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VALIDATION OF HANFORD PERSONNEL AND EXTREMITY DOSIMETERS IN PLUTONIUM ENVIRONMENTS

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January 31, 2000

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ABSTRACT

A study was performed to assess the performance of Hanford personnel neutron dosimetry. Measurements were performed in the Plutonium Finishing Plant (PFP), which is the facility with the most significant worker exposures to neutrons on the Hanford site. The study was conducted in two parts: one assessing whole body dosimetry and one assessing extremity dosimetry. For both parts of the study, the Tissue-Equivalent Proportional Counter (TEPC) was used as the principle instrument for characterizing workplace neutron fields.

In the whole body study, 12.7-cm-diameter TEPCs were used in ten different locations in the facility. At each location, TLD and TED personnel dosimeters were exposed on a water-filled phantom at the same location to enable a comparison of neutron dose equivalents as measured by the TEPC and as determined from the personnel dosimeters.

In the extremity study, 1.27-cm-diameter TEPCs were exposed inside the fingers of gloves worn in gloveboxes. Hanford extremity dosimeters (gamma sensitive ring TLDs) were wrapped around the TEPCs. The glove, loaded with TEPCs and dosimeters, was exposed to six different cans of plutonium, simulating the exposure that a worker's fingers would receive in a glovebox. The comparison of TEPC-measured neutron dose equivalent to TLD-measured gamma dose equivalent provided neutron-to-gamma ratios that can be used to estimate the neutron dose equivalent received by a worker's finger based on the gamma readings of an extremity dosimeter.

The study also utilized other neutron instruments including a Snoopy and detectors based on bubble technology for assessing neutron exposures, providing a comparison of the effectiveness of these instruments for workplace monitoring.

The study concludes that the TLD component of the Hanford Combination Neutron Dosimeter (HCND) performs adequately overall, with a positive bias of 30%, but exhibits excessive variability in individual results due to instabilities in the algorithm. The electrochemically etched TED response was less variable but only 20% of the TEPC reference dose on average because of the low neutron energies involved. The neutron response of the Hanford Standard Dosimeter (TLD) was more variable than the TLD component of the HCND and biased high by a factor of 8 overall due to its calibration to unmoderated ^{252}Cf. The study recommends further work to correct instabilities in the HCND algorithm and to explore the potential shown by the bubble-based dosimeters.

EXECUTIVE SUMMARY

This report describes measurements performed in the Plutonium Finishing Plant (PFP) work environment to validate the recorded neutron dose for Hanford workers. The responses of Hanford dosimeter components, including the Hanford standard dosimeter (HSD), and both the thermoluminescent dosimeter (TLD) and track-etch dosimeter (TED) components of the Hanford combination neutron dosimeter (HCND) have been well characterized under the low-scatter conditions of the Hanford 318 Radiation Standards Laboratory. Hanford whole body personnel dosimeter response has also been measured previously under the relatively high-scatter conditions in the workplace at the PFP, because the majority of personnel neutron dose at Hanford (currently and historically) occurs at the PFP.

To validate the accuracy of recorded neutron doses in work locations at PFP, neutron doses were measured with several methods and compared with doses measured with a tissue equivalent proportional counter (TEPC). Measurements of neutron dose were also made using a Bubble Technology Industries (BTI) bubble detector, an Apfel REMBrandt survey meter, a Snoopy survey meter, and Hanford dosimeters. Measurement locations were selected with the assistance of PFP operational staff to be representative of work areas that currently contribute the majority of personnel neutron dose and represent the type of work planned in the future.

The study also investigated the assessment of extremity neutron dose at PFP. Small TEPC detectors and BTI bubble detectors with extremity dosimeters wrapped around them were exposed inside lead-lined gloves to collect data for determining neutron-to-gamma ratios. Extremity measurements were performed for six different types of plutonium sources.

Conclusions based on these measurements are:

- Measurements indicated that <u>neutron energies</u> in the workplace locations selected for evaluation were significantly moderated, indicative of the scattering that occurs in the extensive shielding used throughout PFP work areas. These neutron energies are important to the dosimeter and instrument response characteristics. Notably, these radiation fields have a substantial number of neutrons with energies below the response threshold for the TED. The TLD responds easily to these neutron energies but accurate calibration and dose interpretation can be difficult.

- <u>Bubble detector</u> performance, based on laboratory exposures in the 318 Calibration Low-Scatter Room (LSR), showed that the bubble detectors could typically give results within 30% of the accepted value when at least 35 bubbles were collected. Reading the detectors by eye gave more accurate results than automated reading of the detector.

  Bubble detector performance in the work environment was not as good. The bubble detectors sometimes read higher, sometimes lower, than the TEPCs. In general, there was not good agreement among the three bubble detectors exposed on each phantom. When the bubble detectors were exposed inside the leaded glove in the extremity study, there was usually good agreement between the two bubble detectors, but the bubble detectors consistently gave lower dose equivalent rates than the TEPCs.

- REMBrandt performance shows an over-response of about 53% in the LSR when exposed to neutrons from an unmoderated ^{252}Cf source. This over-response is partly attributed to a previous calibration appropriate for an AmBe source. However, even with updated calibration factors from the vendor for neutron energies characteristic of moderated fission spectra, there was an over-response. For the analysis of these measurements a calibration factor was derived using LSR exposures. Both calibration factors were used in the field measurements.

  Using the original calibration factor, the REMBrandt had responses similar to the Snoopy. Using the derived calibration factor, the REMBrandt under-responded for high dose rates (greater than 10 mrem/h), and was very close to the TEPC measurements for low dose rates (less than 5 mrem/h).

- Hanford standard dosimeter (HSD) neutron doses were always high, in some cases by as much as a factor of 18, compared with the TEPC for measuring neutron dose equivalent. Because this is a single element dosimeter there is no option but to use a single calibration factor. It may be possible to choose a single factor on the basis of these measurements which would reduce the bias overall, but the variability in individual dose results would be substantially larger than that seen for Hanford combination neutron dosimeters.

- The Hanford combination neutron dosimeter - thermoluminescent dosimeter (HCND-TLD) performed well for evaluating neutron dose equivalent. For the HCNDs exposed on-phantom, there was usually good agreement among the three dosimeters exposed on each face of a phantom, but there were instances where a small difference in chip responses could produce a large difference in evaluated doses because of branching options in the plutonium algorithm. In several cases, there was poor agreement between the HCNDs exposed on one face of a phantom compared with those exposed on another face of the phantom in the same location. This face-to-face disagreement was expected and is an indication of the directionality of the neutron radiation field. Overall, the HCND-TLD results showed a combined positive bias of 1.3, based on a comparison of the HCND-TLD and TEPC dose equivalent rate. However, for individual HCND-TLD results, some dose results were under-reported by a factor of 5.

- The Hanford combination neutron dosimeter - track-etch dosimeter (HCND-TED) performed better than the HCND-TLD in terms of precision for neutrons in the fields measured but showed an under-response bias compared with the TEPC dose measurements. The bias is expected to be a result of the highly scattered neutron fields, resulting in substantially degraded neutron energy spectra, and the angular response characteristics associated with the TED thin rectangular foil. The TED bias would be expected to be relatively small for higher-energy neutrons greater than the response threshold of about 100 keV, because of its relatively flat energy response, and for exposure conditions that are predominantly anterior-posterior.

- The Hanford extremity dosimeter response was generally good in terms of precision among similarly exposed dosimeters. Twelve of the 29 sets of dosimeters had a set of dose equivalent rates with standard deviations less than 10% of the mean; another 15 had standard deviations between 10 and 20%.

- Extremity neutron-to-gamma ratios ranged from 0.09 up to 0.65.

Recommendations based on the study conclusions include:

- Further investigation of the suitability of the BTI bubble detector for use as a supporting real-time personnel neutron monitor and the Apfel REMBrandt for use as a neutron survey instrument in Hanford neutron environments would be valuable. These instruments possess technical attributes of a direct-responding, tissue-like response that are expected to provide superior performance, compared with albedo or track-etch dosimeters, once the technology is fully developed.

- The plutonium algorithm of the HCND needs to be studied and if possible improved to prevent occurrences where similar chip responses can produce different evaluated neutron dose equivalents.

- The following neutron-to-gamma ratios would be suitable for extremity dose assessment:

  - 0.36 for sources similar to the “6% oxide” can
  - 0.14 for sources similar to the “12% oxide” can
  - 0.090 for sources similar to the “20% oxide” can
  - 0.47 for sources similar to the “metal” can
  - 0.25 for sources similar to the “17% oxide” can with 0.02-in. lead foil shielding
  - 0.55 for sources similar to the “17% oxide” can with heavy lead shielding.

  The proper application of these ratios to specific workplace conditions must consider factors such as the type of material in a can, the internal shielding of the can, and the thickness of shielding in the glovebox glove. These ratios are appropriate only for Hanford ring dosimeters worn inside the same type of lead-lined glove used in this study.

- These measurements showed that highly scattered neutron fields exist in PFP work locations. The significant dependence of albedo-type thermoluminescent dosimeters (e.g., HCND and HSD) on neutron energy is well documented. As noted in the DOE Standard *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities*, validation studies of dosimeter performance should be performed periodically and whenever there are major operational changes. A schedule should be adopted to repeat this study every two to three years at a minimum, so that up-to-date validation data are available.

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ACRONYMS

ABS	acrylonitrile-butadiene-styrene
ADC	analog-to-digital converter
ANSI	American National Standards Institute
BTI	Bubble Technology Industries
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DOELAP	U.S. Department of Energy Laboratory Accreditation Program
ECC	element correction coefficient
FCF	facility calibration factor
FN	fast neutron
HCND	Hanford combination neutron dosimeter
HED	Hanford External Dosimetry
HSD	Hanford standard dosimeter
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
LET	linear energy transfer
LSR	Low-Scatter Room
MCA	multichannel analyzer
NCRP	National Council on Radiation Protection and Measurements
NIM	Nuclear Instrument Module
NIST	National Institute of Standards and Technology
NVLAP	National Voluntary Laboratory Accreditation Program
PFP	Plutonium Finishing Plant
PMT	Photomultiplier Tube
PNAD	personnel nuclear accident dosimeter
PNNL	Pacific Northwest National Laboratory
PTFE	polytetrafluroethylene
REX	Radiological EXposure system
RCF	reader calibration factor
RRF	relative response factor
SN	slow neutron

TE	tissue equivalent
TED	track-etch dosimeter
TEPC	tissue-equivalent proportional counter
TLD	thermoluminescent dosimeter

CONTENTS

1.0 INTRODUCTION

This report documents performance of Hanford personnel neutron dosimeters in the complex neutron fields of the Hanford Plutonium Finishing Plant (PFP).

1.1 Background

The existing Hanford personnel dosimetry system was implemented on January 1, 1995. This dosimetry system was first accredited under the U.S. Department of Energy (DOE) Laboratory Accreditation Program (DOELAP) during 1994; and has since been re-accredited during 1996 and 1998. The National Voluntary Laboratory Accreditation Program (NVLAP) also accredited the system during 1997. Pacific Northwest National Laboratory (PNNL)[(1)] administers the Hanford External Dosimetry (HED) program, which provides dosimeter processing and technical support to Hanford contractor organizations. This report documents a study of the accuracy of Hanford personnel dosimeters under actual work environments. Hanford currently uses several dosimeter systems to measure and record personnel neutron dose, as follows:

- Hanford combination neutron dosimeter (HCND) is the whole body dosimeter worn by Hanford workers who have the potential for receiving neutron dose at or above the monitoring level. This dosimeter has three neutron radiation dose capabilities: 1) a Harshaw[(2)] 8816 thermoluminescent dosimeter (TLD) holder with 7666 TLD card, 2) a Harshaw 8825 TLD holder with 7777 TLD card, and 3) a Hanford track-etch dosimeter (TED) consisting of two CR-39 track-etch foils.

- The Hanford standard dosimeter (HSD) is the whole body dosimeter worn by Hanford workers who have the potential for dose from beta/photon radiation at or above the monitoring level. The HSD consists of the Harshaw 8825 dosimeter holder with a 7776 TLD card. In addition to being NVLAP- and DOELAP-accredited for a variety of beta and photon radiations, the HSD is a DOELAP- and NVLAP-accredited neutron dosimeter that can be used to measure neutron dose in cases where the spectra are well characterized, consistent, and the potential neutron dose is less than the DOE administrative guideline for neutron personnel monitoring.

- The Hanford track-etch Dosimeter (TED) is composed of two CR-39 foils. The TED is a component of the HCND. The HCND is DOELAP- and NVLAP-accredited either with or without the TED component.

- The Hanford extremity dosimeter consists of the Harshaw XD740 chipstrate TLD sealed in a hard plastic ring. The XD740 (TLD-700) is sensitive to beta-gamma radiation only. Extremity neutron dose is calculated using the measured gamma dose and an assumed neutron-to-gamma ratio for the workplace in which the dosimeter is used.

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1) Managed for the U.S. Department of Energy by Battelle Memorial Institute under contract DE-AC06-76RLO-1830.
2) Manufactured by Bicron, Saint-Govain/Norton Industrial Ceramic Corporation, Solon, Ohio.

The scientific basis for neutron dose is complicated. The International Commission on Radiological Protection (ICRP) publication 51, *Data for Use in Protection Against External Radiation* (ICRP 1987), provides some guidance and dose conversion factors that can be used to determine effective dose equivalent for external radiation. The DOE has traditionally followed the recommendations of the ICRP and the National Council on Radiation Protection and Measurements (NCRP) (1971) to calculate personnel dose equivalent. Currently, neutron dosimetry practices must comply with the requirements of Occupational Radiation Protection, Title 10 of the Code of Federal Regulations (CFR) Part 835 (1993) that regulates DOE and its contractors. The quality factors and conversion coefficients contained in Part 835, paragraph 835.2 of Subpart A, are identical to those found in Table 2 in NCRP report 38 (1971) and are fluence-to-dose equivalent conversion factors, not the conversion coefficients for effective dose equivalence found in ICRP publication 26 (1977) or ICRP publication 51 (1987).

Validation of dosimeter performance in the complex Hanford neutron radiation work environments is necessary to comply with guidelines in the DOE Standard *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities*. This is necessary to ensure satisfactory performance, even though Hanford dosimeters are DOELAP- and NVLAP-accredited. NVLAP performance testing is based on laboratory irradiations using the American National Standards Institute (ANSI) consensus standard: ANSI/N13.11-1989 and 1993, *American National Standard - Personnel Dosimeter Performance: Criteria for Testing*. DOELAP performance testing is based on a similar standard for DOE contractors, DOE/EH-0027 *Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems* (DOE 1986). Both standards use the same NCRP 38/10CFR835 neutron quality factors and fluence-to-dose equivalent conversion factors to determine the delivered dose equivalent from bare and moderated californium sources. The application of these quality factors to the neutron energy spectra from bare and moderated californium to determine fluence-to-dose equivalent conversion factors for these spectra is based on work conducted at the National Institute of Standards and Technology (NIST) (Schwartz and Eisenhauer 1982). Hanford routinely uses several dosimeter systems to measure and record personnel neutron dose.

Responses of Hanford dosimeter components have been well characterized under the low-scatter conditions of the Hanford 318 Radiation Standards Laboratory. These irradiation fields are essentially identical to those used in DOELAP and NVLAP performance testing. Hanford whole body personnel dosimeter response has also been measured previously under the high-scatter conditions in the workplace at the PFP. The majority of personnel neutron dose at Hanford (currently and historically) occurs at the PFP.

Field neutron spectra and dose measurements are critically important to the technical basis for personnel neutron dose because of the following:

- Increased accuracy is achieved using field calibration factors based on dose measurements.
- Dose and spectral measurements provide a basis for recalculation of dosimetric quantities for future changes in radiation protection standards.

Neutron dosimeters are typically calibrated in the laboratory under carefully controlled conditions. Neutron energy spectra and irradiation geometries in the workplace are usually quite different from those in the calibration laboratory. Correction factors are often applied to compensate for any differences in laboratory and workplace dosimeter dose response. Measurements described in this report provide a technical basis for the use of correction factors specific to actual work locations.

1.2 Objectives

The objectives of the measurements described in this report include the following:

- Evaluate and document the response characteristics of Hanford personnel dosimeters in Hanford PFP work environments.
- Evaluate the neutron-to-gamma ratio used to assess neutron dose to the extremities for Hanford PFP workers.
- Evaluate the response characteristics of the Bubble Technology Industries (BTI) bubble detector(1) and the Apfel REMBrandt(2) survey meter in Hanford neutron environments.
- Evaluate the relative performance of the HSD and the HCND compared with the TEPC measured neutron dose equivalent.
- Evaluate the performance of the HCND with and without the TED component.

1.3 Dosimeter Calibration Sources and Calibration Factors

Radiation sources used for calibrating Hanford personnel dosimeters are traceable to NIST. Primary Hanford dosimeter calibration is routinely based on:

- on-phantom ^{137}Cs irradiations for the deep-dose equivalent photon component,
- on-phantom ^{252}Cf irradiations for the fast-neutron component.

Extensive dosimeter response data are available for many NIST-traceable beta, photon, and neutron radiation sources, including the NIST-traceable bare and moderated ^{252}Cf source.

In general, dose algorithms determined from the respective NIST-traceable calibration sources are used directly to determine dose in Hanford work environments, without any modification for field conditions. For neutron dose, two primary dose algorithms are used for Hanford worker dose. The default algorithm is based on dosimeter response data determined from a NIST-traceable ^{252}Cf source. These irradiations were performed in the Hanford Calibration Laboratory. A plutonium algorithm was developed from dosimeter irradiations at the PFP using plutonium sources (Endres et al. 1996).

1.4 Neutron Dose Measurements

The most significant source of personnel neutron dose at Hanford involves activities associated with the handling and storage of plutonium. The majority of personnel neutron dose at Hanford (currently and historically) occurs at the PFP. Workers receive doses as they work in the vicinity

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1) Manufactured by Bubble Technology Industries, Inc.
2) Manufactured by Apfel Enterprises, Inc.

of process lines and as they work in the 2736 ZB storage vaults, which contain several tons of plutonium. Therefore, PFP was chosen as the location for the validation measurements.

Validation measurements were performed for whole body dose assessment, using HCNDs and HSDs, and for extremity dose assessment, using extremity dosimeters. Several locations within the PFP were selected for evaluation.

For the whole body measurements, dosimeters were mounted on water-filled phantoms to simulate the effect of a person wearing the dosimeter. Tissue-equivalent proportional counters (TEPCs) were used to measure the neutron dose equivalent rate at the phantom locations. Dose equivalent rates from plutonium oxide and plutonium metal sources were measured under various shielding configurations. Results from the TEPC were compared with the dose measured using the HSD, HCND (TLD), and HCND (TED) personnel neutron dosimeters and the bubble dosimeter. The Snoopy, a portable neutron survey meter used by Hanford radiation protection staff to monitor and control worker exposure between personnel dosimeter processings, was also exposed at phantom locations. The performance of BTI bubble detectors and the REMBrandt survey meter were also evaluated in this study for their suitability for future use on the Hanford Site.

For the extremity study, neutron and gamma measurements were made inside a lead-lined glove exposed to several different plutonium oxide and metal sources. These measurements were performed to validate the neutron-to-gamma ratios used for assessing the extremity doses received by workers handling these sources.

1.5 Report Contents

Chapter 2.0 describes characteristics of the instrumentation used to measure neutron dose. Chapter 3.0 describes Hanford personnel neutron dosimeters and the algorithms used to calculate dose. Chapter 4.0 describes measurements made in the 318 Building's Low-Scatter Room to calibrate the detectors and characterize their responses. Chapter 5.0 describes the workplace measurements, both for whole body measurements and for extremity measurements, that compare instrument and dosimeter measured dose. Chapter 6.0 provides conclusions and recommendations based on the measurement results. The ensuing chapters describe instrumentation, dosimeters, algorithms and measurements made to document the performance of Hanford personnel neutron dosimeters. Chapter 7.0 lists references cited in the text and the Appendices contain detailed measurement results.

2.0 INSTRUMENTATION

This chapter describes characteristics of the instrumentation used to measure the neutron dose in PFP work environments.

2.1 Tissue Equivalent Proportional Counter

Tissue-equivalent proportional counters provide an absolute measurement of absorbed dose in a tissue-like material. With appropriate algorithms, TEPCs also provide an estimate of lineal energy distributions and quality factors. From this information, a single TEPC measurement can provide an estimate of dose equivalent. For fission energies, existing algorithms for determining quality factors from absorbed dose distributions measured by the TEPC are reasonably accurate. For example, when a TEPC is exposed to a NIST-calibrated neutron source, the dose equivalent determined from the TEPC is usually within about 10% of the dose equivalent value calculated from the neutron flux and neutron fluence-to- dose-equivalent conversion factors recommended by NIST (Schwartz and Eisenhauer 1982).

The TEPC consists of a hollow sphere of tissue-equivalent (TE) plastic filled with TE gas. Exact compositions of the TE plastic walls and fill gas can be found in Appendix C of International Commission on Radiation Units and Measurements publication 36 (ICRU 1983). The pressure of the TE gas is adjusted so that the sphere of TE gas has the same mass stopping power as a sphere of solid tissue a few micrometers in diameter. For example, the spherical TEPC used in the PFP whole body measurements has an internal diameter of 127 mm (5 in.), a wall thickness of 2.1 mm (0.084 in.), and was filled with a methane-based TE gas at a pressure of 11.3 torr (a near vacuum). The TE gas has the same stopping power as a 2-μm sphere of solid tissue. The smaller TEPC used in the PFP extremity measurements has an internal diameter of 12.7 mm (0.5 in.), a wall thickness of 1.3 mm (0.05 in.), and was filled with a propane-based TE gas at a pressure of 33.5 torr. The TE gas in this smaller chamber has the same stopping power as a 1-μm sphere of solid tissue.

Neutrons and other radiations interact with the TE plastic walls to produce secondary charged particles, which deposit energy in the sphere of TE gas and create ions. The TE gas is the active volume of a proportional counter, which produces a pulse proportional to the number of ions or the energy deposition. For neutrons with energies below about 20 MeV, electronic equilibrium exists, and the ionization in the gas cavity provides an absolute measurement of absorbed dose. Because the composition of the walls and gas are tissue-equivalent, the energy deposition measured in a known mass of TE gas provides an absolute measurement of absorbed dose in tissue.

Unlike most neutron dosimeters, it is not necessary to calibrate the TEPC to a NIST-standard neutron source, but it is necessary to relate the pulse height from the TEPC to energy deposition. This can be accomplished by at least two methods. The first is to use an internal alpha source of known energy (and known linear energy transfer [LET]) to calculate the energy deposited in the counter. The second is to use the characteristic "proton edge" or "proton drop point," which is produced when the TEPC is exposed to neutron sources. From a simplistic point of view, the energy deposited in the TE counter is the product of the LET of the proton recoil times the path length. The maximum energy deposition possible in the gas cavity is the product of the maximum LET (the Bragg peak of the proton) times the diameter of the sphere. This maximum energy deposition for a proton recoil corresponds to an "edge" or discontinuity in the energy deposition spectrum at a lineal energy of 147 keV/µm for methane-based TE gas.

Figure 2.1 shows a typical energy deposition spectrum measured by a TEPC exposed to gamma rays from a ^{60}Co source and 1.3-MeV neutrons produced by an accelerator. It is easy to differentiate gamma rays from neutrons because gamma rays can deposit only a limited amount of energy (event sizes of 10 keV/µm or lineal energies of 15 keV/µm). The dose distribution is easily calculated from the pulse-height data recorded from the TEPC. For a given event size or lineal energy, the absorbed dose contribution is the number of pulses or events multiplied by the size of the event. The total absorbed dose can be found by summing each contribution over the appropriate event sizes or lineal energies.

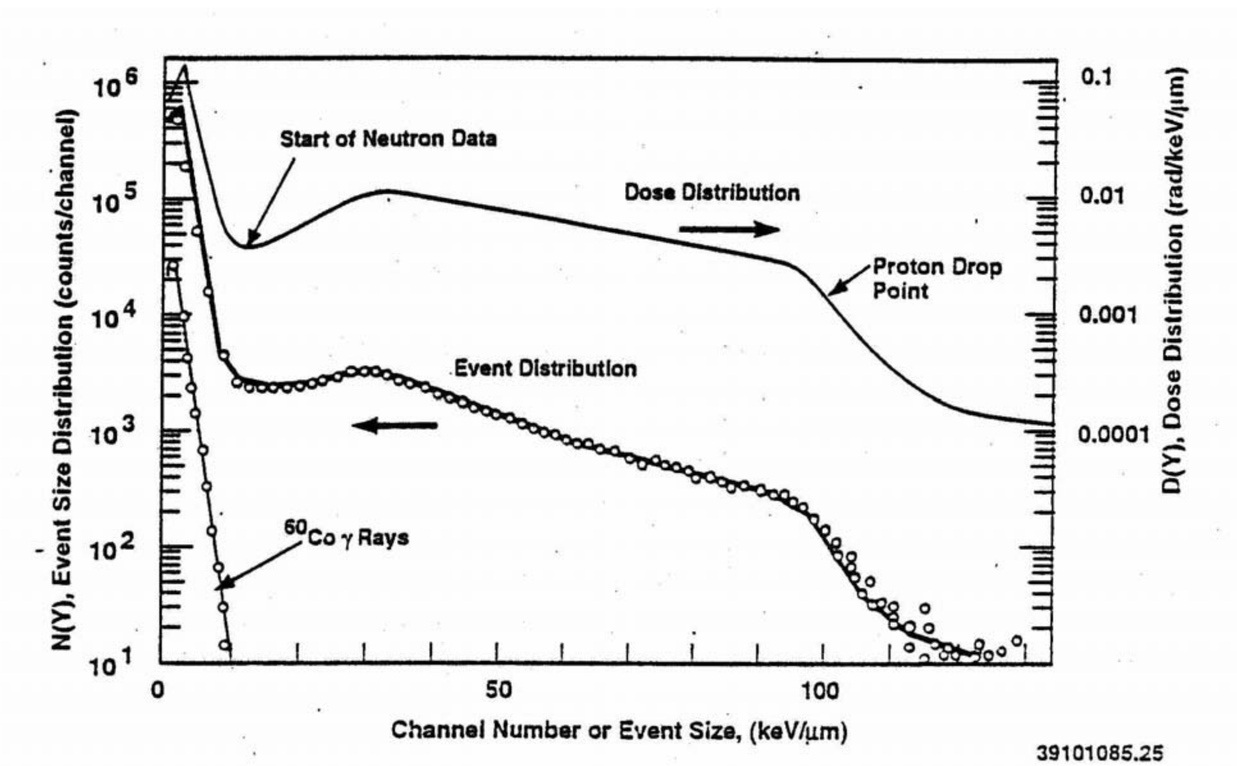


Figure 2.1 Typical Spectrum Recorded from a TEPC Operated with a 2-µm Equivalent Diameter Exposed to Neutrons and Gamma Rays

The absorbed neutron dose (D) can be found from Equation (2.1):

$$D = \left(\frac{c}{m}\right) \sum N(E)\, E \tag{2.1}$$

where

m = mass of gas in the cavity (the product of the volume times the gas density)
c = constant of proportionality relating the energy deposition to the event size or channel number
N(E) = number of events of energy E measured by the TEPC
E = energy deposited in terms of the channel number in a multichannel analyzer.

The most difficult problem in analyzing the data from a TEPC measurement is converting absorbed dose distributions to LET distributions, so that quality factors can be determined. At the present time in the United States, quality factors are defined as a function of LET (NCRP 1971; DOE 1994). The definition of this relationship is given in Table 2.1.

Table 2.1 Relationship Between Quality Factor and Linear Energy Transfer

Quality Factor	**Linear Energy Transfer (keV/µm)**
1	<3.5
2	7
5	23
10	53
20	≥175

Tissue-equivalent proportional counters measure lineal energy, y, defined as the energy deposited in the site (gas cavity) divided by the mean chord length of the site. For spherical proportional counters, the mean chord length is two-thirds of the diameter. For these counters, the theoretical basis for algorithms relating lineal energy (measured by the TEPC) to LET (required for quality factors) was developed by Albrecht Kellerer (1969), as follows:

$$\overline{L_D} = \left(\frac{8}{9}\right)\overline{y_D} \qquad (2.2)$$

where

$\overline{L_D}$ = the dose-mean LET,

$\overline{y_D}$ = the dose mean of the event spectrum measured by the TEPC (i.e., the average lineal energy, or first moment of the dose distribution), so that:

$$\overline{y_D} = \frac{\int y\ D(y)dy}{\int D(y)dy} \tag{2.3}$$

where

y = lineal energy

D(y) = differential absorbed dose distribution as a function of lineal energy.

Because of the linear and additive relationship, this relationship is true for all values of L to determine a quality factor value for each channel number or event size.

The quality factor for each channel number is found by using the above equation to convert from lineal energy to LET, then linearly interpreting the quality-factor/LET relationship given in Table 2.1. The dose equivalent is then found by summing over all channels or LETs of interest, as follows:

$$H = \Sigma\, Q(L)\, D(L) \tag{2.4}$$

where

H = the dose equivalent

Q(L) = the quality factor interpolated for this channel

D(L) = the differential absorbed dose distribution as a function of LET.

This dose equivalent is determined at a depth corresponding to the wall thickness of the TEPC (2.1 mm for a 5-in. detector and 1.3 mm for a ½-in. detector) and is more closely related to the operational quantity ambient dose equivalent than to the protection quantity effective dose equivalent currently required by 10CFR835 for dosimetry at DOE sites. For fission neutrons, however, the dose equivalent measured by the TEPC is a good estimate of dose equivalent.

In practice, data collected by a TEPC is stored on a computer disk and analyzed using a computer code called TEPC_NG. This code performs the calculations described in this section using computer algorithms documented in (Cummings, 1984). TEPC_NG will provide values for measured neutron dose rate, quality factor, and dose equivalent rate.

2.2 Bubble Detectors

Neutron bubble detectors are reusable, integrating, passive dosimeters that allow for instant, visible detection of neutron radiation. A detector consists of an elastic polymer throughout which droplets of superheated liquid have been dispersed. When neutrons strike these drops of liquid they form small but visible gas bubbles that remain fixed in the polymer to provide a real-time, immediately visible record of the dose. The number of bubbles formed is directly proportional to the dose. The detector response is independent of dose rate and is tissue-equivalent. Bubble detectors have a nearly isotropic angular response.

The bubble detectors used in this study were provided by Bubble Technology Industries (BTI), product number BD-PND. They were all chosen with sensitivities of approximately 0.7 bubbles per mrem. They were included in this study to evaluate their effectiveness for use at Hanford as real-time personnel dosimeters.

After a bubble detector has been exposed to radiation, the bubbles must be counted to evaluate the neutron dose. The bubbles can be counted by eye if not more than 40 or 50 bubbles are present in the detector. It is possible, on the other hand, to use an automated reader to count the bubbles in an exposed detector. Both counting-by-eye and automated counting were used in this study. For automated counting, the study used a reader provided by BTI that included a charge-coupled device (CCD) camera and image-recognition software integrated into an attached computer system. After an exposed bubble detector was counted, it could be prepared for reuse by screwing a small piston into the cap. This action recompressed the fluid in the detector and collapsed the bubbles.

2.3 Neutron Survey Meters

Two types of neutron survey meters were used in the field measurements as described in the following sections.

2.3.1 Snoopy

Neutron dose equivalent rates were routinely measured in this study using the Snoopy, which is the instrument used routinely for surveying neutron environments at Hanford. The Snoopy is a version of the Andersson-Braun remmeter, which uses a cylindrical polyethylene moderator surrounding a BF_3 proportional counter. The count rate of the detector is displayed on an analog meter, with the meter calibrated by exposure to neutrons from a ^{252}Cf source. The instrument shows some energy dependence in its response, and performs best when used in a neutron field with very little moderation.

2.3.2 Apfel REMBrandt

This study also used a new type of survey meter, the REMBrandt, Model AP2001. This instrument is manufactured by Apfel Industries, and offers a promising alternative to traditional neutron survey instruments. The REMBrandt uses a superheated drop technology, similar to the BTI bubble detectors. The liquid in the REMBrandt's active cartridge contains microscopic liquid drops that are superheated in typical room temperature ranges. The drops remain in suspension indefinitely, and when a neutron impinges on a drop, the drop rapidly boils and changes into a bubble. There is an audible pop when this occurs, and the detector employs an acoustic sensor that records this event in the detector's microelectronics.

The instrument is designed to serve as a survey meter. It is insensitive to photons. It has a visual display that will give a real-time readout of dose rate, and the internal microelectronics will store many hours of data for later transfer to a computer. It provides a possible lightweight alternative to traditional moderator-based instruments, so it was included in this study for an initial evaluation of its performance in typical Hanford work environments.

2.4 Sphere Measurements

This study did not use any true neutron spectrometer, but parts of a multisphere spectrometer were used to provide a general indication of neutron energy distribution. A LiI(Eu) detector was used inside two polyethylene spheres to determine count rates at selected locations. The LiI(Eu) detector is sensitive to neutrons with thermal energies. Signals from the detector are routed into a MCA, and a pulse-height spectrum is collected. The spectrum will exhibit a peak resulting from the $^{6}Li(n,\alpha)^{3}H$ reaction. The area under this peak can be integrated to determine the neutron counts deposited in the detector.

Since the LiI(Eu) detector is sensitive to thermal neutrons, it can be placed in the center of a moderating sphere, and the detector's count rate will be determined by the amount of moderation surrounding the detector. In this study the detector was used inside two different polyethylene spheres, one with a diameter of 3 in. (7.6 cm) and one with a diameter of 8 in. (20.3 cm). The ratio of the count rates in the two different spheres is an indication of the energy of the neutrons being measured. The count rate inside the 8-in. sphere, when used with a calibration factor that is a function of the 8-in.-to-3-in. ratio, is a reasonable indication of dose equivalent rate.

In the 1995 study of Hanford dosimeter responses in the workplace (Endres et al. 1996), Section 6.1 describes the use of this type of sphere measurement in neutron fields. This study found that 8 in.-to-3 in. ("8-3") sphere ratios ranged from 0.5 for a low-energy neutron spectrum up to 3.0 for a high-energy spectrum. It also determined a calibration factor, as a function of 8-3 sphere ratio, for converting the count rate inside the 8-in. sphere. Using the data presented in this report, the equation for the calibration factor can be stated as:

$$CF = 0.0338 + 0.114\ R \qquad (2.5)$$

where

CF = calibration factor (mrem/h per c/s)

R = ratio of count rate in 8-in sphere to count rate in 3-in sphere.

3.0 HANFORD PERSONNEL NEUTRON DOSIMETERS

This chapter describes the Hanford standard dosimeter (HSD), Hanford combination neutron dosimeter (HCND), track-etch dosimeter (TED), and extremity dosimeter used to determine the personnel neutron dose. Substantial technical documentation for these dosimeters is provided in the Hanford External Dosimetry Technical Basis Manual.(1)

3.1 Hanford TLD Dosimeters

The Hanford HSD and HCND represent TLD-albedo-type personnel neutron dosimeters. This type of dosimeter is the most common type in use throughout DOE facilities. Hanford TLD-albedo dosimeter designs employ a slow neutron detector (TLD-600) worn on the surface of the body. Fast neutrons strike the body and are moderated and reflected, and then return to the surface, where they are detected by the TLDs. Because the neutrons are reflected back from the body, these dosimeter designs are called "albedo." The TLD-600 isotope ^{6}Li absorbs a neutron and creates an alpha particle and a triton, which deposit energy in the TLD chip or phosphor. When the TLD chip is heated, it emits light in proportion to the radiation dose deposited by the neutron-induced events. The cross section for the $^{6}Li(n,\alpha)^{3}H$ reaction is inversely proportional to the velocity or the square root of the energy of the neutron absorbed in the reaction. Thus, the TLD-600 chip is very sensitive to thermal neutrons, where the cross section is about 941 barns. However, the bare TLD is relatively insensitive to fast neutrons, where the cross section is less than 1 barn. A simplified explanation of the energy dependence is that low-energy neutrons enter the body and are easily thermal zed and reflected back to the surface, where they are detected by the TLD crystal. High-energy neutrons, however, must penetrate deep into the body before becoming thermalized, and relatively few are able to diffuse back to the TLD crystal to be detected. Most of these neutrons are absorbed in the body before reaching the surface and the TLD chip. This is the reason for the pronounced energy dependence of the TLD-albedo dosimeter.

3.2 Hanford TLD Processing Data

The Harshaw reader system used to process the TLD cards provides calibrated chip readings. The calibrated chip readings are calculated by the reader using element correction coefficients (ECCs) and reader calibration factors (RCFs) to convert the raw light output (expressed as nanocoulombs of PMT charge collected) to chip readings (X_i) expressed in units of mR. For the TLD reader systems at Hanford, the mR chip reading is a *^{60}Co in air* equivalent reading because the reader is calibrated with bare cards exposed in free air to a known exposure with a NIST-traceable ^{60}Co source. The method used by the reader to obtain calibrated chip readings, X_i, is as follows:

$$X_i \text{ (mR)} = \text{raw chip reading}_i \text{ (nC)} \times ECC_i / RCF_i \text{ (nC/mR)} \quad (3.1)$$

1) PNL-MA-842, *Hanford External Dosimetry Technical Basis Manual*, Pacific Northwest National Laboratory, Richland, WA (internal manual).

The calibrated chip readings obtained from the reader are then adjusted by subtracting background, correcting for fade, correcting for supralinearity, and correcting for the difference in response between bare chips exposed in free air to ^{60}Co and chips exposed in the holder on a phantom to ^{137}Cs. The relationship between chip response to exposure in air and response in holder, on phantom, is referred to as the ^{137}Cs relative response factor (RRF) for the dosimeter and has units of mR/rem. The resulting "adjusted" chip readings thus have units of rem (^{137}Cs rem equivalent). Each adjusted chip reading will accurately reflect the delivered deep dose equivalent when the card is exposed in a holder, on a phantom to ^{137}Cs, and read using a reader calibrated as described above. The following equation describes the method used to obtain "adjusted" chip readings from the "calibrated" chip readings provided by the TLD reader:

$$D_i = (X_i - B_i) / (RRF_i * F_i * S_i) \quad (3.2)$$

where

D_i = adjusted chip reading for chip i (^{137}Cs rem equivalent)
X_i = calibrated chip reading for chip i (mR)
B_I = background for chip i (mR)
RRF_i = ^{137}Cs relative response factor for chip i (mR/rem)
F_i = fade factor for chip i.
S_i = supralinearity correction factor for chip i (dimensionless)

A detailed description of the formulae and methods used for determining the values of B_i, RRF_i, F_i and S_i is given in PNL-MA-842.

Adjusted chip readings are used in the 8825 and 8816 algorithms described in following sections. Before use by the 8825 algorithms proper, the adjusted readings given by chip position are transformed into adjusted readings by element type, where L1 = adjusted reading from deep dose element (bubble), L2 = adjusted reading from eye dose element (copper filter), L3 = adjusted reading from shallow dose element (beta window), and L4 = adjusted reading from photon energy discrimination/neutron detection element. The transformation is performed as follows: L1=D2, L2=D1, L3=D3, and L4=D4. The conversion is done to make the algorithm understandable in terms of element type regardless of physical position on a dosimeter, and it makes the algorithm universally applicable to a variety of holder designs using the same combination of element filtrations.

3.3 Hanford Standard Dosimeter

The 8825 HSD is issued to all Hanford personnel assigned a dosimeter with the exception of identified neutron workers who are assigned the HCND. The HSD is used to measure the shallow, eye, and deep dose equivalent of record from beta and photon radiation. Although not intended for recording dose from neutron radiation, the dosimeter has a neutron-sensitive TLD-600 phosphor for neutron detection capability. The neutron response is intended to identify personnel who may need to wear the HCND which has superior neutron dose capabilities and more recently has been used as the basis for assignment of neutron dose of record for individuals receiving less than 100 mrem of neutron dose per year.

3.3.1 Dosimeter Design

The HSD was designed according to HED specifications, and became commercially available as the Harshaw 8825. The dosimeter card contains TLD-700 phosphors in positions one, two, and three and a TLD-600 phosphor in position four. Table 3.1 provides a summary of the respective filtration for each dosimeter position. Figure 3.1 provides a schematic view of the dosimeter. More detailed information is available in PNL-MA-842. The HSD has no filters on the backside. A rose-colored viewing window is centered on the backside of the dosimeter holder. The viewing window is used to electronically read the permanent identification number of the card enclosed within the holder.

Table 3.1 Description of Filtration Used in the Hanford Standard Dosimeter (8825).

Dosimeter Position	Phosphor Type	Thickness, mm (mass density)	Total Holder Filtration[a]	
			Front	Back
1	TLD-700	0.38 (100 mg/cm^2)	242 mg/cm^2 ABS plastic plus 91 mg/cm^2 copper	173 mg/cm^2 ABS
2	TLD-700	0.38 (100 mg/cm^2)	1000 mg/cm^2 ABS and PTFE plastic	173 mg/cm^2 ABS
3	TLD-700	0.15 (40 mg/cm^2)	17 mg/cm^2 Teflon and Mylar	173 mg/cm^2 ABS
4	TLD-600	0.38 (100 mg/cm^2)	240 mg/cm^2 ABS plastic plus 463 mg/cm^2 tin	173 mg/cm^2 ABS

(a) Values include Teflon (2 mil) used to enclose chips.
ABS = Acrylonitrile-butadiene-styrene
PTFE = Polytetrafluorethylene

3.3.2 Neutron Dose Algorithm

The HSD neutron dose is calculated from the response of the TLD-600 chip after subtraction of the estimated beta and photon signal. The HSD algorithm identifies the type(s) of radiation to which a dosimeter was exposed by comparing adjusted element ratios with those observed to have known radiation exposures. Generally, information from all four chips is used to calculate the shallow, eye and deep dose from beta/photon radiation. However, there are situations where neutrons are detected by the TLD-600 chip in position 4 and the value of this chip cannot be used for photon energy discrimination. The algorithm sets a flag if the value of chip 4 (i.e., TLD-600) indicates neutron exposure. When neutrons are detected, the algorithm calculates neutron dose using a neutron calibration factor determined from the facility calibration code supplied by the user when the dosimeter is returned for processing. Calibration factors based on bare ^{252}Cf, moderated ^{252}Cf, or field measurements are available. When no information is available from the user, the algorithm defaults to use of the bare ^{252}Cf calibration factor as a conservative measure. The respective algorithm steps are illustrated in Figure 3.2.

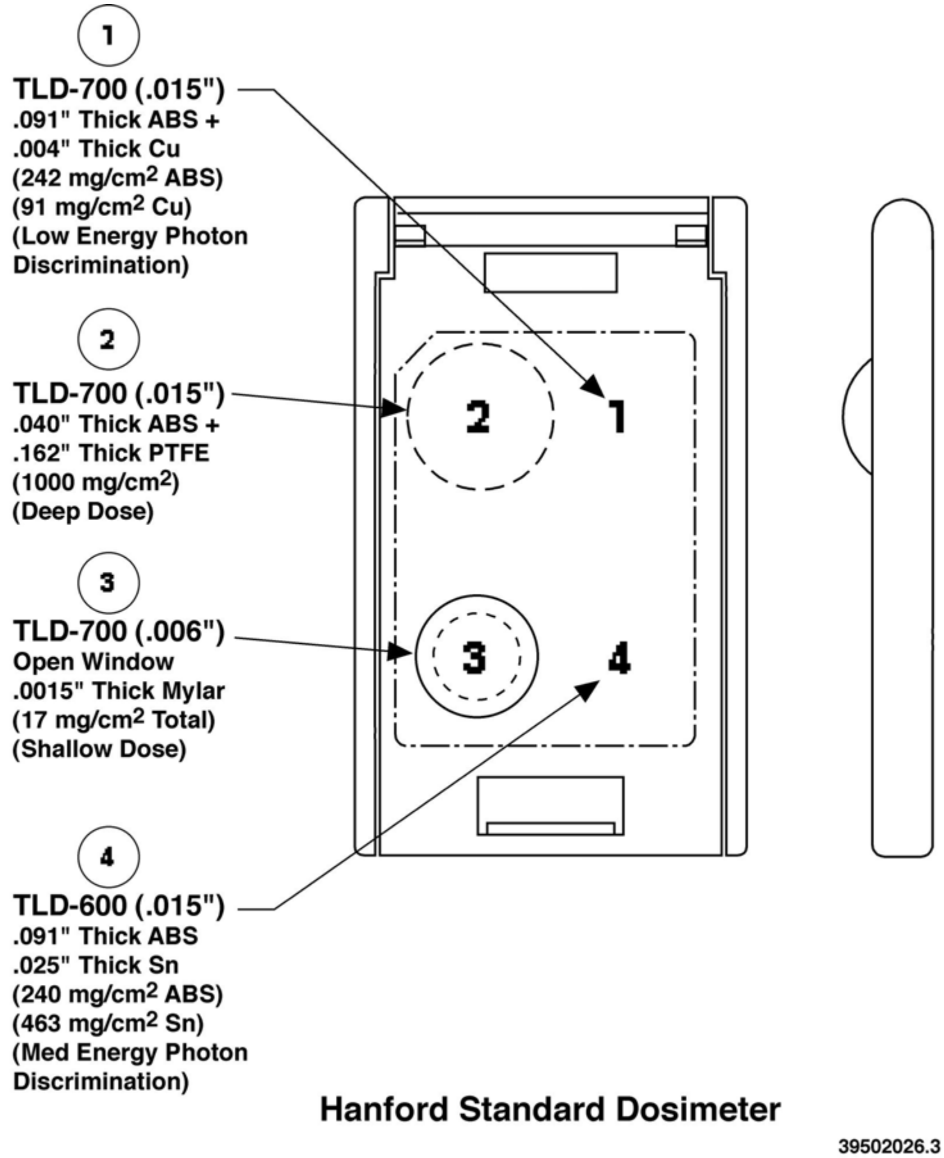


Figure 3.1. Hanford Standard Dosimeter Schematic

Step 0 Input Dose Code Parameters

Step 0

Code Option = Hanford, DOELAP, NVLAP, etc
High Energy Photon Code (HEPH_Type) = 0, 10 ,11,14,28
Gamma + Neutron Code (Default_HEPH) = 12, 13, 15, 29
Beta Code (Beta_Type) = 30 , 31, 49
Neutron Code (Neutron_Type) = 50, 51, 52, 69

Step 1a. Hanford = Harshaw Chip Placement

Step 1a

L1 = D2
L2 = D1
L3 = D3
L4 = D4

Step 1b. Define Variables

L12 = L1/L2	L41 = L4/L1
L31 = L3/L1	L43 = L4/L3
L32 = L3/L2	L3/L2 < 0.7
L14 = L1/L4	L2 - L3 > 0.01

Step 2. QC Flag for "Question Chip Data"

IF {L32<0.7 & [L3>0.01, L2>0.01,(L2-L3)>0.01];
L31<0.7 & [L3>0.01, L1>0.01,(L1-L3)>0.01];
L31<12 & [L3>0.01, L1>0.01,L2>0.01];
L31>3.2 * L32;
L31>[16 - (0.29*L32)]; OR
L31<[0.31 * l32]}
THEN Set Flag "Question Chip Data"

Step 3. Photon Contribution to Potential Neutron Response

IF L12 < 1, THEN L12 = 1; IF L12 > 5, THEN L12 = 5
x = L1/L2
IF (default_HEPH = Cs-137 THEN
$F(x)=1 / (-2.12+3.46x - 0.34x^2)$
ELSE,
$F(x)=1 / (-1.7 + 3.46x - 0.34x^2)$

Step 4. Set Flag for "Neutron Detected"

IF [L4/L1 - F(x) [illegible]0.20} & (L4 - F(x) * L1] > 0.01]
THEN; Set Flag "Neutrons Detected"

Steps 5-9. Evaluate Beta/Photon Field Components

Step 10. Neutron Dose Component

Step 10a.

IF Neutron Dose Selected in Step 0 and If Step 4, "Neutrons Detected" = TRUE, THEN proceed with Step 10a.

Step 10a

IF (Neutron_Type = 51 (bare Cf-252), THEN K_{nd} = 1.16
IF (Neutron_Type = 52 (D2) Moderate Cf-252), THEN K_{nd} = 9.51
IF (Neutron_Type = 69 (User Input), THEN K_{nd} = User Input

Step 10b. Calculate Dose

Step 10b

$H_n = (L4 - F(x) * L1)/ K_{nd}$

Step 10c. IF Neutron Dose Not Selected in Step 0 and

If Step 4, "Neutrons Detected" = TRUE, THEN proceed with Step 10c.

Step 10c

$H_n = (L4 - F(x) * L1)/ K_{nd}$, K_{nd} = User Input

Figure 3.2. HSD Neutron Dose Algorithm

3.3.3 HSD Neutron Dose Calibration

The HSD has been calibrated to bare ^{252}Cf, D_2O-moderated ^{252}Cf, AmBe neutrons, and has passed DOELAP performance testing with both californium sources. However, when no information is provided by the user as to which calibration to use, the algorithm applies the bare ^{252}Cf calibration as a conservative default. This calibration was determined under low-scatter conditions to fission spectra from a bare source. The calibration spectrum contains substantially more energetic neutrons than are present in the highly scattered neutron spectra that are often encountered in PFP workplace conditions. Because of this, HSD-measured neutron dose based on the default neutron calibration is expected to substantially over-estimate the actual neutron dose.

3.4 Hanford Combination Neutron Dosimeter

The HCND is assigned to Hanford personnel identified as working with neutron radiation. The HCND is used to record the shallow, eye, deep, and neutron dose of record for Hanford employees working in neutron radiation fields. The dosimeter consists of three components:

- a beta-photon (8825) TLD
- an albedo neutron (8816) TLD
- a TED (not presently in routine use).

The beta/photon and the albedo neutron TLD are known commercially as the Harshaw 8825 and 8816 dosimeter holders, respectively. In addition, two TED foils (CR-39) are housed in the 8816 holder. Detailed dosimeter specifications are given in PNL-MA-842. The development of the dosimeter design is described by Brackenbush, Baumgartner, and Fix (1991) and Endres et al. (1996). A HCND plastic holder is used to contain all three of these dosimeters, along with the Hanford personnel nuclear accident dosimeter (PNAD).

3.4.1 Dosimeter Design

The HCND neutron 8816 dosimeter design was manufactured according to HED specifications as presented in Table 3.2. A diagram of the dosimeter is presented in Figure 3.3. This design provides for three neutron-responsive TLD-600 chips in three different shielding configurations with a single TLD-700 chip to provide beta/photon radiation compensation. This dosimeter design has asymmetric tin/cadmium filtration on both the holder front and back.

The design of the HCND 8825 component is identical to the HSD design shown in Table 3.1 with the single exception that a TLD-700 chip is used in position 4 of the dosimeter card instead of the TLD-600 chip. This change provides for high-quality shallow, eye, and deep dose calculation in the presence of neutron radiation.

Table 3.2 Description of the Filtration Used in the Hanford Combination Neutron Dosimeter (8816) Component

Dosimeter Position	Phosphor Type	Thickness, mm (mass density)	Total Holder Filtration[a]	
			Front	Back
1	TLD-700	0.38 (100 mg/cm^2)	464 mg/cm^2 Sn plus 80 mg/cm^2 ABS plastic	464 mg/cm^2 Sn plus 80 mg/cm^2 ABS plastic
2	TLD-600	0.38 (100 mg/cm^2)	461 mg/cm^2 Cd plus 80 mg/cm^2 ABS plastic	464 mg/cm^2 Sn plus 80 mg/cm^2 ABS plastic
3	TLD-600	0.38 (100 mg/cm^2)	464 mg/cm^2 Sn plus 80 mg/cm^2 ABS plastic	461 mg/cm^2 Cd plus 80 mg/cm^2 ABS plastic
4	TLD-600	0.38 (100 mg/cm^2)	464 mg/cm^2 Sn plus 80 mg/cm^2 ABS plastic	464 mg/cm^2 Sn plus 80 mg/cm^2 ABS plastic

[a] Values include Teflon (2 mil) used to enclose chips.
ABS = Acrylonitrile-butadiene-styrene

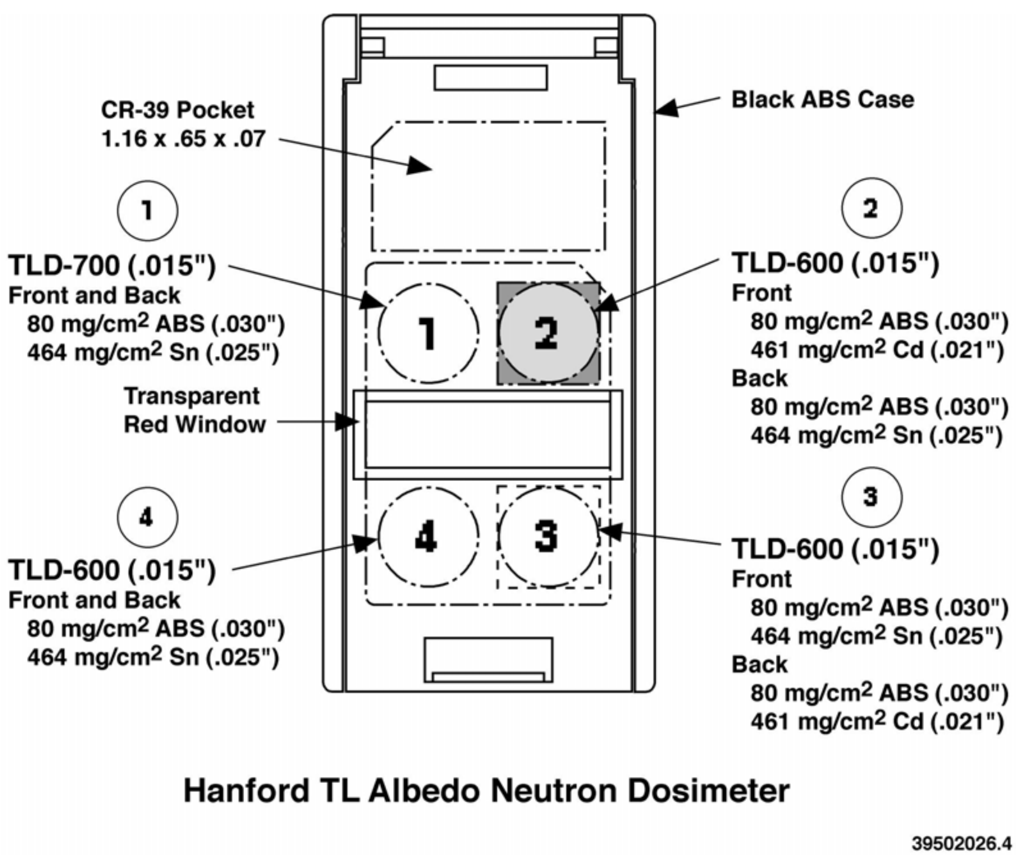


Figure 3.3. Diagram of HCND Neutron 8816 Dosimeter

3.4.2 HCND Neutron Dose Algorithm

There are four neutron dose algorithms available for use with the 8816 TLD component of the HCND. They are referred to as case 0, case 1, case 2, and case 3; flowcharts are presented for all four algorithms in Figure 3.4, and the algorithm for case 1, which is most relevant to this study, will be described in detail.

The contractors submit dosimeters for processing through REX (the Radiological EXposure system) where they are required to provide a two-digit facility calibration code, a two-digit note code (reason and priority for processing), wear dates, and other wearer information. The facility calibration code and other wearer information is passed to the HED processing lab through an electronic file called RETURN.TXT at the time the dosimeter is physically returned for processing. The facility calibration code indicates the type of radiation environment and tells the external dosimetry data management software which algorithm to apply when performing dose calculations. Because there are 100 possible facility calibration codes and the facility calibration code is used to convey information pertinent to more than one type of dosimeter, more than one facility calibration code may translate to a given case for the 8816 dosimeter based on a system table that interprets facility calibration code.

The initial steps in each algorithm are the same and are as follows:

1. Let L1 = D1 (adjusted reading from chip 1) FORMULA = 0
   L2 = D2 (adjusted reading from chip 2)
   L3 = D3 (adjusted reading from chip 3)
   L4 = D4 (adjusted reading from chip 4)

   (Adjusted readings have units of ^{137}Cs rem equivalent.)

2. Calculate net signal (neutron response) on TLD 600 chips (2, 3, and 4).

   N2 = L2 – L1 if N2 < 0; N2 = 0
   N3 = L3 – L1 if N3 < 0; N3 = 0
   N4 = L4 – L1 if N4 < 0; N4 = 0

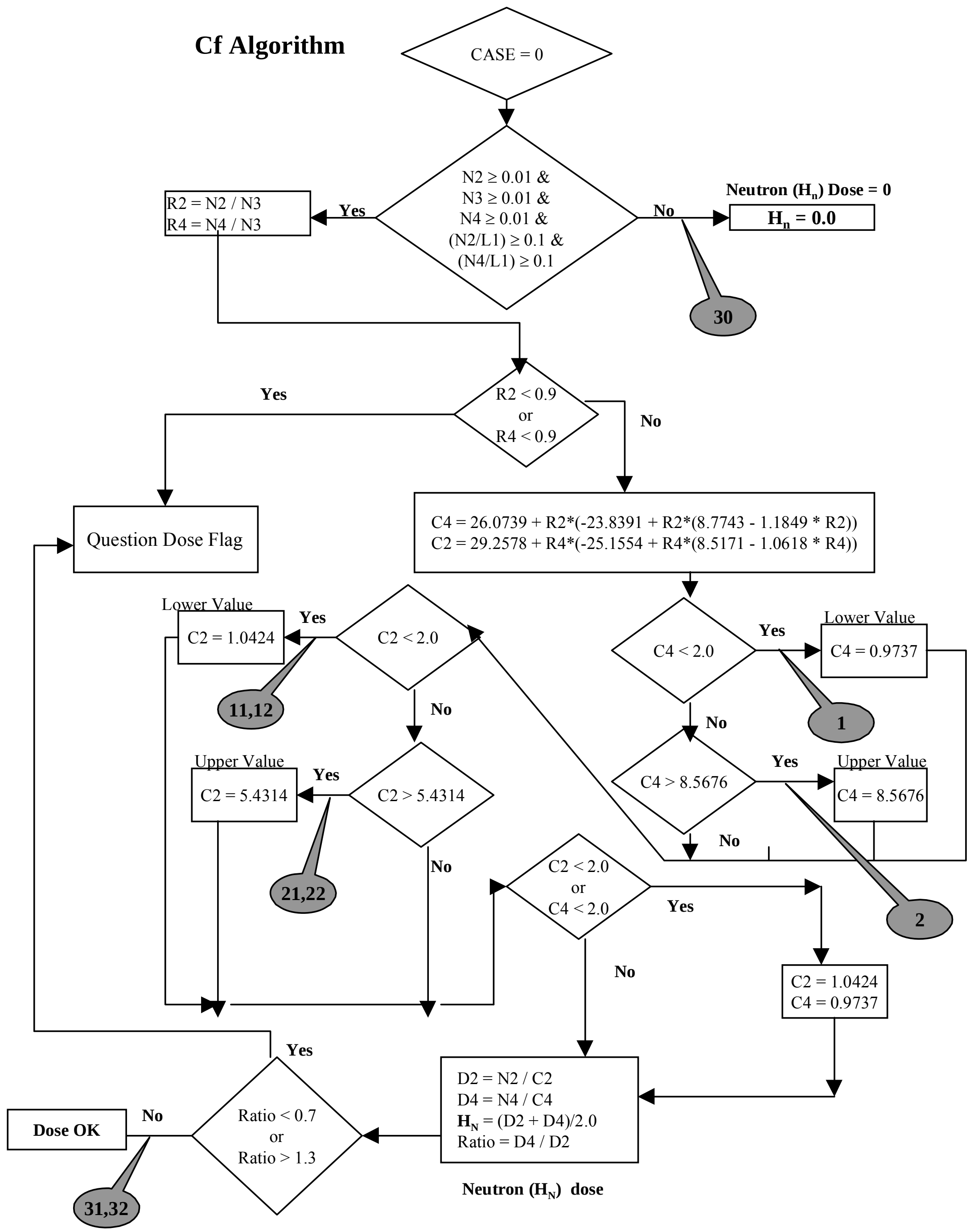


Figure 3.4. HCND Neutron Dose Algorithm

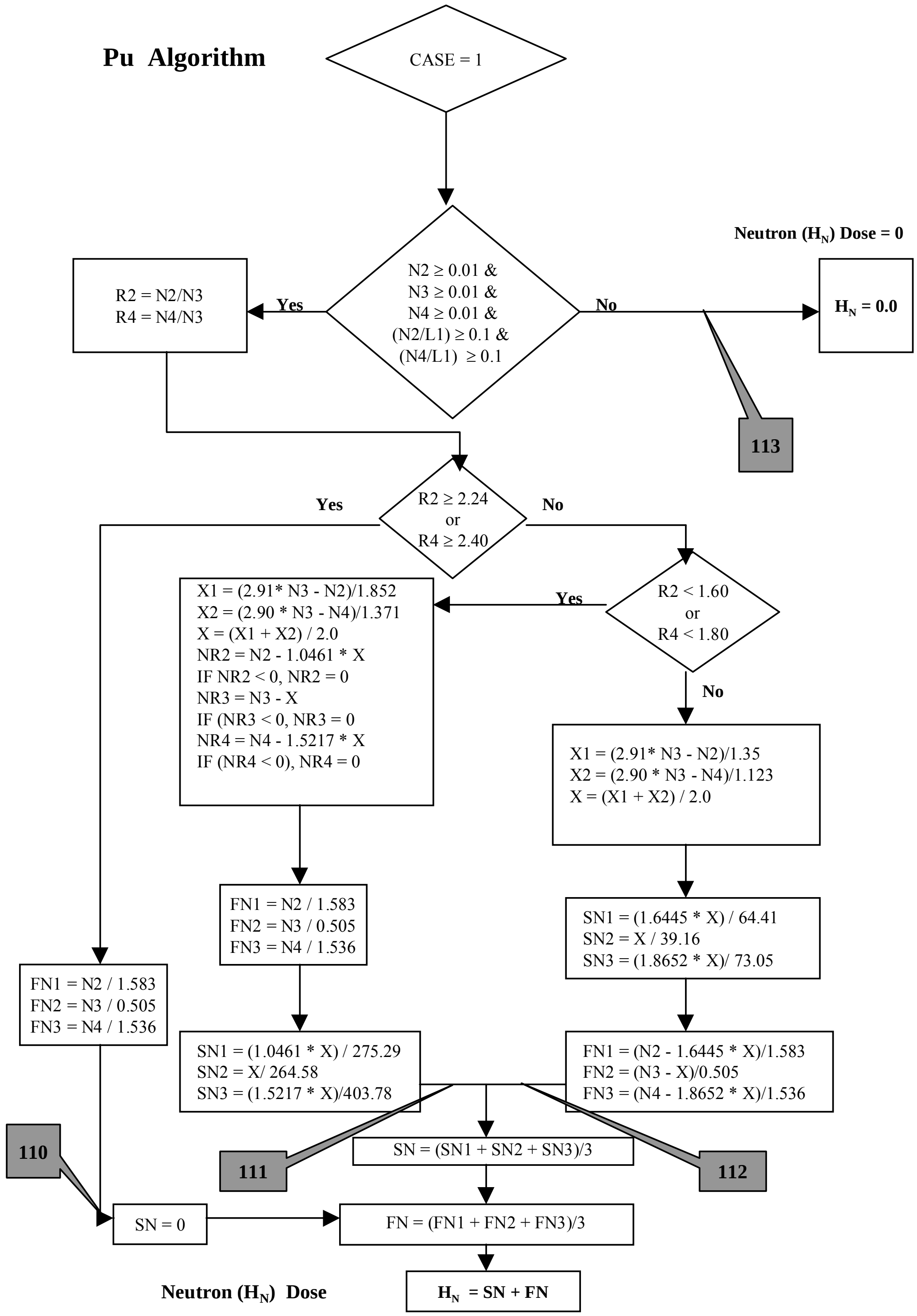
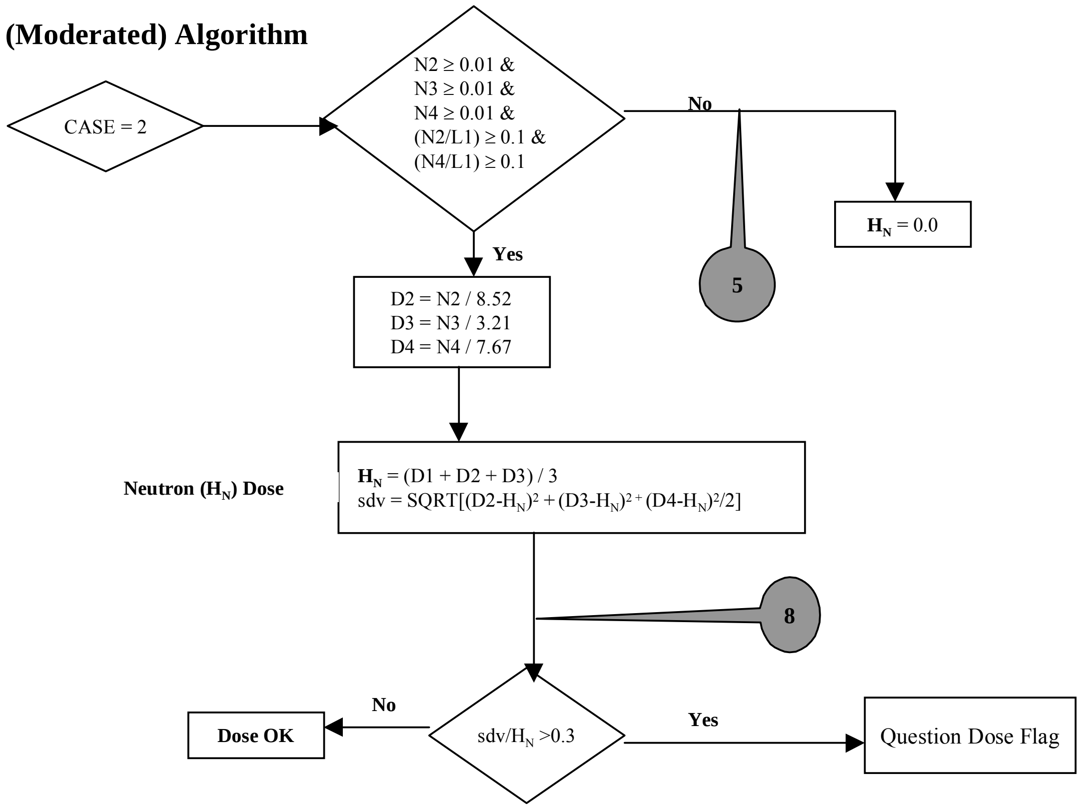


Figure 3.4. Cont'd

^{252}Cf (Moderated) Algorithm



^{252}Cf (Bare)Algorithm

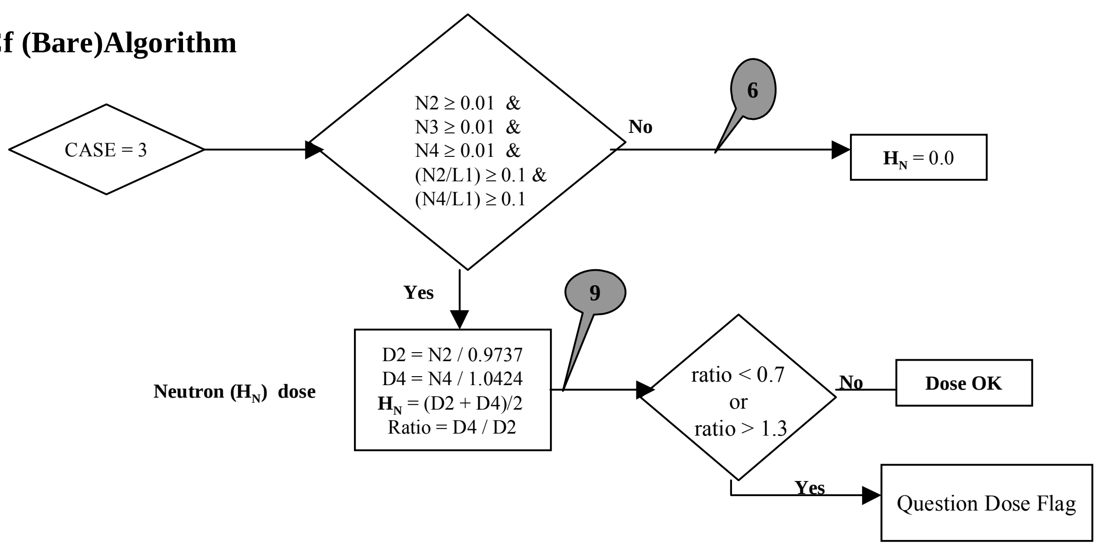


Figure 3.4. Cont'd

3.4.2.1 Californium Algorithm (Case 0)

When the contractor provides a facility calibration code of “00” when returning an HCND 8816 dosimeter, case 0 is used to calculate neutron dose. This is also the default algorithm used when the contractor provides no facility calibration code. As a default, this will generally provide conservative dose results except in cases where the actual neutron spectrum is significantly more energetic than bare californium. This algorithm is intended for use by individuals at Hanford working with ^{252}Cf and other neutron sources or radiation fields characterized by a fission spectrum. The algorithm has the capability to discern neutron energy and the degree of moderation from a bare source, and compensate the dosimeter’s response accordingly. Because of this, the energy dependence of this algorithm is considerably less than the energy dependence for a simple (i.e., single element) albedo neutron TLD.

The gamma component of each TLD-600 chip adjusted reading is approximated by the adjusted reading of the TLD 700 element. The gamma-compensated neutron signal on each TLD 600 chip is calculated by subtracting the TLD-700 adjusted reading. The gamma-compensated chip 2/chip 3 ratio and chip 4/chip 3 ratio are used to estimate the neutron energy and the appropriate calibration factors to be applied to the chip 2 and chip 4 readings to obtain neutron dose equivalent. The fitted response functions used in the algorithm to calculate the neutron calibration factor were derived from the responses of the dosimeter on-phantom to a NIST-traceable ^{252}Cf source with varying thicknesses of Plexiglas moderators between the source and dosimeter. The neutron spectra and neutron dose equivalent rates were determined by multisphere and TEPC measurements of the source. The algorithm is presented in Figure 3.4 and its development is described in detail by Endres et al. (1996).

3.4.2.2 Plutonium Algorithm (Case 1)

The plutonium algorithm as described by Endres et al. (1996) was developed based on measurements made at the PFP with a PuF_4 source and various thicknesses of acrylic plastic between the source and dosimeters. Dosimeters were mounted on an acrylic plastic phantom, 40 by 40 by 15 cm (15.75 by 15.75 by 6 in.). The thicknesses of plastic shielding used were 2.5 cm (1 in.), 5 cm (2 in.), 7.6 cm (3 in.), and 10 cm (4 in.). The dosimeter response data were separated into three components for developing the algorithm, as follows:

- Unmoderated plutonium neutron spectra. Dosimeter response data from the unmoderated PuF_4 source (with no intervening acrylic plastic between the source and dosimeters) at 50 cm and 100 cm were used to develop expressions for fast neutron dose equivalent for the "unmoderated" condition. The data for this component generally correspond to $R2 > 2.24$ or $R4 > 2.40$. A fast neutron dose component is calculated from each of the net adjusted readings N2, N3, and N4 (identified as FN2, FN3, and FN4). The reported neutron dose equivalent is then the average of the three results. This algorithm branch is identified as Formula = 110, and is presented in Step 3, below.

- Partially moderated plutonium neutron spectra. Dosimeter response data from the PuF_4 source with a 2.54-cm (1 in.) slab of plastic between the source and dosimeters, and the dosimeters positioned at 50 cm and 100 cm from the source were used by Endres et al. (1996) to develop expressions for fast neutron (FN) and slow neutron (SN) dose equivalent for the "partially moderated" condition. The reported neutron dose is then the average of the three SN terms and the three FN terms. The data for this component generally correspond to $1.60 < R2 < 2.24$, and $1.80 < R4 < 2.40$, and the algorithm branch is identified as Formula = 111, as presented in Step 4, below.

- Highly moderated plutonium spectra. Dosimeter response data from the PuF_4 source with an intervening 7.62-cm (3-in.) slab of plastic and the dosimeters positioned at 50 cm from the source; and with an intervening 10.16-cm (4-in.) slab of plastic and the dosimeters position at 50 cm from the source, were used to develop expressions for FN dose equivalent and SN dose equivalent. The reported neutron dose is then the average of the three SN terms and the three FN terms. The data for this component generally correspond to $R2 < 1.6$ or $R4 < 1.80$, and the algorithm branch is identified as Formula = 112, as presented in Step 5, below.

The plutonium algorithm is used when the contractor provides a facility calibration code of "01" when returning the dosimeter for processing. The algorithm, as presented in Figure 3.4 and in detail below, is presented in a form that closely matches the calculation steps performed in the external dosimetry data management software. It is possible to algebraically reduce this algorithm to a set of equations in a more compact form. This reduced form is presented by Endres et al. (1996), and the 1996 report also presents a detailed discussion of the development of the algorithm.

1. If $N2/L1 \geq 0.10$ and $N4/L1 \geq 0.10$ and $N2 \geq 0.010$ and $N3 \geq 0.010$ and $N4 \geq 0.010$,
   Continue to Step 2.
   Else,
   $H_n = 0$, END FORMULA = 113 (no dose detected)

2. Calculate the two independent ratios:

   $R2 = N2 / N3$
   $R4 = N4 / N3$

3. If $R2 \geq 2.24$ or $R4 \geq 2.40$, calculate dose as follows: FORMULA = 110 (hard)

   $FN1 = N2 / 1.583$
   $FN2 = N3 / 0.505$
   $FN3 = N4 / 1.536$
   $H_n = (FN1 + FN2 + FN3) / 3.0$

4. If $R2 < 1.60$ or $R4 < 1.80$, calculate dose as follows: FORMULA = 111 (soft)

   $X1 = (2.91 * N3 - N2) / 1.852$
   $X2 = (2.90 * N3 - N4) / 1.371$
   $X = (X1 + X2) / 2.0$
   $NR2 = N2 - 1.0461 * X$

If (NR2 < 0.0); NR2 = 0.0
NR3 = N3 - X
If NR3 < 0.0; NR3 = 0.0
NR4 = N4 - 1.5217 * X
If NR4 < 0.0; NR4 = 0.0
FN1 = NR2 / 1.583
FN2 = NR3 / 0.505
FN3 = NR4 / 1.536
H_n = (FN1 + FN2 + FN3) / 3.0
SN1 = (1.0461 * X) / 275.29
SN2 = X / 264.58
SN3 = (1.5217 * X) / 403.78
H_n = H_n + (SN1 + SN2 + SN3) / 3.0

5. Otherwise calculate neutron dose as follows: FORMULA = 112 (intermediate)

X1 = (2.91 * N3 - N2) / 1.35
X2 = (2.90 * N3 - N4) / 1.123
X = (X1 + X2) / 2.0
FN1 = (N2 - 1.6445 * X) / 1.583
FN2 = (N3 - X) / 0.505
FN3 = (N4 - 1.8652 * X) / 1.536
H_n = (FN1 + FN2 + FN3) / 3.0
SN1 = (1.6445 * X) / 64.41
SN2 = X / 39.16
SN3 = (1.8652 * X) / 73.05
H_n = H_n + (SN1 + SN2 + SN3) / 3.0

3.4.2.3 D_2O Moderated ^{252}Cf Algorithm (Case 2)

This algorithm was developed primarily for NVLAP performance testing where a D_2O moderator sphere with cadmium cover moderates the neutrons. This algorithm is necessary for performance testing because the californium algorithm (case 0) breaks down when exposed to the moderated source. This breakdown occurs because the spectrum is missing the very component (< 0.4 eV) used by the algorithm to discern the degree of moderation. This spectrum, while readily created in a calibration facility, is not encountered in work environments where moderation takes place in hydrogenous materials without cadmium filters. This algorithm basically applies a set of fixed calibration constants to N2, N3, and N4 to obtain neutron dose, and therefore exhibits a large energy dependence.

3.4.2.4 Bare ^{252}Cf Algorithm (Case 3)

This algorithm is used primarily for DOELAP and NVLAP performance testing and in situations where the spectrum is known to be unmoderated fission neutrons. This algorithm basically applies a set of fixed calibration constants to N2 and N4 to obtain neutron dose, and therefore exhibits a large energy dependence.

3.5 Hanford Track Etch Dosimeter

The TED foils in the HCND provide a technique independent from that of the TLD to calculate neutron dose. The CR-39 does not exhibit the severe energy dependence that exists with albedo neutron dosimeters and can provide good results when varied neutron energy spectra are encountered. The CR-39 plastic, with its dense, uniform molecular structure, is susceptible to radiation damage involving scission of the molecular chains. These damage sites produce tracks or "pits" that, when electrochemically etched, can be seen under a microscope. The formation of these tracks is primarily caused by hydrogen recoil with fast neutrons, but can also be caused by alpha particles, protons, and heavy charged particles. Beta and gamma radiation has a low enough LET that a track cannot form, making CR-39 insensitive to these radiation types. To prevent the alpha interaction, a layer of polyethylene covers both sides.

3.5.1 TED Design

The TED consists of two CR-39 foils placed one on top of the other, at the top of the TLD 8816 card in the neutron holder with the topside facing towards the front of the dosimeter. The foils are made from clear CR-39 polycarbonate plastic with a thin polyethylene covering. They are approximately 28 mm long, 16 mm wide, and 0.64 mm thick. The polyethylene covering protects the CR-39 from alpha radiation exposure as well as providing a dense source of hydrogen atoms necessary for proton recoil.

3.5.2 TED Neutron Dose Algorithm

During the processing of each group of 24 foils, two foils in each batch are exposed to bare ^{252}Cf, and two to a blank dose. The results of these four dosimeters are used to calculate a batch calibration factor that relates mrem to track count. The calibration factor has units of mrem/tracks/cm^2. The two blank foils are used to determine a batch background factor having units of tracks/cm^2. Within the dose range 0-1000 mrem, the number of track counts is directly proportional to neutron dose equivalent received. The neutron dose equivalent in mrem is then calculated by averaging the two foil track counts, subtracting the background factor, and multiplying that result by the calibration factor, as follows:

$$H_n = [(T1 + T2)/2 - B] * C \qquad (3.3)$$

where

H_n = neutron dose equivalent
T1 = foil 1 track count in tracks/cm^2
T2 = foil 2 track count in tracks/cm^2
B = batch background factor in tracks/cm^2
C = batch calibration factor in mrem/tracks/cm^2.

The lower energy threshold of CR-39 response to neutrons is approximately 100 keV. For this reason, care must be exercised when using CR-39 in highly scattered neutron fields where lower-energy neutrons may be a significant component of the personnel dose. The PNNL measurements in the PFP work environments have shown significant under-response for TEDs in highly moderated neutron fields (Brackenbush, Baumgartner and Fix 1991; Endres et al. 1996). Based on previous Hanford measurements, a range of acceptable values for each of the albedo TLD chip ratios R2 and R4 has been determined, that indicates sufficient hardness in the neutron spectrum for energy-independent dose measurement with CR-39. If R2 < 1.6 or R4 < 1.8, then the neutron spectrum is too moderated and significant under-response of the CR-39 is likely. Under these circumstances, the CR-39 foils are not processed.

4.0 LOW-SCATTER ROOM MEASUREMENTS

Before the workplace measurements were conducted, measurements were performed in PNNL's Low-Scatter Room (LSR) in the 318 Building. The LSR contains ^{252}Cf neutron sources that have neutron emission rates traceable to NIST. The room is large enough to have irradiation positions located several meters from the walls and floor, creating a low-scatter condition. The neutron fields are very well characterized, so this facility offers an excellent resource for evaluating the operability of the measurement equipment.

4.1 TEPC Measurements in the LSR

The 5-in. TEPC detectors that were used in the workplace measurements were tested in the LSR on June 14 -15, 1999. Irradiations were performed at 100 cm from either of two ^{252}Cf sources:

318-356, with an unscattered dose equivalent rate of 1079 mrem/h at 100 cm
318-016, with an unscattered dose equivalent rate of 3.25 mrem/h at 100 cm.

The accepted value for the unscattered dose equivalent rate from an unmoderated ^{252}Cf source in the LSR uses the neutron emission rate traceable to NIST and a fluence-to-dose conversion factor, valid for an isotropic, unscattered ^{252}Cf spectrum; however, the geometry conditions in which each source is used in the calibration facility may influence the final interpretation of the dose equivalent rate. Consequently, NIST traceability is "implied" and is strictly preserved only when appropriate corrections are made for effects that depreciate isotropic, free-field conditions. An observable portion of the instrument response in the LSR is due to neutrons scattered by the walls, floor, and ceiling of the calibration room. Based on empirical evaluations, an increase to the delivered dose equivalent rate of approximately 5% (or alternatively, a decrease of the instrument response of approximately 5%) gives a more realistic estimate of the apparent dose equivalent rate for the actual irradiation conditions in the LSR specific to this instrument. Making this adjustment is among the prerequisites to preserving traceability to NIST.(1)

Source 318-356 produced a higher count rate in the TEPC and was useful for establishing a good ratio between a detector's alpha peak and its proton drop point. The dose rate, however, was higher than the dose rate encountered in workplace neutron fields, so source 318-016 was used to give an indication of detector response in the workplace.

Exposures to neutrons from source 318-356 were typically conducted for 5 to 10 minutes to obtain sufficient counts for an accurate measurement. Exposures to neutrons from source 318-016 were longer, as much as two hours, but counting statistics were poorer than for the more intense source. The detectors were connected to the same electronic modules, including preamplifier, Nuclear Instrument Module (NIM) high voltage, NIM amplifier, NIM analog-to-digital converter (ADC), and multichannel analyzer (MCA) that were used in the workplace measurements. The MCA data for each measurement were transferred to a computer, and the measurements were analyzed using the computer code TEPC_NG. A summary of the results of the 5-in. TEPC measurements is given in Table 4.1. Detailed TEPC_NG outputs are presented

1) Personal Communication with R.K. Piper, PNNL Calibration Research and Accreditation

in Appendix A. As a result of these measurements, TEPC 1171 was not used in the workplace measurements.

Table 4.1. Summary of 5-in. TEPC Measurements in the LSR

Detector ID	Measured mrem/h	Accepted mrem/h	Percent Difference
185	1040	1079	-3.6%
185	3.49	3.25	+7.4%
504	1180	1079	+9.4%
504	3.78	3.25	+16.3%
1170	1170	1079	+8.4%
1170	3.79	3.25	+16.6%
1171	1340	1079	+24%
1171	3.94	3.25	+21%
1172	1060	1079	-1.8%
1172	3.33	3.25	+2.5%
1173	1190	1079	+10.3%
1173	3.53	3.25	+8.6%

Table 4.1 compares TEPC results with the accepted unscattered, free-field dose equivalent rates for the sources in the LSR. The percent differences for each measurement could be reduced by approximately 5% to account for room scatter, source anisotropy, and other effects.

The two ½-in. TEPC detectors used in this study were also exposed in the LSR, in measurements similar to those for the 5-in. TEPCs. On July 9-13, 1999, the detectors were exposed at 100 cm from source 318-356, which at that time had an accepted dose equivalent rate of 1057 mrem/h (unscattered).

On August 20, they were again exposed to the same source, which now had a nominal unscattered dose equivalent rate of 1028 mrem/h at 1 m. The August 20 measurements used short counting times to approximate the number of events that would be counted in a typical workplace measurement. For calibration purposes, the best detector resolution is usually obtained when at least 100,000 neutron counts are collected in the MCA. A reasonable calibration can be performed when about 20,000 neutron counts are collected. However, it was anticipated that in the workplace, the ½-in. TEPC detectors might only be able to collect a few thousand neutron counts in a reasonable counting time period. Thus the short counts were conducted to see how reliably the ½-in. TEPCs could estimate dose equivalents from a known source. Table 4.2 presents the results of the ½-in. TEPC measurements, stated in terms of integral dose rather than dose rate to show the effect of count duration. Appendix A presents the outputs of the TEPC_NG analyses of these measurements.

Table 4.2. Summary of 1/2-in. TEPC Measurements in the LSR

Detector ID	Measured mrem	Accepted mrem	Percent Difference	Total Neutron Counts
1074	1510	1580	-4.4	23,500
1074	357	301	+19.	5,460
1122	1030	1062	-3.0	15,900
1122	126	110	+14.5	1,900
1122	271	228	+19.	4,020

4.2 Sphere Measurements in the LSR

The LiI(Eu) detector inside 3- and 8-in. polyethylene spheres was exposed to the unmoderated ^{252}Cf source 318-016 on June 15, 1999, when the unscattered dose equivalent rate was 3.25 mrem/h at 100 cm. Counting times ranged from 1000 to 5370 seconds to ensure sufficient counts for good counting statistics. Two different LiI(Eu) detectors were used in the LSR measurements. For each count, the data were collected in an MCA and recorded on computer disk. The area under the neutron peak was found by smoothing the spectrum in the region of the peak and fitting a gaussian shape to the smoothed data. The area under this fitted shape and above a fitted exponential background was then determined. This method provided consistency in determining peak area from run to run. The LiI(Eu) data measured in the LSR are presented in Table 4.3.

Table 4.3. Sphere Measurements in the LSR

Detector ID	Sphere Diameter	Count Time (sec)	Net Peak Area (cts)	Count rate (c/s)	Ratio, 8-in. / 3-in.	8-in. Response (mrem/h per c/s)
WA83751	3 in	5370	88,587	16.5		
WA83751	8 in	1000	50,785	50.8	3.08	0.0640
WA83752	3 in	1147	16,166	14.1		
WA83752	8 in	1436	61,083	42.5	3.02	0.0764

The average ratio for these two detectors was 3.05, which is indicative of an unmoderated fission spectrum, and the average 8-in response was 0.0702 (mrem/h per c/s). These values were used to modify the coefficients of Equation 2.5. The form of Equation 2.5 is a straight line: the slope should remain the same for different detectors, but the intercept could be changed to account for a difference in detector sensitivities. Using the values determined from these LSR measurements, the equation applicable to this study would be as follows:

$$CF = 0.0354 + 0.114R \qquad (4.1)$$

4.3 BTI Bubble Detector Measurements in the LSR

Six BTI bubble detectors were used in this study. On July 13, 1999, they were exposed to neutrons from an unmoderated ^{252}Cf source in the LSR to check their performance in a well-characterized field. Source 318-356 was used for these irradiations. This source produced an unscattered dose equivalent rate of 1057 mrem/h or 17.6 mrem/minute at 100 cm, the irradiation position for the detectors. The bubble detectors were irradiated for 3 minutes, to deliver 52.85 mrem to the detectors, and the bubbles were counted. The six detectors were then recompressed to collapse all the bubbles, and the detectors were then exposed to a series of irradiations, counting the bubbles after each step in the series. The first step was 1 minute, for 17.6 mrem; then a second minute of exposure, for a total of 36.2 mrem; then another minute for a total of 52.85 mrem.

Two methods were available for counting bubbles in an exposed dosimeter: inspection by eye and automated counting. When counting the bubbles by eye, typically the bubbles in the detector were counted three times, and the mean of these three counts was recorded (when the number of bubbles was below 25, only one count would be made). The automated system, provided by BTI, involved a camera and image recognition software that counted the bubbles. When counting automatically, three or four counts would be made, with the detector rotated relative to the camera each time, and the mean of these counts was recorded.

The detectors used in this study had sensitivities, determined for each detector individually by the manufacturer, ranging from 0.67 to 0.75 bubbles per mrem. Table 4.4 summarizes the results of the LSR exposures for the bubble detectors.

Table 4.4 Response of BTI Bubble Detectors in LSR

Detector ID	(Inspect by eye) bubbls countd	(Auto-mated) bubbles counted	Detector Sens. Bubbles /mrem	Counted by eye mrem	Auto-mated count mrem	Deliverd mrem	(by eye) % diff	Automated % diff
121487	36	48	0.72	51.4	67.1	52.9	-2.8	27.0
119504	45	51	0.69	68.1	73.9	52.9	28.9	39.9
121292	42	49	0.67	64.2	73.6	52.9	21.4	39.3
121529	34	40	0.68	50.0	58.3	52.9	-5.4	10.4
121022	43	48	0.74	54.1	65.3	52.9	2.3	23.6
123685	50	55	0.75	61.3	73.3	52.9	16.1	38.8
121487	9		0.72	12.5	0.0	17.6	-29.0	
123685	13		0.75	17.3	0.0	17.6	-1.5	
121292	9		0.67	13.4	0.0	17.6	-23.7	
121529	8		0.68	11.8	0.0	17.6	-33.2	
121022	12		0.74	16.2	0.0	17.6	-7.9	
119504	16		0.69	23.2	0.0	17.6	31.8	
121487	16		0.72	22.2	0.0	35.2	-36.9	
123685	24		0.75	32.0	0.0	35.2	-9.2	
121292	17		0.67	25.4	0.0	35.2	-28.0	
121529	16		0.68	23.5	0.0	35.2	-33.2	
121022	22		0.74	29.7	0.0	35.2	-15.6	
119504	26		0.69	37.7	0.0	35.2	6.9	
121487	36	45	0.72	52.8	63.0	52.9	-0.1	19.1
123685	38	52	0.75	45.3	68.9	52.9	-14.2	30.3
121292	35	38	0.67	53.7	56.7	52.9	1.7	7.3
121529	28	36	0.68	44.1	52.5	52.9	-16.5	-0.8
121022	38	45	0.74	52.7	60.8	52.9	-0.3	15.1
119504	38	50	0.69	53.6	72.5	52.9	1.5	37.1

4.4 REMbrandt Measurements in the LSR

The REMBrandt survey meter was exposed to unmoderated neutrons from ^{252}Cf source #318-016 in the LSR on July 16, 1999. On this date the source produced an unscattered neutron field with a dose equivalent rate of 3.18 mrem/h at 100 cm and 12.7 mrem/h at 50 cm. The instrument was first positioned at 100 cm from the source and data were collected for approximately 20 minutes. The instrument was then set at 50 cm from the source and data were collected for approximately 36 minutes. The instrument was then removed from the LSR and the measurement data were downloaded to a computer disk using the vendor’s computer code. The data were fed into a spreadsheet, and the total dose was summed over a time interval that was within the time that the source was up. This integral dose was divided by the time to get a dose equivalent rate. The dose equivalent rates determined by the REMBrandt are shown in Table 4.5.

Table 4.5. Response of REMBrandt in LSR

Distance from source (cm)	**Irradiation time (hrs)**	**Integral dose equivalent (mrem)**	**Measured dose equivalent rate (mrem/h)**	**Accepted dose equivalent rate (mrem/h)**
100	0.332	1.62	4.88	3.18
50	0.591	11.44	19.36	12.7

5.0 WORKPLACE MEASUREMENTS

This chapter describes dosimeter and TEPC measurements in PFP workplaces. The whole body measurements were done to validate the performance of the HSD and HCND in PFP workplace conditions based on comparative measurements between the dosimeter and TEPC measured dose. The extremity measurements were made to determine neutron-to-gamma ratios that would be effective for extremity exposures in glovebox operations.

5.1 Whole Body Measurements

The whole body measurements used 5-in. diameter TEPCs to assess the neutron dose equivalent rates at a number of workplace locations, and compared these values with the responses of HCND and HSD dosimeters exposed at the same locations on water-filled phantoms. Dosimeters were exposed on each of the four sides of each phantom to account for variations in neutron spectra and dose.

There are variations in the neutron energy spectra encountered at the PFP because of variations in shielding and types of material present, which includes PuO_2, plutonium metal, PuF_4, and mixed oxide fuel rods containing plutonium. Exposure conditions range from essentially no neutron shielding when the plutonium is physically handled to massive neutron shielding with several feet of concrete and iron. The neutron energy spectra encountered range from "hard" spectra, which are essentially fission spectra from the unshielded plutonium, to "soft" low-energy spectra encountered behind the massive shields in the storage vaults, behind water walls, and behind other neutron shields that have been installed to reduce the dose to workers.

5.1.1 Measurement Locations

Ten locations for comparative TEPC and dosimeter measurements were selected based on the potential for worker neutron exposure and a variety of neutron energy conditions. The locations chosen were as follows:

- Two locations in Room 235A-3, near Hood 9A. Neutrons are emitted from plutonium holdup inside the hood, and this location is typical of many worker exposure situations. A water wall is located approximately 5 ft. (1.5 m) to the north of the hood, and a concrete wall is located approximately 4 ft. (1.2 m) south of the hood. The water and concrete provide neutron moderation. Measurement locations were chosen next to the water wall and next to the concrete wall, as illustrated in Figure 5.1.
- Two locations were chosen in Vault 1 of 2736ZB. One location was in the aisle between two cabinets; the other was against a wall next to the corridor. The location between the cabinets was exposed to neutrons with a relatively high-energy distribution. The location next to the wall would receive a component of moderated neutrons scattered off the wall. The measurement locations in Vault 1 are shown in Figure 5.2.
- Two locations were chosen in Vault 2 of 2736ZB, one between two cabinets and one against the wall next to the corridor. The energy characteristics of these two locations should be

similar to the two locations in Vault 1. The measurement locations in Vault 2 are shown in Figure 5.3.

- Two locations were chosen in Vault 4 of 2736ZB, one between two cabinets and one against a wall. The energy characteristics of these two locations should be similar to the two locations in Vault 1 and the two locations in Vault 2. The measurement locations in Vault 4 are shown in Figure 5.4.
- Two locations were chosen in the vault corridor of 2736ZB, one outside Vault 1 and the other outside Vault 3. These locations were chosen to provide relatively low-energy neutron fields, because any neutrons at this location had to pass through thick concrete walls. The locations in the vault corridor are shown in Figure 5.5.

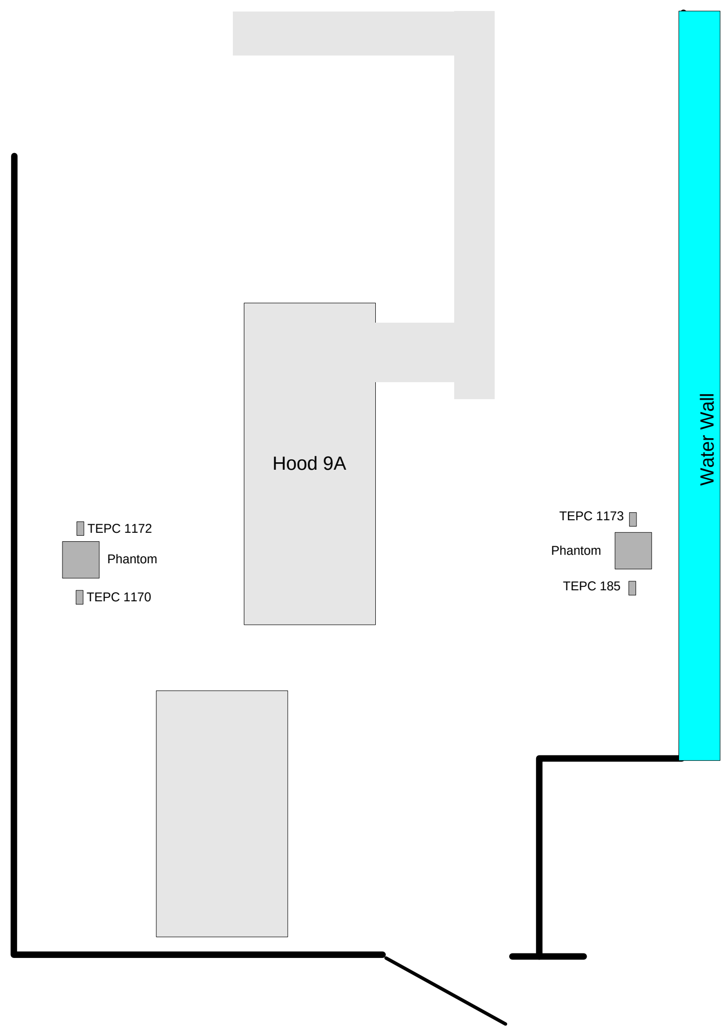


Figure 5.1. Measurement Locations in Room 235A-3

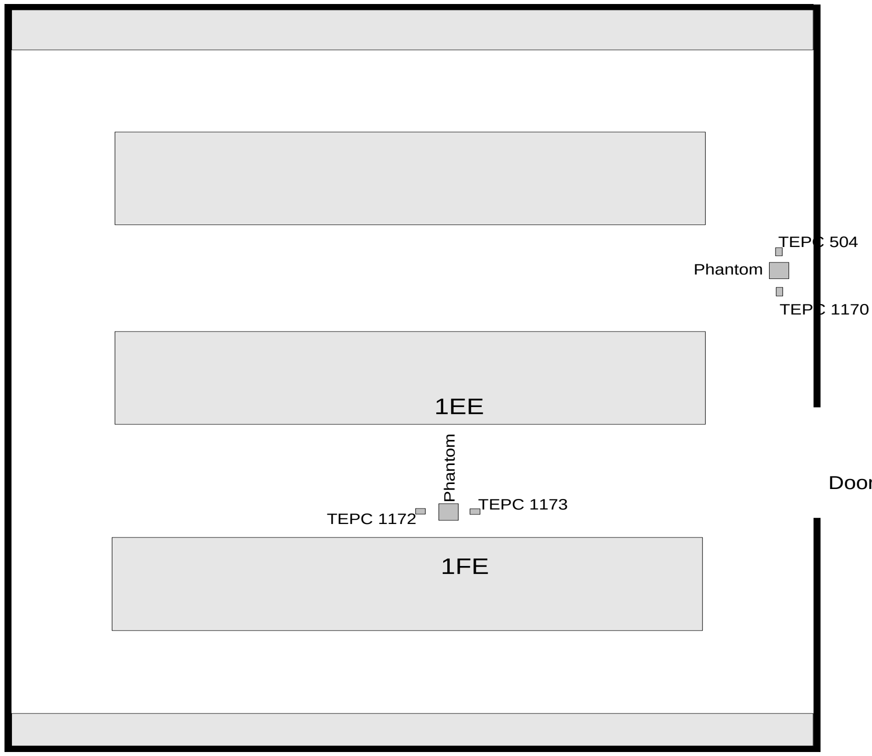


Figure 5.2. Measurement Locations in Vault 1

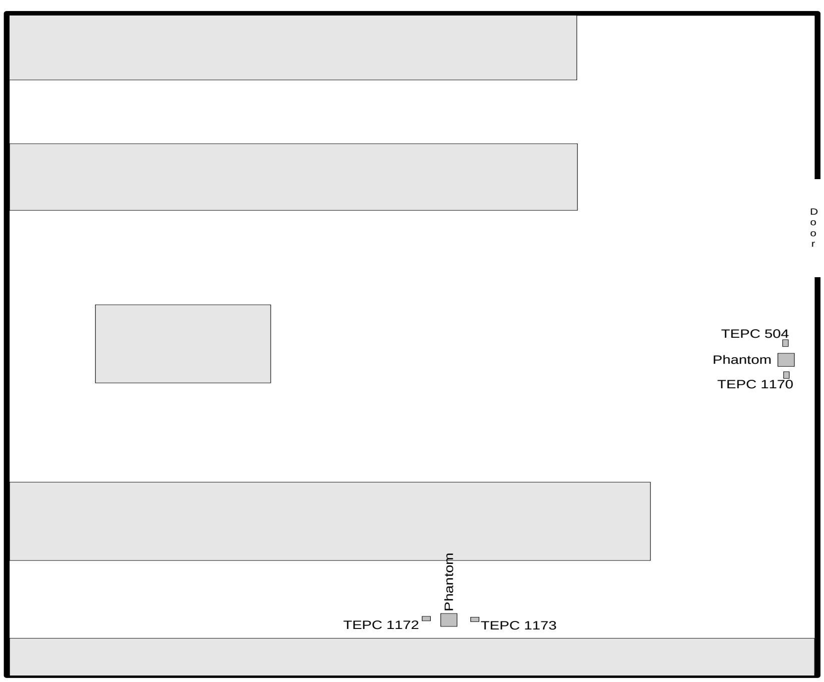


Figure 5.3. Measurement Locations in Vault 2

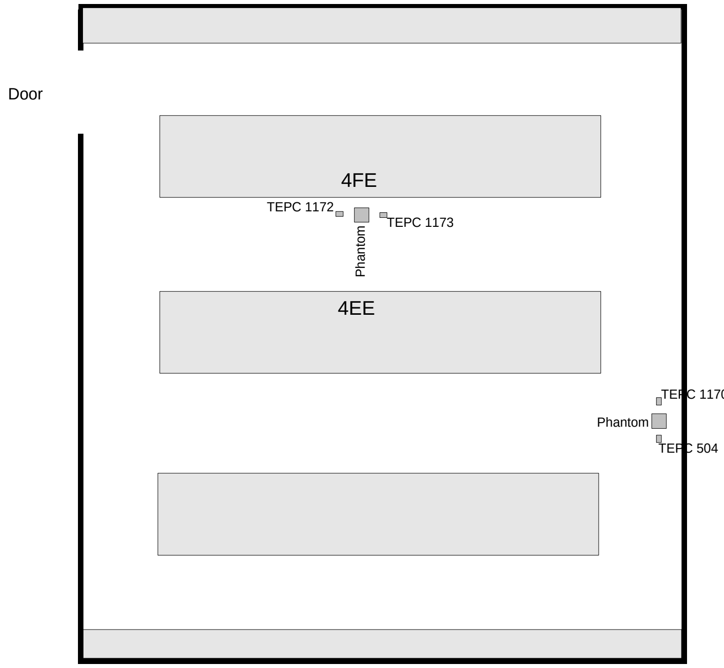


Figure 5.4. Measurement Locations in Vault 4

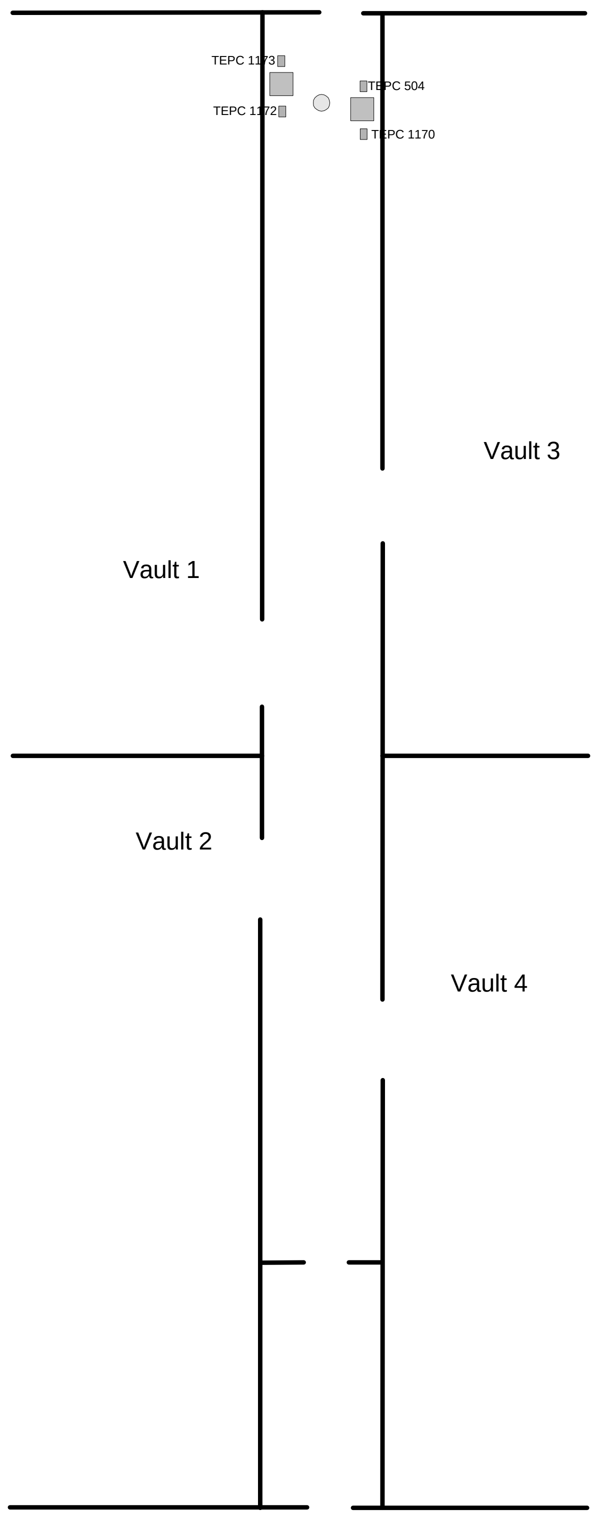


Figure 5.5. Measurement Locations in the Vault Corridor

5.1.2 Equipment Setup and Data Collection

At each location, a water-filled phantom was placed on a stand so that the center of the phantom was approximately 40 in. (102 cm) above the floor. The phantom had thin plastic walls and dimensions of 25 cm by 25 cm by 34 cm high. A packet of dosimeters was positioned on each of the four vertical faces of the phantom. Each packet held three 8816 and three HSD dosimeters. The packets were oriented so that the three 8816 dosimeters were side-by-side across the top of the packet, and the three HSD dosimeters were below the 8816 dosimeters. The 8816 dosimeters were configured the same as they are in a HCND, with the addition of two TED foils. While TED foils are not currently incorporated in HCNDs used for routine worker monitoring, TED response was a focus of this study, so they were included in the workplace measurements. The neutron insensitive 8825BP dosimeter typically used in the HCND package was not included in this study. Placing dosimeters on all four faces of the phantom provided an indication of the directionality of the radiation field at the measurement location and ensured that at least one packet would be facing the "source."

Dosimeters were exposed on-phantom at each location for a time period long enough to give an exposure of at least 100 mrem on each dosimeter. In some high-dose-rate areas, 5 or 6 hours was sufficient to give this exposure; more commonly the exposures were 18 or 20 hours long. In the low-dose-rate areas in the vault corridor, the exposure was 90 hours long. Control dosimeters were used with each dosimeter packet, accompanying the dosimeters whenever they were not in the exposure position, to ensure that an unexpectedly high background that may have been encountered during storage or transport could not influence the measured results. After the conclusion of all 10 measurements, the exposed dosimeters, including TLD and TED components, were read out by HED staff to determine the gamma and neutron dose equivalent.

Two 5-in. TEPC detectors were set up at each phantom location. The detectors were mounted on tripods and positioned so the center of the detector was at the same height as the center of the phantom. The detectors were positioned close to the phantoms, with the distance from the detector centers to the phantom center ranging from 12 to 15 in. (30 to 38 cm). The TEPC detectors were allowed to accumulate data for the same duration as the dosimeter exposures. Signals from the TEPC were collected in a MCA, then transferred to a computer for archiving and analysis. For each TEPC measurement, a dose equivalent rate was determined using the computer code TEPC_NG. The dose equivalent rates measured by the two TEPC detectors at each location could be expected to agree with each other to within about 15% if the neutron field was uniform. In some cases the disagreement was larger than that because of a gradient in the neutron field.

Sphere measurements were made in most locations. For these measurements, a stand to accommodate the sphere was briefly positioned in place of a TEPC detector (TEPC data collection was stopped during the sphere measurement). A LiI(Eu) detector was placed in the center of a 3-in. diameter polyethylene sphere positioned in the stand, and a data spectrum was collected in the MCA, then stored on computer disk. The 3-in. sphere was then replaced with an 8-in. diameter sphere and another MCA spectrum was recorded. After these measurements, the sphere stand was removed and the TEPC replaced and TEPC data collection continued. The areas of the neutron peaks in the MCA spectra from the two LiI(Eu) counts were determined and divided by the count time to give neutron count rates.

The response as a function of neutron energy of a thermal neutron detector inside an 8-in. sphere is similar to the variability of dose equivalent. Thus this count rate can be used as an indicator of dose equivalent rate, when compared to the values found in the LSR calibrations. Also, the ratio of 8-in. count rate to 3-in. count rate varies with neutron energy, so this ratio can be used to obtain some energy information about the neutron field.

A Snoopy survey meter was used at each location to check the dose equivalent rate at the phantom position and to check the variability of the dose rates over the area occupied by the phantom and TEPCs.

Two other neutron detectors were investigated in this study. Three BTI bubble detectors (model BD-PND, with a sensitivity of approximately 0.7 bubbles per mrem) were exposed at eight of the locations, and the Apfel REMBrandt survey meter was exposed at seven locations. The bubble detectors were either attached to a corner of a phantom or positioned adjacent to a TEPC. Exposure of the bubble detectors was usually planned to be in the range of 40 to 70 mrem (based on the Snoopy reading) to provide a number of bubbles that could be accurately read by eye. After the exposures, the bubbles in each of the three detectors were counted and recorded and the detectors recompressed for the next use.

The REMBrandt instrument was placed on the table next to the phantom, and it was allowed to collect data for up to half of the exposure time for each phantom in the room. The shorter exposure times were sufficient for the sensitivity of the instrument, and this method allowed it to make measurements at both phantom locations in the room. After the measurements, the instrument data were downloaded to computer disk using the vendor’s software. The data were imported into a spreadsheet, and the total dose equivalent for several hours’ exposure was summed in the spreadsheet, then divided by the total count time to get a representative dose equivalent rate. This method ensured that the data were representative of only the time that the instrument was in the measurement position and excluded transport time.

5.1.3 Measurement Results and Data Analysis

This section presents the results of measurements performed with the dosimeters on water phantoms.

5.1.3.1 Dose Equivalent Rates

The results of the measurements performed near the phantoms are recorded in Table 5.1. This table lists the dose equivalent rates at each location as determined by the two TEPC detectors (the TEPC results are listed individually), and compares these values with the dose equivalent rates determined by other instruments. The outputs of the TEPC_NG analyses for these measurements are presented in Appendix B.

Table 5.1. Neutron Dose Equivalent Rates Measured at the Phantoms

Room	Location	TEPC (mrem/h)	TEPC (mrem/h)	Snoopy (mrem/h)	8-in Sphere (mrem/h)	Bubble Detectors (avg of 3) (mrem/h)	REM-Brandt (cal 1) (mrem/h)	REM-Brandt (cal 2) (mrem/h)
235A-3	North	7.27	6.45	6	9.2	8.1	---	---
235A-3	South	8.84		7	8.9	8.7	---	----
Vault 4	Between cabinets	32.5	33.4	40	50.0	17.1	40.5	26.5
Vault 4	Back wall	18.8	20.2	16	26.3	10.6	15.4	10.1
Vault 1	Between cabinets	8.34	12.1	12	---	---	---	---
Vault 1	Corridor wall	3.91	4.50	4	---	---	6.34	4.15
Vault 2	Back cabinet	44.4	53.4	50	59.0	34.0	54.8	35.8
Vault 2	Corridor wall	20.4	27.7	20	24.5	30.7	21.8	14.3
Vault Corridor	By Vault 3	1.26	1.19	1	1.59[a]	0.63	1.79	1.17
Vault Corridor	By Vault 1	0.85	0.89	1	1.59[a]	0.46	1.4	0.92

[a] The sphere was set in a position halfway between the two phantom locations for the Vault Corridor.

Notes:

- The value reported for the BTI bubble detectors is the average reading for the three exposed detectors. For some measurement locations (such as Vault 2, by the corridor wall), there was a wide variation in readings from individual detectors; for other locations the agreement was excellent. Detailed results for individual detectors are shown in Appendix C.
- For the REMBrandt, two results are shown. “Cal 1” indicates the dose equivalent rate obtained using the calibration factor, 133, supplied by the vendor. “Cal 2” indicates the dose equivalent rate obtained using a calibration factor, 87, derived during this study from the LSR irradiations.

5.1.3.2. Sphere Ratios

The sphere ratios for the seven locations in which they were taken are presented in Table 5.2.

Table 5.2. Sphere Ratios, Using 8-in and 3-in Sphere Measurements

Room	Location	Ratio, 8" / 3"
235A-3	North	1.14
235A-3	South	1.03
Vault 4	Between cabinets	0.89
Vault 4	Back wall	0.71
Vault 2	Back cabinet	1.46
Vault 2	Corridor wall	1.03
Vault Corridor	Middle of corridor	0.64

5.1.3.3 Dosimeter Results

Table 5.3 presents a summary of the neutron and gamma (deep) dose equivalent rates measured with the 8816 TLD, 8816 TED, and HSD dosimeters, and compares them with the neutron dose equivalent rates determined by the TEPCs. The neutron dose equivalent results from the 8816 TLD were calculated using the plutonium algorithm developed primarily for use in PFP environs. The neutron dose equivalent results from the 8816 TED were calculated based on a calibration of the CR-39 electrochemical etch process to an unmoderated ^{252}Cf source. The reported results are based on the average result from both CR-39 foils in the 8816 holder. The neutron dose equivalent results from the HSD were calculated based on calibration of the HSD to an unmoderated ^{252}Cf source. The gamma (deep) dose results from the HSD were calculated as would normally be done when neutrons are detected with the HSD. Table 5.3 shows the dosimeter results as an average of three dosimeters exposed on the same phantom face in each location. Detailed dosimeter-by-dosimeter results, including adjusted chip responses, are presented in Appendix D.

The dosimeter results for one set of dosimeters in Vault 2, the one exposed by the wall facing TEPC 504, are marked with an asterisk because one strip of tape failed and the packet became partially unsecured from the phantom sometime during the 18.7-hour exposure. At the time of removal from the vault, this packet was hanging down from the phantom. For the time that it was untaped, it was in approximately the correct position, but had no moderator behind it, so the HCND and HSD neutron doses are certainly too low. The HSD gamma and TED neutron results are also not a correct indication of the dose at the phantom face, but the discrepancies would not be as serious as they would be for the albedo neutron dosimeters.

Table 5.3. Summary of on-Phantom Dosimeter Responses

Room	Location	Dosimeter placement on-phantom	8816 TLD neutron (mrem/h)	8816 TED neutron (mrem/h)	HSD neutron (mrem/h)	HSD gamma (mrem/h)	TEPC neutron (mrem/h)	TEPC neutron (mrem/h)
235A-3	North	Facing TEPC 1173	3.40	1.58	24.2	3.11	7.27 [T1173]	6.45 [T185]
235A-3	North	Facing water wall	5.34	0.49	19.9	0.70	7.27	6.45
235A-3	North	Facing TEPC 185	5.51	0.46	21.5	1.07	7.27	6.45
235A-3	North	Facing hood	6.65	3.50	29.5	4.52	7.27	6.45
235A-3	South	Facing hood	7.41	3.12	35.8	2.18	8.84 [T1170]	7.15 [T1172]
235A-3	South	Facing TEPC 1170	4.16	1.18	27.6	1.26	8.84	7.15
235A-3	South	Facing wall	4.17	0.53	25.1	0.55	8.84	7.15
235A-3	South	Facing TEPC 1172	5.65	1.09	28.0	1.21	8.84	7.15
Vault 1	Between Cabinets	Facing Cabn 1EE	17.1	2.03	94.3	1.48	8.34 [T1172]	12.1 [T1173]
Vault 1	Between Cabinets	Facing TEPC 1172	14.2	1.40	75.7	1.49	8.34	12.1
Vault 1	Between Cabinets	Facing Cabn 1FE	23.3	4.60	149.0	1.90	8.34	12.1
Vault 1	Between Cabinets	Facing TEPC 1173	19.7	1.55	92.97	1.64	8.34	12.1
Vault 1	Corridor Wall	Away from wall	7.67	1.09	44.9	0.60	3.91 [T504]	4.50 [T1170]
Vault 1	Corridor Wall	Facing TEPC 504	5.30	0.54	38.8	0.51	3.91	4.50
Vault 1	Corridor Wall	Facing wall	4.25	0.39	37.4	0.46	3.91	4.50
Vault 1	Corridor Wall	Facing TEPC 1170	8.49	1.31	50.2	0.61	3.91	4.50
Vault 2	Between Cabinets	Facing aisle	26.4	14.4	108	42.8	44.4 [T1172]	53.4 [T1173]
Vault 2	Between Cabinets	Facing TEPC 1173	21.7	10.2	107	54.6	44.4	53.4
Vault 2	Between Cabinets	Facing wall cabnt	23.0	11.4	95.2	59.9	44.4	53.4
Vault 2	Between Cabinets	Facing TEPC 1172	26.2	14.1	112	50.3	44.4	53.4
Vault 2	By wall	Away from wall	29.2	8.65	96.0	22.3	20.4 [T504]	27.7 [T1170]
Vault 2	By wall	Facing TEPC 504	10.5*	3.73	81.7*	8.20	20.4	27.7
Vault 2	By wall	Facing wall	18.7	2.14	90.3	6.13	20.4	27.7

Table 5.3 Summary of on-Phantom Dosimeter Responses

Room	Location	Dosimeter placement on-phantom	8816 TLD neutron (mrem/h)	8816 TED neutron (mrem/h)	HSD neutron (mrem/h)	HSD gamma (mrem/h)	TEPC neutron (mrem/h)	TEPC neutron (mrem/h)
Vault 2	By wall	Facing TEPC 1170	19.0	7.48	100	18.8	20.4	27.7
Vault 4	Between Cabinets	Facing TEPC 1172	53.3	9.31	239	13.2	32.5 [T1172]	33.4 [T1173]
Vault 4	Between Cabinets	Facing Cabn 4FE	43.4	7.09	232	5.71	32.5	33.4
Vault 4	Between Cabinets	Facing TEPC 1173	50.2	7.09	193	24.6	32.5	33.4
Vault 4	Between Cabinets	Facing Cabn 4EE	63.9	14.5	258	22.8	32.5	33.4
Vault 4	Back Wall	Away from wall	46.9	7.12	231	3.70	18.8 [T504]	20.2 [T1170]
Vault 4	Back Wall	Facing TEPC 1170	30.7	3.60	162	2.54	18.8	20.2
Vault 4	Back Wall	Facing wall	14.4	0.82	146	1.87	18.8	20.2
Vault 4	Back Wall	Facing TEPC 504	31.1	3.01	188	2.62	18.8	20.2
Vault Corridr	By Vault 1	Facing corridor	1.99	0.24	19.14	0.21	0.85 [T1172]	0.89 [T1173]
Vault Corridr	By Vault 1	Facing TEPC 1172	1.38	0.18	16.9	0.22	0.85	0.89
Vault Corridr	By Vault 1	Facing TEPC 1173	1.11	0.21	17.3	0.23	0.85	0.89
Vault Corridr	By Vault 1	Facing wall	1.93	0.10	13.9	0.21	0.85	0.89
Vault Corridr	By Vault 3	Facing corridor	1.67	0.18	16.5	0.25	1.26 [T504]	1.19 [T1170]
Vault Corridr	By Vault 3	Facing TEPC 504	2.37	0.13	18.9	0.27	1.26	1.19
Vault Corridr	By Vault 3	Facing wall	1.87	0.37	26.6	0.33	1.26	1.19
Vault Corridr	By Vault 3	Facing TEPC 1170	1.75	0.19	19.0	0.29	1.26	1.19

*This dosimeter packet did not remain on the phantom for the entire exposure time; albedo neutron results are suspect

The ratio of TLD response to TEPC measured dose rate ranged from 0.2 to 3.16 for individual 8816 dosimeters, with an average ratio of 1.27. Table 5.4 presents the ratio of the average result for three dosimeters on a given phantom face to the average TEPC dose rate for the phantom location. For 8816 TLDs, the ratio ranged from 0.44 to 2.40 with an average of 1.27.

Table 5.4. Comparison of TEPC Results and Dosimeter Results, Presented for each Phantom Face

Location	**Packet No.**	**On-Phantom Placement**	**8816 TLD/ TEPC**	**8816 TED/ TEPC**	**HSD/ TEPC**
235A-3 North	5	West - facing TEPC 1173	0.50	0.23	3.52
235A-3 North	6	North - facing water wall	0.78	0.07	2.90
235A-3 North	7	East - facing TEPC 185	0.80	0.07	3.13
235A-3 North	9	South - Facing hood	0.97	0.51	4.30
235A-3 South	1	North - Facing hood	0.93	0.39	4.47
235A-3 South	2	East - to TEPC 1170	0.52	0.15	3.46
235A-3 South	3	West - to TEPC 1172	0.71	0.14	3.50
235A-3 South	4	South - Facing wall	0.52	0.07	3.14
Vault 1: betw cabinets	21	facing cabinet 1EE	1.67	0.20	9.23
Vault 1: betw cabinets	22	facing TEPC1172	1.39	0.14	7.41
Vault 1: betw cabinets	23	facing cabn 1FE	2.28	0.45	14.59
Vault 1: betw cabinets	24	facing TEPC1173	1.93	0.15	9.10
Vault 1: by corridor wall	17	away from wall	1.82	0.26	10.68
Vault 1: by corridor wall	18	facing TEPC504	1.26	0.13	9.22
Vault 1: by corridor wall	19	facing wall	1.01	0.09	8.89
Vault 1: by corridor wall	20	facing TEPC1170	2.02	0.31	11.93
Vault 2 - Betw Cabinets	25	to aisle	0.54	0.30	2.22
Vault 2 - Betw Cabinets	26	to TEPC 1173	0.44	0.21	2.20
Vault 2 - Betw Cabinets	27	to wall cabinet	0.47	0.23	1.95
Vault 2 - Betw Cabinets	28	to TEPC 1172	0.54	0.29	2.29
Vault 2 - by wall	29	away from wall	1.21	0.36	3.99
Vault 2 - by wall	30*	to TEPC 504	0.44*	0.16*	3.40*
Vault 2 - by wall	31	to wall	0.78	0.09	3.76
Vault 2 - by wall	32	to TEPC 1170	0.79	0.31	4.17
Vault 4 - Back Wall	8	Away from wall	2.40	0.37	11.83
Vault 4 - Back Wall	10	facing TEPC 1170	1.58	0.18	8.28
Vault 4 - Back Wall	11	toward wall	0.74	0.04	7.51
Vault 4 - Back Wall	12	facing TEPC 504	1.60	0.15	9.65
Vault 4 betw cabinets	13	facing TEPC1172	1.62	0.28	7.24
Vault 4 betw cabinets	14	facing TEPC1173	1.52	0.22	5.87
Vault 4 betw cabinets	15	facing 4FE	1.32	0.22	7.05
Vault 4 betw cabinets	16	facing 4EE	1.94	0.44	7.82
Vault Cor by V1	33	to corridor	2.28	0.28	22.00
Vault Cor by V1	34	to TEPC 1172	1.58	0.20	19.44
Vault Cor by V1	35	to TEPC 1173	1.27	0.24	19.90
Vault Cor by V1	3	to wall	2.21	0.11	15.97
Vault Cor by V3	37	to corridor	1.36	0.15	13.50
Vault Cor by V3	38	to TEPC 504	1.94	0.11	15.39
Vault Cor by V3	39	to wall	1.52	0.30	21.71

Table 5.4 Comparison of TEPC Results and Dosimeter Results, Presented for each Phantom Face.

Location	Packet No.	On-Phantom Placement	8816 TLD/ TEPC	8816 TED/ TEPC	HSD/ TEPC
Vault Cor by V3	40	to TEPC 1170	1.43	0.16	15.54
Minimum			0.44	0.04	1.95
Maximum			2.40	0.51	22.00
Mean			1.27	0.22	8.55
*This dosimeter packet did not remain on the phantom for the entire exposure time.					

The comparisons presented in Table 5.4 are not necessarily a good reflection of how the TLD responds in actual working conditions. It is rare that a worker stands at one location, facing one direction for the entire dosimeter wear period. It is even less likely that the direction the worker faces is consistently away from the "source." A more useful indicator of dosimeter performance in the PFP environments studied can be obtained by comparing the average response of all dosimeters on a phantom with the average TEPC dose rate at the phantom location. The results are presented in Tables 5.5 and 5.6. An even better indicator would have been to rotate each phantom 90 degrees at regular intervals during its exposure cycle such that equal exposure is received in each of the four orientations. This would simulate a randomly oriented worker. Because this was not done, the equivalent result was achieved by taking the average reading for each chip position in the 8816s on a given phantom. These four composite chip responses were then used as input to the 8816 algorithm to calculate the neutron dose response for a "composite" 8816 TLD at each phantom location. In Table 5.5, the average TEPC result for each phantom location is presented along with the composite 8816 TLD result, the mean 8816 TLD result, the mean 8816 TED result, and the mean HSD result. The standard deviations are also presented to provide an indication of uncertainty in the TLD data. Because only two TEPC results are involved in the average, the standard deviation is not presented for the TEPC mean. However, in most cases the two TEPC readings comprising the TEPC average were in good agreement, indicating that the free field neutron dose gradient was not large and that the use of an average TEPC dose rate was valid. For the phantom location described as "Vault 2 – by wall," the dosimeters from the packet that fell off the phantom (packet 30) were not included in any of the TLD or TED response calculations.

Table 5.5. Summary of Dosimeter Response, Presented by Phantom Location

	TEPC (neutron mrem/h)	**8816 TLD (neutron mrem/h)**	**8816 TLD (neutron mrem/h)**		**8816 TED (neutron mrem/h)**		**HSD TLD (neutron mrem/h)**		**HSD TLD (gamma mrem/h)**	
Location	**Mean**	**Composite**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
235A-3 North	6.86	3.01	5.22	1.60	1.51	1.30	23.74	3.94	2.35	1.64
235A-3 South	8.00	2.76	5.35	2.51	1.48	1.03	29.11	4.33	1.30	0.62
Vault 1: betw cabinets	10.22	18.62	18.60	4.00	2.40	1.37	103.02	29.04	1.63	0.20
Vault 1: by corridor wall	4.21	6.43	6.43	2.08	0.83	0.41	42.80	5.41	0.54	0.08
Vault 2 - Betw Cabinets	48.90	24.32	24.30	6.02	12.50	2.03	105.72	8.16	51.88	7.00
Vault 2 - by wall	24.05	26.10	22.29	7.63	6.09	3.06	95.57	5.61	15.72	7.38
Vault 4 - Back Wall	19.50	30.76	30.77	14.20	3.64	2.41	181.68	34.10	2.68	0.69
Vault 4 betw cabinets	32.95	52.70	52.70	9.53	9.50	3.23	230.53	26.42	16.58	8.09
Vault Cor by V1	0.87	1.60	1.60	0.72	0.18	0.06	16.82	2.02	0.22	0.01
Vault Cor by V3	1.23	1.92	1.92	0.48	0.22	0.10	20.25	4.18	0.29	0.03

The TLD/TEPC ratios are presented in Table 5.6. The average 8816 TLD/TEPC ratio varies between 0.50 and 1.84 with a mean value of 1.28 for all locations. The composite 8816 TLD/TEPC ratio varies between 0.34 and 1.84 with a mean value of 1.23 for all locations. As can be seen, the 8816 TED consistently under-responded with an average TED/TEPC ratio of 0.22 and the HSD consistently over-responded with an average TLD/TEPC ratio of 8.57.

Table 5.6. Ratios of Dosimeter Responses to TEPC Dose Rates, Presented by Phantom Location

Location	Composite 8816 TLD / TEPC	Average 8816 TLD / TEPC	Average 8816 TED / TEPC	Average HSD TLD / TEPC
235A-3 North	0.44	0.76	0.22	3.46
235A-3 South	0.34	0.67	0.18	3.64
Vault 1: betw cabinets	1.82	1.82	0.23	10.08
Vault 1: by corridor wall	1.53	1.53	0.20	10.18
Vault 2 - Betw Cabinets	0.50	0.50	0.26	2.16
Vault 2 - by wall	1.09	0.93	0.25	3.97
Vault 4 - Back Wall	1.58	1.58	0.19	9.32
Vault 4 betw cabinets	1.60	1.60	0.29	7.00
Vault Cor by V1	1.84	1.84	0.21	19.33
Vault Cor by V3	1.56	1.56	0.18	16.53
Minimum	0.34	0.50	0.18	2.16
Maximum	1.84	1.84	0.29	19.33
Mean	1.23	1.28	0.22	8.57

One unexpected result that can be observed in Tables D.1 and D.2 for the HCND exposures is the number of occurrences where HCNDs from the same packet produced chip responses that were only moderately different from each other, but were analyzed to give dose equivalents substantially different from each other. As an example, Table 5.7 shows the exposure results for two pairs of HCND dosimeters exposed together on the phantom in the south location of Room 235A-3:

Table 5.7. Chip Readings and Evaluated Doses from Selected HCND Dosimeters

		Adjusted chip readings				
Packet	Dosimeter Card ID	Chip 1	Chip 2	Chip 3	Chip 4	Neutron Dose Eq, mrem
1	4051048	27.29	573.98	348.77	658.69	79.17
1	4007608	34.94	614.47	349.69	738.75	177.78
3	4050749	23.07	406.99	256.81	524.75	83.28
3	4007288	20.55	420.43	271.59	529.44	156.17

In packet 1, the two dosimeters were exposed side-by-side on the same side of a phantom, and the variation in similar chip readings from one dosimeter to the next shows the minor discrepancies that would be expected in an actual field measurement. The Chip 2 responses are 7% different from each other, the Chip 3 responses are nearly identical, and the Chip 4 responses are 12% different from each other. However, the evaluated doses do not agree well — one value is 2.2 times larger than the other. They were both analyzed with algorithm branch 112.

In packet 3, the two dosimeters again exhibited similar chip responses, with the Chip 3 pairs showing only a 5.8% disagreement. However, the algorithm chose two different branches: card 4050749 was analyzed using branch 112, and card 4007288 was analyzed using branch 111, producing an evaluated dose that is 1.9 times higher than its similarly exposed dosimeter.

There were only three packets (out of 40 exposed) where two different algorithm branches were employed, so in most cases the discrimination between algorithm branches was good. There were at least 10 packets, however, where a factor of two difference could be observed in dosimeter pairs with similar chip responses, similar to the packet 1 example in Table 5.7.

5.2 Extremity Measurements

This set of measurements was made to validate the assessment of neutron doses to extremities during glovebox operations. Neutron dose equivalent rates were measured inside the fingers of a glove exposed to plutonium sources, and extremity dosimeters (finger rings) were also exposed inside these gloves. The gamma dose rates recorded by the finger rings can be compared with neutron dose equivalent rates, and used to determine neutron-to-gamma ratios. The measurements were performed under controlled experimental conditions to ensure that the results can be applied to a variety of workplace conditions.

5.2.1 Sources

Six different cans containing plutonium sources were used for these measurements. They were chosen to be representative of the sources that produce significant neutron extremity exposures to Hanford workers. The six sources were all encased in multiple nesting cans (either three or four cans per source), with the outer can measuring 7 in. (17.8 cm) high and 4.125 in. (10.5 cm) in diameter. The six sources can be generally characterized as follows:

- "6% oxide," plutonium oxide source with approximately 6% ^{240}Pu
- "12% oxide," plutonium oxide source with approximately 12% ^{240}Pu
- "20% oxide," plutonium oxide source with approximately 20% ^{240}Pu
- "Metal," plutonium metal with approximately 17% ^{240}Pu
- "Oxide with Pb shield," plutonium oxide with approximately 17% ^{240}Pu, packaged in a container with a .125-in. thick lead shield,
- "Oxide with Pb foil," plutonium oxide with approximately 17% ^{240}Pu and isotopic ratios identical to the "17% oxide with Pb", but packaged in a container with a thin lead foil shield (about .02-in. lead).

The characteristics of each source are given in Table 5.8. Isotopic compositions are decayed from the assay dates to September 1999.

Table 5.8. Characteristics of Measured Source Cans

Source	Sample mass (g Pu)	Percentage isotopic composition (by weight)					
		^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
6% oxide	602	0.28	93.083	5.928	0.37	0.03	0.31
12% oxide	559	0.044	86.540	11.621	0.42	0.20	1.17
20% oxide	642	.35	74.134	20.105	1.39	.996	3.02
Metal	2181	.0553	81.907	16.974	.657	.407	2.181
Oxide with Pb shield	658	0.640	73.914	15.506	2.11	1.52	6.31
Oxide with Pb foil	618	0.638	73.890	15.763	2.14	1.303	6.26

5.2.2 Equipment Setup and Data Collection

The measurement equipment was set up on a table in Room 637 of 2736ZB in the PFP complex. The table is approximately 135 cm above the floor.

A rack was constructed to hold the extremity measurement instruments, as shown in Figure 5.6. The instrument rack was designed to hold a portion of a lead-lined glove, identical to those used in gloveboxes at PFP. The glove was supplied by North Safety Products (product #8YLY3032). The glove is made of 30-mil-thick neoprene, and the lead layer provides attenuation equivalent to a 0.1-mm-thick sheet of lead.

The glove was oriented on the rack with the fingers pointed down and instruments were inserted in the four glove fingers. The rack provided adjustments to position the glove at any desired position above the surface.

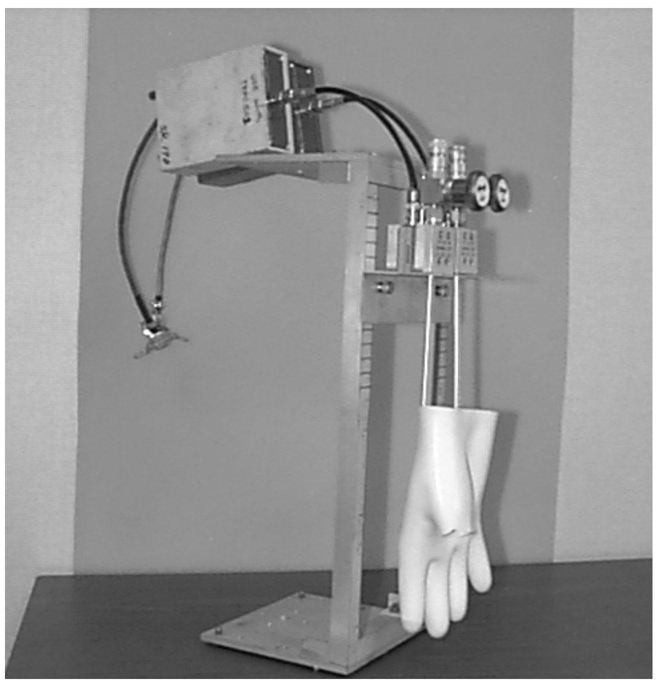


Figure 5.6. Instrument Rack for Extremity Measurements

Inserting instruments inside the glove fingers ensured that the measurements would be typical of exposures received by extremities of workers at PFP gloveboxes. In each of the four fingers, extremity dosimeters were wrapped around the cylindrical neutron detectors (either TEPCs or bubble detectors). The dosimeters were oriented with the sensitive chips facing the radiation source, so they would record the same gamma dose that would be received by an operator handling the same source. The neutron detectors were sensitive to neutrons in a region that would be typical of the volume occupied by the operator's finger. Thus the comparison of dosimeter responses with neutron detector responses will be an excellent analog to the reading of an operator's extremity dosimeter compared with the neutron dose received by the finger wearing the dosimeter. Five extremity dosimeters were placed in each finger to maximize the counting statistics.

For each measurement, the rack was positioned on the table, so that the glove fingers were approximately 15 to 20 cm from the surface of the source can. Half-inch TEPC detectors were positioned in the index and ring fingers of the glove (as shown in Figure 5.6). Five extremity dosimeters were wrapped around the barrel of each TEPC before they were inserted into the glove fingers. A cable extended from each detector to a preamplifier on top of the rack, and a cable bundle led from the preamplifier to the NIM electronics rack, containing the high voltage supplies, amplifiers, and ADCs. Signals from the ADC were transmitted to the MCA for data collection. For each measurement, data collection was initiated in the MCA after the source can was positioned in front of the glove, and the time for start of exposure of the dosimeters was recorded.

Bubble detectors were exposed in the middle and little fingers of the glove. Five extremity dosimeters were wrapped around a spacer tube, which was then placed on a bubble detector. At the beginning of each count, the piston of the bubble detector was removed to activate the detector; it was then inserted into a glove finger, and the time for start of the exposure was recorded for each.

A vertical wooden rod with five dosimeters wrapped around it was positioned next to the little finger of the glove, at the same distance from the can surface as the finger. This set of dosimeters provided the opportunity for a comparison with the dosimeters in the little finger to show the effectiveness of the leaded glove at shielding gamma radiation.

A 5-in. TEPC detector was positioned on the table next to the rack, at a distance of 30.5 cm from the source can (measured from can centerline to detector centerline). This detector collected data for the entire exposure time. A Snoopy neutron survey instrument was also positioned 30.5 cm from the can (centerline-to-centerline) to measure the neutron dose equivalent rate, and a CP survey instrument was positioned by the glove fingertips to measure the gamma dose rate near this position.

Exposures were at least 20 hours per source can (some exposures were as long as 3 days), because the small TEPC detectors are not sensitive instruments, and the extremity dosimeter responses also benefited from long exposures. At the completion of the exposure, the source can was removed from the table, and end-of-exposure times were recorded for the bubble detectors and extremity dosimeters. The detectors were removed from the glove fingers to allow changeout of the dosimeters.

Data collection for each TEPC was terminated when the source can was removed, and the MCA spectra were recorded onto computer disk. The TEPCs were then positioned to activate the internal alpha calibration sources, which were used to determine the proton drop point. MCA spectra with the alpha sources activated were collected for 5 to 10 minutes, and the spectra were then stored on computer disk.

5.2.3 Measurement Results and Data Analysis

This section presents the results of the extremity measurements.

5.2.3.1 Neutron Dose Equivalent Rates

The computer code TEPC_NG was used to analyze the MCA spectra collected from the TEPC detectors. For the ½-in. detectors, the results of calibration measurements with the internal alpha source were used to find the proton drop point, because collected neutron counts were generally too low to provide a well-defined proton drop point in the spectrum collected on the MCA. For TEPC measurements that did not provide a well-developed proton drop point, it was set to 1.05 times the peak channel for the alpha measurement, matching the ratio found in LSR calibration measurements.

TEPC 1074 exhibited an unexpected non-zero count rate from its alpha source. Apparently, when used in the vertical position, the alpha shutter was open slightly, allowing a few alphas to sneak into the sensitive volume of the detector. However, this additional alpha-generated background was mathematically corrected. The area under the unintentional alpha peak was determined above the "background" of the neutron spectrum. An idealized peak with this area was subtracted from the collected spectral data, channel by channel, leaving an adjusted spectrum. This adjusted spectrum could then be analyzed by TEPC_NG to determine the neutron dose equivalent rate. A comparison of the alpha-adjusted TEPC analyses for TEPC 1074 to the results for TEPC 1122, exposed during the same measurement, showed similar results for the two detectors. Thus this alpha adjustment was able to provide a reliable TEPC analysis, but with a greater uncertainty than the measurement for TEPC 1122.

The exposed bubble detectors were read out in the automated counting system. Although the LSR tests of the bubble detector showed better performance when the bubbles were counted by eye rather than by machine, the long exposures in the extremity study produced so many bubbles that they could not be counted by eye.

Table 5.9 presents the measured neutron dose equivalent rates for the extremity study. Appendix E contains detailed outputs from the TEPC_NG runs that were used to analyze the TEPC results. Appendix C contains detailed information on bubble dosimeter counts.

Table 5.9 Neutron Dose Equivalent Rates, Extremity Measurements

	Measured Neutron Dose Equivalent Rate (mrem/h)					
Source Can	**Snoopy 30.5 cm dist.**	**5-in TEPC 30.5 cm dist.**	**TEPC 1074 Index Finger**	**Bubble Det'r Middle Finger**	**TEPC 1122 Ring Finger**	**Bubble Det'r Little Finger**
6% Oxide	5	---	13.1	5.52	10.6	5.41
12% Oxide	1.8	2.55	5.72	2.63	5.34	1.97
20% Oxide	4	6.32	11.2	8.15	10.9	7.14
Metal	7	8.50	15.3	7.65*	14.7	8.30*
17% Oxide with Pb Foil	---	3.93	8.82	5.1	8.93	5.0
17% Oxide with Pb Shield	1.1	1.07	3.25	1.99	2.69	2.08
*Average of two bubble detector measurements						

5.2.3.2 Extremity Dosimeter Results

The extremity dosimeters were read out to determine the gamma dose to each finger inside the leaded glove. The results are presented in Table 5.10. Detailed dosimeter results are presented in Appendix F.

Table 5.10. Gamma Dose Rates Derived From Extremity Dosimeter Exposures

Source Can	**Glove Finger**	**Gamma dose rate (mrem/h)**	**Standard deviation (mrem/h)**
6% Oxide	Index	33.3	3.9
6% Oxide	Middle	40.7	2.0
6% Oxide	Ring	32.8	2.4
6% Oxide	Little	34.5	4.2
6% Oxide	None	5.4*	0.7
		* Dosimeters moved away from glove during exposure	
12% Oxide	Index	36.8	5.2
12% Oxide	Middle	44.2	7.0
12% Oxide	Ring	45.1	4.9
12% Oxide	Little	43.6	12.3
12% Oxide	None	75.1	8.3
20% Oxide	Index	118	14
20% Oxide	Middle	136	18
20% Oxide	Ring	128	19
20% Oxide	Little	134	5
20% Oxide	None	(no measurement)	(no measurement)
Metal	Index	31.6	4.0
Metal	Middle	35.3	4.5
Metal	Ring	32.1	4.0
Metal	Little	36.7	6.1
Metal	None	53.7	4.1
17% Oxide with Pb Foil	Index	33.4	1.9
17% Oxide with Pb Foil	Middle	36.3	8.7
17% Oxide with Pb Foil	Ring	37.6	2.7
17% Oxide with Pb Foil	Little	36.5	5.0
17% Oxide with Pb Foil	None	54.4	2.4
17% Oxide with Pb	Index	4.99	0.49
17% Oxide with Pb	Middle	6.27	0.53
17% Oxide with Pb	Ring	6.12	0.41
17% Oxide with Pb	Little	5.80	0.31
17% Oxide with Pb	None	3.56	0.25

5.2.3.3 Neutron-to-Gamma Ratios for Extremity Doses

The data in Tables 5.9 and 5.10 were combined to determine neutron/gamma ratios. The ratio was determined for each glove finger and for each source can individually, and the results were presented in Table 5.11. The table includes separate columns for TEPC measurements and for bubble detector measurements. (An entry of "NM" indicates no measurement.)

Table 5.11. Neutron/Gamma Ratios Inside A Leaded Glove

Source Can	Glove Finger	TEPC Neutron/Gamma Ratio	Bubble Detector Neutron/Gamma Ratio
6% Oxide	Index	0.394	NM(a)
6% Oxide	Middle	NM	0.136
6% Oxide	Ring	0.324	NM
6% Oxide	Little	NM	0.157
6% Oxide	Can Average	0.36	0.15
12% Oxide	Index	0.155	NM
12% Oxide	Middle	NM	0.060
12% Oxide	Ring	0.118	NM
12% Oxide	Little	NM	0.045
12% Oxide	Can Average	0.14	0.052
20% Oxide	Index	0.095	NM
20% Oxide	Middle	NM	0.060
20% Oxide	Ring	0.085	NM
20% Oxide	Little	NM	0.053
20% Oxide	Can Average	0.090	0.057
Metal	Index	0.484	NM
Metal	Middle	NM	0.217
Metal	Ring	0.458	NM
Metal	Little	NM	0.226
Metal	Can Average	0.47	0.22
17% Oxide with Pb Foil	Index	0.264	NM
17% Oxide with Pb Foil	Middle	NM	0.141
17% Oxide with Pb Foil	Ring	0.238	NM
17% Oxide with Pb Foil	Little	NM	0.137
17% Oxide with Pb Foil	Can Average	0.25	0.14
17% Oxide with Pb	Index	0.652	NM
17% Oxide with Pb	Middle	NM	0.318
17% Oxide with Pb	Ring	0.440	NM
17% Oxide with Pb	Little	NM	0.358
17% Oxide with Pb	Can Average	0.55	0.34
(a)"NM" indicates "No Measurements"			

6.0 CONCLUSIONS AND RECOMMENDATIONS

The study derived conclusions about neutron dose equivalent rates; neutron energies; the performance of dosimeters, REMBrandt and bubble detectors; and extremity neutron-to-gamma ratios, as discussed below.

6.1 Neutron Dose Equivalent Rates

The TEPC detectors were the primary instruments used by this study for determining neutron dose equivalent rates. Because the TEPC has a TE response to neutrons, the assessment of neutron dose equivalent is not affected by the neutron energy spectrum; it will be just as valid for a well-moderated spectrum as it is for an unmoderated ^{252}Cf source in a calibration facility. Thus, the 5-in. detectors used in the whole body study provided a good indication of the neutron dose equivalent rate that a person would be exposed to when standing in that position. The ½-in. detectors used in the extremity measurements provided a good indication of the neutron dose rate that would be received by an operator's finger when working in a glovebox.

The TEPCs used in this study were exposed in the 318 Building Calibration Laboratory LSR to check their performance and verify that they can accurately measure neutron dose equivalents. Table 4.1 showed that the 5-in. detectors used in the workplace measurements, when exposed to the more intense source, gave dose equivalent rates that ranged from 3.6% lower to 10.3% higher than the accepted rate for the unmoderated ^{252}Cf source, ignoring the contribution of effects such as room scatter and source anisotropy. These percentage differences should be adjusted downward by approximately 5% to reflect the influence of these secondary effects. For detectors exposed to the less intense source, the disagreement with the accepted value was as much as 16.6%. These results indicate that the TEPCs will determine dose equivalent rates that are typically within 20% of the accepted values. When these detectors were used in the workplace measurements, on either sides of a phantom, the agreement between the two detectors was excellent.

Table 4.2 shows that the two ½-in. TEPCs used in the study also gave dose equivalent rates very close to the accepted value for exposure to an unmoderated ^{252}Cf source. For high count rates, the results were within 5% of the accepted value; for exposures in the range of a few hundred mrem, similar to the exposures they received in the extremity study, they gave results within 20% of the accepted value. In the extremity measurements in 2736ZB, TEPCs exposed to the same source gave similar results. For two source cans, the agreement between detectors was about 24%; for the other four cans it was 7% or less.

For the workplace measurements, under ideal counting conditions the results of 5-in. TEPC measurements are usually accurate to within 7%. The uncertainty of a measurement would be larger than that if the detector recorded a small number of neutron events, as happened with the ½-inch detectors used in the extremity measurements.

When all measurement uncertainties are considered, it is reasonable to assign an overall uncertainty of ±20% to the workplace dose equivalent measurements.

One of the concerns about a set of measurements such as this is the possibility of the variation of radiation field with time during the measurements. The measurements were long, ranging from a few hours to a few days. Other activities were occurring during the measurements, and it is possible that a source was moved during an exposure, modifying the dose rates at that point. This was a particular concern during the extremity measurements, when the counting lasted for several days. It is possible that another can, which was an intense source of neutrons or gammas, may have been moved close to the measurement table, disrupting either the neutron count rate or the gamma dosimeter exposure. A 5-in. TEPC was positioned near the glove, but further from the source can than the glove fingers. This detector would have indicated if a significant fraction of the neutron counts were originating from behind the glove, as may occur if another source were used nearby. Because this behavior was never seen, we can be reasonably certain that no gross sources of interference were present. It does not guarantee that the neutron and gamma fields were uniform, however.

6.2 Neutron Energies

True neutron spectrometry was not performed in this study. An indication of neutron energies in the measurement locations could be obtained from the 8-in.-to-3-in. sphere ratios. The measurements described by Endres et al. (1996) showed that sphere ratios increased as neutron energies increased, because higher energy neutrons are more effective than lower energy neutrons at penetrating through the thick layer of plastic in the 8-in. sphere to reach the detector at the center of the sphere, while in the 3-in. sphere higher energy neutrons become less effective at producing counts because the smaller amount of moderation produced fewer neutrons with thermal energies that would interact with the detector. The study found that the sphere ratio can range from 3.0 or higher for an unmoderated fission spectrum to 0.5 or lower for a well-moderated spectrum.

The measurements recorded in Section 4.2 confirmed that a sphere ratio of 3.0 is typical of a fission spectrum with little or no scatter. This ratio was seen in the LSR measurements using the unmoderated ^{252}Cf source. No measurements in PFP gave ratios nearly this high, which is understandable because there was some concrete in the vicinity of all measurements made in this study.

In Room 235A-3 the two sphere measurement ratios were similar to each other, 1.14 and 1.03. These ratios indicate some neutron moderation and some unscattered neutrons were present.

Neutron energies were highest in Vault 2, as indicated by sphere ratios. The location by the back cabinet had a ratio of 1.46, the highest seen in a work location in this study. The Vault 2 location by the corridor wall had a ratio of 1.03, indicating a spectrum similar to that in Room 235A-3, with a greater contribution from low-energy neutrons than observed at the position near the cabinets.

The neutron energies in Vault 4 were lower than those in Vault 2. The ratio between the cabinets was 0.89, which shows a substantially lower energy distribution than both measurement locations in Vault 2. The location in Vault 4 near the wall had a ratio of 0.71, showing a large component of moderated neutrons.

The lowest neutron energies were seen in the Vault Corridor, with a ratio of 0.64. Any neutrons in the corridor must pass through concrete walls, and while this will not necessarily provide a completely moderated spectrum, it resulted in lower neutron energies than those seen elsewhere.

In summary, measurements indicated that neutron energies in the workplace locations selected for evaluation were significantly moderated, indicative of the scattering that occurs in the extensive shielding used throughout PFP work areas. These neutron energies are important to the dosimeter and instrument response characteristics. Notably, these radiation fields have a substantial number of neutrons with energies below the response threshold for the TED. The TLD responds easily to these neutron energies but accurate calibration and dose interpretation can be difficult.

6.3 Bubble Detector Performance

The exposures of the bubble detectors in the LSR, as reported in Table 4.4, showed that the bubble detectors could typically give results within 30% of the accepted value when at least 35 bubbles were collected. For detectors with less than 50 bubbles, reading the detectors by eye gave more accurate results than automated reading of the detectors. This discrepancy may be an indication that the settings for the image recognition software were not optimized; this optimization was not attempted in this study.

For exposures in the whole body study, the performance of the bubble detectors was not quite as good, as is shown in Table 5.1 and in Appendix C. The bubble detectors sometimes read higher, sometimes lower, than the TEPCs, but there was often poor agreement between the three bubble detectors as shown in Appendix C. Part of the reason for the poor agreement among the bubble detectors was poor counting statistics: the highest number of bubbles recorded for the whole body measurements was 52, which would have an associated uncertainty of 14% from counting statistics. Many of the bubble detector readings had less than 20 bubbles, which would have a counting statistics uncertainty of 22%.

Another possible cause of poor agreement between the bubble detectors and the TEPC was the placement of these detectors around the phantom — often they were positioned on three corners of the phantom and may have seen different neutron intensities.

When the bubble detectors were exposed inside the leaded glove in the extremity study, there was usually good agreement between the two bubble detectors (the counting statistics were better than in the whole body measurement, and there was no shielding from phantoms), but the bubble detectors consistently gave lower dose equivalent rates than the TEPCs.

This study's observations about the performance of the bubble detectors should be considered as preliminary with respect to their possible use at Hanford. Further study should be conducted, especially with hands-on experience by the PFP Radiological Control staff, before a decision is made. Optimization of automated counting equipment should be investigated as the technology is investigated. One unique feature of this measurement system is the method of counting bubbles. Counting by eye is convenient, because it does not require the use of bulky equipment, and it can be done accurately by a person with some experience. However, counting bubbles is an individual skill, and it is quite likely that several people counting the same detector would get different results.

One operational concern is the requirement to select the dosimeter model with a sensitivity appropriate for the expected range of neutron doses.

Bubble dosimetry is still a promising technology for use as supplemental neutron dosimetry for Hanford, and further investigation would be valuable.

6.4 REMBrandt Performance

Table 4.5 shows that the REMBrandt survey meter over-responded by about 53% in the LSR when exposed to neutrons from an unmoderated ^{252}Cf source. The vendor indicated that this over-response was caused by his previous calibration, which was to an AmBe source with higher neutron energies than ^{252}Cf. However, even with updated calibration factors from the vendor, there was an over-response. It should be possible, however, to derive calibration factors for Hanford using LSR exposures, so this study derived a new calibration factor of 87, rather than the vendor's original value of 133. Both calibration factors were used in the field measurements.

Table 5.1 shows that, using the original calibration factor of 133, the REMBrandt has responses similar to the Snoopy. Using the calibration factor of 87, the REMBrandt under-responded for high dose rates (greater than 10 mrem/h), and was very close to the TEPC measurements for low dose rates (less than 5 mrem/h).

This study indicates that the REMBrandt warrants additional testing for suitability of use in Hanford environments. Its lightweight could be a major advantage over moderator-based survey instruments. There are probably ergonomic issues and operational issues with this new design, but the instrument is in its early stages of development and the vendor is willing to work on the system's design.

6.5 Dosimeter Performance

6.5.1 Whole Body Dosimeter Performance

In this study, the TEPC was used as the instrument that determined the reference neutron dose equivalent rate for comparison with the dosimeter response. The TEPC is well suited for this role, because its response is TE and it can determine reliable results independent of the neutron energy field. Comparing the TEPC results with dosimeter results has a limitation, however, due to the presence of the phantom used for dosimeter irradiation and the consequent disruption of the neutron radiation field. The TEPC detects neutrons as a free-in-air volume with no shield or moderator to disrupt the neutron field. Under parallel beam geometry this approximates the maximum dose equivalent in a phantom. Albedo dosimeters, on the other hand, must be exposed on-phantom, and the bulk of the phantom will disrupt the neutron field. For a broad parallel beam this disruption should make no difference, but in a multi-directional radiation, such as an isotropic neutron field, the phantom will shield neutrons incident on its “back” side from reaching the dosimeter, and thus will produce a response that cannot be easily compared with a TEPC response in the same field. These multi-directional fields are probably more common in the workplace than broad parallel beams.

The HCND performed well for evaluating neutron dose equivalent. For the dosimeters exposed on-phantom, there was usually good agreement among the three dosimeters exposed on each face of a phantom, but there were a number of instances when dosimeters in the same packet produced results that did not agree with each other as well as should be expected. It looked like the disagreements could be traced to the plutonium algorithm used for converting chip responses to dose equivalent. In many cases there was poor agreement between the dosimeters exposed on one face of a phantom compared with those exposed on another face of the phantom in the same location. This face-to-face disagreement was an indication of the directionality of the beam. The dosimeter element ratios, and thus the algorithm response of the 8816, are confounded when a significant fraction of the neutron fluence passes through the phantom from the backside. Because workers are not likely to be facing away from the source all of the time, the errors introduced by this feature of the algorithm are likely to be less than the worst errors seen in the present study where some of the packets were facing away from the radiation source all the time.

Overall, the 8816 neutron TLDs showed a combined positive bias of 1.3, based on a comparison of 8816 TLD and TEPC dose equivalent rate. The ratio of the average TLD response for each phantom to the average TEPC dose equivalent rate at the phantom location ranged from 0.5 to 1.8 with a mean value of 1.3. However, for individual dosimeters, some dose results were under-reported by a factor of 5. It should be noted that dose equivalent, such as that measured by a TEPC, can overestimate effective dose equivalent by as much as a factor of two (DOE 1998). The effective dose equivalent is the basis for the risk-based system of limits promulgated in 10CFR835.

The 8816 TED component did much better than the TLD in terms of precision for neutrons. The TED component of this dosimeter consistently underestimated the neutron dose, however. This bias is expected in highly scattered neutron fields, resulting in substantially degraded neutron energy spectra, and because of the angular response characteristics associated with the TED thin rectangular foil. The TED bias would be expected to be relatively small for higher energy neutrons (greater than the response threshold of about 100 keV) because of its relatively flat energy response, and for exposure conditions that are predominantly anterior-posterior.

The HSD was always high, in some cases by as much as a factor of 18, compared with the TEPC for measuring neutron dose equivalent. Since this is a single element dosimeter there is no option but to use a single calibration factor. It may be possible to choose a single factor on the basis of these measurements which would produce negligible bias overall but the variability would be substantially larger than that seen for the 8816 TLD or TED.

The 8816 plutonium algorithm was developed by comparing the responses of TLDs and TEPCs in directional radiation fields created with point sources. Under these conditions, which are closer to a parallel beam geometry, the TEPC and TLD both "see" the same fluence. An algorithm developed under these conditions will inherently under-respond relative to the TEPC when TLD response on-phantom is compared with TEPC under isotropic field conditions. The 8816 plutonium algorithm appears to require some adjustment to correct cases of under-reported dose.

6.5.2 Extremity Dosimeter Performance

Internal agreement among each batch of similarly exposed dosimeters was excellent. Twelve of the batches of five similarly exposed dosimeters had standard deviations smaller than 10% of the mean value; 15 had standard deviations between 10 and 20%, and two had standard deviations between 20 and 30%. Thus it is reasonable to assume that the measured gamma dose rates show good repeatability.

6.6 Extremity Neutron to Gamma Ratios

Measuring neutron doses to extremities is a very challenging task, and it is not routinely attempted directly. For situations where workers' extremities are exposed to both gamma and neutron radiation, the total extremity dose is typically evaluated by measuring only the gamma dose (typically with a gamma extremity dosimeter) and applying a correction factor, the neutron-to-gamma ratio, to the gamma dose to arrive at the total extremity dose. This study measured neutron-to-gamma ratios for six representative cans of plutonium, providing PFP staff with a sound technical basis for assessing total extremity dose using Hanford ring dosimeters worn inside gloves with the same lead and rubber density thickness as the gloves in this study.

The rack holding a portion of a lead-lined glove for the extremity study provided an excellent method of determining the neutron-to-gamma ratio that would be experienced at a worker's finger. The gamma measurement is exactly the same in the study as it would be for a glovebox worker, because it was measured using finger rings worn inside the glove with the TLD chip pointing toward the radiation source. Because the neutron detector resides in the position that would be occupied by a finger, it provides an excellent estimate of the neutron exposure that would be received by a worker's finger under the same conditions. Thus this comparison provides an excellent estimate of the extremity neutron-to-gamma ratio. While the individual neutron and gamma dose rates are functions of the distance between the detector and the radiation source, the estimate of the ratio did not depend on this distance, so it was not necessary to carefully measure the distance between each glove finger and the source can.

The measurement could be adversely affected, however, if there was significant anisotropy in the radiation emission from a source can. Anisotropy should not be a serious problem with neutron emission, because there should not have been substantial amounts of neutron shielding or moderator inside a can, but it could be a problem with gamma emission if the distribution of gamma attenuators in a source was asymmetrical. It should also be recognized that the effective neutron-to-gamma ratios might be quite different for individuals directly handling cans of material if the glove is different from that used in this study. Table 5.10 presents data comparing ring response under glove (little finger) and ring response under no glove (next to little finger at same distance from source). The data indicate that the gloves may have a photon attenuation effect as large as 42%. Use of gloves with greater lead shielding than the gloves used in the present study would result in an underestimate of neutron dose because of reduced ring response relative to the *neutron* dose received.

Two methods were used for the neutron measurement, in the extremity study: a ½-in. TEPC and a bubble detector. For every measurement, the bubble detector responded lower than the TEPC. The ratio of dose equivalent rates measured by the two different devices ranged from 0.42 up to 0.69. The bubble detectors were used in this study because they are relatively easy to use (compared with a TEPC) and may provide a convenient method for checking the neutron-to-gamma ratio for further investigations. Because they consistently under-responded relative to the TEPC, however, they are not recommended for determining neutron-to-gamma ratios.

The measurements of neutron dose rates for the six cans produced a pattern that was not expected. For the 6%, 12%, and 20% oxide cans, all cans had approximately the same mass of plutonium, so it was expected that the neutron dose rates would increase as ^{240}Pu content increased. These measurements did not follow that pattern: the 6% oxide had the highest neutron dose rates.

The neutron ratios reported under the TEPC column in Table 5.11 are suitable for use in neutron extremity dose assessment, provided the assessment is based on use of the Hanford ring in gloves of the same type as used in this study. The values range from 0.09

up to 0.65. These values are influenced by factors such as ^{240}Pu content, ^{241}Am content, presence or absence of low-Z material for (α,n) generation (oxides vs metals, for example), or the internal gamma shielding, or gamma shielding in the glove. When applying a neutron-to-gamma ratio to any plutonium can, it will be necessary to select a can from the six that were characterized in this study, choosing one that should be representative of the new can. Knowledge of the can's contents, including the characteristics just mentioned, is essential for making a proper selection.

These ratios do not represent dose rate ratios as would be observed with survey instruments, but rather are empirically derived correction factors to be used to correct gamma ring results for unmeasured neutron dose when worn in the specific glove type used in this study. Changes in lead loading or glove thickness from those used in this study could alter the photon attenuation effect, which is accounted for in the observed neutron-gamma ratios. Therefore, changes in a supplier of gloves and or makes of gloves should include an assessment of potential changes in attenuation effect and its impact on the validity of the neutron-to-gamma ratios in use at PFP. Where possible, procurements of replacement gloves for glove boxes should include careful specifications of lead loading, specifically the density thickness of lead and of rubber, to match the gloves used as the basis for this study.

6.7 Recommendations

Several recommendations concerning dose assessment can be supported by the results of this study:

- Further investigation of the suitability of the BTI bubble detector for use as a supporting real-time personnel neutron monitor and the REMBrandt for use as a neutron survey instrument in Hanford neutron environments would be valuable. These instruments possess technical attributes of a direct-responding, tissue-like response that is expected to provide superior performance, compared with albedo or track-etch dosimeters, once the technology is fully developed.

- The plutonium algorithm of the HCND needs to be studied and if possible improved to prevent occurrences where similar chip responses can produce different evaluated neutron dose equivalents.

- The following neutron-to-gamma ratios would be suitable for extremity dose assessment:

  0.36 for sources similar to the "6% oxide" can
  0.14 for sources similar to the "12% oxide" can
  0.090 for sources similar to the "20% oxide" can
  0.47 for sources similar to the "metal" can
  0.25 for sources similar to the "17% oxide" can with .02-inch lead foil shielding

0.55 for sources similar to the “17% oxide” can with heavy lead shielding.

- The proper application of these ratios to specific workplace conditions must consider factors such as the type of material in a can, the internal shielding of the can, and the thickness of shielding in the glovebox glove. These ratios are appropriate only for Hanford ring dosimeters worn inside the same type of lead-lined glove used in this study.

- These measurements showed that highly scattered neutron fields exist in PFP work locations. The significant dependence of albedo-type dosimeters (e.g., HCND and HSD) on neutron energy is well documented. As noted in the DOE Standard, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities*, validation studies of dosimeter performance should be performed periodically and whenever there are major operational changes. A schedule should be adopted to repeat this study every 2 to 3 years at a minimum, so that up-to-date validation data are available.

7.0 REFERENCES

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APPENDIX A

TEPC OUTPUTS FOR LOW SCATTER ROOM MEASUREMENTS

Program TEPC_NG
Version: December, 1989
INPUT FILE NAME: t185cf2.txt
FILE TITLE: TEPC 185 at 100 cm from unmod Cf -356 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 317 sec

Proton Drop Point = Channel 304 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 31 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.50E+05	1.50E+05
Counts*Ch	0.00E+00	1.44E+07	0.00E+00
Counts*Ch2	0.00E+00	2.24E+09	0.00E+00
Y-bar F	.0	31.1	31.1
Y-bar D	.0	50.0	50.0
L-bar D	.0	44.5	44.5

Restricted y-bar D between 10.0 and 115 keV/micron is 45.0
Average Neutron Energy is 1.8 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	8.83E+00	8.83E+00
Standard Deviation	0.00E+00	2.28E-02	2.28E-02
Quality Factors	1.0	10.3	10.3
Integral DE, mrem	0.00E+00	9.12E+01	9.12E+01
Dose Rate, mrad/hr	0.00E+00	1.00E+02	1.00E+02
DE Rate, mrem/hr	0.00E+00	1.04E+03	1.04E+03

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t185cf4.txt
FILE TITLE: TEPC 185 at 100 cm from Unmod Cf252 #318-016. 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 2708 sec

Proton Drop Point = Channel 310 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 31 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.21E+03	4.21E+03
Counts*Ch	0.00E+00	4.17E+05	0.00E+00
Counts*Ch2	0.00E+00	7.13E+07	0.00E+00
Y-bar F	.0	31.4	31.4
Y-bar D	.0	54.0	54.0
L-bar D	.0	48.0	48.0

Restricted y-bar D between 9.8 and 115 keV/micron is 44.7
Average Neutron Energy is 1.8 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	2.50E-01	2.50E-01
Standard Deviation	0.00E+00	3.86E-03	3.86E-03
Quality Factors	1.0	10.5	10.5
Integral DE, mrem	0.00E+00	2.62E+00	2.62E+00
Dose Rate, mrad/hr	0.00E+00	3.33E-01	3.33E-01
DE Rate, mrem/hr	0.00E+00	3.49E+00	3.49E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t504cf1.txt
FILE TITLE: TEPC 504 at 100 cm from Unmod Cf -356 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 286 sec

Proton Drop Point = Channel 302 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 30 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.65E+05	1.65E+05
Counts*Ch	0.00E+00	1.52E+07	0.00E+00
Counts*Ch2	0.00E+00	2.25E+09	0.00E+00
Y-bar F	.0	29.9	29.9
Y-bar D	.0	47.9	47.9
L-bar D	.0	42.6	42.6

Restricted y-bar D between 9.7 and 115 keV/micron is 43.4
Average Neutron Energy is 2.0 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	9.37E+00	9.37E+00
Standard Deviation	0.00E+00	2.31E-02	2.31E-02
Quality Factors	1.0	10.0	10.0
Integral DE, mrem	0.00E+00	9.38E+01	9.38E+01
Dose Rate, mrad/hr	0.00E+00	1.18E+02	1.18E+02
DE Rate, mrem/hr	0.00E+00	1.18E+03	1.18E+03

Version: December, 1989

INPUT FILE NAME: t504cf3.txt

FILE TITLE: TEPC 504 at 100 cm from unmod Cf -016 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 2914 sec

Proton Drop Point = Channel 297 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 30 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.44E+03	5.44E+03
Counts*Ch	0.00E+00	4.91E+05	0.00E+00
Counts*Ch2	0.00E+00	6.95E+07	0.00E+00
Y-bar F	.0	29.8	29.8
Y-bar D	.0	46.6	46.6
L-bar D	.0	41.5	41.5

Restricted y-bar D between 9.9 and 115 keV/micron is 43.6

Average Neutron Energy is 1.9 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.08E-01	3.08E-01
Standard Deviation	0.00E+00	4.17E-03	4.17E-03
Quality Factors	1.0	10.0	10.0
Integral DE, mrem	0.00E+00	3.06E+00	3.06E+00
Dose Rate, mrad/hr	0.00E+00	3.80E-01	3.80E-01
DE Rate, mrem/hr	0.00E+00	3.78E+00	3.78E+00

Version: December, 1989
INPUT FILE NAME: t70cf1.txt
FILE TITLE: TEPC 1170 at 100 cm from unmod Cf -356

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 1060 sec

Proton Drop Point = Channel 287 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 29 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.90E+05	5.90E+05
Counts*Ch	0.00E+00	5.26E+07	0.00E+00
Counts*Ch2	0.00E+00	7.44E+09	0.00E+00
Y-bar F	.0	30.4	30.4
Y-bar D	.0	48.4	48.4
L-bar D	.0	43.0	43.0

Restricted y-bar D between 9.9 and 115 keV/micron is 44.2
Average Neutron Energy is 1.9 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.40E+01	3.40E+01
Standard Deviation	0.00E+00	4.43E-02	4.43E-02
Quality Factors	1.0	10.1	10.1
Integral DE, mrem	0.00E+00	3.44E+02	3.44E+02
Dose Rate, mrad/hr	0.00E+00	1.16E+02	1.16E+02
DE Rate, mrem/hr	0.00E+00	1.17E+03	1.17E+03

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t70cf3.txt
FILE TITLE:TEPC 1170 at 100 cm from unmod Cf252 -016. 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 2652 sec

Proton Drop Point = Channel 287 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 26 equivalent to 8.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.01E+03	5.01E+03
Counts*Ch	0.00E+00	4.31E+05	0.00E+00
Counts*Ch2	0.00E+00	5.93E+07	0.00E+00
Y-bar F	.0	29.4	29.4
Y-bar D	.0	46.9	46.9
L-bar D	.0	41.7	41.7

Restricted y-bar D between 8.9 and 115 keV/micron is 43.0
Average Neutron Energy is 2.0 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	2.79E-01	2.79E-01
Standard Deviation	0.00E+00	3.95E-03	3.95E-03
Quality Factors	1.0	10.0	10.0
Integral DE, mrem	0.00E+00	2.79E+00	2.79E+00
Dose Rate, mrad/hr	0.00E+00	3.79E-01	3.79E-01
DE Rate, mrem/hr	0.00E+00	3.79E+00	3.79E+00

Version: December, 1989
INPUT FILE NAME: t71cf1.txt
FILE TITLE: TEPC 1171 at 100 cm from unmod Cf -356 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 706 sec

Proton Drop Point = Channel 244 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 24 equivalent to 9.6 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.22E+05	4.22E+05
Counts*Ch	0.00E+00	3.30E+07	0.00E+00
Counts*Ch2	0.00E+00	4.18E+09	0.00E+00
Y-bar F	.0	31.4	31.4
Y-bar D	.0	50.8	50.8
L-bar D	.0	45.2	45.2

Restricted y-bar D between 9.6 and 115 keV/micron is 45.5
Average Neutron Energy is 1.7 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	2.52E+01	2.52E+01
Standard Deviation	0.00E+00	3.87E-02	3.87E-02
Quality Factors	1.0	10.4	10.4
Integral DE, mrem	0.00E+00	2.62E+02	2.62E+02
Dose Rate, mrad/hr	0.00E+00	1.28E+02	1.28E+02
DE Rate, mrem/hr	0.00E+00	1.34E+03	1.34E+03

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t71cf3.txt
FILE TITLE: TEPC 1171 at 100 cm from unmod Cf -016 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 2461 sec

Proton Drop Point = Channel 262 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 26 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.57E+03	4.57E+03
Counts*Ch	0.00E+00	3.73E+05	0.00E+00
Counts*Ch2	0.00E+00	4.82E+07	0.00E+00
Y-bar F	.0	30.5	30.5
Y-bar D	.0	48.4	48.4
L-bar D	.0	43.0	43.0

Restricted y-bar D between 9.7 and 115 keV/micron is 44.3
Average Neutron Energy is 1.9 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	2.64E-01	2.64E-01
Standard Deviation	0.00E+00	3.91E-03	3.91E-03
Quality Factors	1.0	10.2	10.2
Integral DE, mrem	0.00E+00	2.69E+00	2.69E+00
Dose Rate, mrad/hr	0.00E+00	3.87E-01	3.87E-01
DE Rate, mrem/hr	0.00E+00	3.94E+00	3.94E+00

Version: December, 1989

INPUT FILE NAME: t72_cf56.txt

FILE TITLE: TEPC 1172, 100 cm from Unmod Cf -356. 6/14/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 785 sec

Proton Drop Point = Channel 287 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 29 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.13E+05	4.13E+05
Counts*Ch	0.00E+00	3.58E+07	0.00E+00
Counts*Ch2	0.00E+00	4.94E+09	0.00E+00
Y-bar F	.0	29.6	29.6
Y-bar D	.0	47.1	47.1
L-bar D	.0	41.9	41.9

Restricted y-bar D between 9.9 and 115 keV/micron is 43.0

Average Neutron Energy is 2.0 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	2.32E+01	2.32E+01
Standard Deviation	0.00E+00	3.61E-02	3.61E-02
Quality Factors	1.0	9.9	9.9
Integral DE, mrem	0.00E+00	2.30E+02	2.30E+02
Dose Rate, mrad/hr	0.00E+00	1.06E+02	1.06E+02
DE Rate, mrem/hr	0.00E+00	1.06E+03	1.06E+03

Program TEPC_NG
Version: December, 1989
INPUT FILE NAME: t72cf4.txt
FILE TITLE: TEPC 1172 at 100 cm from Unmod Cf -016   6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm   SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read   Live time =   6259 sec

Proton Drop Point = Channel   286 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 29 equivalent to   9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.05E+04	1.05E+04
Counts*Ch	0.00E+00	9.00E+05	0.00E+00
Counts*Ch2	0.00E+00	1.21E+08	0.00E+00
Y-bar F	.0	29.5	29.5
Y-bar D	.0	45.9	45.9
L-bar D	.0	40.8	40.8

Restricted y-bar D between 9.9 and 115 keV/micron is 43.0
Average Neutron Energy is   2.0 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	5.85E-01	5.85E-01
Standard Deviation	0.00E+00	5.72E-03	5.72E-03
Quality Factors	1.0	9.9	9.9
Integral DE, mrem	0.00E+00	5.78E+00	5.78E+00
Dose Rate, mrad/hr	0.00E+00	3.36E-01	3.36E-01
DE Rate, mrem/hr	0.00E+00	3.33E+00	3.33E+00

Version: December, 1989

INPUT FILE NAME: t73cf1.txt
FILE TITLE: TEPC 1173 at 100 cm from unmod Cf -356 6/14/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 532 sec

Proton Drop Point = Channel 311 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 31 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	2.98E+05	2.98E+05
Counts*Ch	0.00E+00	2.89E+07	0.00E+00
Counts*Ch2	0.00E+00	4.49E+09	0.00E+00
Y-bar F	.0	30.6	30.6
Y-bar D	.0	49.0	49.0
L-bar D	.0	43.6	43.6

Restricted y-bar D between 9.8 and 115 keV/micron is 44.4
Average Neutron Energy is 1.9 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	1.73E+01	1.73E+01
Standard Deviation	0.00E+00	3.16E-02	3.16E-02
Quality Factors	1.0	10.2	10.2
Integral DE, mrem	0.00E+00	1.76E+02	1.76E+02
Dose Rate, mrad/hr	0.00E+00	1.17E+02	1.17E+02
DE Rate, mrem/hr	0.00E+00	1.19E+03	1.19E+03

Version: December, 1989
INPUT FILE NAME: t73cf4.txt
FILE TITLE: TEPC 1173 at 100 cm from Unmod Cf -016 6/15/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 6388 sec

Proton Drop Point = Channel 322 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 32 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.12E+04	1.12E+04
Counts*Ch	0.00E+00	1.09E+06	0.00E+00
Counts*Ch2	0.00E+00	1.71E+08	0.00E+00
Y-bar F	.0	29.7	29.7
Y-bar D	.0	47.8	47.8
L-bar D	.0	42.5	42.5

Restricted y-bar D between 9.7 and 115 keV/micron is 43.1
Average Neutron Energy is 2.0 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	6.29E-01	6.29E-01
Standard Deviation	0.00E+00	5.95E-03	5.95E-03
Quality Factors	1.0	9.9	9.9
Integral DE, mrem	0.00E+00	6.26E+00	6.26E+00
Dose Rate, mrad/hr	0.00E+00	3.54E-01	3.54E-01
DE Rate, mrem/hr	0.00E+00	3.53E+00	3.53E+00

Version: December, 1989

INPUT FILE NAME: t74c.txt

FILE TITLE: TEPC 1074 at 1m from Unmod Cf252 318-356. 7/9/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 5387 sec

Proton Drop Point = Channel 309 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 30 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	2.35E+04	2.35E+04
Counts*Ch	0.00E+00	2.29E+06	0.00E+00
Counts*Ch2	0.00E+00	3.95E+08	0.00E+00
Y-bar F	.0	31.8	31.8
Y-bar D	.0	56.4	56.4
L-bar D	.0	50.2	50.2

Restricted y-bar D between 9.8 and 115 keV/micron is 45.2

Average Neutron Energy is 1.8 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	1.42E+02	1.42E+02
Standard Deviation	0.00E+00	9.26E-01	9.26E-01
Quality Factors	1.0	10.7	10.7
Integral DE, mrem	0.00E+00	1.51E+03	1.51E+03
Dose Rate, mrad/hr	0.00E+00	9.49E+01	9.49E+01
DE Rate, mrem/hr	0.00E+00	1.01E+03	1.01E+03

Program TEPC_NG Page 1
Version: December, 1989

INPUT FILE NAME: t74_1m.txt
FILE TITLE: TEPC 1074 at 1m from unmod Cf252, 318-356. 8/20/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 1054 sec

Proton Drop Point = Channel 345 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 34 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.46E+03	5.46E+03
Counts*Ch	0.00E+00	6.02E+05	0.00E+00
Counts*Ch2	0.00E+00	1.13E+08	0.00E+00
Y-bar F	.0	32.3	32.3
Y-bar D	.0	54.9	54.9
L-bar D	.0	48.8	48.8

Restricted y-bar D between 10.0 and 115 keV/micron is 46.2
Average Neutron Energy is 1.6 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	3.34E+01	3.34E+01
Standard Deviation	0.00E+00	4.52E-01	4.52E-01
Quality Factors	1.0	10.7	10.7
Integral DE, mrem	0.00E+00	3.57E+02	3.57E+02
Dose Rate, mrad/hr	0.00E+00	1.14E+02	1.14E+02
DE Rate, mrem/hr	0.00E+00	1.22E+03	1.22E+03

Version: December, 1989

INPUT FILE NAME: t22e.txt
FILE TITLE: TEPC 1122 at 100 cm from Unmod Cf252 318-356, LSR 7/13

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 3618 sec

Proton Drop Point = Channel 297 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 29 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.59E+04	1.59E+04
Counts*Ch	0.00E+00	1.50E+06	0.00E+00
Counts*Ch2	0.00E+00	2.47E+08	0.00E+00
Y-bar F	.0	32.0	32.0
Y-bar D	.0	56.0	56.0
L-bar D	.0	49.8	49.8

Restricted y-bar D between 9.9 and 115 keV/micron is 45.5
Average Neutron Energy is 1.7 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	9.67E+01	9.67E+01
Standard Deviation	0.00E+00	7.66E-01	7.66E-01
Quality Factors	1.0	10.7	10.7
Integral DE, mrem	0.00E+00	1.03E+03	1.03E+03
Dose Rate, mrad/hr	0.00E+00	9.63E+01	9.63E+01
DE Rate, mrem/hr	0.00E+00	1.03E+03	1.03E+03

Version: December, 1989

INPUT FILE NAME: t22_1ma.txt

FILE TITLE: TEPC 1122 at 1m from unmod Cf252 srce in LSR. Short count

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER=   1.3 cm   SITE EQUIVALENT DIAMETER= 1.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read   Live time =   386 sec

Proton Drop Point = Channel   302 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 29 equivalent to   9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.90E+03	1.90E+03
Counts*Ch	0.00E+00	1.85E+05	0.00E+00
Counts*Ch2	0.00E+00	3.16E+07	0.00E+00
Y-bar F	.0	32.5	32.5
Y-bar D	.0	57.2	57.2
L-bar D	.0	50.8	50.8

Restricted y-bar D between 9.7 and 115 keV/micron is 46.0

Average Neutron Energy is   1.7 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	1.17E+01	1.17E+01
Standard Deviation	0.00E+00	2.69E-01	2.69E-01
Quality Factors	1.0	10.8	10.8
Integral DE, mrem	0.00E+00	1.26E+02	1.26E+02
Dose Rate, mrad/hr	0.00E+00	1.09E+02	1.09E+02
DE Rate, mrem/hr	0.00E+00	1.18E+03	1.18E+03

Version: December, 1989

INPUT FILE NAME: t22_1mb.txt

FILE TITLE: TEPC 1122 at 1 m from unmod Cf252, 318-356 in LSR. 8/20/9

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 797 sec

Proton Drop Point = Channel 302 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 29 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.02E+03	4.02E+03
Counts*Ch	0.00E+00	3.94E+05	0.00E+00
Counts*Ch2	0.00E+00	7.08E+07	0.00E+00
Y-bar F	.0	32.8	32.8
Y-bar D	.0	60.1	60.1
L-bar D	.0	53.4	53.4

Restricted y-bar D between 9.7 and 115 keV/micron is 46.3

Average Neutron Energy is 1.6 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	2.50E+01	2.50E+01
Standard Deviation	0.00E+00	3.94E-01	3.94E-01
Quality Factors	1.0	10.8	10.8
Integral DE, mrem	0.00E+00	2.71E+02	2.71E+02
Dose Rate, mrad/hr	0.00E+00	1.13E+02	1.13E+02
DE Rate, mrem/hr	0.00E+00	1.22E+03	1.22E+03

APPENDIX B

TEPC RESULTS FOR WHOLE BODY MEASUREMENTS

Version: December, 1989

INPUT FILE NAME: h9ant73.txt

FILE TITLE: TEPC 1173 on North Side of Hood 9A, rm 235A-3, PFP. 6/18/

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 66774 sec

Proton Drop Point = Channel 305 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 31 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.97E+05	1.97E+05
Counts*Ch	0.00E+00	2.06E+07	0.00E+00
Counts*Ch2	0.00E+00	3.03E+09	0.00E+00
Y-bar F	.0	33.6	33.6
Y-bar D	.0	47.1	47.1
L-bar D	.0	41.9	41.9

Restricted y-bar D between 10.0 and 115 keV/micron is 50.2

Average Neutron Energy is 1.3 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	1.26E+01	1.26E+01
Standard Deviation	0.00E+00	2.83E-02	2.83E-02
Quality Factors	1.0	10.7	10.7
Integral DE, mrem	0.00E+00	1.35E+02	1.35E+02
Dose Rate, mrad/hr	0.00E+00	6.78E-01	6.78E-01
DE Rate, mrem/hr	0.00E+00	7.27E+00	7.27E+00

Version: December, 1989
INPUT FILE NAME: h9ant85.txt
FILE TITLE: TEPC 185 at north side of Hood 9A, Rm 235A-3, PFP. 6/18/9

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 68189 sec

Proton Drop Point = Channel 162 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 16 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.73E+05	1.73E+05
Counts*Ch	0.00E+00	9.91E+06	0.00E+00
Counts*Ch2	0.00E+00	7.80E+08	0.00E+00
Y-bar F	.0	34.7	34.7
Y-bar D	.0	47.6	47.6
L-bar D	.0	42.3	42.3

Restricted y-bar D between 9.7 and 115 keV/micron is 51.6
Average Neutron Energy is 1.2 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	1.14E+01	1.14E+01
Standard Deviation	0.00E+00	2.74E-02	2.74E-02
Quality Factors	1.0	10.8	10.8
Integral DE, mrem	0.00E+00	1.22E+02	1.22E+02
Dose Rate, mrad/hr	0.00E+00	6.00E-01	6.00E-01
DE Rate, mrem/hr	0.00E+00	6.45E+00	6.45E+00

Version: December, 1989

INPUT FILE NAME: h9ast70.txt

FILE TITLE: TEPC 1170 on south side of Hood 9A, Rm 235A-3, PFP. 6/18/

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm   SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read   Live time = 67036 sec

Proton Drop Point = Channel   294 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 30 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	2.18E+05	2.18E+05
Counts*Ch	0.00E+00	2.36E+07	0.00E+00
Counts*Ch2	0.00E+00	3.51E+09	0.00E+00
Y-bar F	.0	36.1	36.1
Y-bar D	.0	49.6	49.6
L-bar D	.0	44.1	44.1

Restricted y-bar D between 10.0 and 115 keV/micron is 53.6

Average Neutron Energy is   1.0 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	1.49E+01	1.49E+01
Standard Deviation	0.00E+00	3.20E-02	3.20E-02
Quality Factors	1.0	11.0	11.0
Integral DE, mrem	0.00E+00	1.65E+02	1.65E+02
Dose Rate, mrad/hr	0.00E+00	8.01E-01	8.01E-01
DE Rate, mrem/hr	0.00E+00	8.84E+00	8.84E+00

Version: December, 1989
INPUT FILE NAME: h9ast72.txt
FILE TITLE: TEPC 1172 on south side of Hood 9A, Rm 235A-3, PFP. 6/18/

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 66063 sec

Proton Drop Point = Channel 287 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 29 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.86E+05	1.86E+05
Counts*Ch	0.00E+00	1.88E+07	0.00E+00
Counts*Ch2	0.00E+00	2.65E+09	0.00E+00
Y-bar F	.0	34.6	34.6
Y-bar D	.0	48.1	48.1
L-bar D	.0	42.7	42.7

Restricted y-bar D between 9.9 and 115 keV/micron is 51.3
Average Neutron Energy is 1.2 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	1.22E+01	1.22E+01
Standard Deviation	0.00E+00	2.83E-02	2.83E-02
Quality Factors	1.0	10.8	10.8
Integral DE, mrem	0.00E+00	1.31E+02	1.31E+02
Dose Rate, mrad/hr	0.00E+00	6.63E-01	6.63E-01
DE Rate, mrem/hr	0.00E+00	7.15E+00	7.15E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t72v4r3.txt
FILE TITLE: TEPC 1172 in PFP Vault 4, between cabinets. 7/19/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 8719 sec

Proton Drop Point = Channel 262 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 26 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.22E+05	1.22E+05
Counts*Ch	0.00E+00	1.06E+07	0.00E+00
Counts*Ch2	0.00E+00	1.35E+09	0.00E+00
Y-bar F	.0	32.4	32.4
Y-bar D	.0	47.9	47.9
L-bar D	.0	42.6	42.6

Restricted y-bar D between 9.7 and 115 keV/micron is 47.8
Average Neutron Energy is 1.5 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	7.50E+00	7.50E+00
Standard Deviation	0.00E+00	2.15E-02	2.15E-02
Quality Factors	1.0	10.5	10.5
Integral DE, mrem	0.00E+00	7.87E+01	7.87E+01
Dose Rate, mrad/hr	0.00E+00	3.10E+00	3.10E+00
DE Rate, mrem/hr	0.00E+00	3.25E+01	3.25E+01

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t73v4r3.txt
FILE TITLE: TEPC 1173 in PFP Vault 4, between cabinets. 7/19/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 7254 sec

Proton Drop Point = Channel 229 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 23 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.07E+05	1.07E+05
Counts*Ch	0.00E+00	7.99E+06	0.00E+00
Counts*Ch2	0.00E+00	8.75E+08	0.00E+00
Y-bar F	.0	31.9	31.9
Y-bar D	.0	46.9	46.9
L-bar D	.0	41.7	41.7

Restricted y-bar D between 9.8 and 115 keV/micron is 47.1
Average Neutron Energy is 1.6 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	6.49E+00	6.49E+00
Standard Deviation	0.00E+00	1.98E-02	1.98E-02
Quality Factors	1.0	10.4	10.4
Integral DE, mrem	0.00E+00	6.74E+01	6.74E+01
Dose Rate, mrad/hr	0.00E+00	3.22E+00	3.22E+00
DE Rate, mrem/hr	0.00E+00	3.34E+01	3.34E+01

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t504v4r3.txt
FILE TITLE: TEPC 504 in PFP Vault 4, at Back Wall. 7/19/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm   SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read   Live time = 8194 sec

Proton Drop Point = Channel 295 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 30 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	6.29E+04	6.29E+04
Counts*Ch	0.00E+00	6.35E+06	0.00E+00
Counts*Ch2	0.00E+00	9.29E+08	0.00E+00
Y-bar F	.0	33.5	33.5
Y-bar D	.0	48.6	48.6
L-bar D	.0	43.2	43.2

Restricted y-bar D between 10.0 and 115 keV/micron is 49.5
Average Neutron Energy is 1.3 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	4.00E+00	4.00E+00
Standard Deviation	0.00E+00	1.60E-02	1.60E-02
Quality Factors	1.0	10.7	10.7
Integral DE, mrem	0.00E+00	4.27E+01	4.27E+01
Dose Rate, mrad/hr	0.00E+00	1.76E+00	1.76E+00
DE Rate, mrem/hr	0.00E+00	1.88E+01	1.88E+01

Version: December, 1989

INPUT FILE NAME: t70v4r3.txt
FILE TITLE: TEPC 1170 in PFP Vault 4, at Back Wall. 7/19/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 8468 sec

Proton Drop Point = Channel 324 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 33 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	7.15E+04	7.15E+04
Counts*Ch	0.00E+00	7.83E+06	0.00E+00
Counts*Ch2	0.00E+00	1.25E+09	0.00E+00
Y-bar F	.0	33.1	33.1
Y-bar D	.0	48.2	48.2
L-bar D	.0	42.9	42.9

Restricted y-bar D between 10.0 and 115 keV/micron is 48.8
Average Neutron Energy is 1.4 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	4.49E+00	4.49E+00
Standard Deviation	0.00E+00	1.68E-02	1.68E-02
Quality Factors	1.0	10.6	10.6
Integral DE, mrem	0.00E+00	4.76E+01	4.76E+01
Dose Rate, mrad/hr	0.00E+00	1.91E+00	1.91E+00
DE Rate, mrem/hr	0.00E+00	2.02E+01	2.02E+01

Version: December, 1989

INPUT FILE NAME: t72v1.txt

FILE TITLE: TEPC 1172 in PFP 2736ZB Vault 1, Between Cabinets. 7/20/9

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 3188 sec

Proton Drop Point = Channel 269 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 27 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.20E+04	1.20E+04
Counts*Ch	0.00E+00	1.04E+06	0.00E+00
Counts*Ch2	0.00E+00	1.30E+08	0.00E+00
Y-bar F	.0	31.6	31.6
Y-bar D	.0	45.6	45.6
L-bar D	.0	40.5	40.5

Restricted y-bar D between 9.8 and 115 keV/micron is 46.7

Average Neutron Energy is 1.6 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	7.19E-01	7.19E-01
Standard Deviation	0.00E+00	6.57E-03	6.57E-03
Quality Factors	1.0	10.3	10.3
Integral DE, mrem	0.00E+00	7.38E+00	7.38E+00
Dose Rate, mrad/hr	0.00E+00	8.12E-01	8.12E-01
DE Rate, mrem/hr	0.00E+00	8.34E+00	8.34E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t73v1.txt
FILE TITLE: TEPC 1173 in PFP 2736ZB Vault 1, between Cabinets. 7/20/9

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 3188 sec

Proton Drop Point = Channel 235 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 23 equivalent to 9.6 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.70E+04	1.70E+04
Counts*Ch	0.00E+00	1.31E+06	0.00E+00
Counts*Ch2	0.00E+00	1.45E+08	0.00E+00
Y-bar F	.0	32.1	32.1
Y-bar D	.0	46.2	46.2
L-bar D	.0	41.0	41.0

Restricted y-bar D between 9.6 and 115 keV/micron is 47.5
Average Neutron Energy is 1.5 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	1.04E+00	1.04E+00
Standard Deviation	0.00E+00	7.94E-03	7.94E-03
Quality Factors	1.0	10.4	10.4
Integral DE, mrem	0.00E+00	1.07E+01	1.07E+01
Dose Rate, mrad/hr	0.00E+00	1.17E+00	1.17E+00
DE Rate, mrem/hr	0.00E+00	1.21E+01	1.21E+01

Version: December, 1989

INPUT FILE NAME: t504v1.txt

FILE TITLE: TEPC 504 by Corridor Wall, PFP Vault 1. 7/20/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 3348 sec

Proton Drop Point = Channel 308 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 31 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.51E+03	5.51E+03
Counts*Ch	0.00E+00	5.70E+05	0.00E+00
Counts*Ch2	0.00E+00	8.56E+07	0.00E+00
Y-bar F	.0	32.9	32.9
Y-bar D	.0	47.8	47.8
L-bar D	.0	42.5	42.5

Restricted y-bar D between 9.9 and 115 keV/micron is 48.6

Average Neutron Energy is 1.4 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	3.44E-01	3.44E-01
Standard Deviation	0.00E+00	4.63E-03	4.63E-03
Quality Factors	1.0	10.6	10.6
Integral DE, mrem	0.00E+00	3.64E+00	3.64E+00
Dose Rate, mrad/hr	0.00E+00	3.70E-01	3.70E-01
DE Rate, mrem/hr	0.00E+00	3.91E+00	3.91E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t70v1.txt
FILE TITLE: TEPC 1170 at Corridor wall, PFP 2736ZB Vault 1. 7/20/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 3341 sec

Proton Drop Point = Channel 305 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 31 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.93E+03	5.93E+03
Counts*Ch	0.00E+00	6.28E+05	0.00E+00
Counts*Ch2	0.00E+00	9.95E+07	0.00E+00
Y-bar F	.0	34.1	34.1
Y-bar D	.0	50.9	50.9
L-bar D	.0	45.2	45.2

Restricted y-bar D between 10.0 and 115 keV/micron is 50.0
Average Neutron Energy is 1.3 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.83E-01	3.83E-01
Standard Deviation	0.00E+00	4.97E-03	4.97E-03
Quality Factors	1.0	10.9	10.9
Integral DE, mrem	0.00E+00	4.17E+00	4.17E+00
Dose Rate, mrad/hr	0.00E+00	4.13E-01	4.13E-01
DE Rate, mrem/hr	0.00E+00	4.50E+00	4.50E+00

Version: December, 1989

INPUT FILE NAME: t72v2btw.txt
FILE TITLE: TEPC 1172 between cabinets, Vault 2 2736-ZB. 7/26/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 5521 sec

Proton Drop Point = Channel 266 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 27 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.12E+05	1.12E+05
Counts*Ch	0.00E+00	9.47E+06	0.00E+00
Counts*Ch2	0.00E+00	1.23E+09	0.00E+00
Y-bar F	.0	31.2	31.2
Y-bar D	.0	47.9	47.9
L-bar D	.0	42.6	42.6

Restricted y-bar D between 9.9 and 115 keV/micron is 45.7
Average Neutron Energy is 1.7 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	6.62E+00	6.62E+00
Standard Deviation	0.00E+00	1.98E-02	1.98E-02
Quality Factors	1.0	10.3	10.3
Integral DE, mrem	0.00E+00	6.80E+01	6.80E+01
Dose Rate, mrad/hr	0.00E+00	4.32E+00	4.32E+00
DE Rate, mrem/hr	0.00E+00	4.44E+01	4.44E+01

Version: December, 1989

INPUT FILE NAME: t73v2btw.txt
FILE TITLE: TEPC 1173, 2736-ZB Vault 2, between cabinets. 7/26/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 3950 sec

Proton Drop Point = Channel 231 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 23 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.03E+05	1.03E+05
Counts*Ch	0.00E+00	7.21E+06	0.00E+00
Counts*Ch2	0.00E+00	7.80E+08	0.00E+00
Y-bar F	.0	29.6	29.6
Y-bar D	.0	45.9	45.9
L-bar D	.0	40.8	40.8

Restricted y-bar D between 9.8 and 115 keV/micron is 43.6
Average Neutron Energy is 1.9 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	5.80E+00	5.80E+00
Standard Deviation	0.00E+00	1.81E-02	1.81E-02
Quality Factors	1.0	10.1	10.1
Integral DE, mrem	0.00E+00	5.86E+01	5.86E+01
Dose Rate, mrad/hr	0.00E+00	5.29E+00	5.29E+00
DE Rate, mrem/hr	0.00E+00	5.34E+01	5.34E+01

Version: December, 1989

INPUT FILE NAME: t504v2wl.txt
FILE TITLE: TEPC 504 in Vault 2, Corridor Wall. 2736-ZB. 7/26/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 4778 sec

Proton Drop Point = Channel 364 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 37 equivalent to 10.0 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.10E+04	4.10E+04
Counts*Ch	0.00E+00	5.02E+06	0.00E+00
Counts*Ch2	0.00E+00	9.03E+08	0.00E+00
Y-bar F	.0	33.0	33.0
Y-bar D	.0	48.4	48.4
L-bar D	.0	43.0	43.0

Restricted y-bar D between 10.0 and 115 keV/micron is 48.7
Average Neutron Energy is 1.4 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	2.57E+00	2.57E+00
Standard Deviation	0.00E+00	1.27E-02	1.27E-02
Quality Factors	1.0	10.6	10.6
Integral DE, mrem	0.00E+00	2.71E+01	2.71E+01
Dose Rate, mrad/hr	0.00E+00	1.93E+00	1.93E+00
DE Rate, mrem/hr	0.00E+00	2.04E+01	2.04E+01

Version: December, 1989

INPUT FILE NAME: t70v2wal.txt

FILE TITLE: TEPC 1170, Vault 2 Corridor wall. 2736-ZB. 7/26/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 6574 sec

Proton Drop Point = Channel 323 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 32 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	7.33E+04	7.33E+04
Counts*Ch	0.00E+00	8.19E+06	0.00E+00
Counts*Ch2	0.00E+00	1.33E+09	0.00E+00
Y-bar F	.0	33.9	33.9
Y-bar D	.0	49.1	49.1
L-bar D	.0	43.7	43.7

Restricted y-bar D between 9.7 and 115 keV/micron is 50.0

Average Neutron Energy is 1.3 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	4.71E+00	4.71E+00
Standard Deviation	0.00E+00	1.74E-02	1.74E-02
Quality Factors	1.0	10.8	10.8
Integral DE, mrem	0.00E+00	5.07E+01	5.07E+01
Dose Rate, mrad/hr	0.00E+00	2.58E+00	2.58E+00
DE Rate, mrem/hr	0.00E+00	2.77E+01	2.77E+01

Version: December, 1989

INPUT FILE NAME: t504vcor.txt

FILE TITLE: TEPC 504 in the 2736ZB Vault Corridor - by Vault 3. 8/2/9

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 99999 sec

Proton Drop Point = Channel 369 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 37 equivalent to 9.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.43E+04	5.43E+04
Counts*Ch	0.00E+00	6.61E+06	0.00E+00
Counts*Ch2	0.00E+00	1.20E+09	0.00E+00
Y-bar F	.0	32.4	32.4
Y-bar D	.0	48.4	48.4
L-bar D	.0	43.0	43.0

Restricted y-bar D between 9.8 and 115 keV/micron is 47.5

Average Neutron Energy is 1.5 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.33E+00	3.33E+00
Standard Deviation	0.00E+00	1.43E-02	1.43E-02
Quality Factors	1.0	10.5	10.5
Integral DE, mrem	0.00E+00	3.49E+01	3.49E+01
Dose Rate, mrad/hr	0.00E+00	1.20E-01	1.20E-01
DE Rate, mrem/hr	0.00E+00	1.26E+00	1.26E+00

Version: December, 1989
INPUT FILE NAME: t70vcor.txt
FILE TITLE: TEPC 1170 in 2736ZB Vault Corridor, by Vault 3. 8/2/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 326276 sec

Proton Drop Point = Channel 318 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 32 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.66E+05	1.66E+05
Counts*Ch	0.00E+00	1.76E+07	0.00E+00
Counts*Ch2	0.00E+00	2.74E+09	0.00E+00
Y-bar F	.0	32.5	32.5
Y-bar D	.0	48.1	48.1
L-bar D	.0	42.8	42.8

Restricted y-bar D between 9.9 and 115 keV/micron is 47.8
Average Neutron Energy is 1.5 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	1.03E+01	1.03E+01
Standard Deviation	0.00E+00	2.52E-02	2.52E-02
Quality Factors	1.0	10.5	10.5
Integral DE, mrem	0.00E+00	1.08E+02	1.08E+02
Dose Rate, mrad/hr	0.00E+00	1.13E-01	1.13E-01
DE Rate, mrem/hr	0.00E+00	1.19E+00	1.19E+00

Version: December, 1989

INPUT FILE NAME: t72vcor.txt

FILE TITLE: TEPC 1172 in 2736ZB Vault Corridor, by Vault 1. 8/2/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 326612 sec

Proton Drop Point = Channel 252 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 25 equivalent to 9.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.49E+05	1.49E+05
Counts*Ch	0.00E+00	1.06E+07	0.00E+00
Counts*Ch2	0.00E+00	1.25E+09	0.00E+00
Y-bar F	.0	27.7	27.7
Y-bar D	.0	45.8	45.8
L-bar D	.0	40.7	40.7

Restricted y-bar D between 9.7 and 115 keV/micron is 40.5

Average Neutron Energy is 2.4 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	7.82E+00	7.82E+00
Standard Deviation	0.00E+00	2.03E-02	2.03E-02
Quality Factors	1.0	9.9	9.9
Integral DE, mrem	0.00E+00	7.75E+01	7.75E+01
Dose Rate, mrad/hr	0.00E+00	8.62E-02	8.62E-02
DE Rate, mrem/hr	0.00E+00	8.54E-01	8.54E-01

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t73vcor.txt
FILE TITLE: TEPC 1173 in 2736ZB Vault Corridor, by Vault 1. 8/2/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 99999 sec

Proton Drop Point = Channel 227 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 23 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	3.82E+04	3.82E+04
Counts*Ch	0.00E+00	2.88E+06	0.00E+00
Counts*Ch2	0.00E+00	3.21E+08	0.00E+00
Y-bar F	.0	32.5	32.5
Y-bar D	.0	48.2	48.2
L-bar D	.0	42.9	42.9

Restricted y-bar D between 9.9 and 115 keV/micron is 47.9
Average Neutron Energy is 1.5 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	2.36E+00	2.36E+00
Standard Deviation	0.00E+00	1.20E-02	1.20E-02
Quality Factors	1.0	10.5	10.5
Integral DE, mrem	0.00E+00	2.48E+01	2.48E+01
Dose Rate, mrad/hr	0.00E+00	8.48E-02	8.48E-02
DE Rate, mrem/hr	0.00E+00	8.91E-01	8.91E-01

APPENDIX C

RESULTS OF BUBBLE DETECTOR MEASUREMENTS

Table C.1. Results of bubble detector measurements - whole body study

Bubble Detector ID	**Location**	**Bubbles counted**	**Sensitivity (bubbles / mrem)**	**Measured dose equivalent (mrem)**	**Exposure time (hrs)**	**Dose equivalent rate (mrem/h)**
121292	Rm 235A-3 South	52	0.67	77.1	7.3	10.5
121487	Rm 235A-3 South	47	0.72	65.7	7.3	9.0
121022	Rm 235A-3 South	36	0.74	48.2	7.3	6.6
123685	Rm 235A-3 North	49	0.75	65.8	7.3	9.0
119504	Rm 235A-3 North	46	0.69	67.1	7.3	9.2
121529	Rm 235A-3 North	31	0.68	45.6	7.3	6.2
123685	Vault 4 Betw Cabinets	16	0.75	24.0	1.4	16.7
121487	Vault 4 Betw Cabinets	18	0.72	26.4	1.4	18.4
119504	Vault 4 Betw Cabinets	17	0.69	23.2	1.4	16.2
121022	Vault 4 at Back Wall	17	0.74	23.0	2.2	10.6
121292	Vault 4 at Back Wall	18	0.67	25.4	2.2	11.7
121529	Vault 4 at Back Wall	15	0.68	20.6	2.2	9.5
121529	Vault 2, Cor. Wall	23	0.68	35.3	1.2	29.4
119504	Vault 2, Cor. Wall	6	0.69	8.7	1.2	7.2
123685	Vault 2, Cor. Wall	48	0.75	66.7	1.2	55.6
121292	Vault 2, Betw Cabinets	10	0.67	14.9	0.5	30.9
121022	Vault 2, Betw Cabinets	9	0.74	12.2	0.5	25.2
121487	Vault 2, Betw Cabinets	14	0.72	22.2	0.5	46.0
121529	Vlt Corr, by Vlt 1	42	0.68	63.2	90.8	0.7
119504	Vlt Corr, by Vlt 1	22	0.69	30.4	90.8	0.3
121292	Vlt Corr, by Vlt 1	19	0.67	31.3	90.8	0.3
123685	Vlt Corr, by Vlt 3	48	0.75	66.7	90.8	0.7
121487	Vlt Corr, by Vlt 3	48	0.72	66.7	90.8	0.7
121022	Vlt Corr, by Vlt 3	30	0.74	39.2	90.8	0.4

Table C.2. Results of bubble detector measurements - extremity study.

Bubble ID	Location	Bubbles counted	Sensitivity (bubbles / mrem)	Measured dose equivalent (mrem)	Exposure time (hrs)	Dose equivalent rate (mrem/h)
121022	20% Oxide - Middle Finger	159	0.74	214.9	26.37	8.15
123685	20% Oxide - Little Finger	141	0.75	188	26.33	7.14
119504	12% Oxide Middle Finger	173	0.69	250	95.20	2.63
121529	12% Oxide Little Finger	128	0.68	188	95.18	1.97
123685	Metal Middle Finger	151	0.75	201	23.58	8.54
119504	Metal Middle Finger	210	0.69	304	44.97	6.76
121022	Metal Little Finger	177	0.74	239	23.55	10.16
121529	Metal Little Finger	197	0.68	290	45.07	6.44
121529	6% Oxide Middle Finger	187	0.68	274	49.72	5.52
119504	6% Oxide Little Finger	185	0.69	268	49.67	5.41
121022	17% Oxide with Foil Middle Finger	174	0.74	234	45.87	5.11
123685	17% Oxide with Foil Little Finger	174	0.75	231	45.83	5.05
121529	17% Oxide with Pb Middle Finger	92	0.68	135	67.68	1.99
119504	17% Oxide with Pb Little Finger	97	0.69	141	67.72	2.08

APPENDIX D

DOSIMETER RESULTS

Location	Packet No.	On-Phantom Placement	Exposure Time (hrs)	HCND Neutron Dose rate (mrem/h)	8816 TED Neutron Dose rate mrem/h	HSD Neutron Dose rate (mrem/h)	HSD Gamma Dose rate (mrem/h)
235A-3 North	5	West - facing TEPC 1173	19.95	2.42	1.40	22.60	2.52
235A-3 North	5	West - facing TEPC 1173	19.95	5.05	1.90	26.00	3.70
235A-3 North	5	West - facing TEPC 1173	19.95	2.74	1.43	23.92	3.11
	5	Avg of 3		3.40	1.58	24.17	3.11
235A-3 North	6	North - facing water wall	19.95	4.72	0.45	19.52	0.71
235A-3 North	6	North - facing water wall	19.95	5.54	0.33	19.65	0.65
235A-3 North	6	North - facing water wall	19.95	5.75	0.70	20.43	0.74
	6	Avg of 3		5.34	0.49	19.86	0.70
235A-3 North	7	East - facing TEPC 185	19.95	4.82	0.50	22.64	1.04
235A-3 North	7	East - facing TEPC 185	19.95	5.41	0.38	20.02	0.90
235A-3 North	7	East - facing TEPC 185	19.95	6.28	0.50	21.77	1.29
	7	Avg of 3		5.51	0.46	21.48	1.07
235A-3 North	9	South - Facing hood	19.95	4.91	3.53	29.74	4.52
235A-3 North	9	South - Facing hood	19.95	6.69	3.71	28.53	4.56
235A-3 North	9	South - Facing hood	19.95	8.35	3.26	30.13	4.47
	9	Avg of 3		6.65	3.50	29.46	4.52
235A-3 South	1	North - Facing hood	19.95	3.97	3.23	33.34	2.23
235A-3 South	1	North - Facing hood	19.95	9.35	3.08	36.65	2.15
235A-3 South	1	North - Facing hood	19.95	8.91	3.03	37.26	2.16
	1	Avg of 3		7.41	3.12	35.75	2.18
235A-3 South	2	East - to TEPC 1170	19.95	2.93	0.98	29.15	1.44
235A-3 South	2	East - to TEPC 1170	19.95	7.90	1.48	26.38	1.04
235A-3 South	2	East - to TEPC 1170	19.95	1.64	1.08	27.35	1.29
	2	Avg of 3		4.16	1.18	27.63	1.26
235A-3 South	3	West - to TEPC 1172	19.95	7.83	1.03	27.50	1.00
235A-3 South	3	West - to TEPC 1172	19.95	4.96	1.13	28.88	1.26
235A-3 South	3	West - to TEPC 1172	19.95	4.17	1.10	27.49	1.38
	3	Avg of 3		5.65	1.09	27.95	1.21
235A-3 South	4	South - Facing wall	19.95	4.35	0.33	25.13	0.49
235A-3 South	4	South - Facing wall	19.95	3.60	0.68	24.23	0.57

Table D.1 Summary of Dosimeter Results

Table D.1 Summary of Dosimeter Results

Location	Packet No.	On-Phantom Placement	Exposure Time (hrs)	HCND Neutron Dose rate (mrem/h)	8816 TED Neutron Dose rate mrem/h	HSD Neutron Dose rate (mrem/h)	HSD Gamma Dose rate (mrem/h)
235A-3 South	4	South - Facing wall	19.95	4.56	0.58	25.92	0.58
	4	Avg of 3		4.17	0.53	25.09	0.55
Vault 1: betw cabinets	21	facing cabinet 1EE	18.15	17.94	1.82	93.83	1.49
Vault 1: betw cabinets	21	facing cabinet 1EE	18.15	16.04	2.51	96.24	1.53
Vault 1: betw cabinets	21	facing cabinet 1EE	18.15	17.37	1.76	92.84	1.41
	21	Avg of 3		17.12	2.03	94.30	1.48
Vault 1: betw cabinets	22	facing TEPC1172	18.15	15.81	1.43	75.12	1.43
Vault 1: betw cabinets	22	facing TEPC1172	18.15	12.04	1.10	73.50	1.46
Vault 1: betw cabinets	22	facing TEPC1172	18.15	14.84	1.68	78.57	1.59
	22	Avg of 3		14.23	1.40	75.73	1.49
Vault 1: betw cabinets	23	facing cabn 1FE	18.15	21.43	4.30	152.49	1.95
Vault 1: betw cabinets	23	facing cabn 1FE	18.15	25.97	4.90	154.31	1.96
Vault 1: betw cabinets	23	facing cabn 1FE	18.15	22.64	4.60	140.39	1.79
	23	Avg of 3		23.34	4.60	149.06	1.90
Vault 1: betw cabinets	24	facing TEPC1173	18.15	23.12	1.60	89.84	1.68
Vault 1: betw cabinets	24	facing TEPC1173	18.15	19.18	1.57	96.11	1.80
Vault 1: betw cabinets	24	facing TEPC1173	18.15	16.78	1.49	92.97	1.45
	24	Avg of 3		19.69	1.55	92.97	1.64
Vault 1: by corridor wall	17	away from wall	18.18	6.35	1.02	44.94	0.67
Vault 1: by corridor wall	17	away from wall	18.18	7.07	1.16	44.73	0.57
Vault 1: by corridor wall	17	away from wall	18.18	9.60	1.10	45.05	0.55
	17	Avg of 3		7.67	1.09	44.91	0.60
Vault 1: by corridor wall	18	facing TEPC504	18.18	5.30	0.55	38.51	0.57

Table D.1 Summary of Dosimeter Results

Location	Packet No.	On-Phantom Placement	Exposure Time (hrs)	HCND Neutron Dose rate (mrem/h)	8816 TED Neutron Dose rate mrem/h	HSD Neutron Dose rate (mrem/h)	HSD Gamma Dose rate (mrem/h)
Vault 1: by corridor wall	18	facing TEPC504	18.18	5.38	0.41	38.40	0.42
Vault 1: by corridor wall	18	Facing TEPC504	18.18	5.24	0.66	39.39	0.53
	18	Avg of 3		5.30	0.54	38.77	0.51
Vault 1: by corridor wall	19	Facing wall	18.18	3.86	0.41	36.51	0.43
Vault 1: by corridor wall	19	Facing wall	18.18	3.24	0.25	36.37	0.55
Vault 1: by corridor wall	19	Facing wall	18.18	5.66	0.50	39.24	0.41
	19	Avg of 3		4.25	0.39	37.37	0.46
Vault 1: by corridor wall	20	Facing TEPC1170	18.18	8.76	1.32	48.81	0.63
Vault 1: by corridor wall	20	Facing TEPC1170	18.18	9.57	1.38	50.44	0.62
Vault 1: by corridor wall	20	Facing TEPC1170	18.18	7.13	1.24	51.22	0.58
	20	Avg of 3		8.49	1.31	50.16	0.61
Vault 2 - Betw Cabinets	25	to aisle	18.67	31.28	15.59	112.45	42.98
Vault 2 - Betw Cabinets	25	to aisle	18.67	21.40	14.84	103.26	43.71
Vault 2 - Betw Cabinets	25	to aisle	18.67	26.47	12.91	109.58	41.61
	25	Avg of 3		26.38	14.44	108.43	42.77
Vault 2 - Betw Cabinets	26	to TEPC 1173	18.67	29.06	9.32	110.56	54.75
Vault 2 - Betw Cabinets	26	to TEPC 1173	18.67	14.75	10.55	110.57	51.96
Vault 2 - Betw Cabinets	26	to TEPC 1173	18.67	21.16	10.58	101.05	57.00
	26	Avg of 3		21.65	10.15	107.40	54.57
Vault 2 - Betw Cabinets	27	to wall cabinet	18.67	21.54	11.65	93.95	57.90
Vault 2 - Betw Cabinets	27	to wall cabinet	18.67	30.97	11.03	94.65	60.53
Vault 2 - Betw Cabinets	27	to wall cabinet	18.67	16.42	11.36	96.89	61.24
	27	Avg of 3		22.97	11.35	95.16	59.89

Table D.1 Summary of Dosimeter Results

Location	Packet No.	On-Phantom Placement	Exposure Time (hrs)	HCND Neutron Dose rate (mrem/h)	8816 TED Neutron Dose rate mrem/h	HSD Neutron Dose rate (mrem/h)	HSD Gamma Dose rate (mrem/h)
Vault 2 - Betw Cabinets	28	to TEPC 1172	18.67	20.72	14.09	102.26	48.88
Vault 2 - Betw Cabinets	28	to TEPC 1172	18.67	33.58	14.86	118.21	55.69
Vault 2 - Betw Cabinets	28	to TEPC 1172	18.67	24.27	13.20	115.24	46.28
	28	Avg of 3		26.19	14.05	111.90	50.28
Vault 2 - by wall	29	Away from wall	18.73	28.16	7.66	101.20	22.33
Vault 2 - by wall	29	Away from wall	18.73	23.37	9.45	93.20	22.59
Vault 2 - by wall	29	Away from wall	18.73	36.04	8.84	93.63	21.87
	29	Avg of 3		29.19	8.65	96.01	22.26
Vault 2 - by wall	30	to TEPC 504	18.73	8.57	3.66	86.22	10.47
Vault 2 - by wall	30	to TEPC 504	18.73	13.25	4.38	76.94	6.13
Vault 2 - by wall	30	to TEPC 504	18.73	9.69	3.15	81.98	8.02
	30	Avg of 3		10.50	3.73	81.71	8.20
Vault 2 - by wall	31	to wall	18.73	17.41	2.11	94.30	7.03
Vault 2 - by wall	31	to wall	18.73	19.67	2.16	88.59	5.64
Vault 2 - by wall	31	to wall	18.73	18.87	2.14	88.07	5.72
	31	Avg of 3		18.65	2.14	90.32	6.13
Vault 2 - by wall	32	to TEPC 1170	18.73	12.46	7.96	95.59	19.67
Vault 2 - by wall	32	to TEPC 1170	18.73	29.42	6.73	103.56	19.14
Vault 2 - by wall	32	to TEPC 1170	18.73	15.17	7.77	101.95	17.46
	32	Avg of 3		19.02	7.48	100.37	18.76
Vault 4 - Back Wall	8	Away from wall	5.92	46.87	6.25	226.29	3.59
Vault 4 - Back Wall	8	Away from wall	5.92	34.03	7.60	237.60	3.77
Vault 4 - Back Wall	8	Away from wall	5.92	59.75	7.52	228.00	3.75

Table D.1 Summary of Dosimeter Results							
Location	**Packet No.**	**On-Phantom Placement**	**Exposure Time (hrs)**	**HCND Neutron Dose rate (mrem/h)**	**8816 TED Neutron Dose rate mrem/h**	**HSD Neutron Dose rate (mrem/h)**	**HSD Gamma Dose rate (mrem/h)**
	8	Avg of 3		46.88	7.12	230.63	3.70
Vault 4 - Back Wall	10	Facing TEPC 1170	5.92	27.52	3.21	149.11	2.55
Vault 4 - Back Wall	10	Facing TEPC 1170	5.92	34.01	4.39	170.38	2.75
Vault 4 - Back Wall	10	Facing TEPC 1170	5.92	30.63	3.21	165.14	2.33
	10	Avg of 3	5.92	30.72	3.60	161.55	2.54
Vault 4 - Back Wall	11	Toward wall	5.92	8.66	0.93	148.56	1.87
Vault 4 - Back Wall	11	toward wall	5.92	18.01	0.76	141.90	1.93
Vault 4 - Back Wall	11	toward wall	5.92	16.46	0.76	148.63	1.81
	11	Avg of 3		14.37	0.82	146.36	1.87
Vault 4 - Back Wall	12	facing TEPC 504	5.92	35.67	2.79	197.89	2.66
Vault 4 - Back Wall	12	facing TEPC 504	5.92	38.77	2.87	179.91	2.57
Vault 4 - Back Wall	12	facing TEPC 504	5.92	18.88	3.38	186.74	2.62
	12	Avg of 3		31.11	3.01	188.18	2.62
Vault 4 betw cabinets	13	facing TEPC1172	5.62	45.54	9.43	244.48	13.07
Vault 4 betw cabinets	13	facing TEPC1172	5.62	61.77	8.27	229.43	12.90
Vault 4 betw cabinets	13	facing TEPC1172	5.62	52.60	10.23	242.03	13.53
	13	Avg of 3		53.30	9.31	238.65	13.16
Vault 4 betw cabinets	14	facing TEPC1173	5.62	49.24	6.76	187.52	21.51
Vault 4 betw cabinets	14	facing TEPC1173	5.62	48.97	6.32	205.31	25.55
Vault 4 betw cabinets	14	facing TEPC1173	5.62	52.47	8.19	187.23	26.86
	14	Avg of 3		50.23	7.09	193.35	24.64
Vault 4 betw cabinets	15	facing 4FE	5.62	42.35	7.30	246.85	6.07
Vault 4 betw cabinets	15	facing 4FE	5.62	40.83	6.49	239.61	5.94

Table D.1 Summary of Dosimeter Results

Location	Packet No.	On-Phantom Placement	Exposure Time (hrs)	HCND Neutron Dose rate (mrem/h)	8816 TED Neutron Dose rate mrem/h	HSD Neutron Dose rate (mrem/h)	HSD Gamma Dose rate (mrem/h)
Vault 4 betw cabinets	15	facing 4FE	5.62	46.88	7.47	210.68	5.11
	15	Avg of 3		43.35	7.09	232.38	5.71
Vault 4 betw cabinets	16	facing 4EE	5.62	74.71	14.59	253.81	23.77
Vault 4 betw cabinets	16	facing 4EE	5.62	60.21	14.68	258.74	23.27
Vault 4 betw cabinets	16	facing 4EE	5.62	56.83	14.23	260.69	21.39
	16	Avg of 3		63.92	14.50	257.74	22.81
Vault Cor by V1	33	to corridor	90.80	2.44	0.25	18.57	0.21
Vault Cor by V1	33	to corridor	90.80	0.92	0.25	19.91	0.21
Vault Cor by V1	33	to corridor	90.80	2.59	0.23	18.95	0.21
	33	Avg of 3		1.99	0.24	19.14	0.21
Vault Cor by V1	34	to TEPC1172	90.80	0.51	0.15	17.28	0.21
Vault Cor by V1	34	to TEPC1172	90.80	1.75	0.20	17.21	0.23
Vault Cor by V1	34	to TEPC1172	90.80	1.86	0.18	16.25	0.21
	34	Avg of 3		1.38	0.18	16.92	0.22
Vault Cor by V1	35	to TEPC1173	90.80	1.47	0.21	18.09	0.22
Vault Cor by V1	35	to TEPC1173	90.80	1.06	0.21	16.98	0.24
Vault Cor by V1	35	to TEPC1173	90.80	0.79	0.20	16.89	0.23
	35	Avg of 3		1.11	0.21	17.32	0.23
Vault Cor by V1	36	to wall	90.80	1.48	0.10	13.81	0.20
Vault Cor by V1	36	to wall	90.80	1.55	0.10	13.92	0.21
Vault Cor by V1	36	to wall	90.80	2.75	0.08	13.96	0.23
	3	Avg of 3		1.93	0.10	13.90	0.21
Vault Corr - by Vault 3	37	to corridor	90.80	1.61	0.23	16.59	0.25
Vault Cor by V3	37	to corridor	90.80	2.03	0.18	16.12	0.26
Vault Cor by V3	37	to corridor	90.80	1.37	0.14	16.89	0.25
	37	Avg of 3		1.67	0.18	16.54	0.25
Vault Cor by V3	38	to TEPC 504	90.80	2.87	0.12	16.42	0.24
Vault Cor by V3	38	to TEPC 504	90.80	2.01	0.14	21.61	0.29
Vault Cor by V3	38	to TEPC 504	90.80	2.24	0.14	18.52	0.28
	38	Avg of 3		2.37	0.13	18.85	0.27
Vault Cor by V3	39	to wall	90.80	2.50	0.36	25.53	0.36
Vault Cor by V3	39	to wall	90.80	1.14	0.34	28.00	0.29
Vault Cor by V3	39	to wall	90.80	1.96	0.40	26.27	0.32
	39	Avg of 3		1.87	0.37	26.60	0.33
Vault Cor by V3	40	to TEPC 1170	90.80	1.84	0.19	18.04	0.30

Table D.1 Summary of Dosimeter Results

Location	Packet No.	On-Phantom Placement	Exposure Time (hrs)	HCND Neutron Dose rate (mrem/h)	8816 TED Neutron Dose rate mrem/h	HSD Neutron Dose rate (mrem/h)	HSD Gamma Dose rate (mrem/h)
Vault Cor by V3	40	to TEPC 1170	90.80	1.86	0.18	18.97	0.28
Vault Cor by V3	40	to TEPC 1170	90.80	1.55	0.21	20.10	0.30
	40	Avg of 3		1.75	0.19	19.04	0.29

Table D.2 HCND Dosimeter Response

Location	Packet #	Card ID	Formula	Adjusted Chip Readings				Neutron (mrem)	Exp Time (hrs)	Neutron DE Rate (mrem/h)
				Chip 1	Chip 2	Chip 3	Chip 4			
235A-3 South	1	4051048	112	27	574	349	659	79	19.95	3.97
235A-3 South	1	4007608	112	32	614	350	739	178	19.95	8.91
235A-3 South	1	4006161	112	29	565	332	739	187	19.95	9.35
235A-3 South	2	4051032	112	19	448	283	515	33	19.95	1.64
235A-3 South	2	4006326	112	21	493	299	556	58	19.95	2.93
235A-3 South	2	4006512	111	25	460	300	565	158	19.95	7.90
235A-3 South	3	4050709	112	23	440	264	538	99	19.95	4.96
235A-3 South	3	4050749	112	23	407	257	525	83	19.95	4.17
235A-3 South	3	4007288	111	21	420	272	529	156	19.95	7.83
235A-3 South	4	4007039	111	14	394	299	514	87	19.95	4.35
235A-3 South	4	4050908	111	13	362	271	481	91	19.95	4.56
235A-3 South	4	4050876	111	12	356	279	477	72	19.95	3.60
235A-3 North	5	4007320	112	51	453	290	511	48	19.95	2.42
235A-3 North	5	4050637	112	49	466	294	523	55	19.95	2.74
235A-3 North	5	4050599	112	44	477	283	539	101	19.95	5.05
235A-3 North	6	4050882	111	13	335	216	408	115	19.95	5.75
235A-3 North	6	4050860	111	13	322	211	400	111	19.95	5.54
235A-3 North	6	4006424	111	14	340	235	418	94	19.95	4.72
235A-3 North	7	4004320	111	20	344	235	433	108	19.95	5.41
235A-3 North	7	4050802	111	16	312	212	431	125	19.95	6.28
235A-3 North	7	4003300	111	17	284	210	405	96	19.95	4.82
235A-3 North	9	4050741	112	43	505	308	593	98	19.95	4.91
235A-3 North	9	4050888	112	45	504	297	636	167	19.95	8.35
235A-3 North	9	4007557	112	46	479	297	620	133	19.95	6.69
	Control	4006450	113	0	1	0	1	0		
Vault 4 - Back Wall	8	4007083	111	22	1004	763	1291	201	5.92	34.0
Vault 4 - Back Wall	8	4050855	111	21	990	685	1350	354	5.92	59.7
Vault 4 - Back Wall	8	4002767	111	23	991	736	1352	277	5.92	46.9
Vault 4 - Back Wall	10	4050647	111	14	625	482	907	181	5.92	30.6
Vault 4 - Back Wall	10	4000763	111	15	669	520	931	163	5.92	27.5

Table D.2 HCND Dosimeter Response

				Adjusted Chip Readings						
Location	Packet #	Card ID	Formula	Chip 1	Chip 2	Chip 3	Chip 4	Neutron (mrem)	Exp Time (hrs)	Neutron DE Rate (mrem/h)
Vault 4 - Back Wall	10	4005149	111	16	751	540	970	201	5.92	34.0
Vault 4 - Back Wall	11	4002166	111	13	606	517	892	107	5.92	18.0
Vault 4 - Back Wall	11	4000384	111	12	556	521	857	51	5.92	8.66
Vault 4 - Back Wall	11	4006094	111	12	548	481	838	97	5.92	16.5
Vault 4 - Back Wall	12	4001587	111	17	822	643	1173	211	5.92	35.7
Vault 4 - Back Wall	12	4004979	111	16	762	552	1033	229	5.92	38.8
Vault 4 - Back Wall	12	4005668	111	16	681	572	967	112	5.92	18.9
	Control	4004319	113	0	0	0	0	0		
Vault 4 - Betw Cabinets	13	4003683	111	45	962	698	1241	256	5.62	45.5
Vault 4 - Betw Cabinets	13	4005548	111	51	903	666	1270	295	5.62	52.6
Vault 4 - Betw Cabinets	13	4005222	111	55	971	660	1276	347	5.62	61.8
Vault 4 - Betw Cabinets	14	4004879	111	89	923	648	1157	275	5.62	49.0
Vault 4 - Betw Cabinets	14	4003880	111	86	911	639	1150	277	5.62	49.2
Vault 4 - Betw Cabinets	14	4006701	111	81	880	615	1149	295	5.62	52.5
Vault 4 - Betw Cabinets	15	4000453	111	30	956	724	1289	238	5.62	42.3
Vault 4 - Betw Cabinets	15	4002901	111	33	983	744	1350	263	5.62	46.9
Vault 4 - Betw Cabinets	15	4002494	111	30	943	741	1327	229	5.62	40.8
Vault 4 - Betw Cabinets	16	4006047	111	56	1158	768	1338	319	5.62	56.8
Vault 4 - Betw Cabinets	16	4005920	111	64	1160	807	1454	338	5.62	60.2
Vault 4 - Betw Cabinets	16	4002525	111	63	1064	739	1493	420	5.62	74.7
	Control	4000817	113	0	0	0	0	0		
Vault 1 - By Corr Wall	17	4002970	111	13	572	444	777	128	18.18	7.07
Vault 1 - By Corr Wall	17	4001040	111	14	562	462	809	115	18.18	6.35
Vault 1 - By Corr Wall	17	4003993	111	13	626	461	844	175	18.18	9.60
Vault 1 - By Corr Wall	18	4001329	111	11	489	410	718	96	18.18	5.30
Vault 1 - By Corr Wall	18	4003680	111	11	484	395	683	95	18.18	5.24
Vault 1 - By Corr Wall	18	4001594	111	12	508	410	704	98	18.18	5.38
Vault 1 - By Corr Wall	19	4007283	111	12	460	385	691	103	18.18	5.66
Vault 1 - By Corr Wall	19	4004948	111	11	411	380	652	59	18.18	3.24
Vault 1 - By Corr Wall	19	4002396	111	11	448	387	657	70	18.18	3.86
Vault 1 - By Corr Wall	20	4005541	111	13	649	509	917	159	18.18	8.76

Table D.2 HCND Dosimeter Response

				Adjusted Chip Readings						
Location	Packet #	Card ID	Formula	Chip 1	Chip 2	Chip 3	Chip 4	Neutron (mrem)	Exp Time (hrs)	Neutron DE Rate (mrem/h)
Vault 1 - By Corr Wall	20	4007341	111	12	622	484	901	174	18.18	9.57
Vault 1 - By Corr Wall	20	4050901	111	12	543	448	813	130	18.18	7.13
	Control	4003275	113	0	0	0	0	0		
	Control	4000072	113	0	0	0	2	0		
Vault 1: Betw Cabinets	21	4050896	111	29	1183	868	1563	315	18.15	17.4
Vault 1: Betw Cabinets	21	4006145	111	33	1224	931	1695	326	18.15	17.9
Vault 1: Betw Cabinets	21	4050827	111	29	1076	833	1532	291	18.15	16.0
Vault 1: Betw Cabinets	22	4007047	111	32	953	778	1389	218	18.15	12.0
Vault 1: Betw Cabinets	22	4007028	111	34	1056	734	1303	287	18.15	15.8
Vault 1: Betw Cabinets	22	4050811	111	33	1158	823	1405	269	18.15	14.8
Vault 1: Betw Cabinets	23	4001229	111	43	1975	1422	2467	471	18.15	26.0
Vault 1: Betw Cabinets	23	4000637	111	46	1816	1475	2595	389	18.15	21.4
Vault 1: Betw Cabinets	23	4050693	111	44	1757	1431	2573	411	18.15	22.6
Vault 1: Betw Cabinets	24	4007108	111	40	1356	936	1737	420	18.15	23.1
Vault 1: Betw Cabinets	24	4050880	111	34	1181	830	1523	348	18.15	19.2
Vault 1: Betw Cabinets	24	4050926	111	34	1134	847	1535	305	18.15	16.8
	Control	4004927	113	0	0	1	0	0		
	Control	4006058	113	0	0	0	0	0		
Vault 2: Betw Cabinets	25	4006211	112	479	2245	1401	2438	494	18.67	26.5
Vault 2: Betw Cabinets	25	4003675	112	469	2266	1353	2390	584	18.67	31.3
Vault 2: Betw Cabinets	25	4005819	112	471	1884	1311	2364	399	18.67	21.4
Vault 2: Betw Cabinets	26	4002775	112	703	2285	1650	2639	275	18.67	14.7
Vault 2: Betw Cabinets	26	4002552	112	680	2444	1672	2918	542	18.67	29.1
Vault 2: Betw Cabinets	26	4005268	112	696	2290	1591	2603	395	18.67	21.2
Vault 2: Betw Cabinets	27	4007392	112	687	2331	1611	2534	306	18.67	16.4
Vault 2: Betw Cabinets	27	4005201	112	664	2338	1546	2676	578	18.67	31.0
Vault 2: Betw Cabinets	27	4000139	112	651	2168	1518	2542	402	18.67	21.5
Vault 2: Betw Cabinets	28	4002815	112	676	2311	1492	2575	627	18.67	33.6
Vault 2: Betw Cabinets	28	4007143	112	629	2390	1578	2627	453	18.67	24.3
Vault 2: Betw Cabinets	28	4001420	112	618	2345	1620	2734	387	18.67	20.7
	Control	4007391	113	0	0	0	0	0		

Table D.2 HCND Dosimeter Response

Location	Packet #	Card ID	Formula	Adjusted Chip Readings				Neutron (mrem)	Exp Time (hrs)	Neutron DE Rate (mrem/h)
				Chip 1	Chip 2	Chip 3	Chip 4			
	Control	4003646	113	0	0	0	0	0		
Vault 2 - By Wall	29	4001582	111	213	1578	1127	1941	438	18.73	23.4
Vault 2 - By Wall	29	4005963	111	223	1674	1136	2240	675	18.73	36.0
Vault 2 - By Wall	29	4000879	111	224	1507	1105	2078	528	18.73	28.2
Vault 2 - By Wall	30	4005883	111	86	1145	953	1563	181	18.73	9.7
Vault 2 - By Wall	30	4000082	111	92	1088	945	1554	161	18.73	8.6
Vault 2 - By Wall	30	4004309	111	107	1216	976	1647	248	18.73	13.2
Vault 2 - By Wall	31	4005051	111	108	1213	893	1635	368	18.73	19.7
Vault 2 - By Wall	31	4001035	111	82	1207	954	1736	326	18.73	17.4
Vault 2 - By Wall	31	4005964	111	73	1233	925	1692	353	18.73	18.9
Vault 2 - By Wall	32	4001647	111	226	1653	1128	2048	551	18.73	29.4
Vault 2 - By Wall	32	4001767	112	215	1639	1096	2092	284	18.73	15.2
Vault 2 - By Wall	32	4001519	112	203	1516	1000	1852	233	18.73	12.5
	Control	4050839	113	1	0	0	0	0		
	Control	4002355	113	0	0	0	0	0		
Vault Corridor - by V1	33	4005247	111	26	1190	1003	1740	222	90.80	2.44
Vault Corridor - by V1	33	4006737	111	28	1126	969	1731	236	90.80	2.59
Vault Corridor - by V1	33	4006209	111	27	1051	993	1619	84	90.80	0.92
Vault Corridor - by V1	34	4007540	111	26	1044	921	1583	169	90.80	1.86
Vault Corridor - by V1	34	4000927	111	27	931	925	1493	46	90.80	0.51
Vault Corridor - by V1	34	4004017	111	27	1109	944	1569	159	90.80	1.75
Vault Corridor - by V1	35	4007280	111	25	1038	956	1523	72	90.80	0.79
Vault Corridor - by V1	35	4000105	111	27	1038	935	1567	133	90.80	1.47
Vault Corridor - by V1	35	4001088	111	26	1024	963	1589	97	90.80	1.06
Vault Corridor - by V1	36	4005611	111	24	931	735	1356	250	90.80	2.75
Vault Corridor - by V1	36	4000535	111	24	841	746	1280	134	90.80	1.48
Vault Corridor - by V1	36	4001117	111	25	914	774	1296	141	90.80	1.55
	Control	4006511	113	1	1	0	0	0		
Vault Corridor - by V3	37	4002694	111	27	1049	907	1477	124	90.80	1.37
Vault Corridor - by V3	37	4000305	111	26	1089	909	1483	146	90.80	1.61
Vault Corridor - by V3	37	4001499	111	28	1045	876	1498	184	90.80	2.03

Table D.2 HCND Dosimeter Response

				Adjusted Chip Readings						
Location	Packet #	Card ID	Formula	Chip 1	Chip 2	Chip 3	Chip 4	Neutron (mrem)	Exp Time (hrs)	Neutron DE Rate (mrem/h)
Vault Corridor - by V3	38	4002322	111	31	1249	1016	1779	261	90.80	2.87
Vault Corridor - by V3	38	4003465	111	32	1185	1019	1719	183	90.80	2.01
Vault Corridor - by V3	38	4003954	111	29	1087	904	1559	203	90.80	2.24
Vault Corridor - by V3	39	4002130	111	36	1546	1467	2368	103	90.80	1.14
Vault Corridor - by V3	39	4003256	111	38	1648	1443	2339	178	90.80	1.96
Vault Corridor - by V3	39	4000006	111	35	1624	1422	2386	227	90.80	2.50
Vault Corridor - by V3	40	4004706	111	31	1064	999	1706	141	90.80	1.55
Vault Corridor - by V3	40	4000126	111	33	1064	1004	1758	167	90.80	1.84
Vault Corridor - by V3	40	4003090	111	33	1240	1065	1762	169	90.80	1.86
	Control	4007070	113	1	0	0	0	0		
	Control	4003232	113	0	1	0	1	0		
	Control	4002390	113	0	0	1	0	0		

Table D.3. TED Dosimeter Response

				Foil 1		Foil 2		Both Foils		
Location	Packet #	On-Phantom Placement	Holder ID	CR-39 ID	Dose (mrem)	CR-39 ID	Dose (mrem)	Mean Dose (mrem)	% Diff.	Mean Dose rate (mrem/h)
235A-3 North	5	West - facing TEPC 1173	4004869	11161	31	11167	25	28	21.4	1.40
235A-3 North	5	West - facing TEPC 1173	4002047	11164	38	11166	38	38	0.0	1.90
235A-3 North	5	West - facing TEPC 1173	4004462	11151	33	11169	24	28.5	31.6	1.43
235A-3 North	6	North - facing water wall	4002958	11183	13	11175	5	9	88.9	0.45
235A-3 North	6	North - facing water wall	4004438	11157	6	11163	7	6.5	-15.4	0.33
235A-3 North	6	North - facing water wall	4000532	11180	6	11150	22	14	-114.3	0.70
235A-3 North	7	East - facing TEPC 185	4004304	11178	14	11149	6	10	80.0	0.50
235A-3 North	7	East - facing TEPC 185	4004478	11093	3	11111	12	7.5	-120.0	0.38
235A-3 North	7	East - facing TEPC 185	4004286	11148	10	11152	10	10	0.0	0.50
235A-3 North	9	South - Facing hood	4005325	11088	75	11098	66	70.5	12.8	3.53
235A-3 North	9	South - Facing hood	4004444	11086	71	11091	77	74	-8.1	3.71
235A-3 North	9	South - Facing hood	4004394	11095	61	11085	69	65	-12.3	3.26
235A-3 South	1	North - Facing hood	4004882	11299	63	11313	66	64.5	-4.7	3.23
235A-3 South	1	North - Facing hood	4000403	11179	69	11165	54	61.5	24.4	3.08
235A-3 South	1	North - Facing hood	4001330	11168	55	11174	66	60.5	-18.2	3.03
235A-3 South	2	East - to TEPC 1170	4004537	11156	18	11171	21	19.5	-15.4	0.98
235A-3 South	2	East - to TEPC 1170	4004464	11153	32	11154	27	29.5	16.9	1.48
235A-3 South	2	East - to TEPC 1170	4001329	11173	23	11162	20	21.5	14.0	1.08
235A-3 South	3	West - to TEPC 1172	4003058	11315	23	11296	18	20.5	24.4	1.03
235A-3 South	3	West - to TEPC 1172	4000295	11155	21	11176	24	22.5	-13.3	1.13
235A-3 South	3	West - to TEPC 1172	4001419	11160	17	11158	27	22	-45.5	1.10
235A-3 South	4	South - Facing wall	4001149	11318	4	11309	9	6.5	-76.9	0.33
235A-3 South	4	South - Facing wall	4004866	11308	13	11302	14	13.5	-7.4	0.68
235A-3 South	4	South - Facing wall	4004546	11319	10	11294	13	11.5	-26.1	0.58
Vault 1: betw cabinets	21	facing cabinet 1EE	4001686	11321	38	11304	28	33	30.3	1.82
Vault 1: betw cabinets	21	facing cabinet 1EE	4001159	11326	41	11327	50	45.5	-19.8	2.51
Vault 1: betw cabinets	21	facing cabinet 1EE	4000166	11293	34	11301	30	32	12.5	1.76
Vault 1: betw cabinets	22	facing TEPC1172	4004867	11310	20	11316	32	26	-46.2	1.43
Vault 1: betw cabinets	22	facing TEPC1172	4004571	11298	18	11303	22	20	-20.0	1.10
Vault 1: betw cabinets	22	facing TEPC1172	4000509	11325	30	11317	31	30.5	-3.3	1.68
Vault 1: betw cabinets	23	facing cabn 1FE	4000103	11323	83	11324	73	78	12.8	4.30

Table D.3. TED Dosimeter Response

				Foil 1		Foil 2		Both Foils		
Location	Packet #	On-Phantom Placement	Holder ID	CR-39 ID	Dose (mrem)	CR-39 ID	Dose (mrem)	Mean Dose (mrem)	% Diff.	Mean Dose rate (mrem/h)
Vault 1: betw cabinets	23	facing cabn 1FE	4002926	11305	77	11320	101	89	-27.0	4.90
Vault 1: betw cabinets	23	facing cabn 1FE	4000482	11307	83	11297	84	83.5	-1.2	4.60
Vault 1: betw cabinets	24	facing TEPC1173	4002059	11311	28	11295	30	29	-6.9	1.60
Vault 1: betw cabinets	24	facing TEPC1173	4004449	11314	30	11312	27	28.5	10.5	1.57
Vault 1: betw cabinets	24	facing TEPC1173	4000188	11322	28	11306	26	27	7.4	1.49
Vault 1: by corridor wall	17	away from wall	4001364	11290	16	11268	21	18.5	-27.0	1.02
Vault 1: by corridor wall	17	away from wall	4001422	11275	23	11258	19	21	19.0	1.16
Vault 1: by corridor wall	17	away from wall	4001383	11274	19	11281	21	20	-10.0	1.10
Vault 1: by corridor wall	18	facing TEPC504	4002893	11262	9	11195	11	10	-20.0	0.55
Vault 1: by corridor wall	18	facing TEPC504	4001527	11256	6	11277	9	7.5	-40.0	0.41
Vault 1: by corridor wall	18	facing TEPC504	4002852	11265	10	11286	14	12	-33.3	0.66
Vault 1: by corridor wall	19	facing wall	4000585	11288	4	11285	11	7.5	-93.3	0.41
Vault 1: by corridor wall	19	facing wall	4000311	11259	1	11278	8	4.5	-155.6	0.25
Vault 1: by corridor wall	19	facing wall	4001567	11266	4	11280	14	9	-111.1	0.50
Vault 1: by corridor wall	20	facing TEPC1170	4003222	11272	25	11283	23	24	8.3	1.32
Vault 1: by corridor wall	20	facing TEPC1170	4002981	11263	27	11267	23	25	16.0	1.38
Vault 1: by corridor wall	20	facing TEPC1170	#REF!	11292	20	11300	25	22.5	-22.2	1.24
Vault 2 - Betw Cabinets	25	to aisle	4003239	11182	293	11222	289	291	1.4	15.59
Vault 2 - Betw Cabinets	25	to aisle	4001251	11247	281	11225	273	277	2.9	14.84
Vault 2 - Betw Cabinets	25	to aisle	4001280	11235	245	11231	237	241	3.3	12.91
Vault 2 - Betw Cabinets	26	to TEPC 1173	4000547	11232	180	11238	168	174	6.9	9.32
Vault 2 - Betw Cabinets	26	to TEPC 1173	4002936	11251	203	11242	191	197	6.1	10.55
Vault 2 - Betw Cabinets	26	to TEPC 1173	4001731	11228	193	11250	202	197.5	-4.6	10.58
Vault 2 - Betw Cabinets	27	to wall cabinet	4002986	11328	208	11331	227	217.5	-8.7	11.65
Vault 2 - Betw Cabinets	27	to wall cabinet	4000234	11330	193	11335	219	206	-12.6	11.03
Vault 2 - Betw Cabinets	27	to wall cabinet	4002894	11142	225	11126	199	212	12.3	11.36
Vault 2 - Betw Cabinets	28	to TEPC 1172	4000386	11249	258	11221	268	263	-3.8	14.09
Vault 2 - Betw Cabinets	28	to TEPC 1172	4002040	11351	264	11348	291	277.5	-9.7	14.86
Vault 2 - Betw Cabinets	28	to TEPC 1172	4002069	11245	247	11227	246	246.5	0.4	13.20

Table D.3. TED Dosimeter Response

				Foil 1		Foil 2		Both Foils		
Location	Packet #	On-Phantom Placement	Holder ID	CR-39 ID	Dose (mrem)	CR-39 ID	Dose (mrem)	Mean Dose (mrem)	% Diff.	Mean Dose rate (mrem/h)
Vault 2 - by wall	29	away from wall	4001600	11102	133	11132	154	143.5	-14.6	7.66
Vault 2 - by wall	29	away from wall	4000554	11143	162	11146	192	177	-16.9	9.45
Vault 2 - by wall	29	away from wall	4004474	11113	175	11124	156	165.5	11.5	8.84
Vault 2 - by wall	30	to TEPC 504	4004521	11123	72	11127	65	68.5	10.2	3.66
Vault 2 - by wall	30	to TEPC 504	#REF!	11141	75	11144	89	82	-17.1	4.38
Vault 2 - by wall	30	to TEPC 504	4004547	11131	53	11129	65	59	-20.3	3.15
Vault 2 - by wall	31	to wall	4002848	11115	36	11120	43	39.5	-17.7	2.11
Vault 2 - by wall	31	to wall	4000424	11119	46	11134	35	40.5	27.2	2.16
Vault 2 - by wall	31	to wall	4002959	11145	42	11116	38	40	10.0	2.14
Vault 2 - by wall	32	to TEPC 1170	4001370	11114	145	11122	153	149	-5.4	7.96
Vault 2 - by wall	32	to TEPC 1170	4002907	11133	122	11130	130	126	-6.3	6.73
Vault 2 - by wall	32	to TEPC 1170	4001479	11140	137	11138	154	145.5	-11.7	7.77
Vault 4 - Back Wall	8	Away from wall	4001212	11181	33	11177	41	37	-21.6	6.25
Vault 4 - Back Wall	8	Away from wall	4000353	11172	40	11159	50	45	-22.2	7.60
Vault 4 - Back Wall	8	Away from wall	4004431	11097	36	11170	53	44.5	-38.2	7.52
Vault 4 - Back Wall	10	facing TEPC 1170	4003199	11078	20	11077	18	19	10.5	3.21
Vault 4 - Back Wall	10	facing TEPC 1170	4001209	11103	28	11109	24	26	15.4	4.39
Vault 4 - Back Wall	10	facing TEPC 1170	4003139	11094	15	11107	23	19	-42.1	3.21
Vault 4 - Back Wall	11	toward wall	4004871	11110	7	11092	4	5.5	54.5	0.93
Vault 4 - Back Wall	11	toward wall	4003194	11076	4	11104	5	4.5	-22.2	0.76
Vault 4 - Back Wall	11	toward wall	4004465	11080	1	11084	8	4.5	-155.6	0.76
Vault 4 - Back Wall	12	facing TEPC 504	4000244	11101	16	11082	17	16.5	-6.1	2.79
Vault 4 - Back Wall	12	facing TEPC 504	4000098	11090	16	11087	18	17	-11.8	2.87
Vault 4 - Back Wall	12	facing TEPC 504	4001160	11079	18	11099	22	20	-20.0	3.38
Vault 4 betw cabinets	13	facing TEPC1172	4000578	11202	37	11187	69	53	-60.4	9.43
Vault 4 betw cabinets	13	facing TEPC1172	4003134	11185	39	11196	54	46.5	-32.3	8.27
Vault 4 betw cabinets	13	facing TEPC1172	4000179	11216	47	11219	68	57.5	-36.5	10.23
Vault 4 betw cabinets	14	facing TEPC1173	4001397	11212	31	11189	45	38	-36.8	6.76
Vault 4 betw cabinets	14	facing TEPC1173	4000212	11207	33	11190	38	35.5	-14.1	6.32
Vault 4 betw cabinets	14	facing TEPC1173	4000090	11213	36	11184	56	46	-43.5	8.19
Vault 4 betw cabinets	15	facing 4FE	#REF!	11264	34	11261	48	41	-34.1	7.30

Table D.3. TED Dosimeter Response

				Foil 1		Foil 2		Both Foils		
Location	Packet #	On-Phantom Placement	Holder ID	CR-39 ID	Dose (mrem)	CR-39 ID	Dose (mrem)	Mean Dose (mrem)	% Diff.	Mean Dose rate (mrem/h)
Vault 4 betw cabinets	15	facing 4FE	4000326	11210	31	11215	42	36.5	-30.1	6.49
Vault 4 betw cabinets	15	facing 4FE	4003131	11217	28	11191	56	42	-66.7	7.47
Vault 4 betw cabinets	16	facing 4EE	4000283	11197	75	11199	89	82	-17.1	14.59
Vault 4 betw cabinets	16	facing 4EE	4001328	11203	66	11192	99	82.5	-40.0	14.68
Vault 4 betw cabinets	16	facing 4EE	#REF!	11193	69	11186	91	80	-27.5	14.23
Vault Corr - by Vault 1	33	to corridor	4000128	11214	27	11206	18	22.5	40.0	0.25
Vault Cor by V1	33	to corridor	4003095	11118	24	11112	21	22.5	13.3	0.25
Vault Cor by V1	33	to corridor	4001298	11147	19	11128	23	21	-19.0	0.23
Vault Cor by V1	34	to TEPC1172	4002815	11125	10	11121	18	14	-57.1	0.15
Vault Cor by V1	34	to TEPC1172	4000504	11139	14	11117	22	18	-44.4	0.20
Vault Cor by V1	34	to TEPC1172	4000060	11135	13	11136	19	16	-37.5	0.18
Vault Cor by V1	35	to TEPC1173	4001681	11188	19	11198	20	19.5	-5.1	0.21
Vault Cor by V1	35	to TEPC1173	4002937	11208	12	11211	26	19	-73.7	0.21
Vault Cor by V1	35	to TEPC1173	4001647	11205	17	11218	19	18	-11.1	0.20
Vault Cor by V1	36	to wall	4001535	11200	9	11201	10	9.5	-10.5	0.10
Vault Cor by V1	36	to wall	4001230	11204	4	11209	14	9	-111.1	0.10
Vault Cor by V1	36	to wall	4001222	11194	2	11137	13	7.5	-146.7	0.08
Vault Corr - by Vault 3	37	to corridor	4002839	11237	16	11246	25	20.5	-43.9	0.23
Vault Cor by V3	37	to corridor	4001672	11244	10	11224	23	16.5	-78.8	0.18
Vault Cor by V3	37	to corridor	4001467	11223	18	11230	8	13	76.9	0.14
Vault Cor by V3	38	to TEPC 504	4000232	11248	9	11234	13	11	-36.4	0.12
Vault Cor by V3	38	to TEPC 504	4000153	11252	11	11240	14	12.5	-24.0	0.14
Vault Cor by V3	38	to TEPC 504	4001293	11269	7	11287	19	13	-92.3	0.14
Vault Cor by V3	39	to wall	4003205	11243	31	11254	34	32.5	-9.2	0.36
Vault Cor by V3	39	to wall	4000086	11226	20	11255	42	31	-71.0	0.34
Vault Cor by V3	39	to wall	4001405	11253	37	11233	36	36.5	2.7	0.40
Vault Cor by V3	40	to TEPC 1170	4002983	11279	19	11229	15	17	23.5	0.19
Vault Cor by V3	40	to TEPC 1170	4001685	11239	16	11241	16	16	0.0	0.18
Vault Cor by V3	40	to TEPC 1170	4001616	11236	12	11220	27	19.5	-76.9	0.21

Table D.4. HSD Dosimeter Response

				Adjusted Chip Counts				Shallow			Eye			Deep	
Location	Packet #	Card ID #	Form-ula	Chip 1	Chip 2	Chip 3	Chip 4	Beta	Photon	Total	Beta	Photon	Total	Photon (mrem)	Neutron (mrem)
235A-3 South	1	4309	7303	47	44	46	816	0	46	46	0	44	44	44	665
235A-3 South	1	40744	7303	47	43	47	905	0	47	47	0	43	43	43	743
235A-3 South	1	21637	7303	46	43	44	891	0	44	44	0	43	43	43	731
235A-3 South	2	22248	7303	20	21	21	630	0	21	21	0	21	21	21	526
235A-3 South	2	32709	7303	26	26	26	659	0	26	26	0	26	26	26	546
235A-3 South	2	17188	9111	31	32	36	705	10	29	38	0	29	29	29	582
235A-3 South	3	41492	7303	33	27	29	664	0	29	29	0	27	27	27	548
235A-3 South	3	26734	7303	29	25	26	693	0	26	26	0	25	25	25	576
235A-3 South	3	21790	7303	23	20	20	656	0	20	20	0	20	20	20	549
235A-3 South	4	33420	7303	13	11	12	572	0	12	12	0	11	11	11	483
235A-3 South	4	42051	7303	12	12	12	611	0	12	12	0	12	12	12	517
235A-3 South	4	18946	9111	12	11	13	592	4	10	14	0	10	10	10	501
235A-3 South	5	12508	8111	57	67	79	568	0	56	56	0	55	55	50	451
235A-3 North	5	34819	8111	69	84	96	606	0	67	67	0	66	66	62	477
235A-3 North	5	20200	8111	82	94	106	669	0	78	78	0	76	76	74	519
235A-3 North	6	6484	9111	16	14	17	469	6	13	18	0	13	13	13	392
235A-3 North	6	40580	7303	15	15	15	487	0	15	15	0	15	15	15	408
235A-3 North	6	4108	8111	16	17	20	466	0	15	15	0	15	15	14	389
235A-3 North	7	30323	7303	31	26	25	530	0	26	26	0	26	26	26	434
235A-3 North	7	13374	7303	24	21	21	545	0	21	21	0	21	21	21	452
235A-3 North	7	29625	7303	19	18	18	481	0	18	18	0	18	18	18	399
235A-3 North	9	1115	8111	104	111	131	781	0	99	99	0	96	96	90	593
235A-3 North	9	43505	8111	101	107	123	789	0	96	96	0	92	92	89	601
235A-3 North	9	36361	8111	99	102	115	753	0	94	94	0	91	91	91	569
	Control	46971	9515	0	0	0	1	0	0	0	0	0	0	0	0
Vault 4 - back wall	8	5918	7303	22	21	22	1574	0	22	22	0	21	21	21	1339
Vault 4 - back wall	8	22863	7303	22	22	21	1587	0	22	22	0	22	22	22	1349
Vault 4 - back wall	8	8912	7303	22	22	19	1653	0	22	22	0	22	22	22	1406
Vault 4 - back wall	10	670	8111	14	15	11	1037	0	15	15	0	15	15	15	882
Vault 4 - back wall	10	38939	7303	14	14	12	1147	0	14	14	0	14	14	14	977
Vault 4 - back wall	10	22844	7303	17	16	14	1186	0	16	16	0	16	16	16	1008
Vault 4 - back wall	11	32241	7303	12	11	10	1031	0	11	11	0	11	11	11	879

Table D.4. HSD Dosimeter Response

				Adjusted Chip Counts				Shallow			Eye			Deep	
Location	Packet #	Card ID #	Form-ula	Chip 1	Chip 2	Chip 3	Chip 4	Beta	Photon	Total	Beta	Photon	Total	Photon (mrem)	Neutron (mrem)
Vault 4 - back wall	11	37609	7303	10	11	9	1030	0	11	11	0	11	11	11	879
Vault 4 - back wall	11	33560	7303	13	11	11	985	0	11	11	0	11	11	11	840
Vault 4 - back wall	12	26677	7303	18	16	17	1374	0	17	17	0	16	16	16	1171
Vault 4 - back wall	12	47161	7303	15	16	17	1297	0	17	17	0	16	16	16	1105
Vault 4 - back wall	12	29919	7303	16	15	14	1250	0	15	15	0	15	15	15	1064
	Control	31706	7101	0	0	0	0	0	0	0	0	0	0	0	0
Vault 4 - betw cabinets	13	2852	7303	73	73	77	1665	0	77	77	0	73	73	73	1373
Vault 4 - betw cabinets	13	46321	7303	78	76	78	1653	0	78	78	0	76	76	76	1359
Vault 4 - betw cabinets	13	3390	7303	79	72	71	1567	0	72	72	0	72	72	72	1289
Vault 4 - betw cabinets	14	37832	7303	147	151	149	1360	0	151	151	0	151	151	151	1052
Vault 4 - betw cabinets	14	33350	7303	142	143	147	1478	0	147	147	0	143	143	143	1153
Vault 4 - betw cabinets	14	27275	7303	132	121	114	1343	0	121	121	0	121	121	121	1053
Vault 4 - betw cabinets	15	46440	9111	34	32	44	1404	18	29	47	0	29	29	29	1183
Vault 4 - betw cabinets	15	15712	7303	34	33	33	1594	0	33	33	0	33	33	33	1346
Vault 4 - betw cabinets	15	3377	7303	35	34	36	1642	0	36	36	0	34	34	34	1387
Vault 4 - betw cabinets	16	41215	7303	115	120	117	1805	0	120	120	0	120	120	120	1464
Vault 4 - betw cabinets	16	17606	7303	135	134	139	1787	0	139	139	0	134	134	134	1426
Vault 4 - betw cabinets	16	28992	7303	137	131	138	1816	0	138	138	0	131	131	131	1453
	Control	46107	7101	0	0	0	0	0	0	0	0	0	0	0	0
Vault 1: Corridor	17	10025	7303	13	12	12	960	0	12	12	0	12	12	12	817
Vault 1: Corridor	17	23341	9212	13	12	25	962	15	10	25	2	10	12	10	819
Vault 1: Corridor	17	16922	9111	15	12	14	955	5	10	15	1	10	11	10	813
Vault 1: Corridor	18	37182	9111	10	9	11	818	4	8	11	0	8	8	8	698
Vault 1: Corridor	18	40416	7303	12	10	10	840	0	10	10	0	10	10	10	716
Vault 1: Corridor	18	26787	7303	11	10	11	823	0	11	11	0	10	10	10	700
Vault 1: Corridor	19	37063	9111	11	8	10	836	4	8	11	0	8	8	8	713
Vault 1: Corridor	19	31062	7303	10	10	10	777	0	10	10	0	10	10	10	661
Vault 1: Corridor	19	10556	9111	10	9	12	779	5	8	12	0	8	8	8	664
Vault 1: Corridor	20	42860	9111	13	12	15	1092	5	11	16	0	11	11	11	931
Vault 1: Corridor	20	39602	7303	12	11	12	1075	0	12	12	0	11	11	11	917
Vault 1: Corridor	20	31107	7303	13	11	12	1041	0	12	12	0	11	11	11	887
	Control	36724	8212	0	0	0	0	0	0	0	0	0	0	0	0

Table D.4. HSD Dosimeter Response

				Adjusted Chip Counts				Shallow			Eye			Deep	
Location	Packet #	Card ID #	Form-ula	Chip 1	Chip 2	Chip 3	Chip 4	Beta	Photon	Total	Beta	Photon	Total	Photon (mrem)	Neutron (mrem)
Vault 1: Betw cabinets	21	42970	7303	29	26	29	1980	0	29	29	0	26	26	26	1685
Vault 1: Betw cabinets	21	12091	7303	31	27	27	2003	0	27	27	0	27	27	27	1703
Vault 1: Betw cabinets	21	40423	7303	29	28	30	2054	0	30	30	0	28	28	28	1747
Vault 1: Betw cabinets	22	13266	7303	27	26	28	1608	0	28	28	0	26	26	26	1363
Vault 1: Betw cabinets	22	22465	7303	29	26	26	1574	0	26	26	0	26	26	26	1334
Vault 1: Betw cabinets	22	35946	7303	30	29	29	1683	0	29	29	0	29	29	29	1426
Vault 1: Betw cabinets	23	43091	9111	39	36	41	2992	11	33	44	0	33	33	33	2548
Vault 1: Betw cabinets	23	15081	9111	43	39	50	3288	17	36	53	0	36	36	36	2801
Vault 1: Betw cabinets	23	2667	9111	43	39	45	3250	12	35	47	0	35	35	35	2768
Vault 1: Betw cabinets	24	25467	7303	37	33	33	2056	0	33	33	0	33	33	33	1744
Vault 1: Betw cabinets	24	25743	9111	32	29	34	1987	9	26	36	0	26	26	26	1687
Vault 1: Betw cabinets	24	3041	7303	32	30	31	1922	0	31	31	0	30	30	30	1631
	Control	36234	7101	0	0	0	0	0	0	0	0	0	0	0	0
	Control	16222	7101	0	0	0	0	0	0	0	0	0	0	0	0
Vault 2: Betw cabinets	25	6409	7303	817	802	813	3237	0	813	813	0	802	802	802	2099
Vault 2: Betw cabinets	25	35275	7303	828	777	791	3149	0	791	791	0	777	777	777	2046
Vault 2: Betw cabinets	25	22089	7303	835	816	821	3052	0	821	821	0	816	816	816	1927
Vault 2: Betw cabinets	26	23553	7303	1091	1064	1038	3252	0	1064	1064	0	1064	1064	1064	1886
Vault 2: Betw cabinets	26	14206	7303	985	970	958	3364	0	970	970	0	970	970	970	2064
Vault 2: Betw cabinets	26	5804	7303	961	1022	998	3263	0	1022	1022	0	1022	1022	1022	2064
Vault 2: Betw cabinets	27	40868	7303	1104	1130	1071	3110	0	1130	1130	0	1130	1130	1130	1767
Vault 2: Betw cabinets	27	44135	7303	1138	1143	1063	3227	0	1143	1143	0	1143	1143	1143	1809
Vault 2: Betw cabinets	27	31839	7303	1096	1081	1018	3115	0	1081	1081	0	1081	1081	1081	1754
Vault 2: Betw cabinets	28	2873	7303	973	912	897	3127	0	912	912	0	912	912	912	1909
Vault 2: Betw cabinets	28	31582	7303	899	864	893	3359	0	893	893	0	864	864	864	2151
Vault 2: Betw cabinets	28	3064	7303	978	1040	1007	3445	0	1040	1040	0	1040	1040	1040	2207
	Control	3845	9515	0	0	0	0	0	0	0	0	0	0	0	0
	Control	3894	6011	0	0	8	0	11	0	11	1	0	1	0	0
Vault 2 - by wall	29	44026	7303	399	410	417	2417	0	417	417	0	410	410	410	1754
Vault 2 - by wall	29	16423	7303	417	418	424	2613	0	424	424	0	418	418	418	1896
Vault 2 - by wall	29	43120	7303	420	423	425	2439	0	425	425	0	423	423	423	1746
Vault 2 - by wall	30	40546	9111	127	127	144	1798	38	115	153	0	115	115	115	1441

Table D.4. HSD Dosimeter Response

				Adjusted Chip Counts				Shallow			Eye			Deep	
Location	Packet #	Card ID #	Form-ula	Chip 1	Chip 2	Chip 3	Chip 4	Beta	Photon	Total	Beta	Photon	Total	Photon (mrem)	Neutron (mrem)
Vault 2 - by wall	30	45659	7303	145	150	157	1917	0	157	157	0	150	150	150	1536
Vault 2 - by wall	30	5954	7303	182	196	198	2036	0	198	198	0	196	196	196	1615
Vault 2 - by wall	31	40593	7303	161	132	132	2181	0	132	132	0	132	132	132	1767
Vault 2 - by wall	31	42560	7303	120	107	106	2021	0	107	107	0	107	107	107	1650
Vault 2 - by wall	31	42272	7303	107	106	107	2031	0	107	107	0	106	106	106	1660
Vault 2 - by wall	32	25822	7303	373	369	368	2446	0	369	369	0	369	369	369	1791
Vault 2 - by wall	32	31145	7303	373	359	358	2609	0	359	359	0	359	359	359	1940
Vault 2 - by wall	32	34438	7303	345	327	329	2542	0	329	329	0	327	327	327	1910
	Control	22799	7101	0	0	0	1	0	0	0	0	0	0	0	0
	Control	10825	9515	0	1	3	0	3	0	3	0	0	0	0	0
	Control	46090	6011	0	0	5	0	6	0	6	1	0	1	0	0
Vault Corridor - by V1	33	57774	9111	25	21	25	2017	7	19	26	0	19	19	19	1721
Vault Corridor - by V1	33	42955	9111	25	21	25	2118	7	19	26	0	19	19	19	1808
Vault Corridor - by V1	33	28591	9111	23	21	24	1976	7	19	26	0	19	19	19	1686
Vault Corridor - by V1	34	29821	9111	24	21	27	1842	10	19	29	0	19	19	19	1569
Vault Corridor - by V1	34	36873	7303	23	21	23	1834	0	23	23	0	21	21	21	1563
Vault Corridor - by V1	34	37791	9111	23	21	30	1733	13	19	32	0	19	19	19	1476
Vault Corridor - by V1	35	12335	7303	23	22	23	1810	0	23	23	0	22	22	22	1541
Vault Corridor - by V1	35	6551	9111	25	22	26	1927	8	20	27	0	20	20	20	1642
Vault Corridor - by V1	35	30830	7303	23	21	23	1799	0	23	23	0	21	21	21	1533
Vault Corridor - by V1	36	45443	7303	23	21	21	1492	0	21	21	0	21	21	21	1268
Vault Corridor - by V1	36	41556	9111	22	20	25	1474	8	18	26	0	18	18	18	1254
Vault Corridor - by V1	36	43156	9111	22	21	25	1488	7	19	26	0	19	19	19	1264
	Control	20227	9515	0	0	0	0	0	0	0	0	0	0	0	0
	Control	33482	8212	0	1	1	1	0	1	1	0	1	1	1	0
Vault Corridor - by V3	37	41258	7303	25	23	25	1722	0	25	25	0	23	23	23	1464
Vault Corridor - by V3	37	44338	7303	25	23	23	1802	0	23	23	0	23	23	23	1534
Vault Corridor - by V3	37	40747	7303	26	23	25	1770	0	25	25	0	23	23	23	1507
Vault Corridor - by V3	38	31657	7303	28	27	30	2303	0	30	30	0	27	27	27	1962
Vault Corridor - by V3	38	16530	9111	28	24	29	1753	8	22	30	0	22	22	22	1491
Vault Corridor - by V3	38	41235	7303	29	26	27	1976	0	27	27	0	26	26	26	1681
Vault Corridor - by V3	39	18997	7303	31	29	32	2796	0	32	32	0	29	29	29	2385

Table D.4. HSD Dosimeter Response

				Adjusted Chip Counts				Shallow			Eye			Deep	
Location	Packet #	Card ID #	Form-ula	Chip 1	Chip 2	Chip 3	Chip 4	Beta	Photon	Total	Beta	Photon	Total	Photon (mrem)	Neutron (mrem)
Vault Corridor - by V3	39	3385	7303	34	33	33	2722	0	33	33	0	33	33	33	2318
Vault Corridor - by V3	39	7020	9111	33	29	35	2979	11	26	37	0	26	26	26	2543
Vault Corridor - by V3	40	39158	7303	30	26	28	2023	0	28	28	0	26	26	26	1722
Vault Corridor - by V3	40	29151	7303	30	27	27	1927	0	27	27	0	27	27	27	1638
Vault Corridor - by V3	40	41084	7303	30	27	28	2144	0	28	28	0	27	27	27	1825
	Control	29306	8212	1	0	0	0	0	0	0	0	0	0	0	0
	Control	20387	8212	2	1	0	1	0	1	1	0	1	1	1	0

APPENDIX E

EXTREMITY TEPC RESULTS

Program TEPC_NG

Version: December, 1989

INPUT FILE NAME: t04ox20b.txt

FILE TITLE: TEPC 504 at 12” from 20% Oxide can. Rm 637, ZB. 9/7-9/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 183943 sec

Proton Drop Point = Channel 205 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 20 equivalent to 9.6 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.06E+05	5.06E+05
Counts*Ch	0.00E+00	3.48E+07	0.00E+00
Counts*Ch2	0.00E+00	3.45E+09	0.00E+00
Y-bar F	.0	32.8	32.8
Y-bar D	.0	47.5	47.5
L-bar D	.0	42.2	42.2

Restricted y-bar D between 9.6 and 115 keV/micron is 48.0

Average Neutron Energy is 1.5 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.15E+01	3.15E+01
Standard Deviation	0.00E+00	4.43E-02	4.43E-02
Quality Factors	1.0	10.3	10.3
Integral DE, mrem	0.00E+00	3.23E+02	3.23E+02
Dose Rate, mrad/hr	0.00E+00	6.17E-01	6.17E-01
DE Rate, mrem/hr	0.00E+00	6.32E+00	6.32E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t74ox2~1.dat
FILE TITLE: TEPC 1074 in Index finger by 20% oxide,Rm 637 ZB. 9/7-9/9
(728 alpha cts subtracted off)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 184139 sec

Proton Drop Point = Channel 294 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 55 equivalent to 18.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.68E+03	5.68E+03
Counts*Ch	0.00E+00	7.20E+05	0.00E+00
Counts*Ch2	0.00E+00	1.38E+08	0.00E+00
Y-bar F	.0	43.6	43.6
Y-bar D	.0	65.7	65.7
L-bar D	.0	58.4	58.4

Restricted y-bar D between 18.9 and 115 keV/micron is 59.6
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	4.70E+01	4.70E+01
Standard Deviation	0.00E+00	6.23E-01	6.23E-01
Quality Factors	1.0	12.3	12.3
Integral DE, mrem	0.00E+00	5.75E+02	5.75E+02
Dose Rate, mrad/hr	0.00E+00	9.18E-01	9.18E-01
DE Rate, mrem/hr	0.00E+00	1.12E+01	1.12E+01

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t22ox2~1.dat
FILE TITLE: TEPC 1122 in Ring finger, 20% Oxide, ZB 637. 9/7-9/99.
(2769 alpha cts subtracted off)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 184137 sec

Proton Drop Point = Channel 359 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 75 equivalent to 21.1 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.56E+03	5.56E+03
Counts*Ch	0.00E+00	8.67E+05	0.00E+00
Counts*Ch2	0.00E+00	2.06E+08	0.00E+00
Y-bar F	.0	43.9	43.9
Y-bar D	.0	66.8	66.8
L-bar D	.0	59.4	59.4

Restricted y-bar D between 21.1 and 115 keV/micron is 58.4
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	4.63E+01	4.63E+01
Standard Deviation	0.00E+00	6.21E-01	6.21E-01
Quality Factors	1.0	12.1	12.1
Integral DE, mrem	0.00E+00	5.60E+02	5.60E+02
Dose Rate, mrad/hr	0.00E+00	9.05E-01	9.05E-01
DE Rate, mrem/hr	0.00E+00	1.09E+01	1.09E+01

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t04ox12b.txt
FILE TITLE: TEPC 504 at 12-in from Oxide 12% can, ZB. 9/9-13/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 342813 sec

Proton Drop Point = Channel 188 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 19 equivalent to 9.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	3.29E+05	3.29E+05
Counts*Ch	0.00E+00	2.30E+07	0.00E+00
Counts*Ch2	0.00E+00	2.17E+09	0.00E+00
Y-bar F	.0	36.4	36.4
Y-bar D	.0	49.2	49.2
L-bar D	.0	43.8	43.8

Restricted y-bar D between 9.9 and 115 keV/micron is 53.2
Average Neutron Energy is 1.1 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	2.27E+01	2.27E+01
Standard Deviation	0.00E+00	3.96E-02	3.96E-02
Quality Factors	1.0	10.7	10.7
Integral DE, mrem	0.00E+00	2.42E+02	2.42E+02
Dose Rate, mrad/hr	0.00E+00	2.39E-01	2.39E-01
DE Rate, mrem/hr	0.00E+00	2.55E+00	2.55E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t74ox1~1.dat
FILE TITLE: TEPC 1074, index finger: 12% oxide, ZB 637, 9/9-13/99.
(subtracted of 1415 alpha counts)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 343216 sec

Proton Drop Point = Channel 302 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 56 equivalent to 18.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.97E+03	4.97E+03
Counts*Ch	0.00E+00	6.76E+05	0.00E+00
Counts*Ch2	0.00E+00	1.50E+08	0.00E+00
Y-bar F	.0	45.5	45.5
Y-bar D	.0	74.2	74.2
L-bar D	.0	66.0	66.0

Restricted y-bar D between 18.7 and 115 keV/micron is 59.4
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	4.29E+01	4.29E+01
Standard Deviation	0.00E+00	6.08E-01	6.08E-01
Quality Factors	1.0	12.7	12.7
Integral DE, mrem	0.00E+00	5.45E+02	5.45E+02
Dose Rate, mrad/hr	0.00E+00	4.50E-01	4.50E-01
DE Rate, mrem/hr	0.00E+00	5.72E+00	5.72E+00

Version: December, 1989

INPUT FILE NAME: t22ox12.txt
FILE TITLE:

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 343099 sec

Proton Drop Point = Channel 344 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 64 equivalent to 18.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.36E+03	5.36E+03
Counts*Ch	0.00E+00	7.43E+05	0.00E+00
Counts*Ch2	0.00E+00	1.52E+08	0.00E+00
Y-bar F	.0	40.7	40.7
Y-bar D	.0	59.9	59.9
L-bar D	.0	53.3	53.3

Restricted y-bar D between 18.8 and 115 keV/micron is 57.8
Average Neutron Energy is .8 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	4.14E+01	4.14E+01
Standard Deviation	0.00E+00	5.65E-01	5.65E-01
Quality Factors	1.0	11.7	11.7
Integral DE, mrem	0.00E+00	4.83E+02	4.83E+02
Dose Rate, mrad/hr	0.00E+00	4.34E-01	4.34E-01
DE Rate, mrem/hr	0.00E+00	5.07E+00	5.07E+00

Version: December, 1989

INPUT FILE NAME: t04mtl~1.txt

FILE TITLE: TEPC 504 at 12” from Pu Metal can. 9/13-16/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns

GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 4532 sec

Proton Drop Point = Channel 339 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 86 equivalent to 24.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.04E+04	1.04E+04
Counts*Ch	0.00E+00	1.63E+06	0.00E+00
Counts*Ch2	0.00E+00	3.22E+08	0.00E+00
Y-bar F	.0	45.2	45.2
Y-bar D	.0	57.3	57.3
L-bar D	.0	50.9	50.9

Restricted y-bar D between 24.9 and 115 keV/micron is 65.9

The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	8.93E-01	8.93E-01
Standard Deviation	0.00E+00	8.75E-03	8.75E-03
Quality Factors	1.0	12.0	12.0
Integral DE, mrem	0.00E+00	1.07E+01	1.07E+01
Dose Rate, mrad/hr	0.00E+00	7.09E-01	7.09E-01
DE Rate, mrem/hr	0.00E+00	8.48E+00	8.48E+00

Version: December, 1989

INPUT FILE NAME: t74mtl~1.dat
FILE TITLE: TEPC 1074, index finger: Metal can. ZB 637. 9/13-16/99.
(subtracted off 861 alpha counts)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 162355 sec

Proton Drop Point = Channel 302 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 56 equivalent to 18.7 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	7.36E+03	7.36E+03
Counts*Ch	0.00E+00	9.23E+05	0.00E+00
Counts*Ch2	0.00E+00	1.72E+08	0.00E+00
Y-bar F	.0	41.9	41.9
Y-bar D	.0	62.3	62.3
L-bar D	.0	55.3	55.3

Restricted y-bar D between 18.7 and 115 keV/micron is 58.8
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	5.85E+01	5.85E+01
Standard Deviation	0.00E+00	6.82E-01	6.82E-01
Quality Factors	1.0	11.8	11.8
Integral DE, mrem	0.00E+00	6.92E+02	6.92E+02
Dose Rate, mrad/hr	0.00E+00	1.30E+00	1.30E+00
DE Rate, mrem/hr	0.00E+00	1.53E+01	1.53E+01

Version: December, 1989

INPUT FILE NAME: t22mtl2.txt
FILE TITLE: TEPC 1122 in Ring Finger, glove. Pu Metal can. 9/16/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER=   1.3 cm   SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read   Live time = 162265 sec

Proton Drop Point = Channel   361 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 85 equivalent to 23.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.98E+03	5.98E+03
Counts*Ch	0.00E+00	1.01E+06	0.00E+00
Counts*Ch2	0.00E+00	2.30E+08	0.00E+00
Y-bar F	.0	47.1	47.1
Y-bar D	.0	64.0	64.0
L-bar D	.0	56.9	56.9

Restricted y-bar D between 23.8 and 115 keV/micron is 67.2
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	5.35E+01	5.35E+01
Standard Deviation	0.00E+00	6.91E-01	6.91E-01
Quality Factors	1.0	12.4	12.4
Integral DE, mrem	0.00E+00	6.62E+02	6.62E+02
Dose Rate, mrad/hr	0.00E+00	1.19E+00	1.19E+00
DE Rate, mrem/hr	0.00E+00	1.47E+01	1.47E+01

Version: December, 1989

INPUT FILE NAME: t74ox6~1.dat

FILE TITLE: TEPC 1074 in Index finger by 6% Oxide can. 9/20-22/99
(subtracted off 671 alpha counts)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 178328 sec

Proton Drop Point = Channel 300 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 50 equivalent to 16.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	6.98E+03	6.98E+03
Counts*Ch	0.00E+00	8.48E+05	0.00E+00
Counts*Ch2	0.00E+00	1.65E+08	0.00E+00
Y-bar F	.0	40.9	40.9
Y-bar D	.0	65.5	65.5
L-bar D	.0	58.2	58.2

Restricted y-bar D between 16.8 and 115 keV/micron is 56.1
Average Neutron Energy is .9 MeV

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	5.41E+01	5.41E+01
Standard Deviation	0.00E+00	6.48E-01	6.48E-01
Quality Factors	1.0	11.9	11.9
Integral DE, mrem	0.00E+00	6.47E+02	6.47E+02
Dose Rate, mrad/hr	0.00E+00	1.09E+00	1.09E+00
DE Rate, mrem/hr	0.00E+00	1.31E+01	1.31E+01

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t22ox6.txt
FILE TITLE: TEPC 1122 in Ring finger by 6% Oxide can, ZB. 9/20-22/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 178326 sec

Proton Drop Point = Channel 335 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 69 equivalent to 20.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	5.51E+03	5.51E+03
Counts*Ch	0.00E+00	7.79E+05	0.00E+00
Counts*Ch2	0.00E+00	1.51E+08	0.00E+00
Y-bar F	.0	42.6	42.6
Y-bar D	.0	58.6	58.6
L-bar D	.0	52.1	52.1

Restricted y-bar D between 20.8 and 115 keV/micron is 61.4
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	4.45E+01	4.45E+01
Standard Deviation	0.00E+00	6.00E-01	6.00E-01
Quality Factors	1.0	11.8	11.8
Integral DE, mrem	0.00E+00	5.24E+02	5.24E+02
Dose Rate, mrad/hr	0.00E+00	8.99E-01	8.99E-01
DE Rate, mrem/hr	0.00E+00	1.06E+01	1.06E+01

Version: December, 1989

INPUT FILE NAME: t70foil.txt
FILE TITLE: TEPC 1170 at 12” from 17% Oxide can with foil. ZB. 9/22-24/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 164311 sec

Proton Drop Point = Channel 271 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 70 equivalent to 25.3 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.74E+05	1.74E+05
Counts*Ch	0.00E+00	2.18E+07	0.00E+00
Counts*Ch2	0.00E+00	3.49E+09	0.00E+00
Y-bar F	.0	45.4	45.4
Y-bar D	.0	57.9	57.9
L-bar D	.0	51.5	51.5

Restricted y-bar D between 25.3 and 115 keV/micron is 65.8
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

Integral Dose, mrad	0.00E+00	1.50E+01	1.50E+01
Standard Deviation	0.00E+00	3.59E-02	3.59E-02
Quality Factors	1.0	12.0	12.0
Integral DE, mrem	0.00E+00	1.79E+02	1.79E+02
Dose Rate, mrad/hr	0.00E+00	3.28E-01	3.28E-01
DE Rate, mrem/hr	0.00E+00	3.93E+00	3.93E+00

Version: December, 1989

INPUT FILE NAME: t74foi~1.dat
FILE TITLE: TEPC 1074, Index finger, 17% Oxide w/ foil. ZB 637. 9/22-24/99
(subtracted off 862 alpha counts)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 164816 sec

Proton Drop Point = Channel 295 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 58 equivalent to 19.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	4.00E+03	4.00E+03
Counts*Ch	0.00E+00	5.10E+05	0.00E+00
Counts*Ch2	0.00E+00	1.07E+08	0.00E+00
Y-bar F	.0	43.7	43.7
Y-bar D	.0	72.0	72.0
L-bar D	.0	64.0	64.0

Restricted y-bar D between 19.9 and 115 keV/micron is 57.2
Average Neutron Energy is .8 MeV

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.31E+01	3.31E+01
Standard Deviation	0.00E+00	5.24E-01	5.24E-01
Quality Factors	1.0	12.2	12.2
Integral DE, mrem	0.00E+00	4.04E+02	4.04E+02
Dose Rate, mrad/hr	0.00E+00	7.24E-01	7.24E-01
DE Rate, mrem/hr	0.00E+00	8.82E+00	8.82E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t22foil.txt
FILE TITLE: TEPC 1122 in Ring finger, near 17% Oxide w/ Foil. ZB Rm 6

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 164296 sec

Proton Drop Point = Channel 314 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 71 equivalent to 22.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	3.91E+03	3.91E+03
Counts*Ch	0.00E+00	5.49E+05	0.00E+00
Counts*Ch2	0.00E+00	1.04E+08	0.00E+00
Y-bar F	.0	45.2	45.2
Y-bar D	.0	60.7	60.7
L-bar D	.0	54.0	54.0

Restricted y-bar D between 22.8 and 115 keV/micron is 64.8
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	3.35E+01	3.35E+01
Standard Deviation	0.00E+00	5.36E-01	5.36E-01
Quality Factors	1.0	12.2	12.2
Integral DE, mrem	0.00E+00	4.08E+02	4.08E+02
Dose Rate, mrad/hr	0.00E+00	7.34E-01	7.34E-01
DE Rate, mrem/hr	0.00E+00	8.93E+00	8.93E+00

Version: December, 1989

INPUT FILE NAME: t70wpb.txt
FILE TITLE: TEPC 1170 at 12" from 17% Oxide w/ Pb shield. ZB 637. 9/24-27/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Methane-TE	20.0	11.3	1.138	.016909

CHAMBER DIAMETER= 12.7 cm   SITE EQUIVALENT DIAMETER= 2.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read   Live time = 243274 sec

Proton Drop Point = Channel   273 equivalent to 98.0 keV/micron

Neutron Start Point = Channel 69 equivalent to 24.8 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	7.13E+04	7.13E+04
Counts*Ch	0.00E+00	8.92E+06	0.00E+00
Counts*Ch2	0.00E+00	1.42E+09	0.00E+00
Y-bar F	.0	44.9	44.9
Y-bar D	.0	56.9	56.9
L-bar D	.0	50.6	50.6

Restricted y-bar D between 24.8 and 115 keV/micron is 65.2
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	6.08E+00	6.08E+00
Standard Deviation	0.00E+00	2.28E-02	2.28E-02
Quality Factors	1.0	11.9	11.9
Integral DE, mrem	0.00E+00	7.23E+01	7.23E+01
Dose Rate, mrad/hr	0.00E+00	8.99E-02	8.99E-02
DE Rate, mrem/hr	0.00E+00	1.07E+00	1.07E+00

Version: December, 1989

INPUT FILE NAME: t74wpb~2.dat
FILE TITLE: TEPC 1074 in Index finger, 17% Oxide can with Pb shield. 9/24-27/99 (1017 alpha cts subtracted off)

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 242962 sec

Proton Drop Point = Channel 295 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 58 equivalent to 19.9 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.74E+03	1.74E+03
Counts*Ch	0.00E+00	2.53E+05	0.00E+00
Counts*Ch2	0.00E+00	6.16E+07	0.00E+00
Y-bar F	.0	50.0	50.0
Y-bar D	.0	83.3	83.3
L-bar D	.0	74.0	74.0

Restricted y-bar D between 19.9 and 115 keV/micron is 60.7
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	1.65E+01	1.65E+01
Standard Deviation	0.00E+00	3.95E-01	3.95E-01
Quality Factors	1.0	13.3	13.3
Integral DE, mrem	0.00E+00	2.19E+02	2.19E+02
Dose Rate, mrad/hr	0.00E+00	2.44E-01	2.44E-01
DE Rate, mrem/hr	0.00E+00	3.25E+00	3.25E+00

Program TEPC_NG
Version: December, 1989

INPUT FILE NAME: t22wpb.txt
FILE TITLE:TEPC 1122 in Ring finger, 17% Oxide with Pb Shield 9/24-27/99

TEPC OUTPUT SUMMARY

----TEPC OPERATING PARAMETERS----

GAS	GAS TEMPERATURE (deg-C)	GAS PRESSURE (torr)	GAS DENSITY (g/l)	GAS MASS (g)
Propane-TE	22.0	33.5	1.929	.000084

CHAMBER DIAMETER= 1.3 cm SITE EQUIVALENT DIAMETER= 1.00 microns
GEOMETRY FACTOR : 1.5

2048 Data Channels read Live time = 243121 sec

Proton Drop Point = Channel 313 equivalent to 101.0 keV/micron

Neutron Start Point = Channel 70 equivalent to 22.6 keV/micron

No Gamma Data

----DISTRIBUTION PARAMETERS----

	gamma	neutron	total
Counts/Ch	0.00E+00	1.62E+03	1.62E+03
Counts*Ch	0.00E+00	2.37E+05	0.00E+00
Counts*Ch2	0.00E+00	4.65E+07	0.00E+00
Y-bar F	.0	47.2	47.2
Y-bar D	.0	63.3	63.3
L-bar D	.0	56.2	56.2

Restricted y-bar D between 22.6 and 115 keV/micron is 68.2
The average energy cannot be calculated

----DOSE AND DOSE EQUIVALENT DATA----

	gamma	neutron	total
Integral Dose, mrad	0.00E+00	1.45E+01	1.45E+01
Standard Deviation	0.00E+00	3.61E-01	3.61E-01
Quality Factors	1.0	12.5	12.5
Integral DE, mrem	0.00E+00	1.82E+02	1.82E+02
Dose Rate, mrad/hr	0.00E+00	2.15E-01	2.15E-01
DE Rate, mrem/hr	0.00E+00	2.69E+00	2.69E+00

APPENDIX F

EXTREMITY DOSIMETER RESULTS

EXTREMITY DOSIMETER RESULTS

Source Can	Glove Finger	Dosimeter ID	Exposure Time (hrs)	Integrated Dose (mrem)	Dose rate mrem/h	Std Dev	Comments
	Control	34605		2			
20% Oxide	Index	34598	51.2	5892	115		
20% Oxide	Index	34644	51.2	7009	137		
20% Oxide	Index	34696	51.2	5137	100		
20% Oxide	Index	34731	51.2	6380	125		
20% Oxide	Index	34778	51.2	5853	114		
20% Oxide	Index				118	14	Avg, std dev
	Control	34650		3			
20% Oxide	Middle	34539	146.9	11535	79		left in glove finger for 2 cans
20% Oxide	Middle	34568	51.2	6144	120		
20% Oxide	Middle	34649	51.2	8160	159		
20% Oxide	Middle	34671	51.2	7154	140		
20% Oxide	Middle	34743	51.2	6435	126		
20% Oxide	Middle				136	18	4-dosimeter average, std dev
	Control	34560		10			
20% Oxide	Ring	34542	51.4	7281	142		
20% Oxide	Ring	34602	51.4	7964	155		
20% Oxide	Ring	34669	51.4	5958	116		
20% Oxide	Ring	34748	51.4	5844	114		
20% Oxide	Ring	34758	51.4	5899	115		
20% Oxide	Ring				128	19	Avg, std dev
	Control	34625		4			
20% Oxide	Little	34628	51.1	7201	141		
20% Oxide	Little	34631	51.1	6626	130		
20% Oxide	Little	34656	51.1	6653	130		
20% Oxide	Little	34683	51.1	6805	133		
20% Oxide	Little	34704	51.1	6936	136		
20% Oxide	Little				134	5	Avg, std dev
	Control	34593		0			
12% Oxide	Index	34536	95.4	2719	29		
12% Oxide	Index	34577	95.4	3600	38		
12% Oxide	Index	34662	95.4	4046	42		
12% Oxide	Index	34663	95.4	3423	36		
12% Oxide	Index	34760	95.4	3765	39		
12% Oxide	Index				37	5	Avg, std dev
	Control	34585		7			
12% Oxide	Middle	34626	95.2	5281	55		
12% Oxide	Middle	34678	95.2	4194	44		
12% Oxide	Middle	34679	95.2	3816	40		
12% Oxide	Middle	34707	95.2	4230	44		
12% Oxide	Middle	34750	95.2	3507	37		
12% Oxide	Middle				44	7	Avg, std dev

Source Can	Glove Finger	Dosimeter ID	Exposure Time (hrs)	Integrated Dose (mrem)	Dose rate mrem/h	Std Dev	Comments
	Control	34595		0			
12% Oxide	Ring	34537	95.3	4179	44		
12% Oxide	Ring	34627	95.3	3715	39		
12% Oxide	Ring	34665	95.3	5008	53		
12% Oxide	Ring	34681	95.3	4236	44		
12% Oxide	Ring	34757	95.3	4343	46		
12% Oxide	Ring				45	5	Avg, std dev
	Control	34596		10			
12% Oxide	Little	34619	95.2	4467	47		
12% Oxide	Little	34645	95.2	6070	64		
12% Oxide	Little	34648	95.2	3414	36		
12% Oxide	Little	34668	95.2	3301	35		
12% Oxide	Little	34701	95.2	3520	37		
12% Oxide	Little				44	12	Avg, std dev
	Control	34768		2			
12% Oxide	None	34541	95.2	6688	70		
12% Oxide	None	34551	95.2	6332	67		
12% Oxide	None	34621	95.2	8191	86		
12% Oxide	None	34661	95.2	7756	81		
12% Oxide	None	34700	95.2	6759	71		
12% Oxide	None				75	8	Avg, std dev
	Control	34741		0			
Metal	Index	34612	69.1	2162	31		Possible confusion between
Metal	Index	34653	69.1	1931	28		packets 10, 11 & 13
Metal	Index	34694	69.1	1965	28		(not completely sure which packet
Metal	Index	34713	69.1	2242	32		was on which finger)
Metal	Index	34776	69.1	2625	38		
Metal	Index				32	4	Avg, std dev
	Control	34710		6			
Metal	Middle	34558	69.0	2831	41		Possible confusion between
Metal	Middle	34616	69.0	2426	35		packets 10, 11 & 13
Metal	Middle	34622	69.0	2180	32		(not completely sure which packet
Metal	Middle	34667	69.0	2648	38		was on which finger)
Metal	Middle	34717	69.0	2088	30		
Metal	Middle				35	5	Avg, std dev
	Control	34685		1			
Metal	Ring	34591	69.2	2519	36		
Metal	Ring	34673	69.2	2054	30		
Metal	Ring	34716	69.2	2505	36		
Metal	Ring	34759	69.2	1912	28		
Metal	Ring	34765	69.2	2118	31		
Metal	Ring				32	4	Avg, std dev
	Control	34753		0			
Metal	Little	34615	69.1	2300	33		Possible confusion between

Source Can	Glove Finger	Dosimeter ID	Exposure Time (hrs)	Integrated Dose (mrem)	Dose rate mrem/h	Std Dev	Comments
Metal	Little	34684	69.1	1901	28		packets 10, 11 & 13
Metal	Little	34719	69.1	2853	41		(not completely sure which packet
Metal	Little	34761	69.1	2797	40		was on which finger)
Metal	Little	34764	69.1	2810	41		
Metal	Little				37	6	Avg, std dev
	Control	34550		3			
Metal	None	34569	69.0	3490	51		
Metal	None	34620	69.0	3714	54		
Metal	None	34688	69.0	4196	61		
Metal	None	34749	69.0	3591	52		
Metal	None	34767	69.0	3552	51		
Metal	None				54	4	Avg, std dev
	Control	34538		9			
Wkend Bkgd	Index	34547	98.3	9	0.087		
Wkend Bkgd	Index	34557	98.3	8	0.083		
Wkend Bkgd	Index	34566	98.3	20	0.199		
Wkend Bkgd	Index	34640	98.3	14	0.140		
Wkend Bkgd	Index	34771	98.3	9	0.096		
Wkend Bkgd	Index				0.121	0.049	Avg, std dev
	Control	34763		0			
Wkend Bkgd	Middle	34647	98.3	0	0.001		
Wkend Bkgd	Middle	34703	98.3	7	0.073		
Wkend Bkgd	Middle	34705	98.3	24	0.239		
Wkend Bkgd	Middle	34728	98.3	12	0.120		
Wkend Bkgd	Middle	34738	98.3	2	0.023		
Wkend Bkgd	Middle				0.091	0.095	Avg, std dev
	Control	34586		4			
Wkend Bkgd	Ring	34543	98.3	1	0.008		
Wkend Bkgd	Ring	34581	98.3	3	0.028		
Wkend Bkgd	Ring	34639	98.3	36	0.367		
Wkend Bkgd	Ring	34682	98.3	0	0.002		
Wkend Bkgd	Ring	34782	98.3	10	0.107		
Wkend Bkgd	Ring				0.102	0.154	Avg, std dev
	Control	34601		22			
Wkend Bkgd	Little	34575	98.3	9	0.090		
Wkend Bkgd	Little	34583	98.3	13	0.134		
Wkend Bkgd	Little	34611	98.3	3	0.030		
Wkend Bkgd	Little	34618	98.3	5	0.051		
Wkend Bkgd	Little	34672	98.3	0	0.001		
Wkend Bkgd	Little				0.061	0.052	Avg, std dev
	Control	34570		3			
Wkend Bkgd	None	34540	98.3	0	0.001		
Wkend Bkgd	None	34556	98.3	9	0.093		
Wkend Bkgd	None	34564	98.3	15	0.155		

Source Can	Glove Finger	Dosimeter ID	Exposure Time (hrs)	Integrated Dose (mrem)	Dose rate mrem/h	Std Dev	Comments
Wkend Bkgd	None	34608	98.3	14	0.138		
Wkend Bkgd	None	34698	98.3	4	0.042		
Wkend Bkgd	None				0.086	0.064	Avg, std dev
	Control	34582		6			
6% Oxide	Index	34563	49.7	1958	39		
6% Oxide	Index	34607	49.7	1445	29		
6% Oxide	Index	34637	49.7	1530	31		
6% Oxide	Index	34657	49.7	1685	34		
6% Oxide	Index	34670	49.7	1652	33		
6% Oxide	Index				33	4	Avg, std dev
	Control	34599		2			
6% Oxide	Middle	34535	49.7	2175	44		
6% Oxide	Middle	34548	49.7	1962	39		
6% Oxide	Middle	34579	49.7	2072	42		
6% Oxide	Middle	34580	49.7	2001	40		
6% Oxide	Middle	34594	49.7	1916	39		
6% Oxide	Middle				41	2	Avg, std dev
	Control	34747		3			
6% Oxide	Ring	34578	49.7	1456	29		
6% Oxide	Ring	34641	49.7	1646	33		
6% Oxide	Ring	34643	49.7	1596	32		
6% Oxide	Ring	34690	49.7	1780	36		
6% Oxide	Ring	34715	49.7	1668	34		
6% Oxide	Ring				33	2	Avg, std dev
	Control	34740		0			
6% Oxide	Little	34546	49.7	1978	40		
6% Oxide	Little	34565	49.7	1686	34		
6% Oxide	Little	34600	49.7	1402	28		
6% Oxide	Little	34654	49.7	1768	36		
6% Oxide	Little	34746	49.7	1735	35		
6% Oxide	Little				35	4	Avg, std dev
	Control	34686		0			
6% Oxide	None	34590	49.6	272	5.5		Sometime during the mmt
6% Oxide	None	34632	49.6	257	5.2		these dosimeters were
6% Oxide	None	34642	49.6	297	6.0		moved behind the glove:
6% Oxide	None	34714	49.6	296	6.0		perhaps 12-in from can CL.
6% Oxide	None	34735	49.6	216	4.4		Don't know when
6% Oxide	None				5.4	0.7	Avg, std dev
	Control	34609		0			
17% Ox w/ Foil	Index	34676	45.8	1413	31		
17% Ox w/ Foil	Index	34691	45.8	1596	35		
17% Ox w/ Foil	Index	34712	45.8	1570	34		
17% Ox w/ Foil	Index	34727	45.8	1464	32		

Source Can	Glove Finger	Dosimeter ID	Exposure Time (hrs)	Integrated Dose (mrem)	Dose rate mrem/h	Std Dev	Comments
17% Ox w/ Foil	Index	34780	45.8	1605	35		
17% Ox w/ Foil	Index				33	2	Avg, std dev
	Control	34553		0			
17% Ox w/ Foil	Middle	34572	45.9	1956	43		
17% Ox w/ Foil	Middle	34658	45.9	2054	45		
17% Ox w/ Foil	Middle	34697	45.9	1038	23		
17% Ox w/ Foil	Middle	34755	45.9	1649	36		
17% Ox w/ Foil	Middle	34783	45.9	1626	35		
17% Ox w/ Foil	Middle				36	9	Avg, std dev
	Control	34766		7			
17% Ox w/ Foil	Ring	34571	45.9	1616	35		
17% Ox w/ Foil	Ring	34576	45.9	1908	42		
17% Ox w/ Foil	Ring	34606	45.9	1794	39		
17% Ox w/ Foil	Ring	34633	45.9	1620	35		
17% Ox w/ Foil	Ring	34708	45.9	1688	37		
17% Ox w/ Foil	Ring				38	3	Avg, std dev
	Control	34655		0			
17% Ox w/ Foil	Little	34597	45.9	1905	42		
17% Ox w/ Foil	Little	34617	45.9	1321	29		
17% Ox w/ Foil	Little	34646	45.9	1661	36		
17% Ox w/ Foil	Little	34724	45.9	1854	40		
17% Ox w/ Foil	Little	34732	45.9	1626	35		
17% Ox w/ Foil	Little				36	5	Avg, std dev
	Control	34574		0			
17% Ox w/ Foil	None	34545	45.8	2460	54		
17% Ox w/ Foil	None	34604	45.8	2322	51		
17% Ox w/ Foil	None	34709	45.8	2587	56		
17% Ox w/ Foil	None	34774	45.8	2509	55		
17% Ox w/ Foil	None	34781	45.8	2592	57		
17% Ox w/ Foil	None				54	2	Avg, std dev
	Control	34730		0			
17% Ox w/ Pb	Index	34629	67.7	344	5.1		
17% Ox w/ Pb	Index	34720	67.7	340	5.0		
17% Ox w/ Pb	Index	34722	67.7	357	5.3		
17% Ox w/ Pb	Index	34729	67.7	281	4.2		
17% Ox w/ Pb	Index	34777	67.7	366	5.4		
17% Ox w/ Pb	Index				5.0	0.5	Avg, std dev
	Control	34666		8			
17% Ox w/ Pb	Middle	34680	67.7	456	6.7		
17% Ox w/ Pb	Middle	34693	67.7	430	6.4		
17% Ox w/ Pb	Middle	34726	67.7	408	6.0		
17% Ox w/ Pb	Middle	34736	67.7	455	6.7		
17% Ox w/ Pb	Middle	34751	67.7	370	5.5		
17% Ox w/ Pb	Middle				6.3	0.5	Avg, std dev

Source Can	Glove Finger	Dosimeter ID	Exposure Time (hrs)	Integrated Dose (mrem)	Dose rate mrem/h	Std Dev	Comments
	Control			4			
17% Ox w/ Pb	Ring	34561	67.8	395	5.8		
17% Ox w/ Pb	Ring	34660	67.8	431	6.4		
17% Ox w/ Pb	Ring	34718	67.8	457	6.7		
17% Ox w/ Pb	Ring	34733	67.8	399	5.9		
17% Ox w/ Pb	Ring	34770	67.8	393	5.8		
17% Ox w/ Pb	Ring				6.1	0.4	Avg, std dev
	Control	34613		3			
17% Ox w/ Pb	Little	34554	67.7	370	5.5		
17% Ox w/ Pb	Little	34674	67.7	403	5.9		
17% Ox w/ Pb	Little	34721	67.7	424	6.3		
17% Ox w/ Pb	Little	34737	67.7	382	5.6		
17% Ox w/ Pb	Little	34772	67.7	387	5.7		
17% Ox w/ Pb	Little				5.8	0.3	Avg, std dev
	Control			0			
17% Ox w/ Pb	None	34544	67.6	242	3.6		
17% Ox w/ Pb	None	34687	67.6	267	3.9		
17% Ox w/ Pb	None	34689	67.6	242	3.6		
17% Ox w/ Pb	None	34711	67.6	232	3.4		
17% Ox w/ Pb	None	34769	67.6	221	3.3		
17% Ox w/ Pb	None				3.6	0.3	Avg, std dev

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