	3
4039	0.042	0.015	3
6465	0.018	0.014	3
6606	0.019	0.014	3
6618	0.018	0.014	3
6556	0.019	0.013	3
6133	0.018	0.014	3

WIPP LLD - 1989 DOELAP Session Nine Transit Results

WIPP Transit LLD Data

Dose Equivalent, rem

	Shallow	Deep
Ho'	0.018	0.013
So	0.006	0.003

Number of cards: 24
t(23,0.95) = 1.714

LLD = LOWER LIMIT OF DETECTION
- = Level which must be present in order to obtain 95% confidence of positive detection a priori
- = 2(t*So + (Factor**2)*Ho')/(1 - Factor**2)
  where "Factor" = 1.75*S/(1+B). See DOE/EH-0027, pp. 14-15.
  Values for S and B are from 1989 WIPP DOELAP performance testing (session nine).

Ho' = average of the unirradiated dosimeter values (rem) with no background subtraction. See page 15 of DOE/EH-0027.

So = standard deviation of the unirradiated dosimeter values. See equation (16) in DOE/EH-0027.

WIPP LLD - 1989 DOELAP Session Nine Transit Results

	I Deep	II Deep	IIIB Shallow	IIIB Deep	IV Shallow	IV Deep
S	0.054	0.046	0.123	0.157	0.035	0.068
B	-0.010	-0.032	0.079	0.027	-0.045	-0.068
1.75*S/(1+B)	0.095	0.083	0.199	0.268	0.064	0.128
LLD, rem	0.010	0.010	0.024	0.012	0.022	0.010

WIPP LLD - 1989 DOELAP Session Nine Transit Results

	VA Shallow	VI Deep	IIIB+IV Shallow	IIIB+IV Deep	IIIB+VA Shallow	IIIB+VA Deep
S	0.030	0.059	0.088	0.129	0.113	0.145
B	-0.099	-0.076	0.084	0.103	0.072	0.180
1.75*S/(1+B)	0.058	0.112	0.142	0.205	0.184	0.215
LLD, rem	0.022	0.010	0.023	0.011	0.024	0.011

WIPP LLD - 1989 DOELAP Session Nine Transit Results

	IV+VA Shallow	IV+VA Deep	IIIB+VI Deep	IV+VI Deep
S	0.080	0.088	0.068	0.047
B	-0.026	-0.035	0.021	-0.103
1.75*S/(1+B)	0.144	0.160	0.117	0.092
LLD, rem	0.023	0.010	0.010	0.010

APPENDIX B

ANGULAR DEPENDENCE OF THE HARSHAW 8800C/8805 TLD SYSTEM

RECORD

Angular Dependence of the Harshaw 8800C/8805 TLD System

at the

Waste Isolation Pilot Plant (WIPP)

Westinghouse Electric Corporation
Waste Isolation Division
P.O. Box 2078
Carlsbad, NM 88220

Prepared by ____ Date 12/6/89

Reviewed by ____ Date 12/6/89

Dosimetry Manager ____ Date 12-06-89

Quality Assurance ____ Date 12/6/89

Table of Contents

1.0 Introduction

This report is intended to address the following requirement from the *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems*, DOE/EH-0027, p. 14 (December, 1986):

> "For each dosimeter design submitted for testing and for each type of radiation in Categories III through VI for which performance is tested, a study of dosimeter performance when the incident radiation is nonperpendicular shall be carried out one."

This study is required by the Department of Energy Laboratory Accreditation Program (DOELAP) for external personnel dosimetry systems. At this time, no performance criteria are applied to the results of this study.

Since the both the Waste Isolation Pilot Plant (WIPP) and Oak Ridge National Laboratory (ORNL) dosimetry programs use the Harshaw model 8800C/8805 TLD system, the ORNL results are taken to be indicative of the WIPP results. This is a reasonable assumption since the angular dependence characteristics of a dosimetry system are primarily dependent on the dosimeter design and construction; no effects of personnel or location differences are expected. The request for this information exchange is shown in Attachment A. The corresponding agreement to supply this information is shown in Attachment B.

The design of the model Harshaw model 8805 dosimeter will easily accommodate any upcoming angular dependence requirements. The 1000 mg/cm^2 element has a teflon and plastic filter which is designed for angular dependence. Radiation incident normally, (e.g., perpendicular to front face of the dosimeter) "sees" an average density thickness of very nearly 1000 mg/cm^2, regardless of whether it reaches the left edge, center, or right edge of the chip. This is true for all angles of incidence up to sixty degrees. Element 2, which is used for X-ray discrimination, also utilizes an oversized filter. The beta window (element 3) also has an opening which allows an approximate sixty-degree field of view. Element 4 is has no filtration other than the normal ABS plastic of the holder front and, therefore, affords a very wide "filter."

The methodology used in this study followed the requirements of DOE/EH-0027; the results are shown in Section 2.0. Since ORNL uses a separate neutron dosimeter; the results shown in Section 2.0 for that neutron dosimeter are not applicable to WIPP.

2.0 Methodology and Results

Angular Response of the Harshaw TLD Dosimetry System

W.H. Casson, M.A. Buckner, C.S. Sims

Abstract

Oak Ridge National Laboratory has used the Harshaw TLD Beta/Gamma dosimeter system since early 1989 and will start using the neutron dosimeter in early 1990. Continued use of this system requires that the performance be evaluated in accordance with the standards set forth by the Department of Energy Laboratory Accreditation Program (DOELAP) (DOE 1986). In partial fulfillment of these requirements, the dosimeters were tested with calibrated exposures of gamma, beta, and neutron radiation at 13 different angles about the vertical and horizontal axes. The angular response was then normalized to the perpendicular response and plotted as a function of angle. Based upon comparison with other dosimeter systems and the proposed directional dose equivalent (ICRU 1985) the performance of the Harshaw/ORNL system was found to be adequate and to meet all proposed criteria for angular response.

Introduction

In 1983 the American National Standards Institute with the assistance of the Health Physics Society published a set of standards for the testing and performance of personnel radiation dosimeters (ANSI 1983). These standards became guidelines for dosimeter testing in both the National Voluntary Laboratory Accreditation Program (NVLAP) and the Department of Energy Laboratory Accreditation Program (DOELAP). Both programs require performance testing of dosimeter systems and set performance criteria for the accreditation of the dosimeter processor. Part of the requirements set forth by ANSI and adopted by both accreditation programs include evaluating the angular response of the dosimeter badges to uni-directional radiation beams of photon, beta, and neutron sources. Although no performance criteria is set for angular response, comparison can be made with the directional dose equivalent ($H'(\theta,d)$) and the angular response of other dosimeter systems.

Oak Ridge National Laboratory (ORNL) incorporated the Harshaw beta/gamma dosimeter into their personnel radiation monitoring program in early 1989 as part of an overall health physics program upgrade. One of the major goals of this upgrade was to meet the necessary criteria and to be certified as a dosimeter processor under the DOELAP program. In early 1990 the Harshaw Albedo TLD dosimeter will be incorporated into the program as a continuation of this upgrade. Testing of the dosimeter angular response was carried out at the ORNL RADCAL facility in the Dosimeter Applications Research

Group. Dosimeters were exposed to gamma, beta, and neutron irradiations at angles of -85, -60, -30, 0, 30, 60, and 85 degrees by rotation about the vertical and horizontal axes for a total of 13 irradiation setups per radiation source. Since the neutron dosimeter is used for neutron dose assessment only and the beta/gamma dosimeter is not used for neutron dose assessment at all, only the neutron dosimeter was tested with the neutron source and was not included in any other test. Results of the dose assignments made by the Harshaw dosimeter processing system were normalized by dividing the response at each angle by the calibrated dose assigned based on normal incidence. These results were then plotted vs. angle. Measurements were not made with x-rays during this test due to the unavailability of the appropriate x-ray beam codes. These measurements will be conducted during the next year dependent upon installation of the appropriate equipment.

Dosimeter System

The Harshaw dosimeter system installed at ORNL consists of a beta/gamma personal dosimeter, and neutron albedo personal dosimeter, a Harshaw 8800 automatic TLD reader, and computerized data acquisition, processing, and storage systems. The beta/gamma badge consists of an ABS plastic holder and an aluminum TLD carrier card with four TLDs mounted between thin layers of teflon sheet material. The TLDs numbered from 1 to 4 are 3.2 mm square with numbers 1, 2, and 4 being .38 mm thick and number 3 being .09 mm thick. Number 1

TLD is made from TLD 700 material with a 1 cm tissue equivalent teflon and ABS plastic hemispherical filter placed in front to give direct deep dose equivalent measurement of photon exposure. Number 2 TLD is also TLD 700 material and has 242 mg/cm^2 ABS and a .1 mm thick copper filter for photon discrimination. TLD 3 is made from TLD 700 with a thin mylar covered open window. The .09 mm thickness combined with the open window allows evaluation of shallow dose, especially for beta irradiations. TLD 4 is made from TLD 600 material and is sensitive to neutrons. In this capacity it is used only to indicate neutron exposure and not for assigning neutron dose. The 300 mg/cm^2 ABS filter allows evaluation of lens of the eye dose for photon and beta exposures. The neutron dosimeter is identical in size to the beta/gamma holder and aluminum TLD carrier card. All four TLDs measure 3.2 mm square by .38 mm thick. TLDs 1 and 4 are TLD 600s and TLDs 2 and 3 are TLD 700s. TLDs 1 and 2 are filtered by .46 mm cadmium and .7 mm ABS while 3 and 4 are covered by 3 mm of ABS plastic. This combination of filters and TLDs allows subtraction of the gamma component as well as an estimate of the thermal component of the neutron dose.

The dosimeter cards were processed by a Harshaw 8800 automatic reader. This unit reads all four chips on a single card at the same time. Each chip is heated by a stream of hot nitrogen gas while the photo emission is measured by a separate photo-multiplier unit. Data recorded from the PMTs are transferred to a local personal computer for processing. Dose assignment is made using the ratios of the integrated peak areas over the range of 100 to 300 degrees celcius.

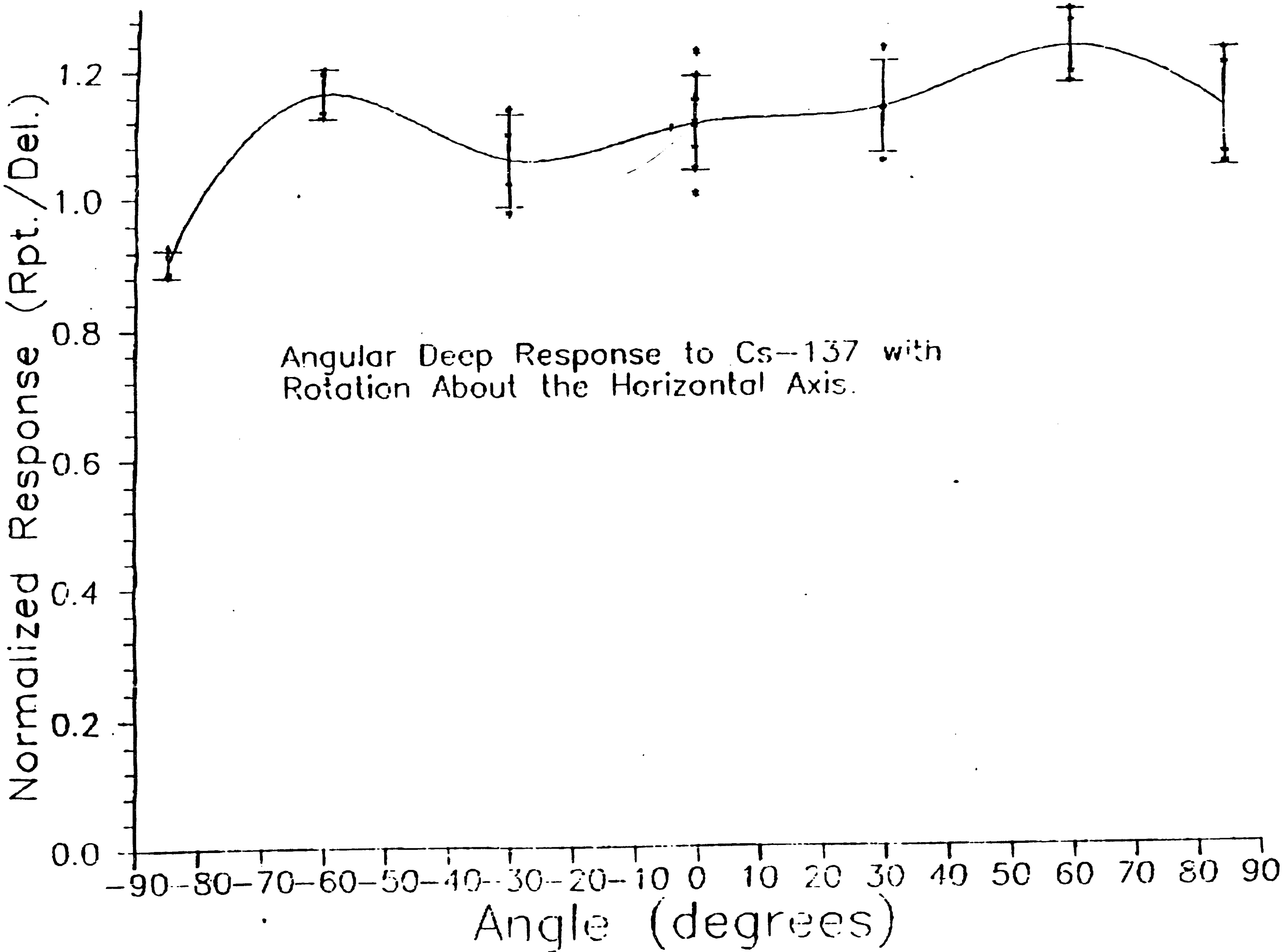
This calculation is done according to algorithms provided by Harshaw. Peak 2 fading times are at least 48 hrs for all dosimeters while processing is accomplished as soon after exposure as possible, in this case approximately 60 to 72 hours. Corrections are made to variations in the system response by reading calibrated cards at random intervals during the read process and applying an appropriate average response correction factor called the reader calibration factor (RCF). Also the response of each TLD chip to a calibrated gamma exposure is on record and is used to correct the relative response to a gamma equivalence number using a correction factor called the element correction coefficient (ECC). The final outcome of the appropriate algorithm gives the measured dose equivalent in terms of the deep dose and the shallow dose for each of the three radiation types (beta, photon, and neutron).

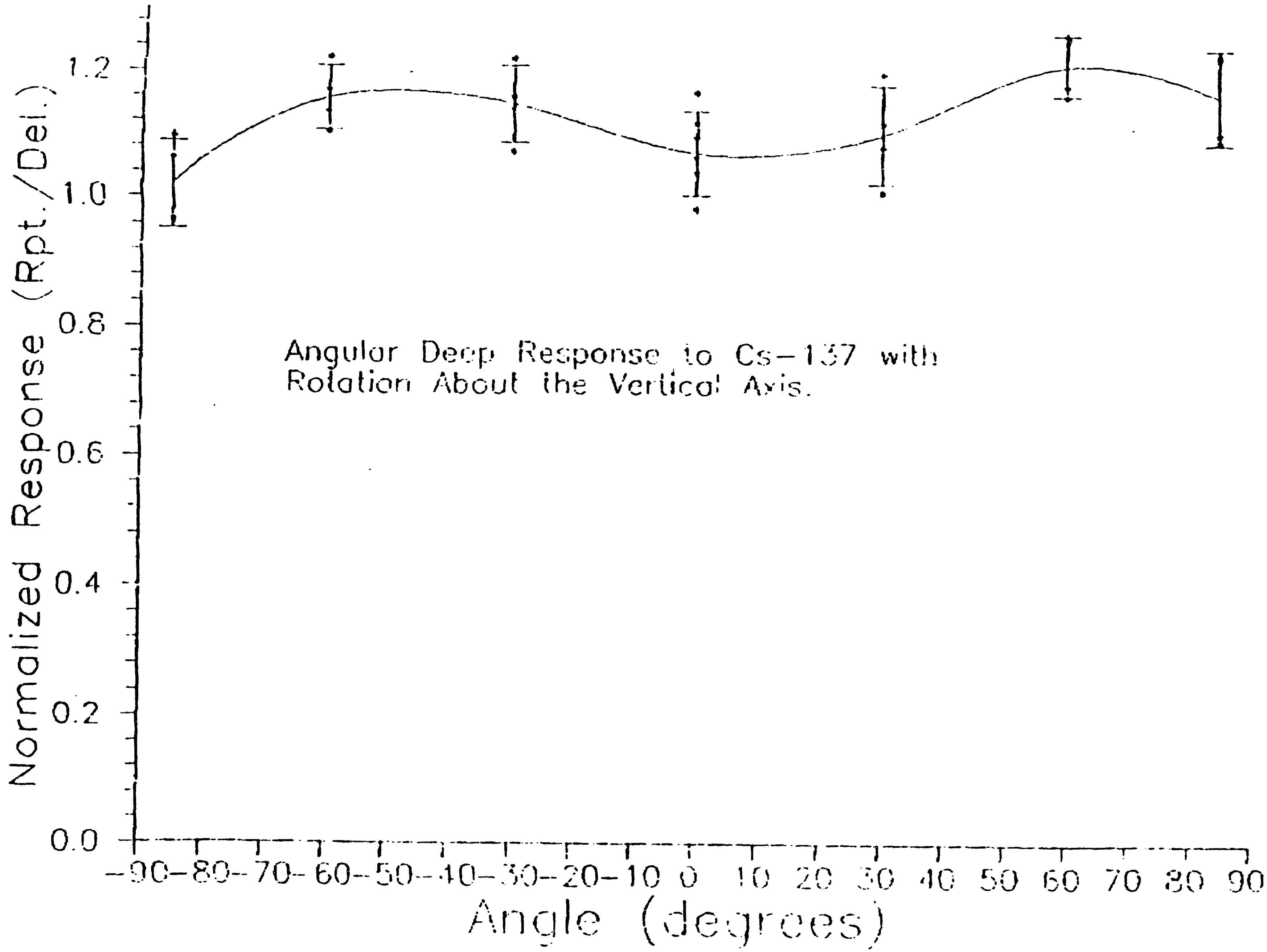
Experimental Method

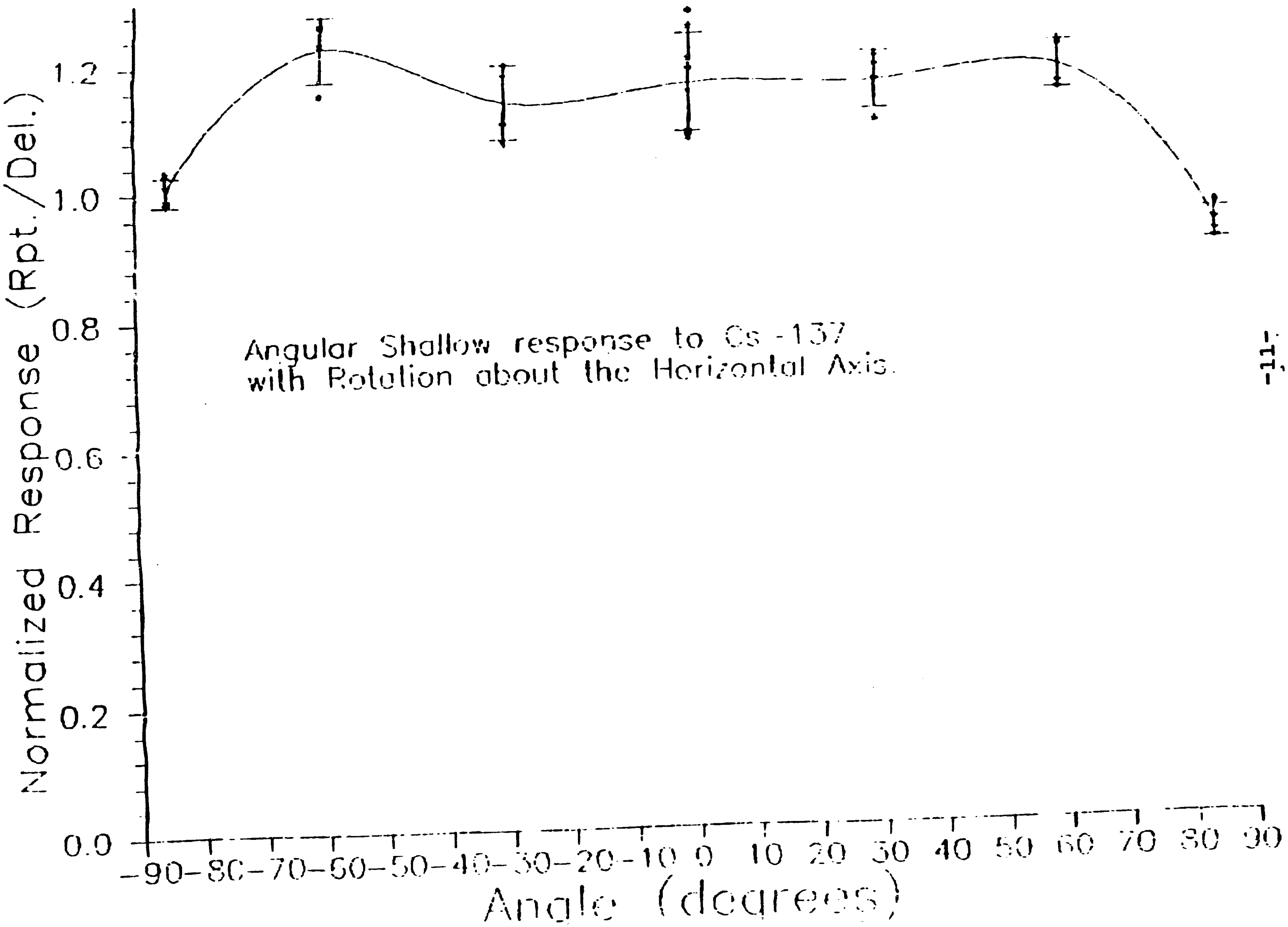
Measurement of the angular response on the beta/gamma dosimeter was accomplished using a Cs-137 gamma irradiator. Four phantoms measuring 40 cm by 40 cm by 15 cm thick were set up around a panaramic irradiator at a distance from the source center to the front edge vertical centerline of the phantom of 1 meter. One phantom was rotated to each of the angles of 0, 30, 60, and 85 degrees clockwise as viewed from overhead. The dosimeters were mounted on thin plexiglass sheets which were then mounted on the front surface of the appropriate phantom. Four dosimeters were mounted on each phantom along the vertical centerline maintaining a distance from the phantom edge to the dosimeter center of at least 10 cm. The uppermost dosimeter and the lowermost dosimeter were mounted with the dosimeter vertical centerline parallel with the phantom vertical centerline but in opposite orientations. The two dosimeters in between were mounted with the vertical axis (longest axis) perpendicular but again with opposite orientations. With this mounting arrangement, one dosimeter is mounted at a positive rotation angle about the vertical axis, one at a negative rotation about the vertical axis, one at a positive rotation about the horizontal axis, and one with a negative rotation about the horizontal axis. The measurement was then repeated with each new dosimeter mounted in the same position but rotated 180 degrees from the previous setup. Using this procedure allows measurement of all four rotation directions on a single phantom at one time. As an added benefit averaging the two measurements together reduces the effects of timing variations and field aberrations. On a relative response vs. angle plot any amount of skew in symmetry about the zero angle will be the result of structure within the dosimeter and not due to nonsymmetrical scattering or other field nonuniformity. The total exposure of 5.15 mSv (500 mR) was given to the dosimeters based upon the original source calibration traceable to NBS.

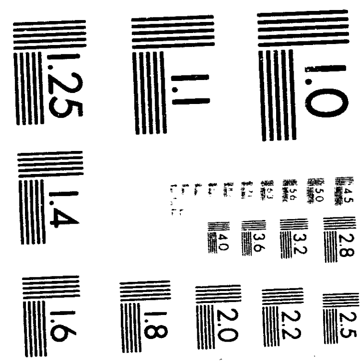
The beta exposures were made in the same manner using two 30 cm by 30 cm by 5 cm phantoms and eight different exposures. A Sr-90/Y-90 beta irradiator was used which allowed exposures at two phantom positions and with sufficient beam homogeneity to mount two dosimeters, one above the other, on each phantom. The source calibration was taken from measurements made with an extrapolation chamber and with comparison to measurements made on the source by NBS. Since the dosimeter response to beta is solely based on TLD 3 data when no gamma or neutrons are involved, then the dosimeters were mounted with the window on the centerline of rotation and with the vertical distance from the phantom mid-line to the window constant. A total exposure of 5 mGy (500 mrad) were given each dosimeter at a distance of 37.6 cm from the source.

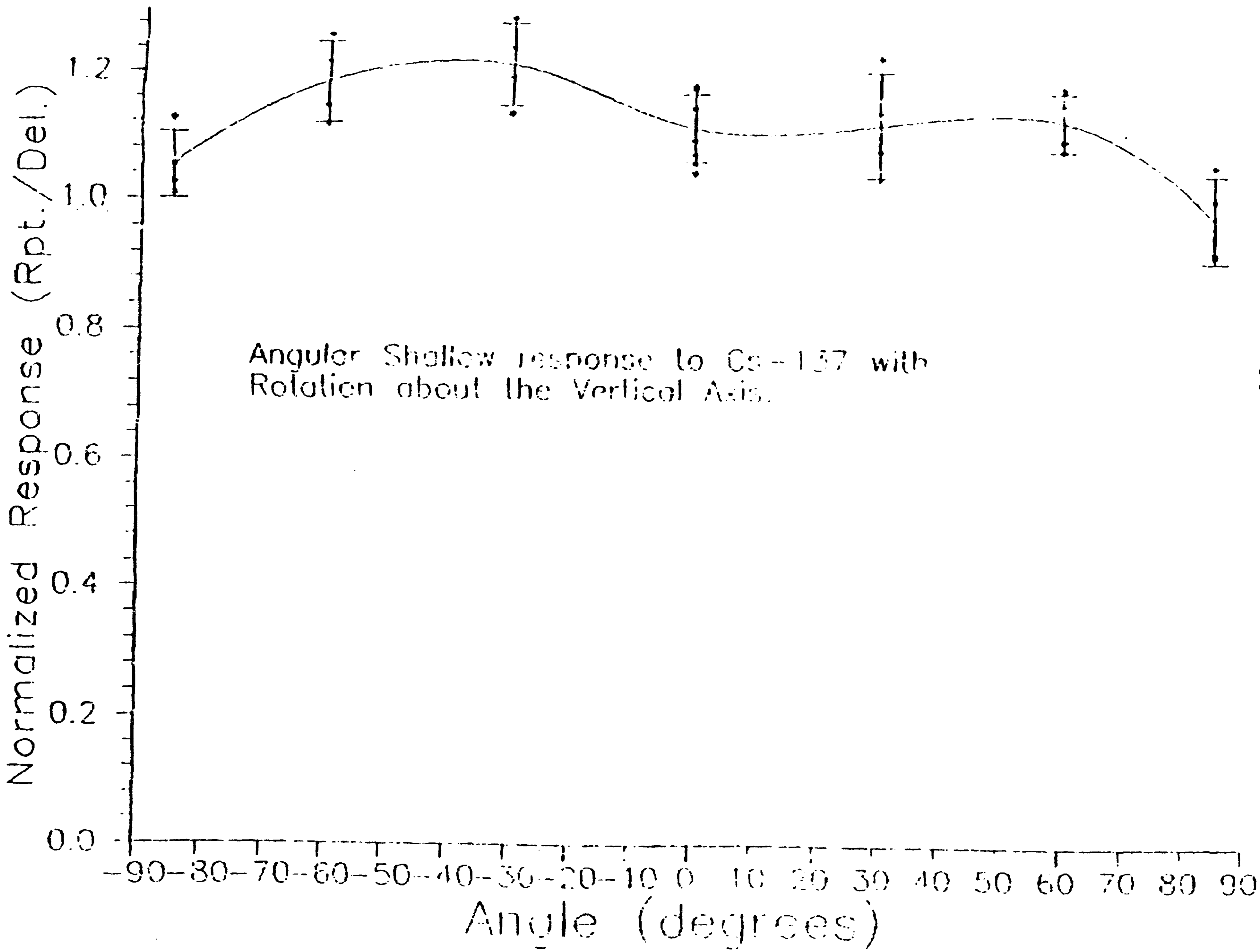
Neutron measurements were made with both a bare C_f-252 source and a D_2O moderated C_f-252 source. Calibration of the sources were taken from the NBS measured total neutron emission rate, the characteristic spectra, and the fluence to dose conversion factors (ICRP, 1973). One phantom measuring 40 by 40 by 15 cm was used at a distance of .75 meters from the source center to the vertical center of the front face. Four dosimeters were mounted with the same spacing and orientation as in the gamma exposures. Only neutron badges were used in this phase of the measurements. Each exposure was timed to expose the dosimeters to approximately 5 mSv (500 mrem) of combined neutron and gamma with care being taken to ensure each exposure was the same (no correction was made for scattering as it is a small constant fraction of the total exposure at this distance).

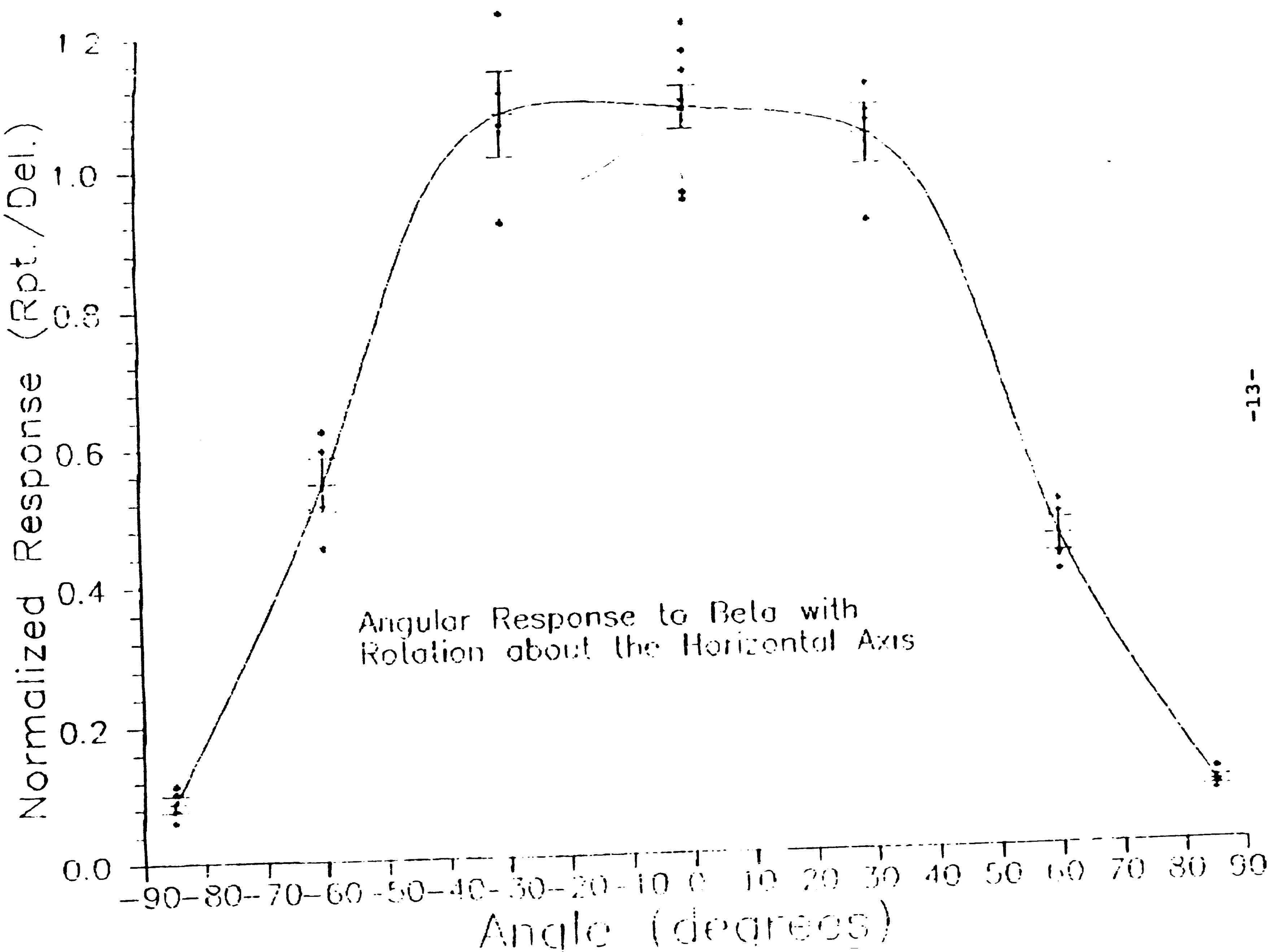

Angular Deep Response to Cs-137 with
Rotation About the Horizontal Axis.
Normalized Response (Rpt./Del.)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)

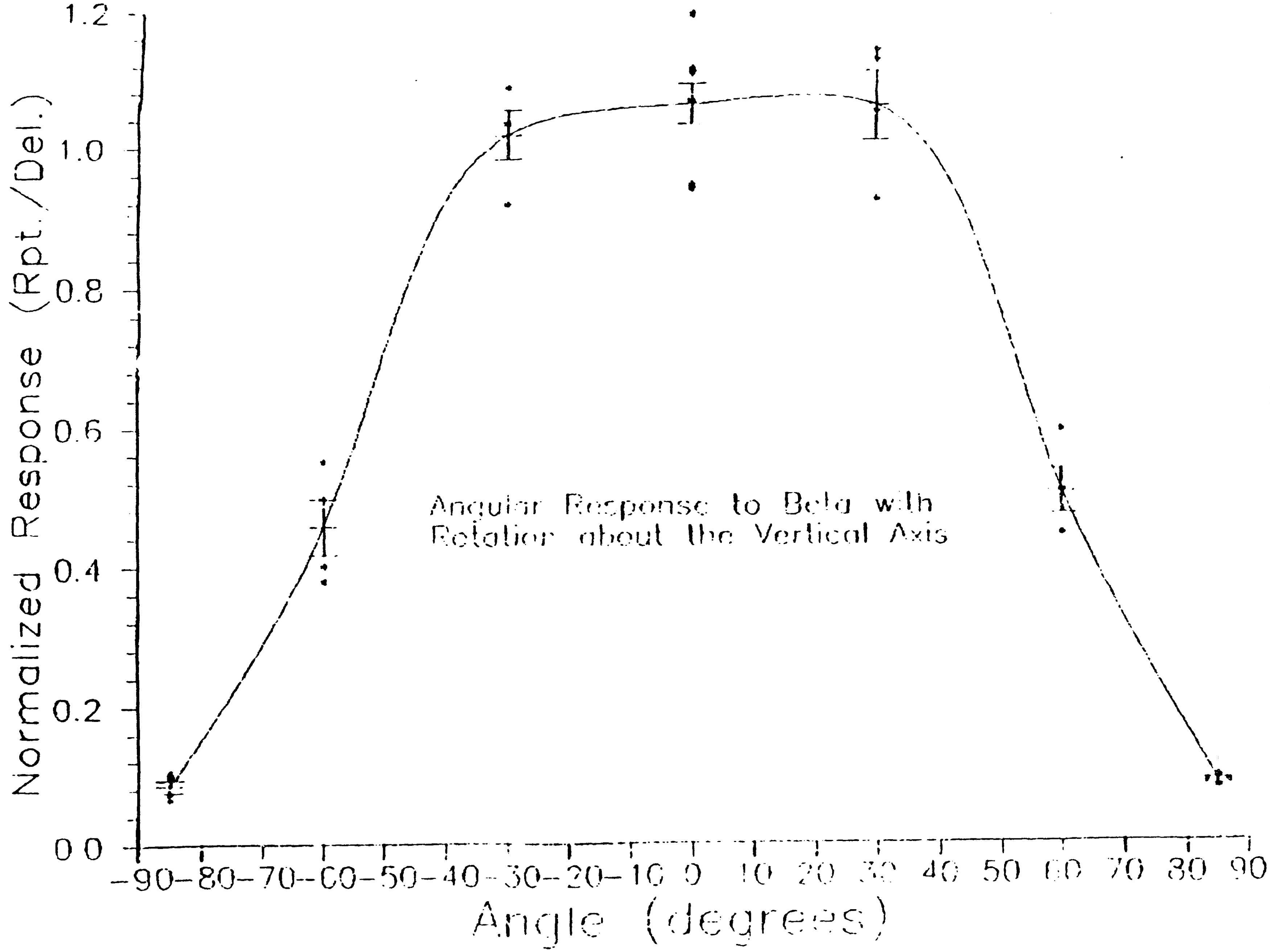

Angular Deep Response to Cs−137 with
Rotation About the Vertical Axis.
Normalized Response (Rpt./Del.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
−90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)

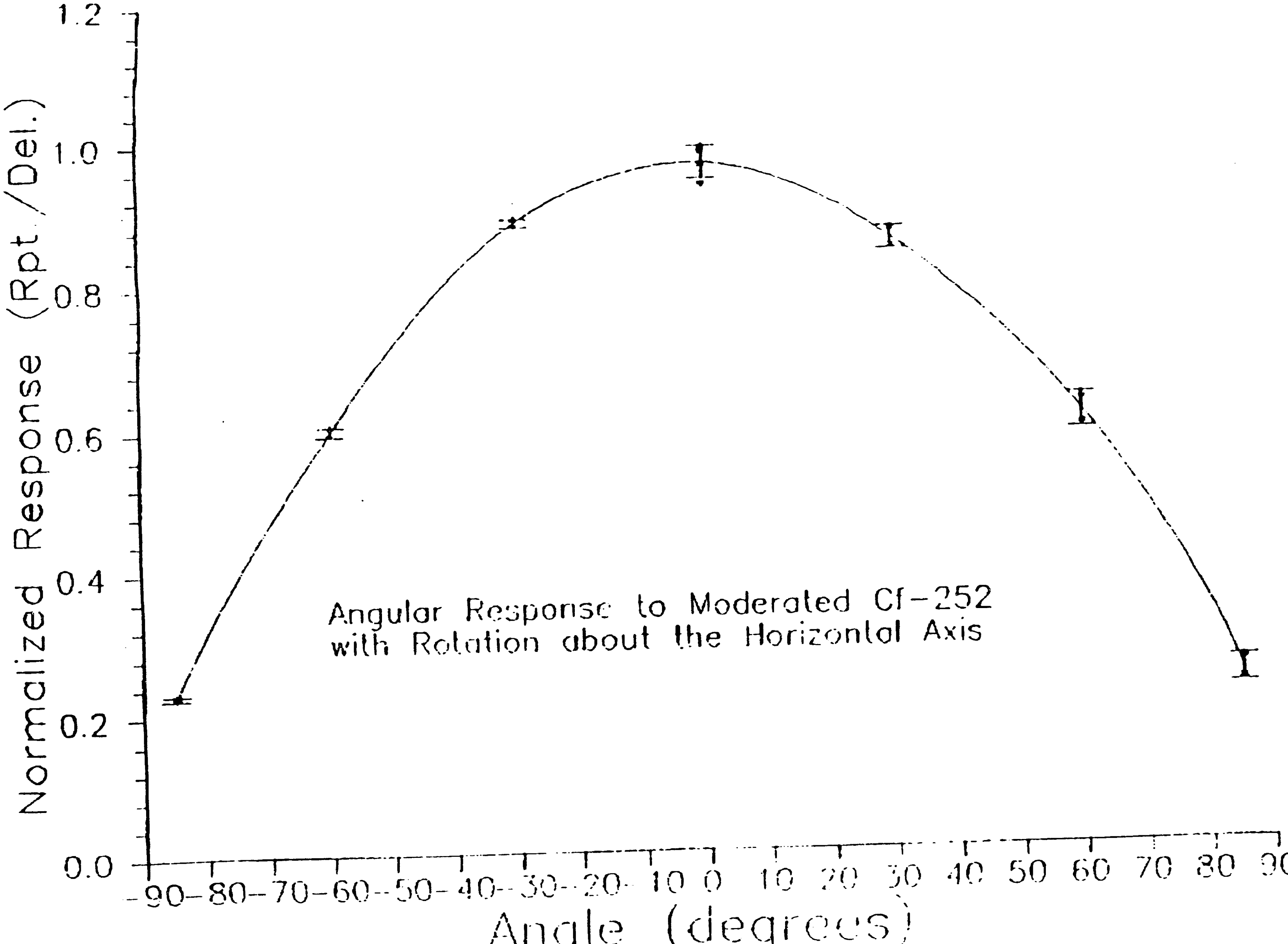

Angular Shallow response to Cs -137
with Rotation about the Horizontal Axis.
Normalized Response (Rpt./Del.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)

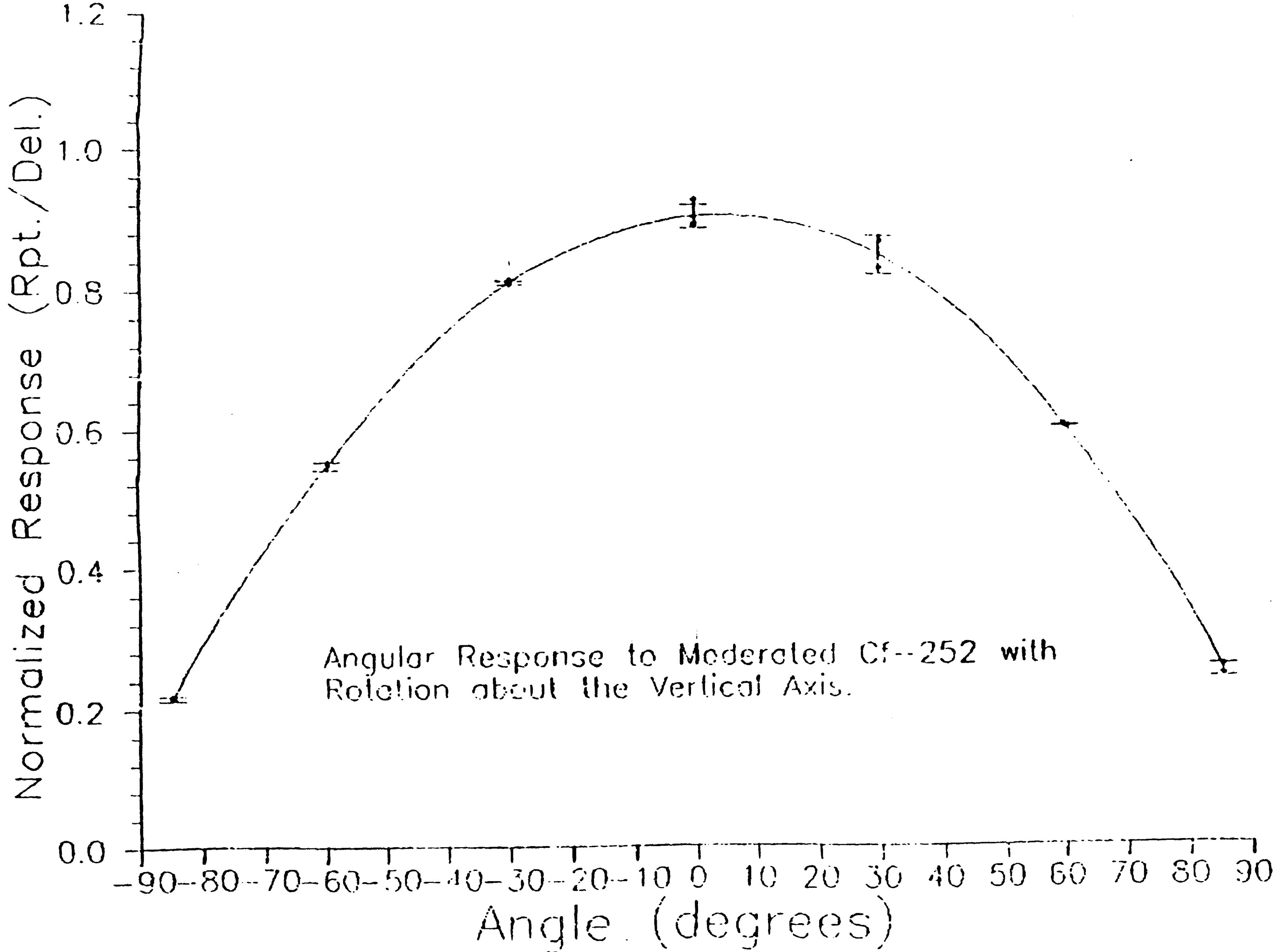

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0

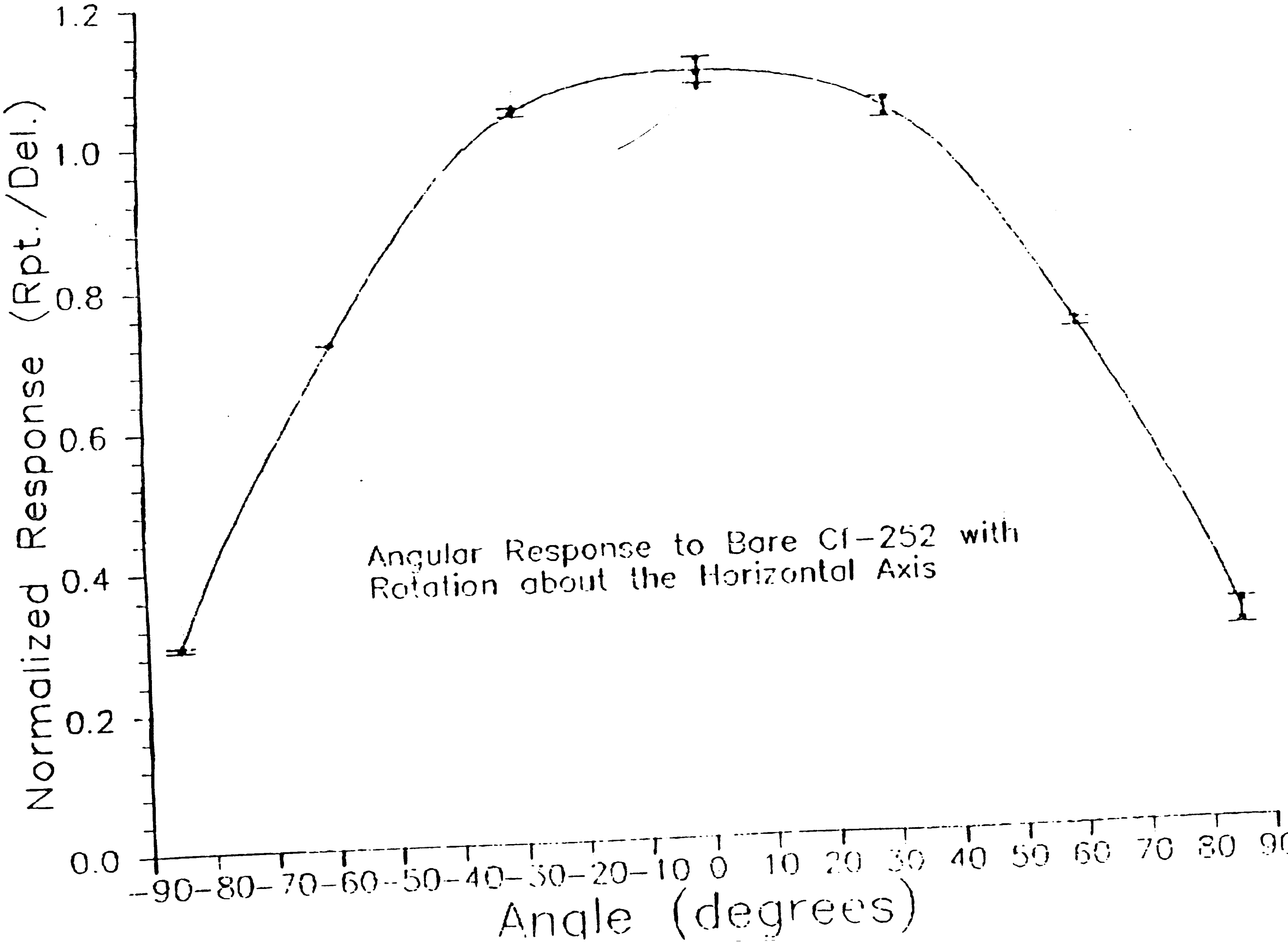

Angular Shallow response to Cs-137 with
Rotation about the Vertical Axis.
Normalized Response (Rpt./Del.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)


Angular Response to Beta with
Rotation about the Horizontal Axis
Normalized Response (Rpt./Del.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
-90-80-70-60-50-40-30-20-10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)

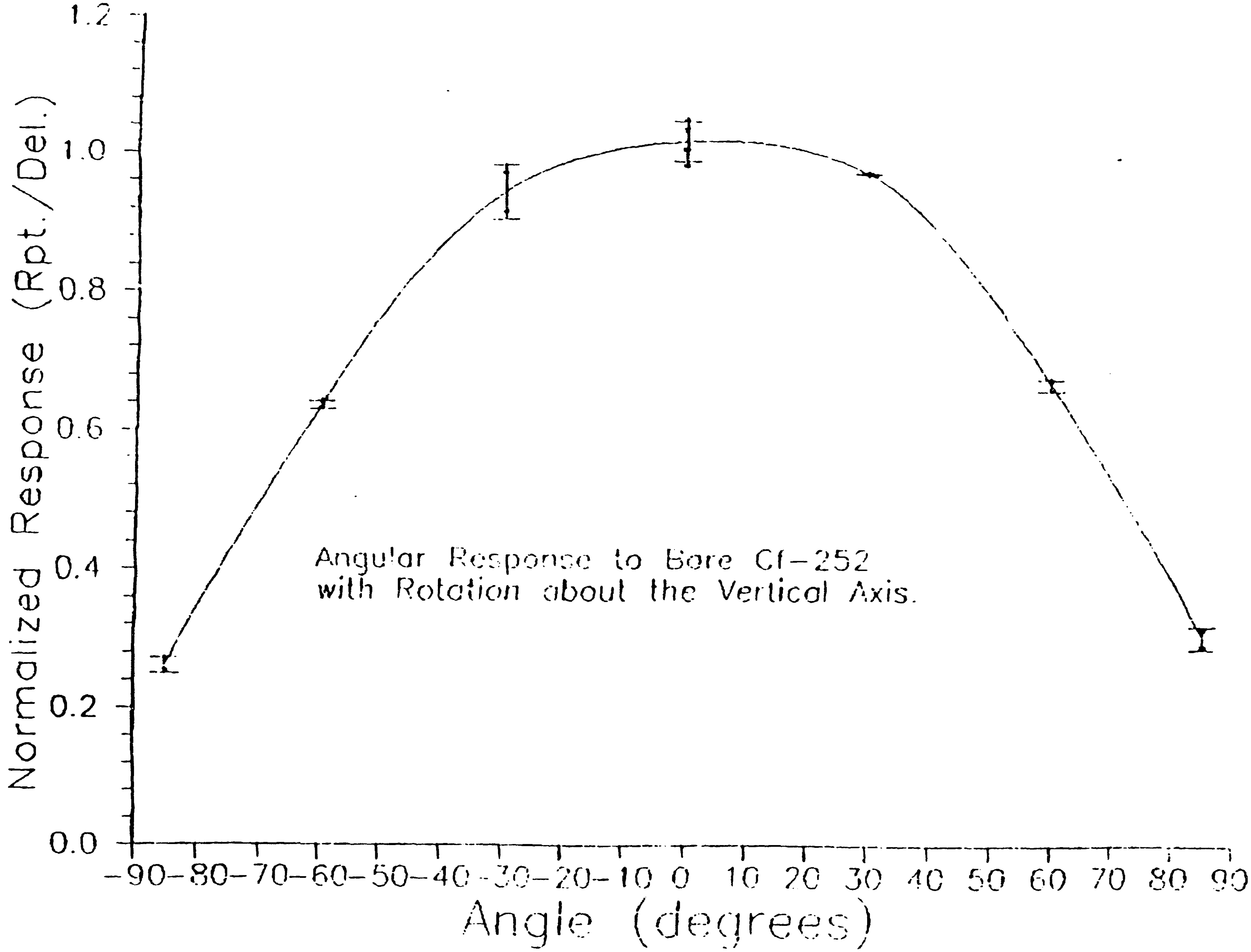

Angular Response to Beta with
Rotation about the Vertical Axis
Normalized Response (Rpt./Del.)
Angle (degrees)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90


Angular Response to Moderated Cf-252
with Rotation about the Horizontal Axis
Normalized Response (Rpt./Del.)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-90-80-70-60-50-40-30-20-10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)


Angular Response to Moderated Cf--252 with
Rotation about the Vertical Axis.
Normalized Response (Rpt./Del.)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)



Angular Response to Bare Cf-252 with
Rotation about the Horizontal Axis
Normalized Response (Rpt./Del.)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)


Angular Response to Bare Cf-252
with Rotation about the Vertical Axis.
Normalized Response (Rpt./Del.)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Angle (degrees)

APPENDIX C

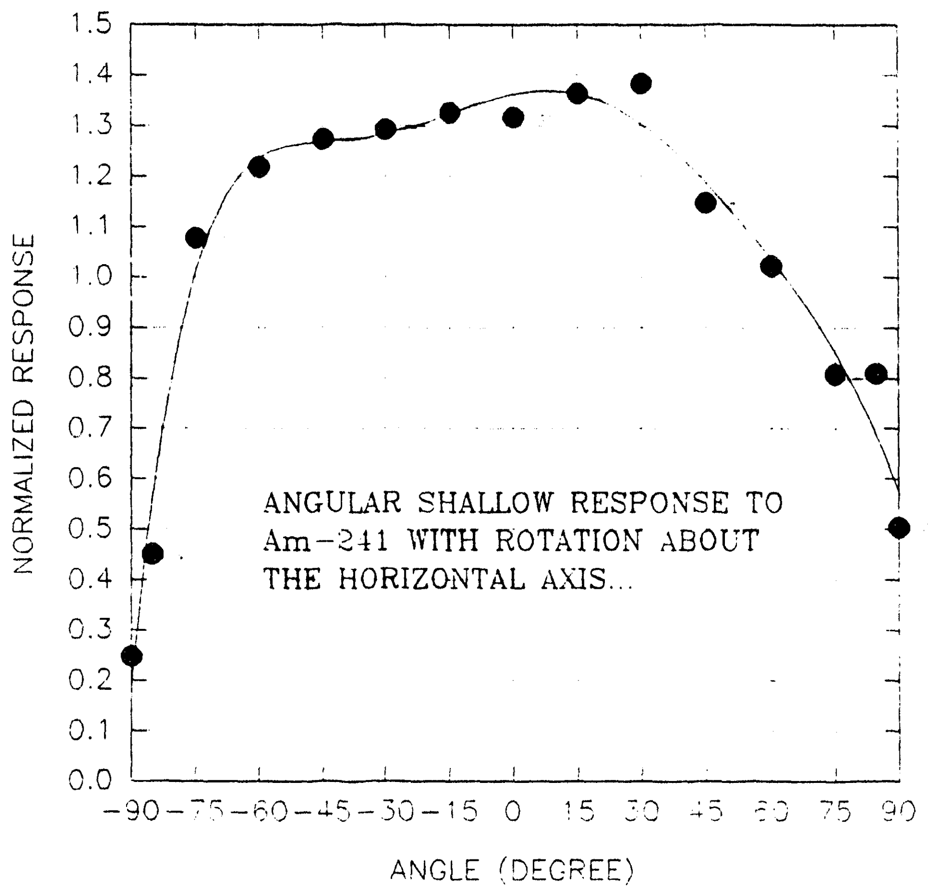
TRANSMITTAL FROM A. M. NAZARALI

From: A. M. Nazaraali
To : C. F. Wu
Subject: Angular dependence of Harshaw 8800C/8805 TLD System
Date : June 28, 1991

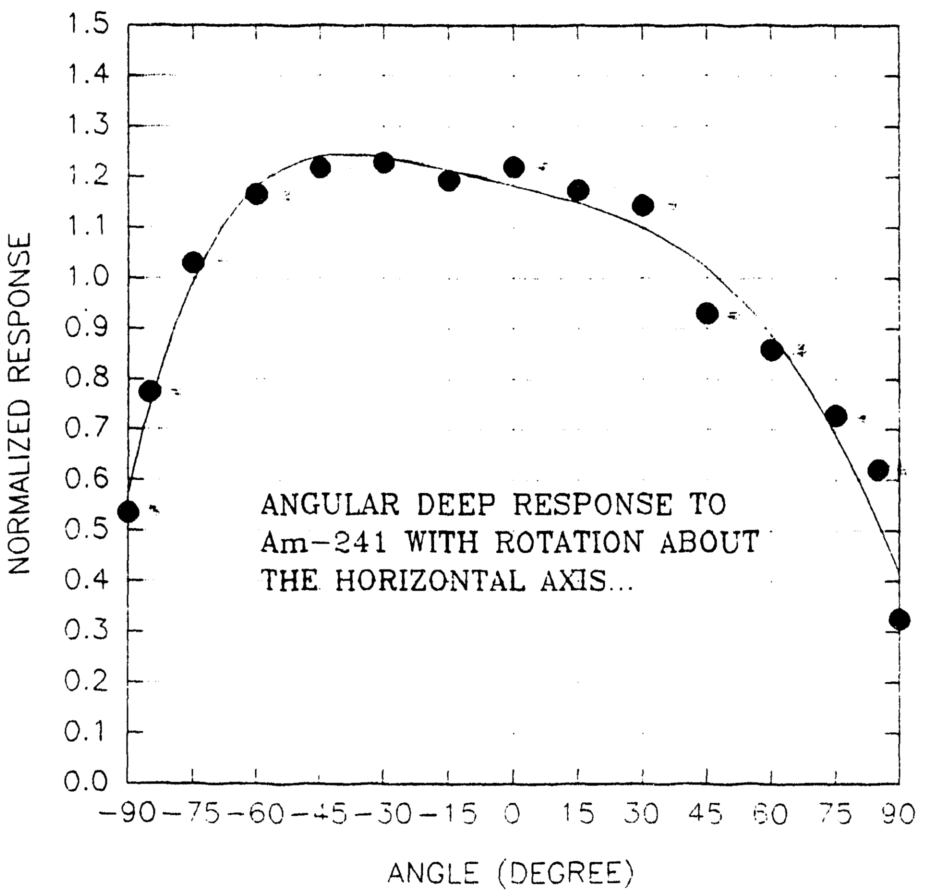
This study is done in accordance with DOE/EH-0027 performance standard. The methodology and technique in this study is the same as the previous study performed on 12/6/89 with the following exceptions. The number of dosimeters for each angle is doubled, and one extra irradiation category III (Am-241 & K-17) is added. In addition to the previous study angles, -90 and +90 are being incorporated in the analysis for all the categories. The results for 50% of the dosimeters irradiated at these two angles are questionable due to the geometry. Depending on the orientation of the dosimeters the two elements closer to the irradiation source have higher response than the other two elements, this causes the value of element ratio fall out side of the algorithm calculation range. These questionable results were revaluated manually and the calculated values are incorporated in the analysis.

The results of this study is summarized in the graphical presentation. The results of the Am-241, K-17, Cs-137, and moderated Cf-252 are presented for the deep and shallow dose for both vertical and horizontal orientation. The Beta (Sr/Y-90) shallow dose in presented for vertical and horizontal rotation. The horizontal axis represent the orientation of the dosimeter from -90 to +90 degree, and the vertical axis represent the normalized response which is the reported dose to delivered dose ratio.

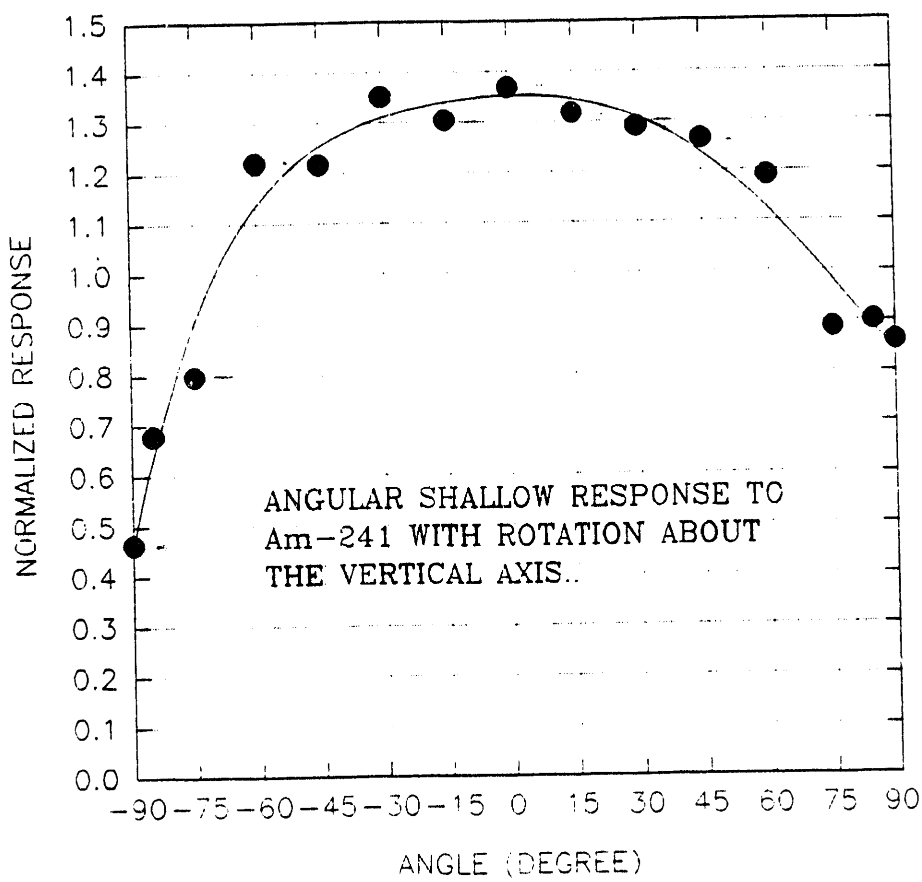
A. M. Nazarali
Dosimetry Senior Engineer



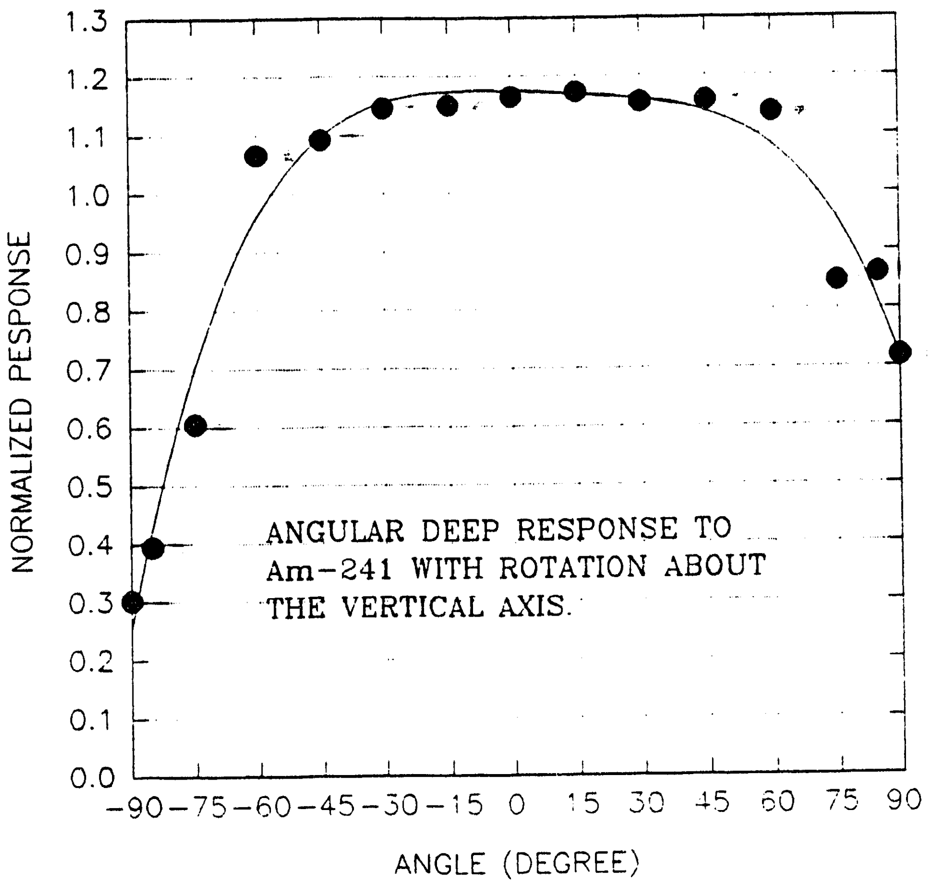
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NORMALIZED RESPONSE
ANGULAR SHALLOW RESPONSE TO
Am-241 WITH ROTATION ABOUT
THE HORIZONTAL AXIS...
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

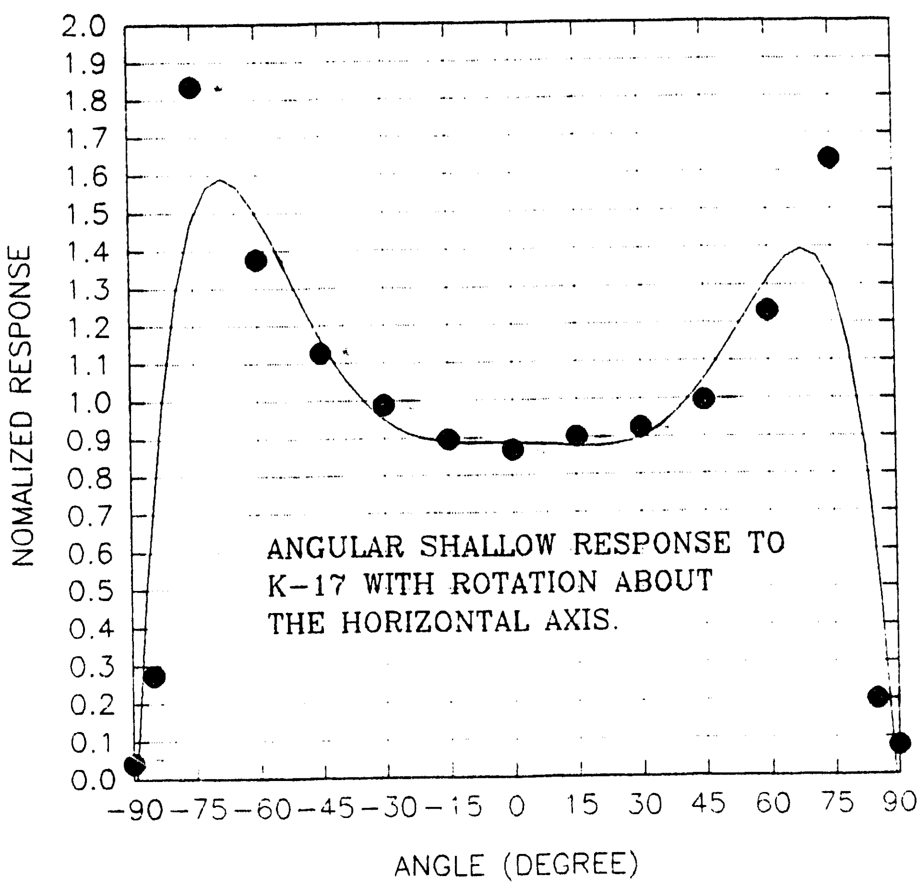


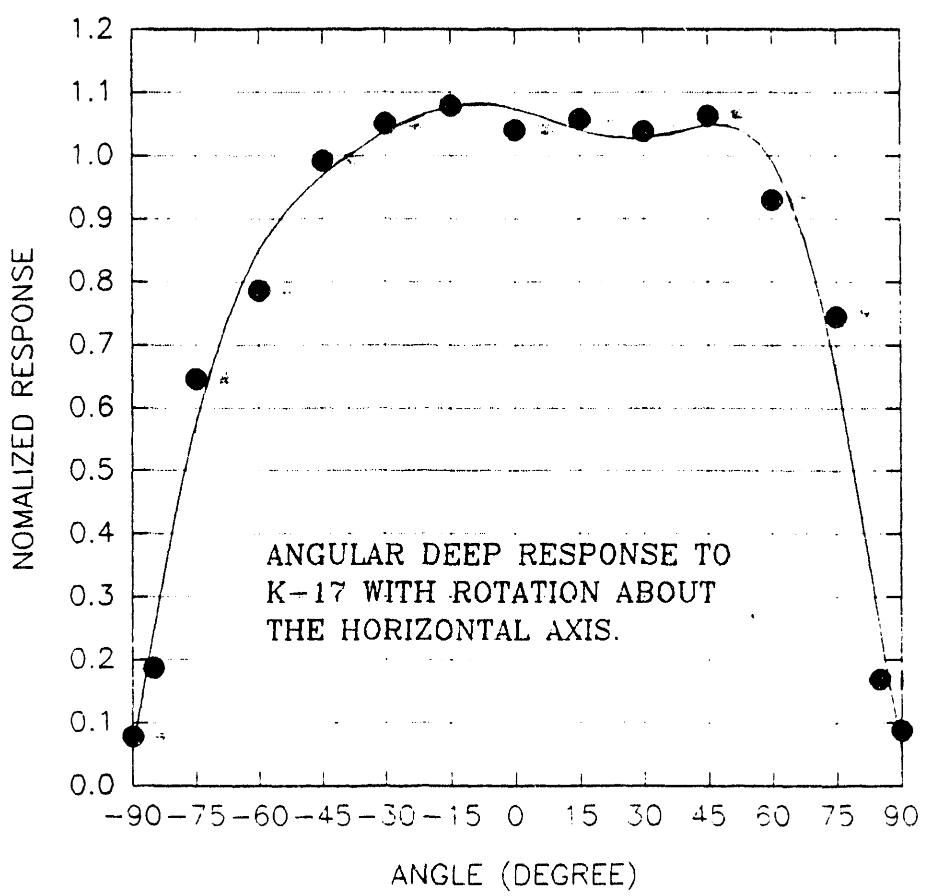
ANGULAR DEEP RESPONSE TO
Am−241 WITH ROTATION ABOUT
THE HORIZONTAL AXIS...
NORMALIZED RESPONSE
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
ANGLE (DEGREE)



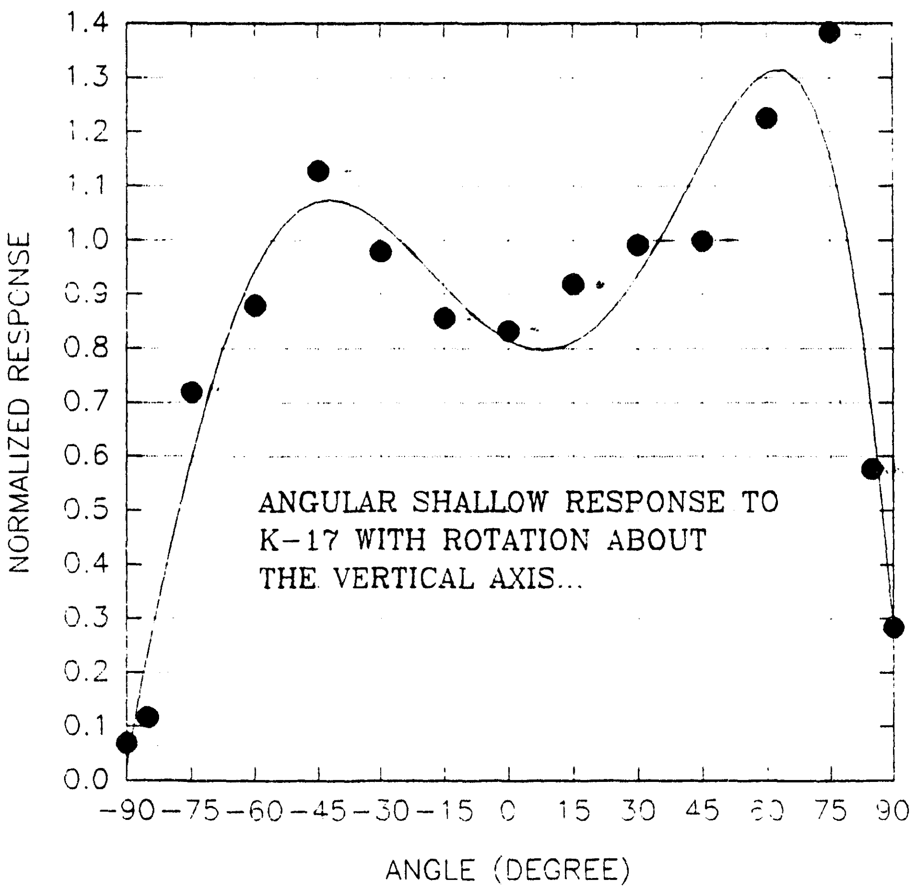
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NORMALIZED RESPONSE
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)
ANGULAR SHALLOW RESPONSE TO
Am-241 WITH ROTATION ABOUT
THE VERTICAL AXIS..


1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NORMALIZED PESPONSE
ANGULAR DEEP RESPONSE TO
Am-241 WITH ROTATION ABOUT
THE VERTICAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

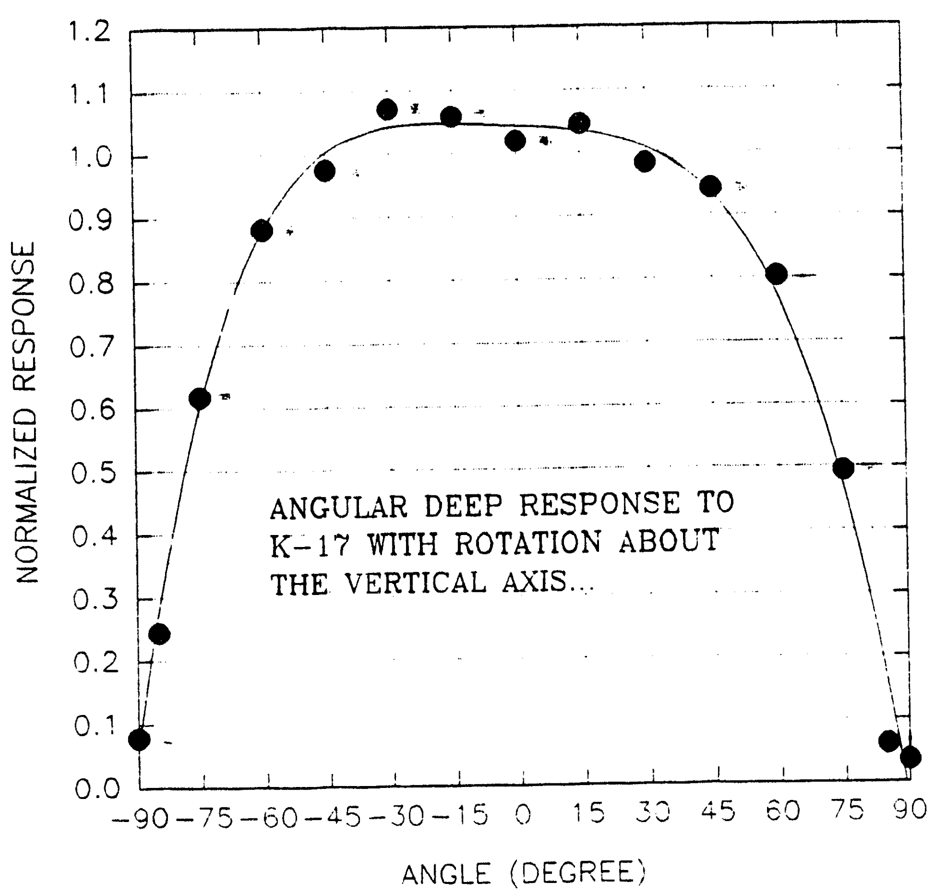

2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)
ANGULAR SHALLOW RESPONSE TO
K-17 WITH ROTATION ABOUT
THE HORIZONTAL AXIS.



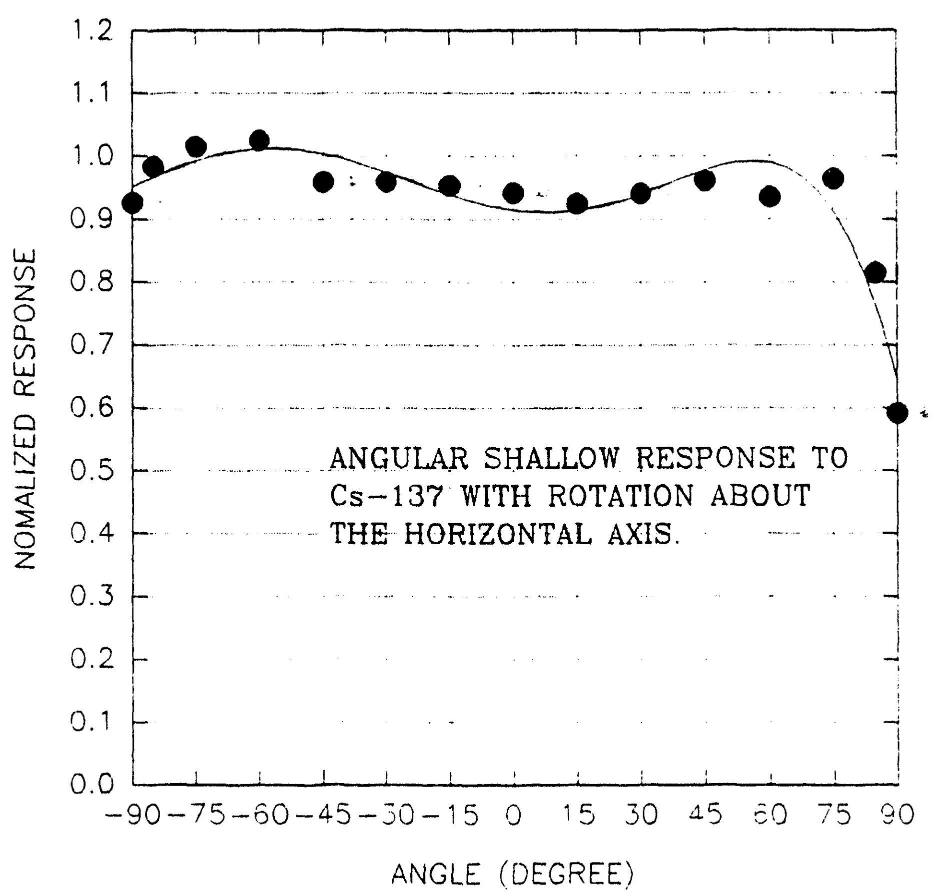
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR DEEP RESPONSE TO
K-17 WITH ROTATION ABOUT
THE HORIZONTAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)



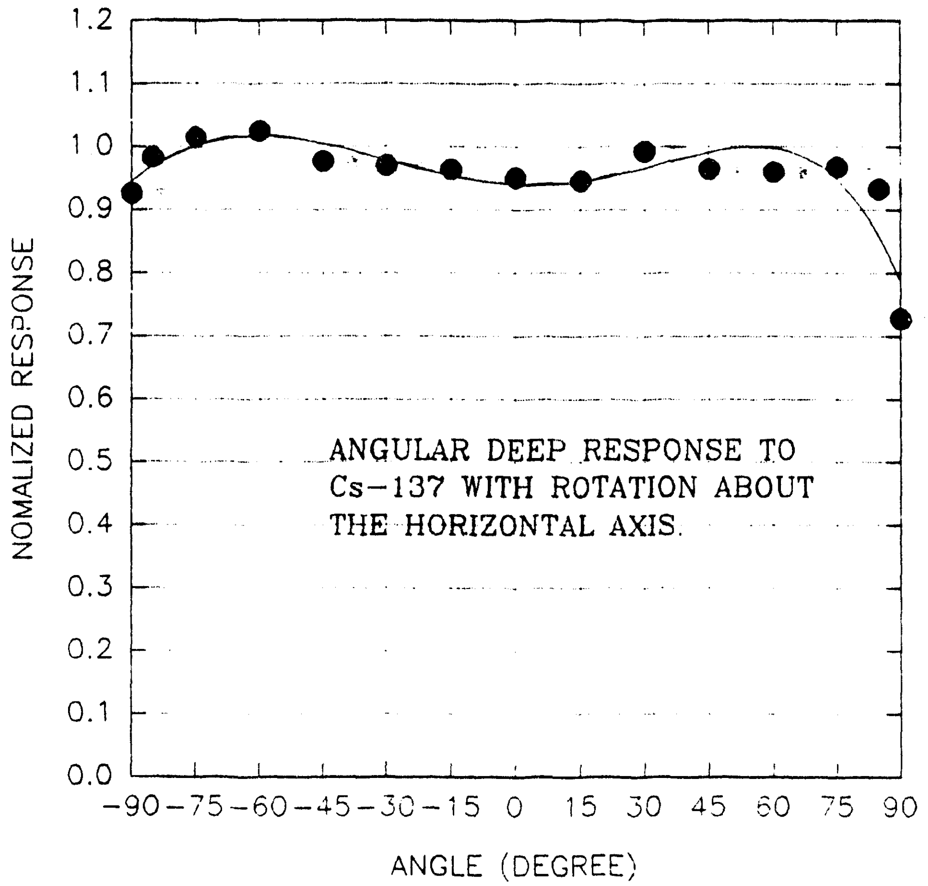
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NORMALIZED RESPONSE
ANGULAR SHALLOW RESPONSE TO
K-17 WITH ROTATION ABOUT
THE VERTICAL AXIS...
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

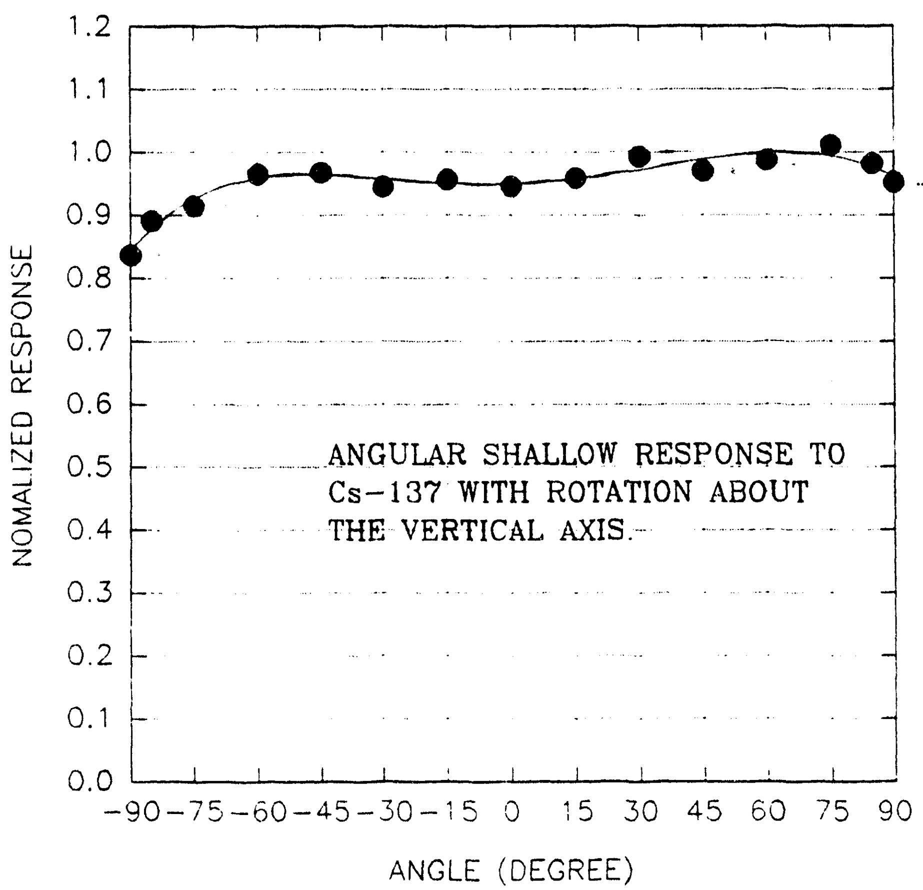


NORMALIZED RESPONSE
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
ANGULAR DEEP RESPONSE TO
K-17 WITH ROTATION ABOUT
THE VERTICAL AXIS...
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

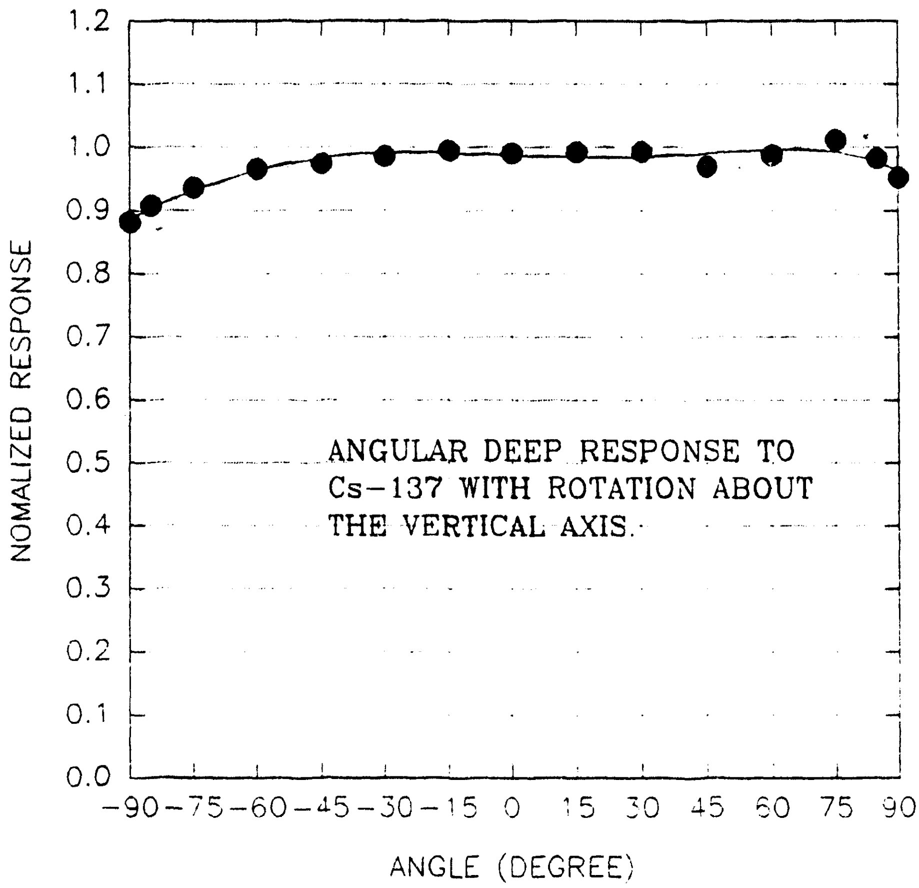


1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR SHALLOW RESPONSE TO
Cs-137 WITH ROTATION ABOUT
THE HORIZONTAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

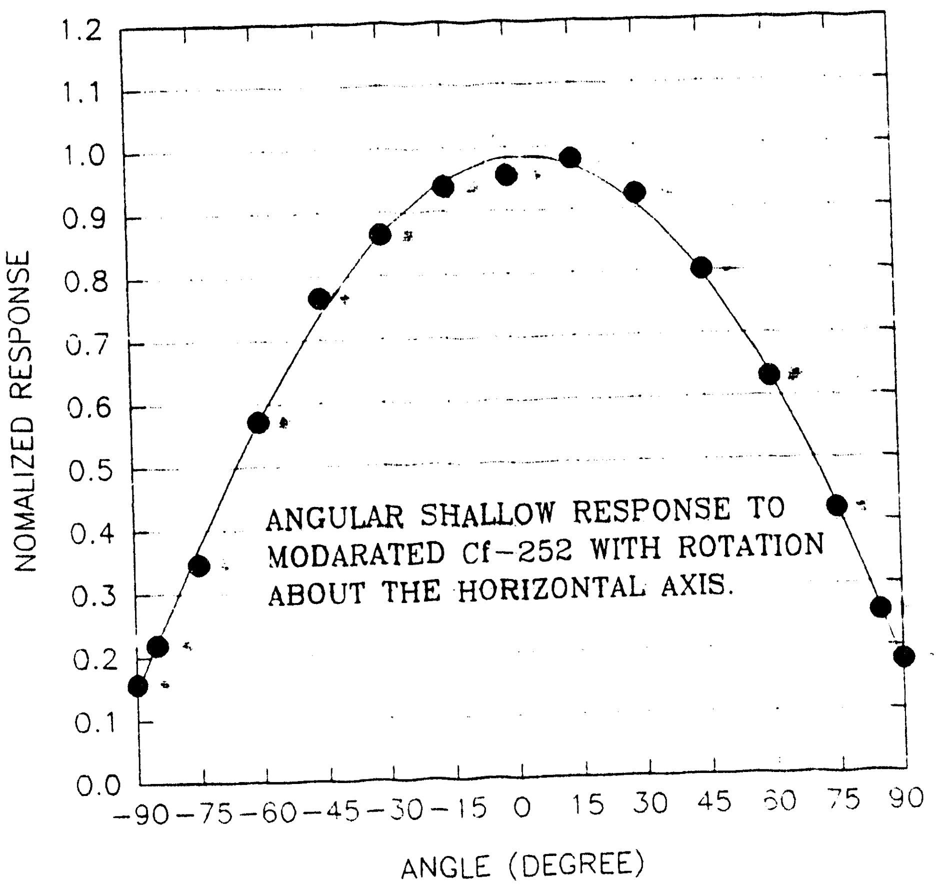

1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR DEEP RESPONSE TO
Cs-137 WITH ROTATION ABOUT
THE HORIZONTAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

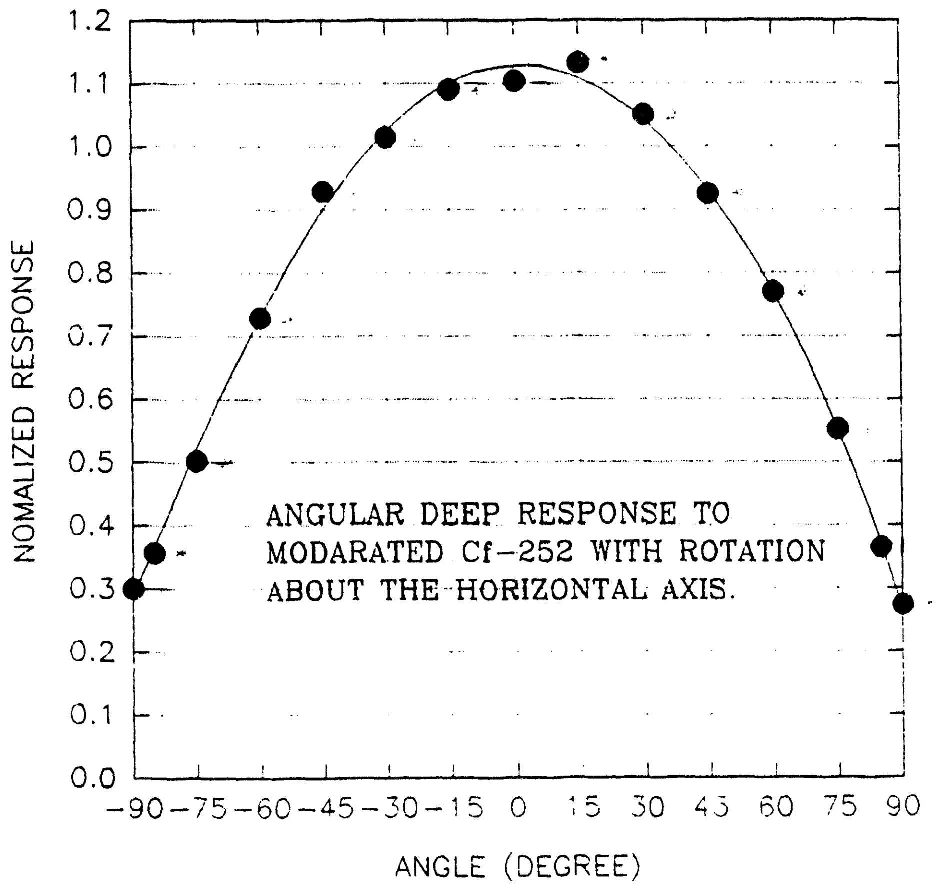


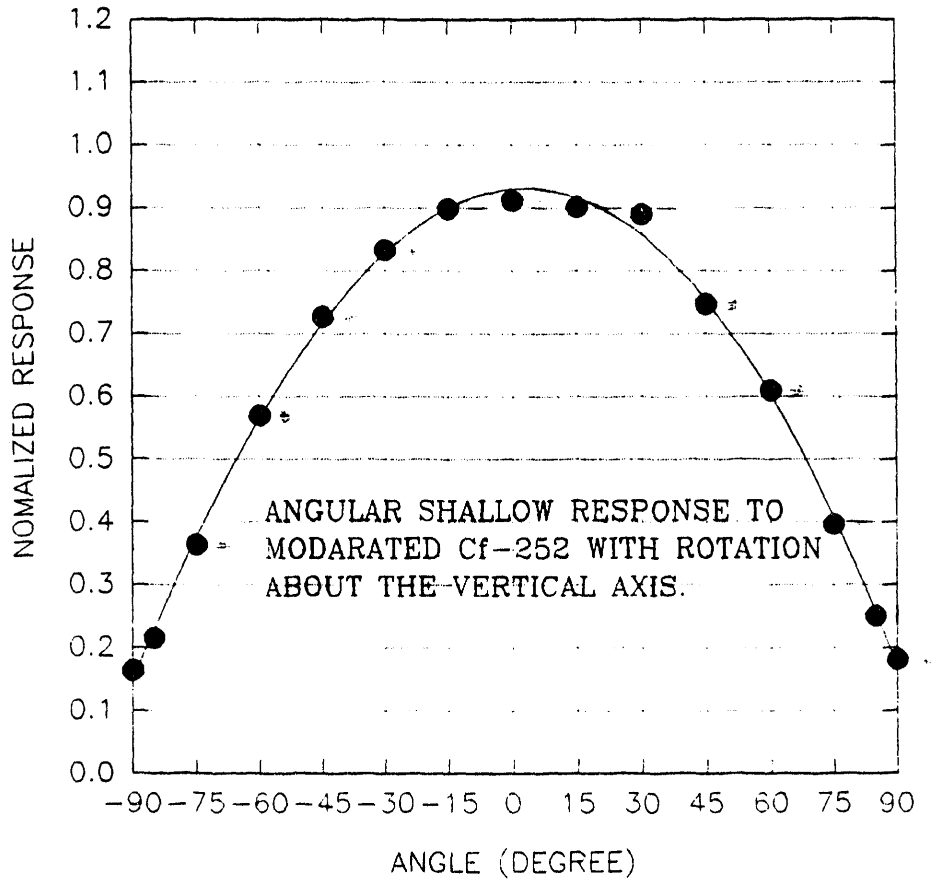
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR SHALLOW RESPONSE TO
Cs-137 WITH ROTATION ABOUT
THE VERTICAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)

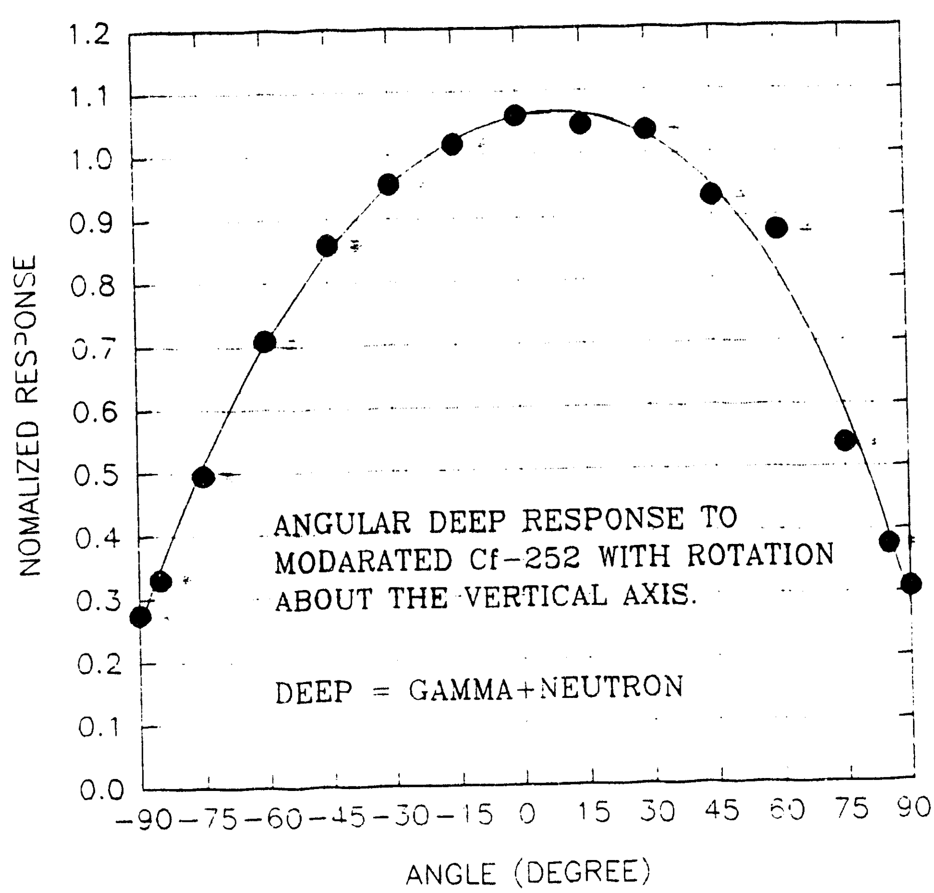


1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR DEEP RESPONSE TO
Cs−137 WITH ROTATION ABOUT
THE VERTICAL AXIS.
−90 −75 −60 −45 −30 −15 0 15 30 45 60 75 90
ANGLE (DEGREE)

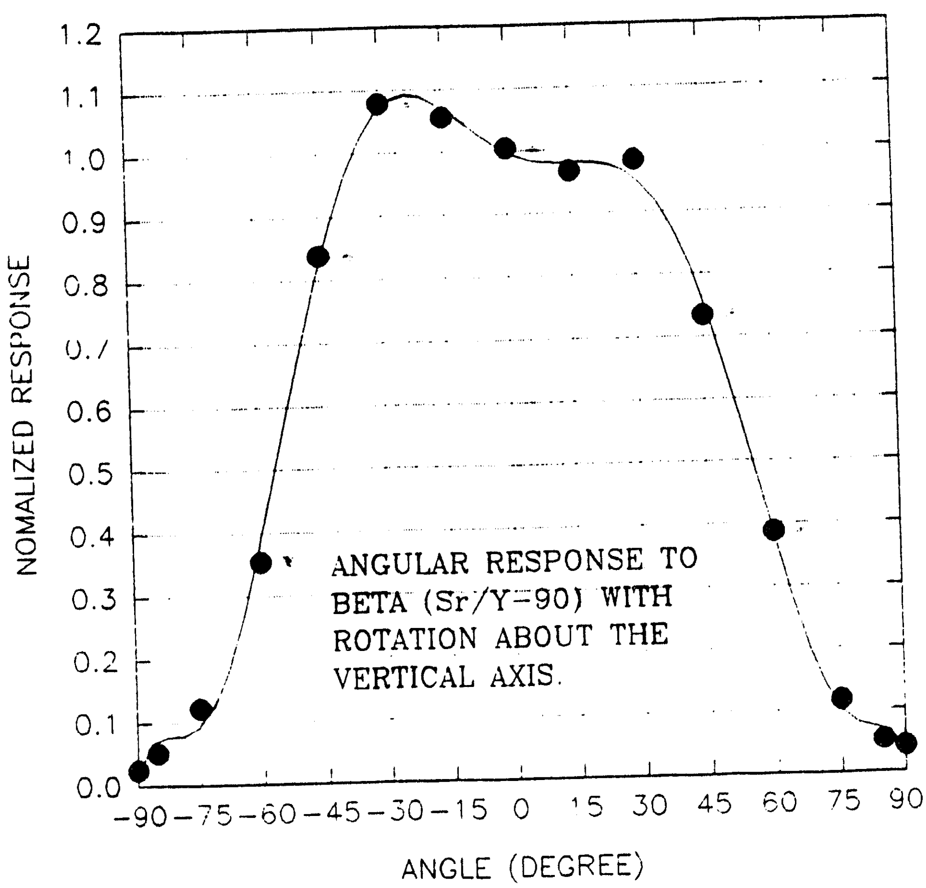

1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)
ANGULAR SHALLOW RESPONSE TO
MODARATED Cf-252 WITH ROTATION
ABOUT THE HORIZONTAL AXIS.


1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR DEEP RESPONSE TO
MODARATED Cf-252 WITH ROTATION
ABOUT THE HORIZONTAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)


1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR SHALLOW RESPONSE TO
MODARATED Cf-252 WITH ROTATION
ABOUT THE VERTICAL AXIS.
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)



1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
NOMALIZED RESPONSE
ANGULAR DEEP RESPONSE TO
MODARATED Cf-252 WITH ROTATION
ABOUT THE VERTICAL AXIS.
DEEP = GAMMA+NEUTRON
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
ANGLE (DEGREE)


ANGULAR RESPONSE TO
BETA (Sr/Y-90) WITH
ROTATION ABOUT THE
VERTICAL AXIS.
NOMALIZED RESPONSE
ANGLE (DEGREE)
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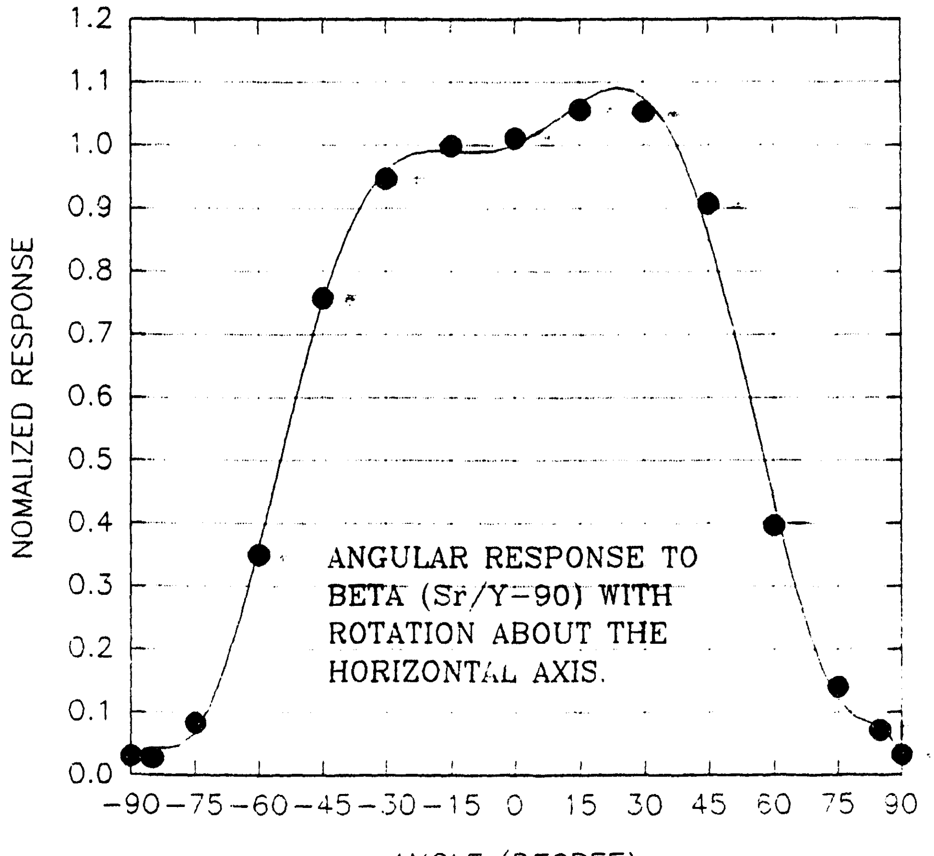
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90



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NOMALIZED RESPONSE
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ANGLE (DEGREE)
ANGULAR RESPONSE TO BETA (Sr/Y-90) WITH ROTATION ABOUT THE HORIZONTAL AXIS.

APPENDIX D

WIPP NEUTRON DOSIMETRY PROGRAM

FOR INFORMATION ONLY 5/24/92 WD:90:00843

RECORD

Westinghouse Electric Corporation

Government Operations

Waste Isolation Division

Box 2078
Carlsbad NM 88221

August 3, 1990

Dr. J. A. Mewhinney, Branch Chief
Environment, Safety & Health
U.S. Department of Energy
WIPP Project Office
P.O. Box 3090
Carlsbad, NM 88221-3090

Subject: WIPP NEUTRON DOSIMETRY PROGRAM

Reference: Mr. R. H. Neill letter to Mr. W. J. Arthur dated November 8, 1989

Dear Dr. Mewhinney:

Attached please find the results of our investigation of the neutron monitoring requirements for handling transuranic waste at the Waste Isolation Pilot Plant (WIPP).

The study indicates that the current WIPP Harshaw 8805 (8801-7776 card) Thermoluminescent Dosimeter (TLD), calibrated for moderated Cf-252, can provide adequate neutron dosimetry during bin scale testing, and initial periods of waste receipt. The neutron dose response of the system will be verified by irradiating TLDs to known neutron doses at some waste generation sites.

The Harshaw 8806 (8801-6776 card) TLD will provide a more accurate determination of neutron dose. This system has been ordered and should be accredited by DOELAP by January 1992. In addition to the normal accreditation process, the response of the system should be verified by waste generation site irradiations prior to being placed in service.

Please contact Dr. C. F. Wu or T. E. Goff of my staff if you require further information.

Very truly yours,

L. R. Fitch

L. R. Fitch, Assistant General Manager
Environment, Safety, Health & Quality Assurance

TEG:pzw

Attachment

cc: R. D. Boyer, WID
J. W. Bowen, WID
O. L. Cordes, WID
G. W. Pohl, WID
W. P. Poirier, WID
L. L. Reed, WID
C. F. Wu, WID

DA:90:7563

Neutron Dosimetry Program at the Waste Isolation Pilot Plant Carlsbad, New Mexico

June 15, 1990

I. INTRODUCTION

Planned waste streams to the Waste Isolation Pilot Plant (WIPP) will include materials that emit neutron radiation. Initially, the major volume of waste will be from the Idaho National Engineering Laboratory (INEL) and the Rocky Flats Plant (RFP) (U.S. DOE, 1989).

It is expected that neutron dose equivalent rates from waste coming to the WIPP will be very low. Survey documents indicate the average neutron dose equivalent rate, on a sample 4,000 drums in the Air Support Building at INEL, is 0.04 mrem/hour. Surveillance/area thermoluminescent dosimeters (TLDs) in a waste building at INEL indicated neutron dose rates between 250 and 550 mrem/quarter (Blume, 1990). While these levels are difficult to measure directly, neutron dosimetry may be required for personnel with high occupancy times in areas around the waste.

DOE Order 5480.11 requires that personnel dosimetry be provided to radiation workers who are likely to exceed 100 mrem annual effective dose equivalent from external sources. This requirement, however, does not discriminate neutron radiation from other penetrating radiations.

The Nuclear Regulatory Commission, Regulatory Guide (NUREG) 8.14, Section C 1.e, specifies that neutron dosimeters be provided if personnel may exceed a 30 mrem/quarter neutron dose rate. Based on the INEL surveillance TLD readings, it is possible that personnel could reach this dose equivalent rate working around the expected waste streams. Therefore, a personnel neutron dosimeter system is recommended for neutron dose equivalent monitoring at the WIPP.

II. DOSE RATE DETERMINATIONS

If neutron radiation is indicated on the shipping documents for waste arriving at the WIPP, the containers will be surveyed with an Eberline PNR-4/NRD Neutron rem-Counter. This instrument consists of a boron trifluoride proportional detector inside a nine-inch polyethylene neutron moderating sphere. Because of the large size of the sphere, the response as a function of neutron energy is similar to the dose equivalent per neutron fluence (Turner, 1986).

Figure 1 compares the response of the PNR-4/NRD to the actual neutron dose at a given neutron fluence for a range of neutron energies (solid curve). The dose curve is based on the dose per fluence data in ICRP 21 (dotted curve).

The curves coincide with each other for neutrons with energies between 400 keV and 4 MeV. At lower energies, the instruments over-respond relative to the true neutron dose rates (Eberline, July 1984). It is thus reasonably conservative to use the PNR-4 Neutron rem-Counter for TRU waste neutron dose monitoring.

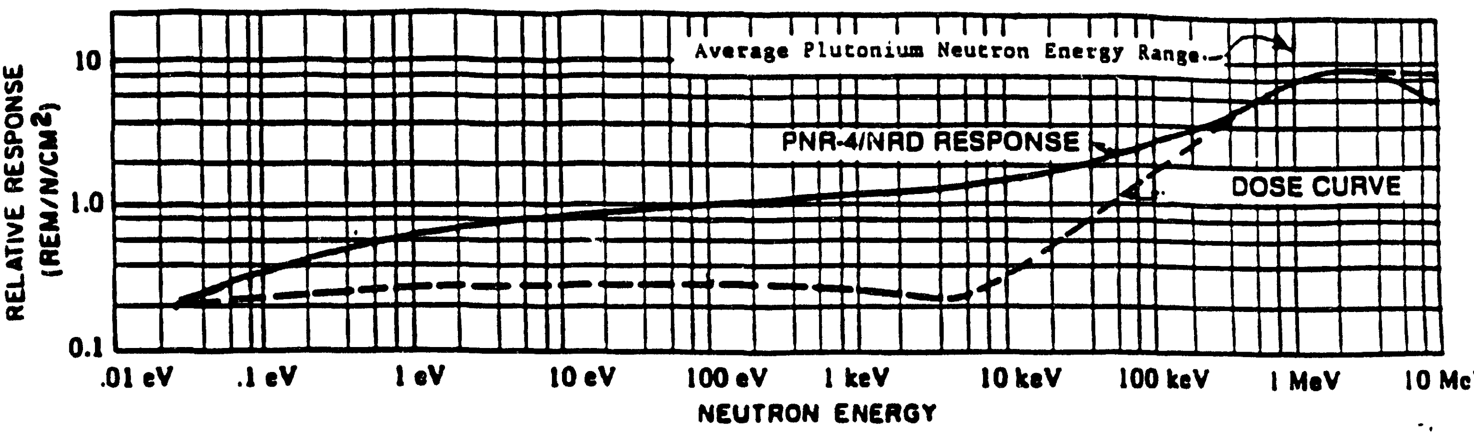

Figure 1 PNR-4/NRD Neutron REM-counter response versus Energy relative to expected waste averag. neutron energy

The rem-Counters are calibrated with moderated californium-252 semiannually (as per WP 12-555) by Eberline in Santa Fe using National Institute of Standards and Technology (NIST) traceable sources (Eberline, 1986). Continued stable performance is ensured by daily source checks using a 40 millicurie americium-241/beryllium and 8 millicurie cesium-137 source contained in a Troxler moisture/density gage (model #3411-B). This source provides a neutron response of approximately 2.5 mrem per hour. This is high enough to provide a meaningful check of response, but low enough to ensure continued sensitivity of the instruments to detect low levels of neutron exposure. The actual check source value will be determined for each instrument when it is returned from calibration.

If surveys indicate the possibility of significant neutron dose (that is, approaching administrative limits), Operational Health Physics will require that Dosimetry read the individual's neutron TLD. Normally, the TLDs would be read monthly or quarterly to ensure neutron doses approaching the TLD system lower limit of detection are not lost.

III. NEUTRON DOSE DETERMINATION

Neutron dose may be determined from radiation survey results using neutron dose rate instruments. Surveys are performed of work areas where work is to be performed and personnel occupancy periods (stay times) are recorded for

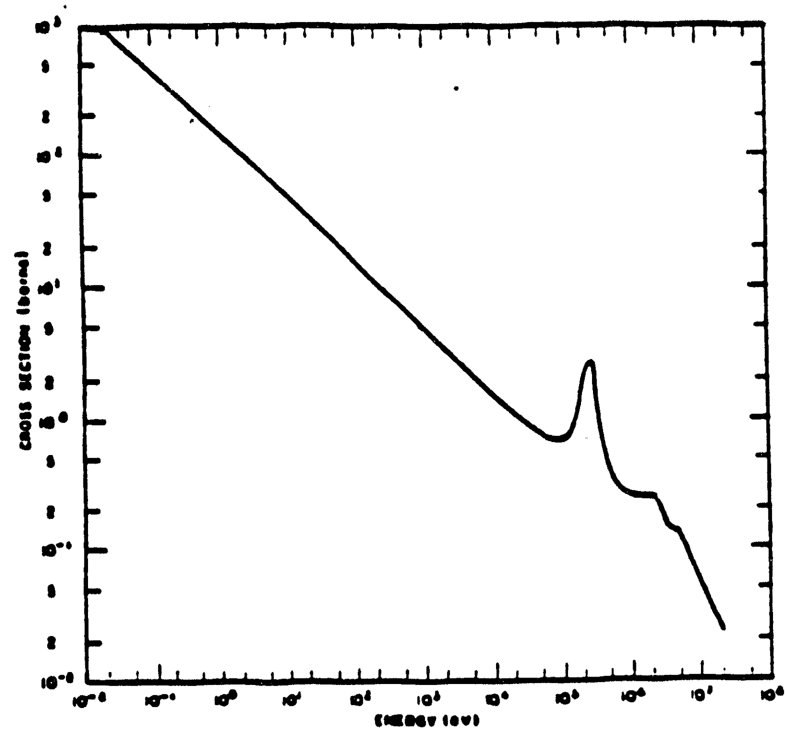

Figure 2. Lithium-6 Neutron Absorption Cross Section versus Neutron Energy

As shown in Figure 3, for neutrons with energies above 0.025 eV (thermal neutron energy), the relative number of neutrons reflected back from the wearer's body decreases as the neutron energy increases. Thus for an increasing energy of incident neutron radiation, the response difference between the neutron-sensitive and neutron-insensitive elements decreases. Therefore, determination and use of an neutron calibration factor (that is, rem per unit element reading difference) based on a spectrum different from actual field conditions will result in large errors in the neutron dose equivalent determination.

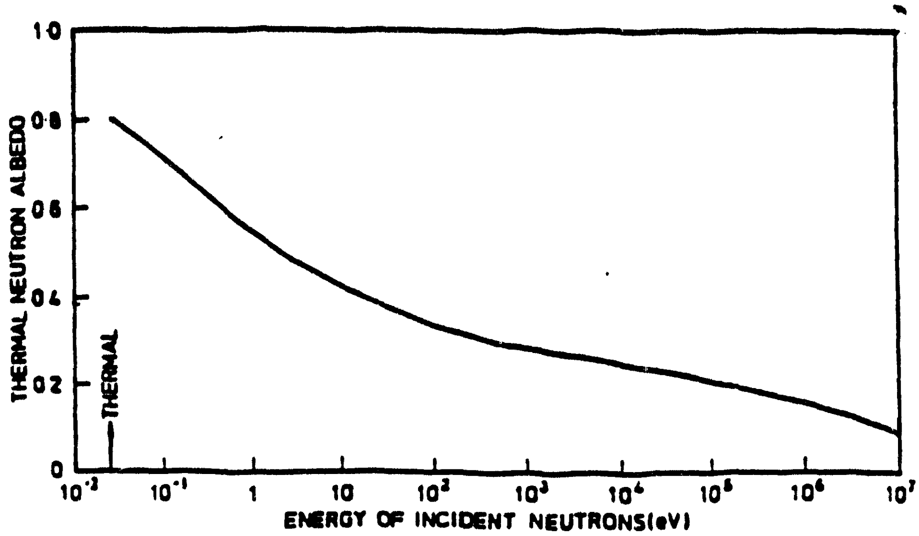

Figure 3. Albedo Effect versus Neutron Energy

The expected waste streams to be handled by the WIPP will contain a wide variety of materials and isotopes. This will result in potential differences in neutron source terms and moderation effects not only between shipments, but also between containers in any given shipment. This makes determination of an accurate and consistent neutron correction factor nearly impossible. Therefore, the neutron correction factor used must at least result in a conservative, yet reasonable, estimate of personnel neutron dose equivalent when applied to TLD neutron signals.

The calibration of the TLD system should be based on response to neutron sources moderated by actual waste matrix conditions. The net result of the moderation of the waste can be observed in neutron calibration factors determined by the Oak Ridge National Laboratory (ORNL) for the Harshaw TLD system. The multiplicative neutron correction factor for ORNL's Solid Waste Storage Area #5 is 0.101. This is less than the neutron correction factor for moderated Cf-252 of 0.115 (McMahan, 1990). These values are applied to the difference in readings between the unshielded lithium-6 / lithium -7 elements. This indicates that the use of a neutron correction factor based on moderated Cf-252 will result in a conservative neutron dose estimate.

<u>Harshaw 8806 Dosimeter</u>

Because of the variability of the neutron sources and materials in the waste matrix, the neutron spectrum will vary greatly over a monitoring period. A method of discriminating between the low-energy direct and high-energy neutrons thermalized and reflected by the albedo effect would result in a more accurate determination of the neutron dose from widely varying spectrums. The Harshaw 8806 holder with 8801-6776 card (hereafter referred to as the 8806 TLD) consists of two pairs of lithium-6/lithium-7 elements with one pair shielded by a layer of cadmium.

The primary response of the 8806 TLD element shielded by cadmium is from high-energy neutrons thermalized and reflected by the albedo effect. The unshielded element responds to both direct and albedo thermal energy neutrons. The response difference of the shielded elements is multiplied by a neutron calibration factor based on a high-energy neutron spectrum. The shielded response is subtracted from the unshielded response to determine the thermal neutron response. The thermal neutron response is then multiplied by the lower energy neutron calibration factor. These quantities are summed to give a close approximation of the actual total neutron dose equivalent.

TLD Selection

If neutron doses are very low (that is, usually equal to or smaller than the lower limit of detection of the TLD), the current Harshaw 8805 TLD could be utilized with a neutron calibration factor based on moderated Cf-252. If neutron dose levels are significantly above the lower limit of detection (LLD) of the dosimeter, use of the highly conservative neutron calibration factors could impact As Low As Reasonably Achievable (ALARA) measures.

Determination of actual neutron spectra on site is not considered viable because of the expected low neutron dose rates from the waste and the extreme variability of the neutron spectra between containers. Instruments used to characterize neutron spectra, such as "Bonner Spheres," are not sensitive enough to detect the low neutron levels expected at the WIPP.

The Harshaw 8806 TLD will reduce the impact of the over-response to low-energy neutrons and should result in dose determinations that are closer to the true neutron doses expected from the transuranic (TRU) waste. These values, in reality, should not represent a significant portion of personnel dose. The 8806 TLD is compatible with the WIPP Harshaw 8800C TLD reader and received DOELAP accreditation at the Oak Ridge National Laboratory for both moderated and unmoderated neutrons.

Implementation of the Neutron Monitoring Program

Approximately 600 Harshaw Model 8806 TLDs will be required to provide neutron monitoring for personnel working on a routine basis with contact-handled TRU waste:

25/month for Area Monitoring	50
200/month for Exposure Group 1 and 2 Personnel (expected to work in radiation areas on a regular basis)	400
50 DOELAP Performance Testing 2 Categories x 5 TLDs/month x 3 months 5 Spares in first shipment 5 controls / shipment x 3 shipments	50
100 Spares (misc. testing, lost TLDs, monitoring temporary personnel)	100

The 8806/8801-6776 dose algorithm needs to be developed and implemented on the WIPP Dosimetry On-line Information System.

The 8806 neutron dosimetry system must complete performance testing and be accredited by DOELAP for the WIPP.

The 8806 (and possibly the 8805) response to neutron-emitting waste at the INEL, RFP and other waste generator facilities should be determined. Comparing the neutron dose from the TLDs to that determined by instrument will verify the accuracy of the neutron dose determined using the moderated Cf-252 neutron calibration factor.

Interim Neutron Monitoring

If neutron-emitting waste is expected to arrive at the WIPP before the 8806 neutron dosimetry system can be implemented, the current 8805/8801-7776 system will provide a conservative dose estimate using a moderated Cf-252 neutron correction factor. As neutron dose rates from the waste are expected to be very low, small inaccuracies in the neutron calibration factor will not result in a significant overestimation of the total dose to personnel.

Long-Term Neutron Monitoring Program

Current information about waste neutron spectra and dose rates does not exist at a level where a decision can be made as to the adequacy of the neutron dosimetry system for contact-handled waste. It does appear, however, that remote-handled waste streams could contain significant neutron dose equivalent rates (Harrington, 1984). Shielding calculations for the facility cask are based on limiting the neutron dose equivalent rates to 50 mrem/hour outside the cask (U.S. DOE, 1984). In addition, some waste streams may contain higher neutron dose equivalent rates than those expected from INEL and RFP. This waste may contain lower concentrations of the materials contributing to the neutron radiation levels in the remote-handled waste. Therefore, more accurate determinations of the neutron doses may be necessary to avoid impacting the WIPP ALARA measures or administrative limits.

The key to more accurate neutron dose equivalent determinations with the 8806 system is better determination of the neutron calibration factor for the waste involved. The neutron spectrum for waste at each generator site should be quantified and the 8806 exposed to a known dose range and the neutron calibration factors determined for each site. Additional spectrum characterization should occur at the WIPP site if waste with significant dose rates is received. ALARA considerations would have to be resolved as to whether the dose received performing the surveys was justified by the dose "saved" by lowering the neutron calibration factors.

If the waste spectra are too variable and neutron doses too high, other dosimeters may have to be investigated. This decision will be based on the impact of the conservative neutron dose equivalents indicated by the TLDs relative to those indicated by surveys and shipping documents and their impact on WIPP operations and ALARA goals. At present, it appears that the 8806 TLD system will provide an adequate neutron dosimetry system for the foreseeable future.

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