LA-UR- 99-662

Title: A METHOD FOR CHARACTERIZING PHOTON RADIATION FIELDS

CONF-990614--

Author(s): Jeffrey J. Whicker, Los Alamos National Laboratory
Fu-Hsing Hsieh, Colorado State University
Hsioa-Hua Hsu, Los Alamos National Laboratory
Thomas B. Borak, Colorado State University

Submitted to: Annual Health Physics Meeting
Philadelphia, PA
June 28-July 1, 1999

Los Alamos
NATIONAL LABORATORY

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Title: A METHOD FOR CHARACTERIZING PHOTON RADIATION FIELDS

Authors: J.J. Whicker[1]; F.H. Hsieh[2] ; H.H. Hsu[1]; T.B. Borak[2] ([1]Los Alamos National Laboratory, Mail Stop G761, Los Alamos, NM 87545; [2] Department of Radiological Health Sciences, Colorado State University, Ft. Collins, CO 80523)

Abstract

Uncertainty in dosimetric and exposure rate measurements can increase in areas where multi-directional and low-energy photons (<100keV) exist because of variations in energy and angular measurement response. Also, accurate measurement of external exposures in spatially non-uniform fields may require multiple dosimetry. Therefore, knowledge of the photon fields in the workplace is required for full understanding of the accuracy of dosimeters and instruments, and for determining the need for multiple dosimeters. This project was designed to develop methods to characterize photon radiation fields in the workplace, and to test the methods in a plutonium facility. The photon field at selected work locations was characterized using TLDs and a collimated NaI(Tl) detector from which spatial variations in photon energy distributions were calculated from measured spectra. Laboratory results showed the accuracy and utility of the method. Field measurement results combined with observed work patterns suggested the following: 1) workers are exposed from all directions, but not isotropically, 2) photon energy distributions were directionally dependent, 3) stuffing nearby gloves into the glovebox reduced exposure rates significantly, 4) dosimeter placement on the front of the chest provided for a reasonable estimate of the average dose equivalent to workers' torsos, 5) justifiable conclusions regarding the need for multiple dosimetry can be made using this quantitative method, and 6) measurements of the exposure rates with ionization chambers pointed with open beta windows toward the glovebox provided the highest measured rates, although absolute accuracy of the field measurements still needs to be assessed.

*(Work supported by the U.S. DOE under contract W7405 ENG-36.)

Introduction

Workers at TA-55 use personnel dosimeters and workplace exposure rate measurements from ionization chambers for their protection from external radiation hazards. Ionization chambers are used to measure exposure rates from photon fields at work locations, and dosimeters measure a worker's Effective Dose Equivalent (EDE) from external radiation. In combination, these measurements help assure workers that their EDE is below regulatory limits and as low as reasonably achievable.

Because of variations in energy and angular response for the dosimeters and ionization chambers, uncertainty in their measurements could increase in areas like PF-4 where multidirectional and low-energy photons (<100 keV) exist. The energy and angular responses of the LANL dosimeter and ionization chambers have been thoroughly measured under ideal laboratory conditions. However, conditions in the workplace are not ideal but highly complex. Characterization of photon fields includes determination of energy and intensity of the fields and their spatial distributions. Measurements of photon fields and the response of personnel dosimeters and ionization chambers to these fields would increase our understanding of the uncertainty in our measurements and provide a valuable complement to existing laboratory studies.

Measurements of the energy and spatial distribution of the photon fields will increase our understanding of dosimeter response under field conditions. Christensen, et al. (1994) concluded that uncertainties in dosimeter response resulting from angular and energy dependence are large compared with other sources of measurement error. The angular and energy dependencies are especially pronounced for photons with low energies (<100 keV), an energy range that includes a significant fraction of the photons emitted from transuranics. The Implementation Guide (IG) "External Dosimetry Program" describes acceptable methodologies for ensuring compliance with 10 CFR Part 835. Specifically mentioned in the IG as a topic that should be included in the technical basis document is that of characterizing the photon energies and direction of incidence, especially when the estimated annual EDE approaches established limits.

Additionally, measurements of the spatial distribution of the photon fields would also provide information on the need for multiple dosimetry. The recent American National Standard for multiple dosimetry (HPS N13.41) recommends supplemental dosimeters when the two conditions are met: "1) The radiation dose to any portion to the body has the potential to exceed 30% of the expected dose equivalent at the reference dosimeter location on the body; and 2) the dose equivalent has the potential to exceed 10% of the limiting value when a significant component of the effective dose equivalent comes from a non-uniform radiation field." Therefore, the need for multiple dosimetry for worker in TA-55 should be assessed because of the potential for nonuniform radiation fields resulting from glovebox irregularities (i.e., streaming through glove ports and other penetrations) and large material concentrations in small locations that could result in dose equivalent (an organ dose) rates that could exceed 5 rem in a year (10% of annual 50 rem limit).

Finally, the accuracy of workplace measurement made by ionization chambers of differing designs can be better assessed knowing the energy and directional characteristics of the photon fields. The ionization chambers such as the ones used to measure exposure rates in PF-4 (i.e., Eberline R0-3C and Eberline R0-20) are calibrated using high-energy photons (0.662 MeV, Cs-137 photons), but have been tested at lower energies. These instruments exhibit a relatively flat energy response down to low energies (<10 keV) when taking measurements using an open beta shield and when the radioactive source is directly in front of the instrument. However, both the RO-3C and the R0-20 instruments exhibit a directional response for photons with energies less than about 60 keV. For example, the normalized response for 17 keV photons in the RO-3C is about 70% of the true exposure rate when the source is at 90° to the long axis (Olsher 1995). Comparatively, the normalized responses of the R0-20 ionization chambers were about 20% of the true exposure rates when the source is 90° to the instrument for this photon energy (Seagraves et al. 1997). It is common during operations in TA-55 that workers are positioned at workstations where the radiation is scattered into it from large angles from radioactive sources in neighboring workstations, and possibly even from the glovebox line behind them. Photons entering the measurement volume at these large angles could affect the measurement accuracy.

The objective of this study was to develop new methods designed to characterize photon radiation fields in critical workplaces inside the plutonium facility. Characterization of photon fields includes determination of photon energy distributions, direction of these incident photons, and the spatial distributions of the EDE rates

Methods and Materials

Characterization of the photon field requires determining the photon energy distribution and the directional aspects of the field. Photon energy distribution measurements were made using a NaI(Tl) detector, and the energy distributions were then calculated from the measured spectra. A highly collimated field of view was created using copper shielding around the detector. TLDs and ionization chamber measurements were also made to explore the characteristics of the photon fields and their response.

Photon Energy Distribution Measurements

Measured spectra from NaI(Tl) detectors provide direct information on the distribution of energies deposited within the active detector volume, but they do not give complete information on the photon energy distribution that produced the observed spectrum. Determining photon energy distributions from measured spectra can be especially challenging when the distribution is complex with many photon energies, as expected in TA-55. To determine the photon energy distributions, spectrometers such as sodium iodide detectors coupled to a multi-channel analyzer are used to obtain pulse height spectra. Such spectra provide direct information on the events of energy deposited within the active volume of the detector, but not for the energies of incident photons responsible for these events, so the photon energy distribution has to be unfolded from the measured spectra. Spectrum unfolding consists of multiplying the measured spectrum with an inverted response matrix or using spectrum stripping techniques (Knoll 1979). The unfolded spectrum then can be converting to EDE using dose conversion factors. We used the MICROSPEC-2™ from Bubble Technologies which is a NaI(Tl) based instrument incorporating software that calculates EDE rates from stripped photon energy distributions under broad beam geometry conditions.

For the photon energy distribution measurements, the MICROSPEC-2™ was used. This instrument is a portable spectroscopic survey system that provides the calculation of dose equivalent and radionuclide identification through spectroscopy. There are three gamma ray (or X-ray) probes offered with the MICROSPEC-2™ for the different measurement purposes: the E-Probe for use in environmental surveys; the G-Probe for use in high gamma-ray fields; the X-Probe for use in low energy gamma or X-ray fields.

The MICROSPEC-2 use a spectral stripping technique to convert the acquired spectrum into a pure incident photon energy spectrum which is then multiplied with fluence to dose conversion factors and integrated to calculated dose-equivalent rates at skin, eye, and deep dose depths. The fluence-to-dose conversion factors used are found in ICRU report 47(1992). Accounted for are the efficiency of the detector, photofraction for different photon energy, and cross-sectional area of probe which are stored in computer memory. The advantage of this system is that it provides not only dose-equivalent rates in the environmental radiation fields but also information on energies of photons existing in the fields

There were two probes used in this work. First, the G-Probe is designed to detect high-energy gamma rays from 60keV to above 3 MeV in a high photon field. It is a 38mmx38mm (1.5"x1.5") NaI detector. The other one is the X-Probe, a 50mmx1mm (2"x0.04") NaI, with 0.127 (0.005") Beryllium window. The X-probe has a range of 5-200keV and is capable of measuring low energy photons. To estimate the accuracy of MICROSPEC-2™ using the G-Probe and X-Probe, dose equivalent rates were measured at different distances and compared with calculated dose equivalent rates. These calculated values were determined from a known radioactivity and fluence-to-dose equivalent conversion factors published in the ICRU report 47

Determination of Directional Aspects of the Photon Fields

The directional aspects of the photon field were assessed using TLDs and a collimated NaI(Tl) detector. In order to determine fractional contributions to worker's exposure from all directions of the radiation fields inside the plutonium facility, the collimator was designed to be used with the MICROSPEC-2™ system. Figure 1 illustrates the design of the collimator used throughout the tests. To minimize X-rays generated by interaction of photon with the attenuator, copper was used to attenuate low-energy photons. The X-probe was placed in the copper box.

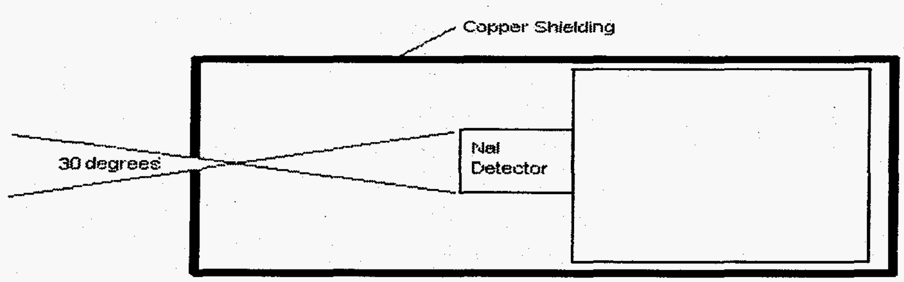


Figure 1. Schematic representation of the collimator

The photon beam was collimated through a small hole just large enough to cover the dimension of the sodium iodide crystal. This shielding arrangement provided only an approximate, not exact, broad beam parallel geometry. The LANL TLD dosimeters were mounted on cylinder water phantoms to simulate placement on a worker. The dimensions of the cylindrical water phantoms, which were filled with water, are 11" in diameter and 18" high. One phantom containing 12 LANL personnel dosimeters was placed at each work location for about 16 hours. Four sets of three dosimeters were positioned on the phantom, and each set was positioned at 90° to each other. The three dosimeter in each set were positioned at a different heights on the phantom and separated by about 4 inches. The distance from the closest dosimeters to the glovebox face was about 3 inches, and the height from the floor to the top dosimeters was about 50 inches.

LANL Personnel Dosimeter

At present, the Model 8823 TLD dosimeter is used to measure personnel exposure to external source of radiation at Los Alamos National Laboratory. The dosimeter contains two Harshaw/Bicron TLD cards each of which contains four TLD chips of varying thickness and of different composition. One TLD card is a Harshaw/Bicron-NE Model 7774 TLD card containing three TLD-700 (LiF:Mg,Ti enriched in ^{7}Li) chips in position 1, 2 and 3, and one TLD-400 (CaF:Mn) chip in position 4. This card is used for estimating beta and photon dosimetry at deep, shallow and lens-of-the-eye depths. The other card is a Harshaw/Bicron-NE Model 6776 TLD card containing two paired TLD-700 and TLD-600 (LiF:Mg,Ti enriched in ^{6}Li) chips. This card placed in the Model 8823 TLD cardholder within a cadmium box is used for evaluating neutron doses. The Model 8823 dosimeter has been developed to separate the responses due to photon, beta, and neutron radiation. As to the angular dependence for low energy photons, Mallett (1997) demonstrated that the normalized angular response at 90^{0} for ^{241}Am in the LANL Model 8823 dosimeters is about 60% of the deep dose equivalent at 0^{0} with vertical axis.

Ionization Chambers

The ionization chambers, such as the ones used to measure exposure rates in the plutonium facility (i.e., Eberline RO-3C and RO-20), are calibrated using high energy photon field (0.662 MeV ^{137}Cs photons). These instruments exhibit a relatively flat energy response down to low energy (<10keV) when taking a measurement with open beta shields and when the window of the instrument directly faces toward the radioactive source. However, both the Eberline RO-20 and RO-3C exhibit a noticeable directional response for photons with energies less than 60keV (Olsher 1995, Seagraves et al. 1997).

Experimental Setup

The selected site for measurements was a glovebox located in the plutonium facility 4, PF-4 (shown in Figure 2). This site was selected because workers assigned to work at this glovebox line received some of the highest photon doses in the facility due to the high Am-241 content in the material in the glovebox. There are four work locations encircling the glovebox. Near this glovebox there are several other process gloveboxes that contain transuranic material as well.

The measurement distance from the face of the glovebox to the center of the detector was about 5 inches. When working in and around the workstation, the actual distance to a workers torso from the glovebox varies considerably. The measurement distance of 5 inches was as close as we could get the instrumentation to the glovebox face and still maneuver it to make the measurements at the various orientations. The response to these radiation fields was estimated using both instruments and dosimeters as mentioned above.

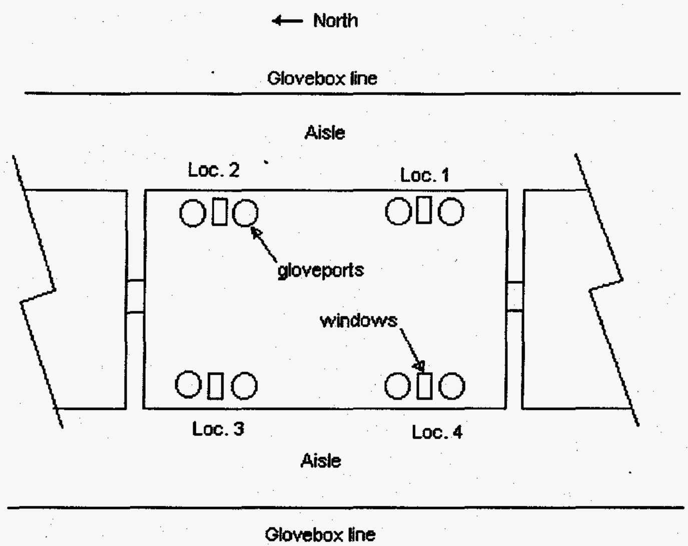


Figure 2.Schematic of the glovebox around which photon fields were measured.

Two types of ionization chambers (i.e., RO-3C and RO-20) with open shield were used to measure radiation exposure rates at each work location. The three positions at which measurements were made included the: 1) window, 2) left glove port, and 3) right glove port. When measurements were made at the glove ports, the gloves were pushed into the glove ports.

MICROSPEC-2™ equipped with the X-probe and the copper collimator was used to measure photon energy distributions at each specific work location in various source-detector geometries. MICROSPEC-2™ coupled with the G-probe, but not with the collimator, was also used to make measurements at multiple locations. These measurements then were unfolded and provided estimates for the EDE rates.

Data Analysis

First, the accuracy of the MICROSPEC-2™ instrument was tested by making measurements at different distances from Cs-137 and Am-241 sources and comparing the measured values to the calculated values. Additionally, data were categorized into front, nonfront, and gloveport categories for both the TLD and the MICROSPEC-2™ measurements. Comparisons were then made between these two categories. Because of the lack of normality in the measurements or in log transformed values, the nonparametric Mann-Whitney test was used to evaluate for differences. Additional paired comparisons between measurements from the two types of ion chambers were made using the nonparametric sign test.

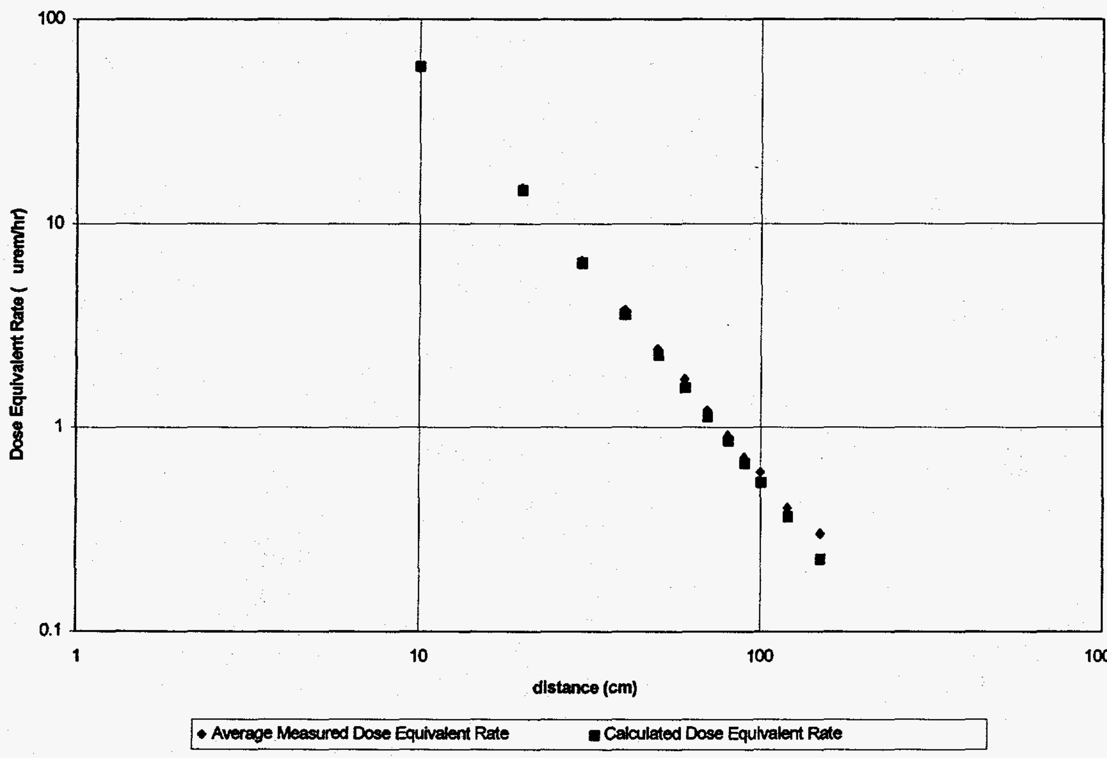
Results and Discussions

Using the instruments and measurement techniques described above, we were able to characterize photon radiation fields in a plutonium facility. Overall, the results at this glovebox suggest that dosimeters worn on the upper chest, as per procedure, will likely record a reasonable estimate of workers average EDE values for photons. Although the results are preliminary and confined to one high exposure box, we have found no evidence for the need of multiple dosimetry for photon EDE measurements. Also, we found that deposits of transuranic dust on the inside of the glovebox gloves are a significant contributor to a workers dose when the gloves are hanging out the glove ports. Finally, a paired comparison of measurements made with ionization chambers at different orientations suggested some directional dependence. Further investigations would be required to fully test the accuracy of the ionization chambers under field conditions.

MICROSPEC-2™ Accuracy

The measurement results from the MICROSPEC-2™ , equipped with the G-probe, were compared to the calculated EDE rates using a ^{137}Cs source. The percent differences were less than 3%. However, the response from the same system for ^{241}Am had relatively larger differences from the calculated values. In comparison, the measurement results obtained using the X-probe and the calculated dose equivalent rates for low energy photons generated by ^{241}Am, showed percent differences that ranged from -1.4% to 20%. Figure 3 shows the result of the measurements of dose equivalent rates at different distances from an Am-241 source. Generally, the measured values match closely (within a few percent) to the calculated values except at the longer distances where the counting statistics become poorer and effects of photon build-up might be more pronounced.

Figure 3. Total Dose Equivalent Rate Varying with Distance from an Am-241 source.



Spatial distribution of DE

At individual locations, photons are incident to workers omnidirectionally, but were not completely uniform, unless averaged over all locations. Both the TLD and Microspec-2 data showed that when averaged over all 4 workstations, no significant differences were found in photon EDE rates between front and non front measurements (Fig. 4 and Fig. 5). However, when TLD measurements were analyzed by individual locations, the highest measurements were always those at 90 degrees facing the center of the glovebox. But, as we witnessed, workers moved from one workstation to the next and so the dose distribution would be determined from a combination of work performed at all the workstations. It would be helpful to know the work patterns around this glovebox to better assess the spatial dose distribution to the workers. Additionally, the EDE rates at a workstation were significantly reduced when the nearby gloves were inserted into the glove ports.

Measurements at the gloveports (more correlated to extremity dose) were significantly higher than those at the window (more correlated to whole body dose). This finding suggests that some streaming of photons out through the port occurs and also supports the use of extremity dosimeters when inserting hands into the gloveports.

Dosimeters placed at the upper chest level measured significantly higher doses than those at a waist level. Fig. 6 shows the results from this analysis. These results were averaged over all locations

Assessment of need for multiple dosimetry:

The implications of all our finding with regard to multiple dosimetry is that whole body dosimeters worn according to LANL procedures (chest level in front of body) should provide a reasonable estimate of the average whole body dose, especially considering the work patterns of the workers at this particular high gamma field glovebox. In addition, use of extremity dosimetry is recommended when inserting hands into the gloveboxes due to the much higher exposure rates, as is the current policy. The possibility of the need for multiple dosimetry at other locations, or for other processes can be assessed using the same techniques described in this paper.

Energy spectra measured at different orientations

In most cases, when the collimated Microspec system was pointed at 90 or 180 degrees to the workstation, 60 keV photons were measured. These photons were not measured when the system was pointed directly at the glovebox. At 0 degrees, we speculate that the metal plate covering the middle window effectively shielded out the 60 keV photons but it was not thick enough to completely shield out the more energetic Pu x-rays above 100 keV. That is, the window shielding effectively "hardened" the photon energy distribution. Figures 7 and 8 show the measured and unfolded energy distributions for the orientations of $0^0$and 90^0 for work location 2, respectively.

The source of the 60 keV photons measured at 90 degrees was the gloves hanging out of the boxes, and this was confirmed by direct measurement of the gloves. It is believed that the inside of these gloves have a layer of transuranic "dust", including Am-241, and the thickness of Pb layer in the gloves was not sufficient to completely eliminate the 60 keV photons. The 60 keV photons measured at 180 degrees likely originated from gloves and gloveports on the opposite side of the aisle.

Figure 7. Measured and Unfolded Spectra obtained with a X-probe at location #2 with a 0 degree orientation.

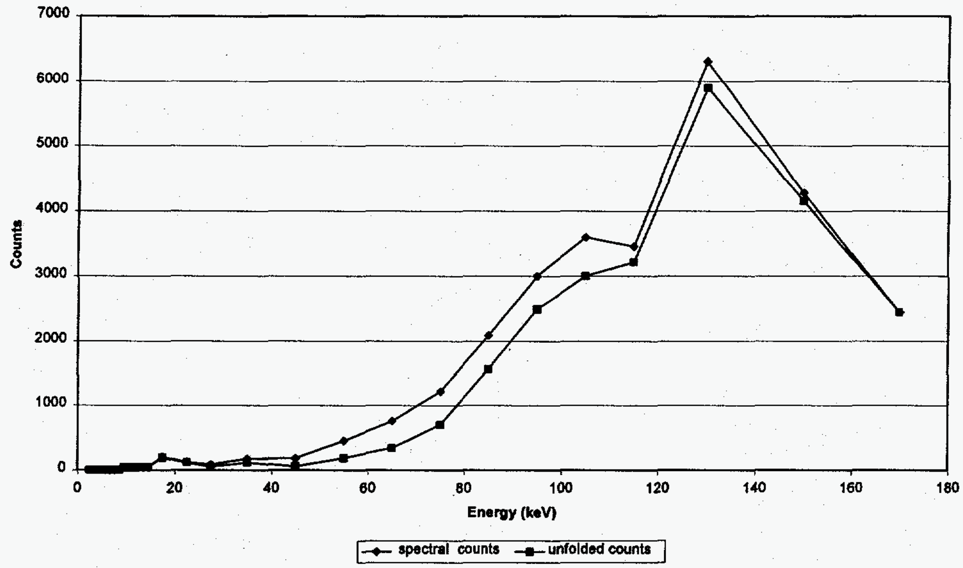
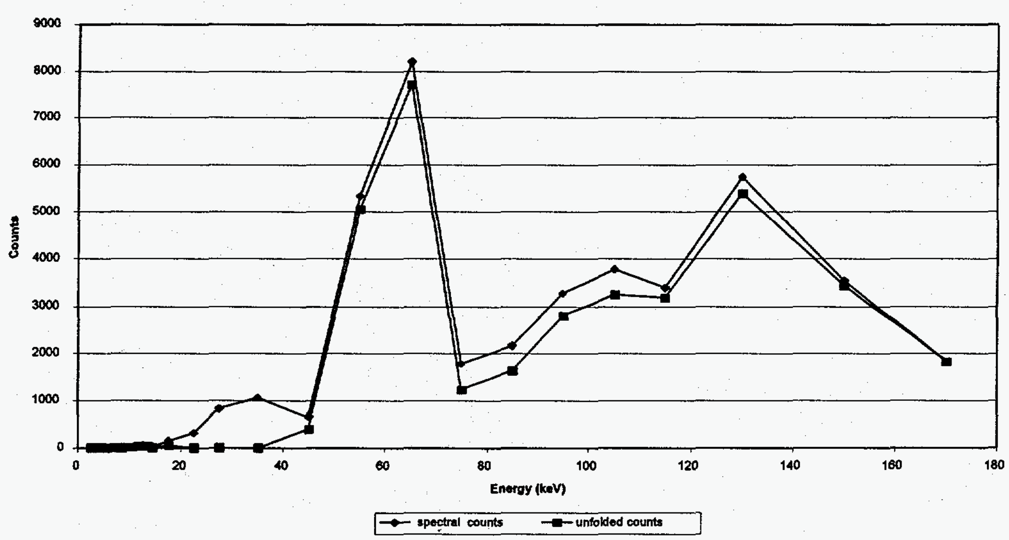


Figure 8. Measured and Unfolded Spectra obtained with a X-probe at location #2 using a 90 degree orientation toward the North.



Ion Chamber Results

Overall, the energy spectra measured showed that most of the photons were of energies ≥60 keV, and therefore the ionization chambers should give reasonably accurate measurements. But, some directional dependence would be expected. In fact, we found limited evidence that the this was the case. For example, the highest measurements were recorded when the instrument was at 0 degrees to the glovebox for both the Eberline RO20 and the RO3C models when compared to measurements made at 90 degrees. The percent differences in median exposure rates measured at 0^{o} and 90^{o} at the window locations was about 20% for both instruments. However, to fully test the effects of orientation, more measurements are needed and the confounding effects of the photons from nearby hanging gloves and partial shielding of photons from the person making the measurements need to be addressed. On the other hand, the ion chamber measurements were made under normal operating conditions (i.e., gloves outside the boxes, person holding the instrument, and at the same distance defined in ESH-1 procedures). The ESH-1 procedure of pointing the "open" beta window of the ion chamber at 0 degrees generally provided the most conservative (highest) measurement. The absolute accuracy of the field measurement with the ionization chambers still needs to be assessed.

Conclusions and Deliverables

Techniques were developed to help measure the spatial and energy characteristics of photon radiation fields. These techniques were then tested for accuracy and used to characterize the photon radiation field at a process line in PF-4 where assigned workers had some of the highest photon exposures relative to other workers in PF-4. The results of this investigation showed that the torsos of workers are exposed to photons from all directions. The intensities of the fields at individual locations of the process line studied were unevenly distributed. However, when averaged over all the work locations in the line, we found no differences between photon field intensities directed to the front of the torso (to be measured by the dosimeter without shielding by the body) and those to the side and the back. Averaging over all work locations is more appropriate estimate of a worker's actual dose because workers move quickly and frequently from one workstation to the next. The worker's dose then reflects the time-weighted average of the exposures received at each location. Based on these preliminary findings, we have found no evidence for the need for multiple dosimetry. The energy distribution measurements showed the significant contribution to a worker's dose from the nearby gloves that are typically left hanging out of the gloveports. Inserting the gloves into the ports reduced the dose rates at the neighboring workstations significantly.

References

American National Standards Institute. Criteria for performing multiple dosimetry. HPS N13.41; 1997.

Bubble Technology Industries. Spectroscopic Survey System, MICROSPEC-2™, for High-Sensitivity Radiation Surveying with Isotopic Identification Manual. Chalk River, Ontario, Canada: Bubble Technology Industries Inc.; 1995.

Department of Energy. External Dosimetry Program. Implementation Guide Guide G-10 CFR 835/C2-Rev.1. 1994.

Hoffman, J.M., Mallett, M.W. The LANL model 8823 whole body dosimeter and associated dose algorithm. Draft LANL internal report, ESH4-PDO-TD-01, RO; 1998.

International Commission on Radiation Units and Measurements. Measurement of dose equivalents from external photon and electron radiations. ICRU Report 47; 1992.

Knoll, G.F. Radiation detection and measurement. John Wiley and Sons: New York, New York; 1979

Mallett, M.W. Model 8823 Personnel Dosimeter: Lower Limit of Detectability and Angular Dependence Studies. ESH-4-MTS-97:047. 1997.

Olsher, R. Technical basis document, Eberline RO-3C survey meter, portable air ionization chamber exposure rate meter. LANL internal report ESH4-RIC-TBD-008; 1995.

Seagraves, D. T., Bates, R.L., Olsher, R.H. Photon Energy Response of Exposure Rate Meters in

Use at the Los Alamos National Laboratory. Presented at the 42nd Annual Health Physics Society Meeting. Abstract: Health Physics, Supplement to Vol.72(6):S7, 1997.

Publications and Presentations

Hsieh, F.H.; Borak, T.B.; Whicker, J.J. Measurements of equivalent dose using a photon spectrometer. Presented at the Technical Meeting of the Rocky Mountain Chapter of the Health Physics Society; 1998.

Whicker, J.J.; Borak, T.B.; Hsieh, F.H.; Hsu, H.H. Characterization of photon radiation fields in a LANL plutonium facility. LANL internal newsletter, The Quarterly Dose, Vol. 2(2); 1998.

Figure 4. Dose equivalent rates measured by the collimated MICROSPEC-2 at different orientations.

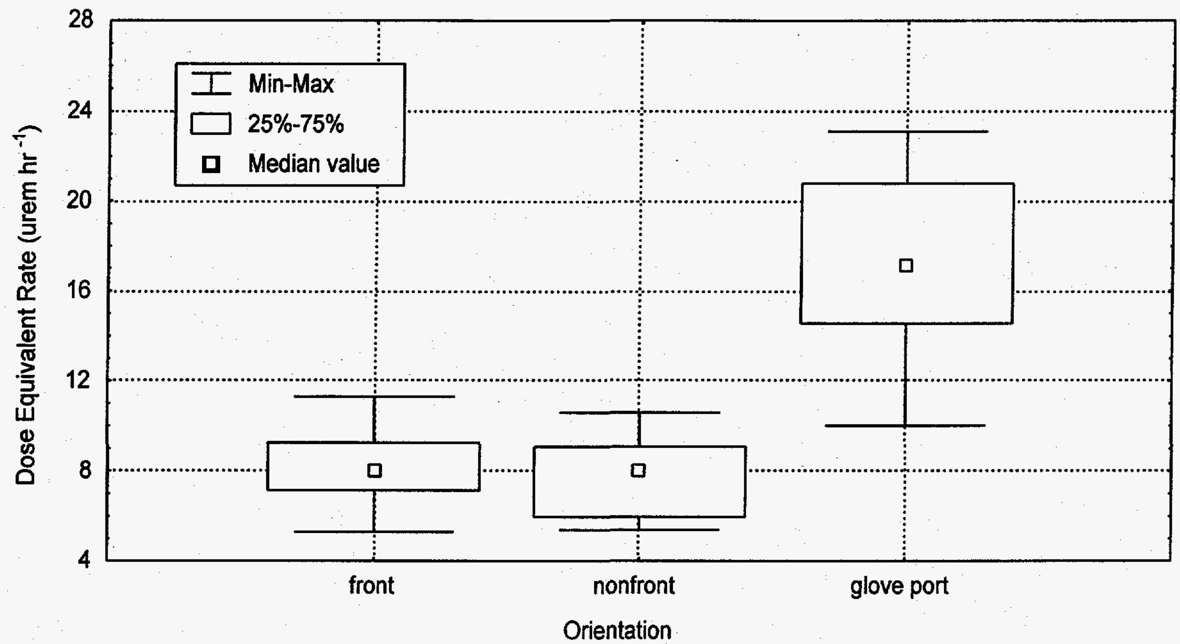


Figure 5. Dose equivalent rates measured by TLDs at different orientations.

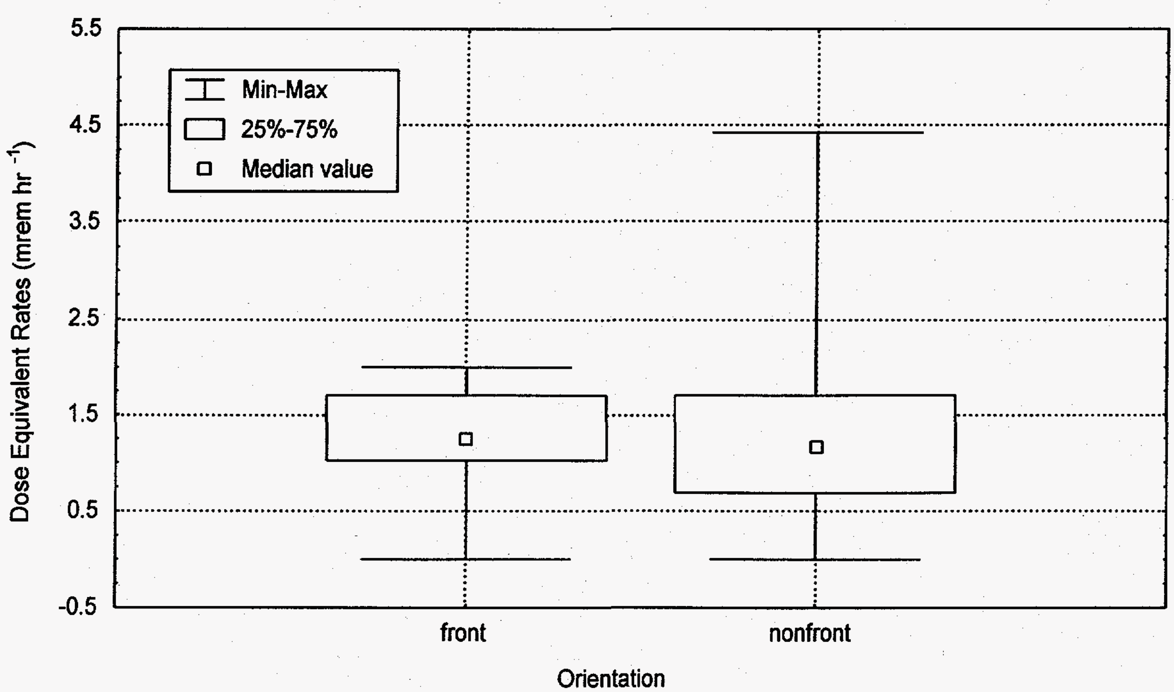


Figure 6. Dose equivalent rates at all work locations measured by TLDs on phantoms at three heights.