SLAC TN 87-2
March 1987

PERSONNEL DOSE EQUIVALENT MONITORING AT SLAC USING LITHIUM-FLUORIDE TLD'S*

T.M. JENKINS AND D.D.BUSICK

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Abstract

This note presents the results of calibrations of the wallet LiF thermoluminescent dosimeters (TLD) used for personnel and accident dosimetry at SLAC.

* Work supported by the US Department of Energy under contract DE-AC03-76SF00515

1. Introduction

TLD's replaced film badges in the early 1970's for all dose equivalent monitoring, both neutron and photon, and for all locations at SLAC. The photon TLD's, composed of Li-7 loaded teflon discs, are calibrated using conventional gamma-ray sources; *i.e.*, Co-60, Cs-137, etc. For these TLD's, a nominal value of 1 nC/mrem is used, and is independent of source energy for 100 keV to 3 MeV.

Since measured dose equivalents at SLAC are only a small fraction of the allowable levels, it was not deemed necessary to develop neutron dosimeters which would measure dose equivalent accurately for all possible neutron spectra. Also, simplicity was a key feature in badge design; it would be advantageous if the dosimeter were small enough to fit into a wallet or carried in a shirt pocket. So-called 'albedo' dosimeters, which are cumbersome, were ruled out, as were film badges with their inherent fading and energy dependent problems. Also, it was desired that the badge should be a part of the entry system within the fenced area. And finally, the response should be location independent; that is, it should respond the same for all locations at SLAC.

Today, wallet TLD's, composed of pairs of Li-7 and Li-6 discs, are used, with the Li-6 measuring only thermal neutrons; *i.e.*, they aren't moderated in any way to make them sensitive to neutrons with energies greater than thermal. The assumption is made that there is a correlation between thermal neutron fluences and fast neutron fluences around the research area where almost all neutron doses (exclusive of sealed sources) are received.

The calibration factor for these Li-6 TLD's is 1 nC/mrem of fast neutrons. The method of determining the validity of this calibration is the subject of this note.

2. General

Neutron fields at SLAC, exclusive of sealed sources used only by the Health Physics group, are associated with the high energy accelerator in some way; *i.e.*, the linac and the research area, which includes the end stations, SPEAR, PEP and soon the new SLC. In addition, there may be devices under development at various locations around the site capable of producing neutrons. In all cases, these potential neutron sources are located inside concrete shields.

Since the first acceleration of beams, area monitoring (both n and γ) has been an integral part of the monitoring system at SLAC. Locations for area monitoring are shown on the site plan, Fig. 1. These locations were chosen to be close to potential sources (*i.e.*, ESA, ESB, various components in the C-line, and SPEAR). The two locations in the Computer building (Bldg 5) were chosen because they have a direct line-of-sight to the top of ESA, and are continuously occupied. These last two locations are in spots of little local shielding, *i.e.*, one is on a window ledge and the other behind a door leading to the outside. Measurements from these locations cover the period from 1971 to the present time.

In addition to these, monitors are also located at the site boundary surrounding the research area, but since these never measure more than 5-to-25 mrem above background per year, they don't figure in any personnel dose projections.

Radiation fields around the research area are measured as needed using a combination of roving and fixed detectors. The roving monitors are bare and moderated BF_3 detectors operating in the pulsed mode for neutrons, and ionization chambers for measuring ionizing radiation. Fixed monitors are mostly composed of LiF discs (both Li-6 and Li-7) which are both moderated and unmoderated for detecting fast and thermal neutrons as well as gammas. Moderators are Cd-covered polyethylene cylinders 15 cm diameter and 15 cm high which respond to neutron fluences in the energy range of a few keV to about 10 MeV [1]. In addition, a few 30 cm diameter polyethylene pseudo-spheres with LiF discs are used which give a quasi-rem response [2]. Finally, there are one or two locations monitored by moderated BF_3's operating in the pulse mode which run continuously, and can be read out whenever desired. The neutron spectrum in the research area near ESA was measured and found to be comparable to those measured at other high energy installations [3].

All of these, in combination with pocket ion chambers which are located in fixed positions, measure the total neutron and photon dose equivalents over each running cycle.

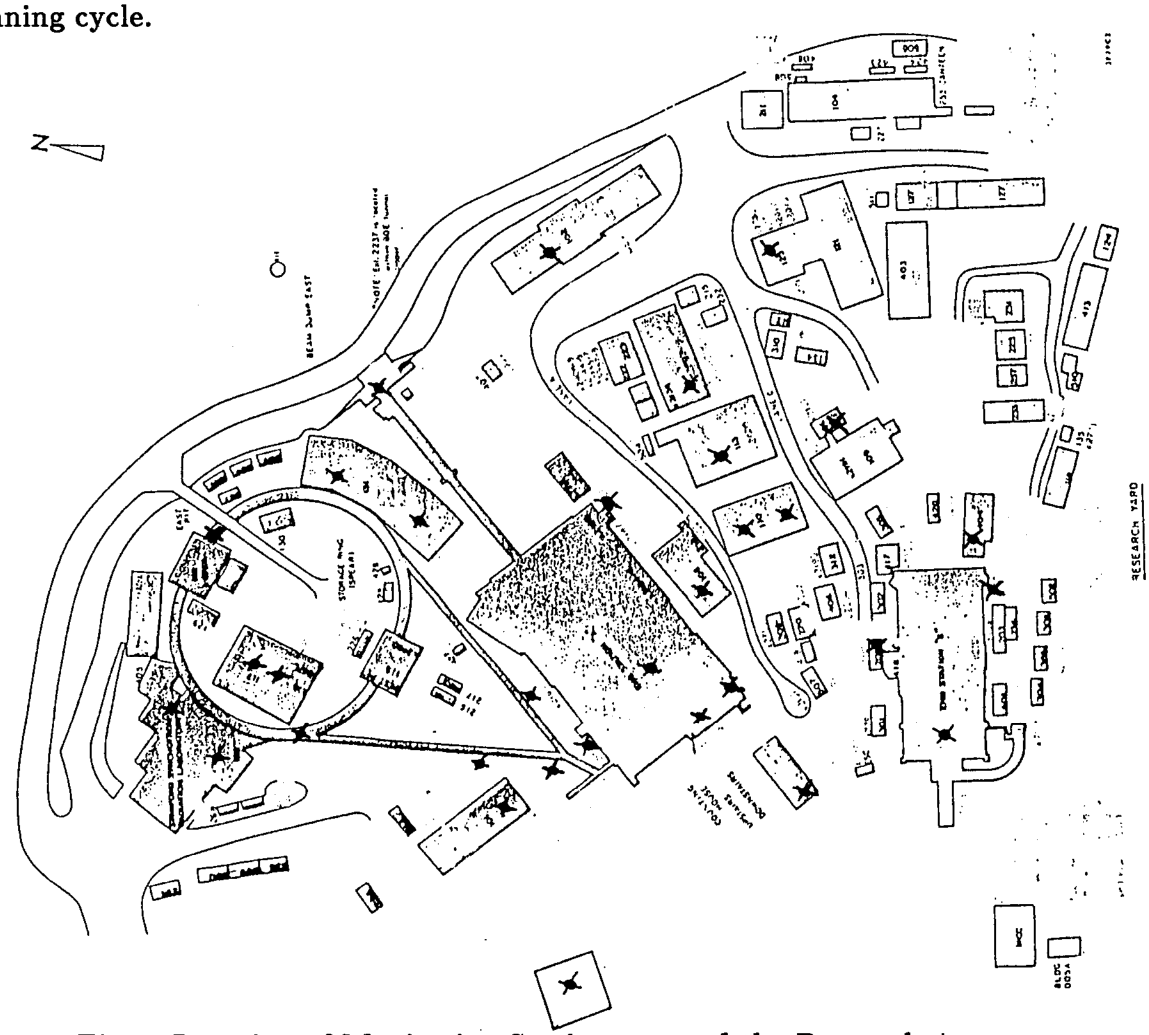

Fig 1. Location of Monitoring Stations around the Research Area

3. Neutron Dose Equivalents Determined from Area Monitors

The annual dose equivalents at these locations from fast neutrons are shown in Fig. 2 (thermal neutron doses, which are very small, are not included). The majority of dose equivalents lie in the range between 50 and 500 mrem/y. Of the areas with values greater than 1 rem/y, only the Counting House is normally occupied. Access to the roofs of ESA and ESB could be controlled, but isn't since these aren't normal work areas. Building 405 is locked, and access controlled.

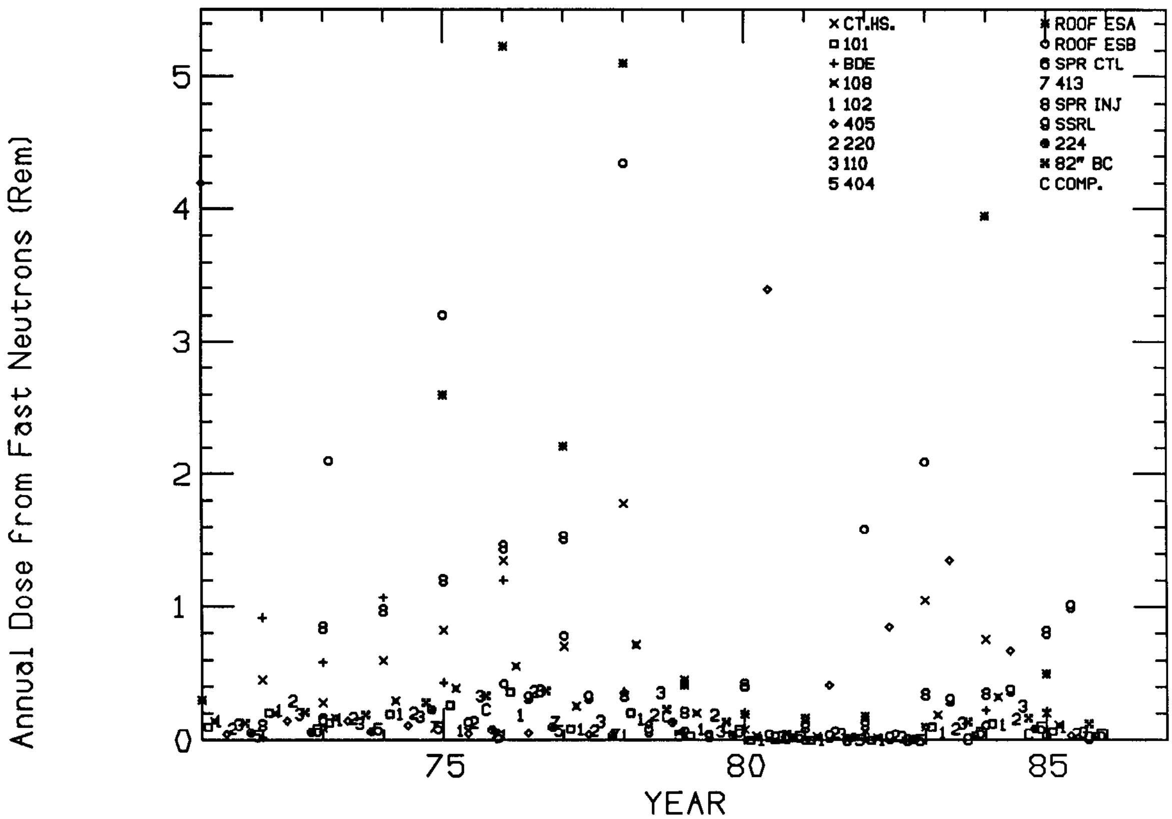

Figure 2. Location of area monitoring stations around the Research Yard.

Fig. 3 gives the ratio of fast neutron-to-ionizing radiation doses for the years 1971 through 1984 at these monitoring stations. A fluence-to-dose conversion factor of about 4×10^{-8} rem per $n - cm^{-2}$ was used. This assumes an average neutron energy of between 1 and 5 MeV, whereas the actual neutron average energy is between 0.5-1 MeV. From previous measurements, we know that some neutrons are above the range of the detector, and so the use of a conservative fluence-to-dose conversion factor is justified.

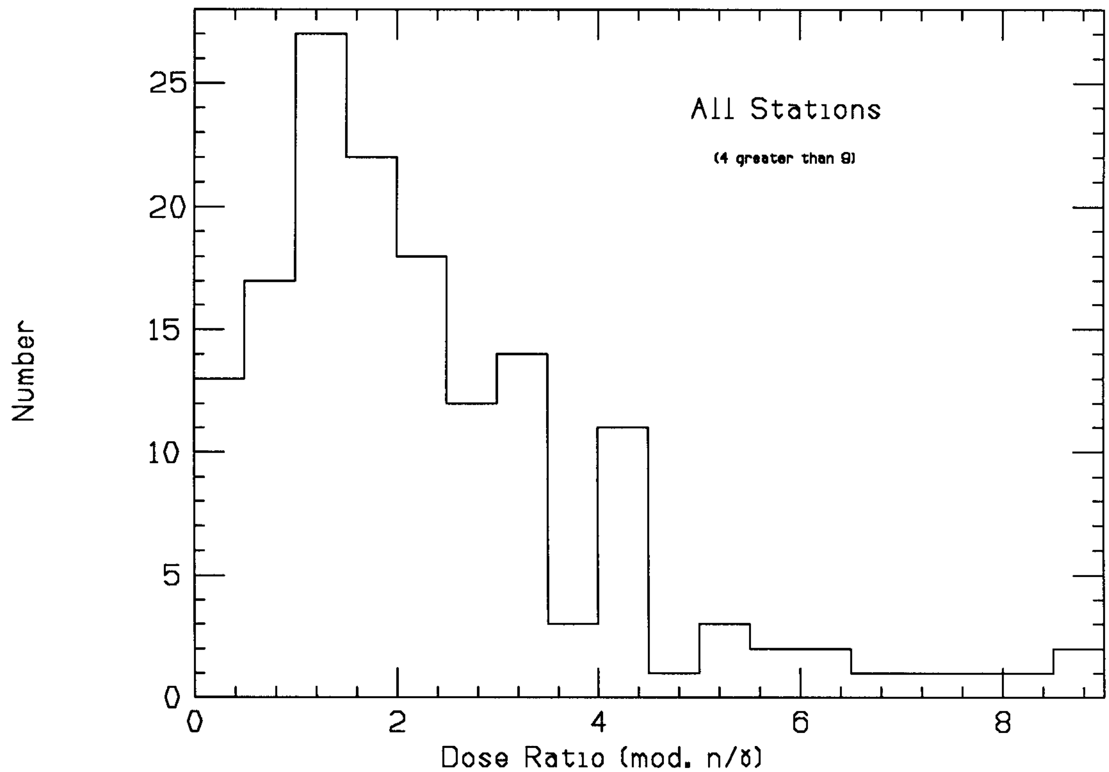

Figure 3. Frequency of fast neutron/gamma-ray dose ratios in the Research Yard.

Fig 3 gives a median value of about 2.3; that is, dose equivalents from neutrons are 2.3 times higher, on the average, than photons in the research areas. About the only place where this isn't true is in the forward direction from BDE.

Since the TLD's carried by personnel at SLAC are not moderated in any way except for their close proximity to the body, the thermal neutron fields where people will be working are of prime importance. More importantly, the ratio of moderated-to-unmoderated neutron fluence (or dose) is important. If this ratio is more-or-less constant everywhere, then the assumption will be made that the neutron spectra are the same, and that measuring the thermal neutron fluence will suffice to assign a fast neutron dose to all personnel.

At this point, something should be said about the limits of detection of the dosimeters. First, moderated and unmoderated points are always exposed using pairs of Li-7, Li-6 discs. Readings of the Li-7 discs are straight forward, since they

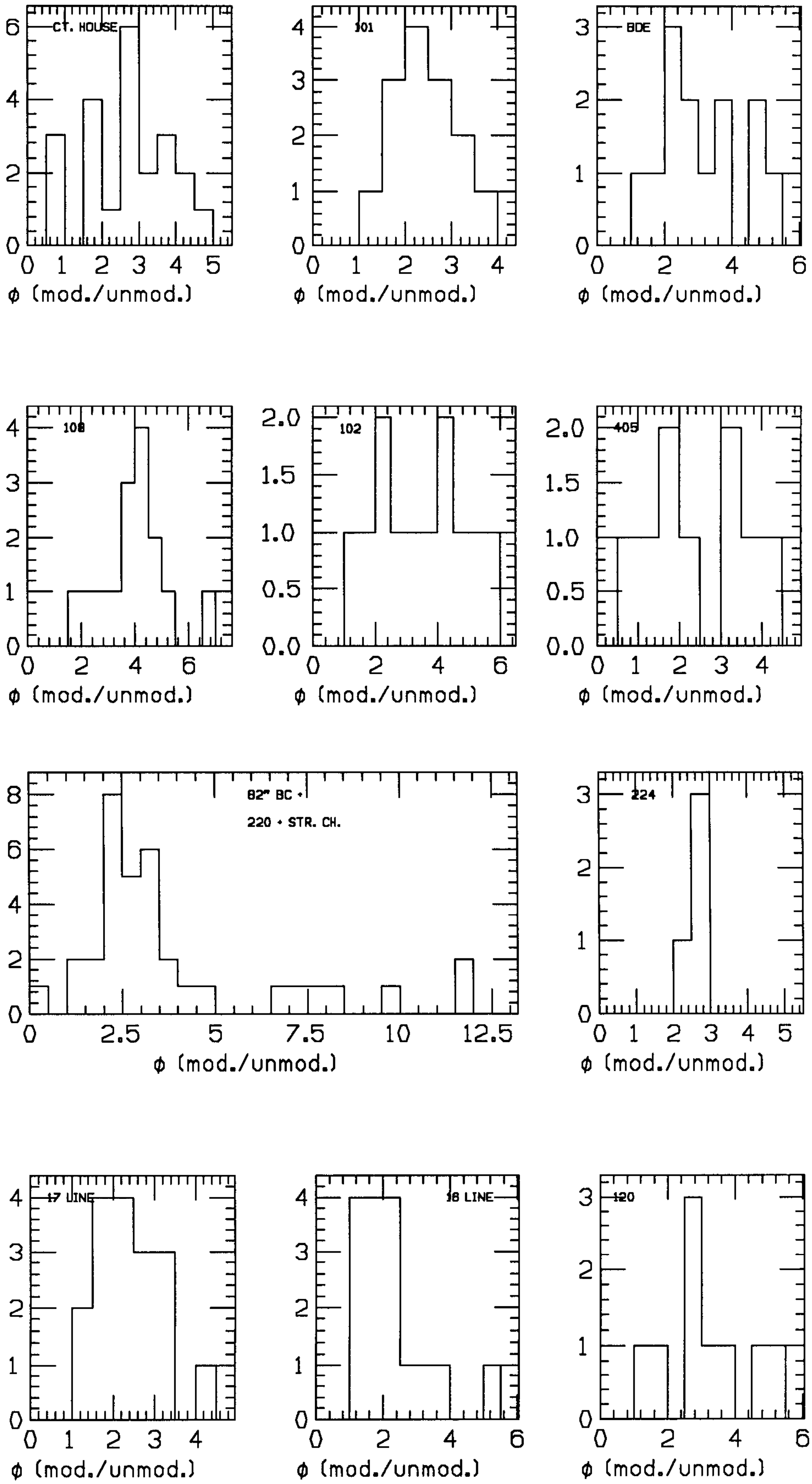

Fig. 4. Frequency of mod./unmod. neutron fluences.

respond only to ionizing radiation. Li-6 discs, however, respond both to ionizing radiation and to neutrons. In order to determine the neutron portion, the response due to ionizing radiation must first be subtracted. This value is determined from the Li-7 companion disc. For most locations, ionizing radiation from natural background is much larger than that from accelerator-produced neutrons, and so a large number must be subtracted from the total signal. Because of these uncertainties, a minimum detection limit of 30 mrad (photon) and 40 mrem (neutron) is used for all the numbers which follow, even though 20 mrem is considered as the lower limit for recording each type of dosimeter.

The ratios of moderated/unmoderated neutron fluences at each of the locations are shown in Figs. 4 a-b. At most locations, there haven't been many years where annual doses are above the limit of 40 mrem used in this study, and so the statistics aren't good. However, all locations can be summed together under the assumption that the spectra are the same, and this is shown in Fig 5. The ratio of moderated/unmoderated fluences in this figure has a median value of 2.75, with the 10 and 90% values lying between 1.6 and 4.4.

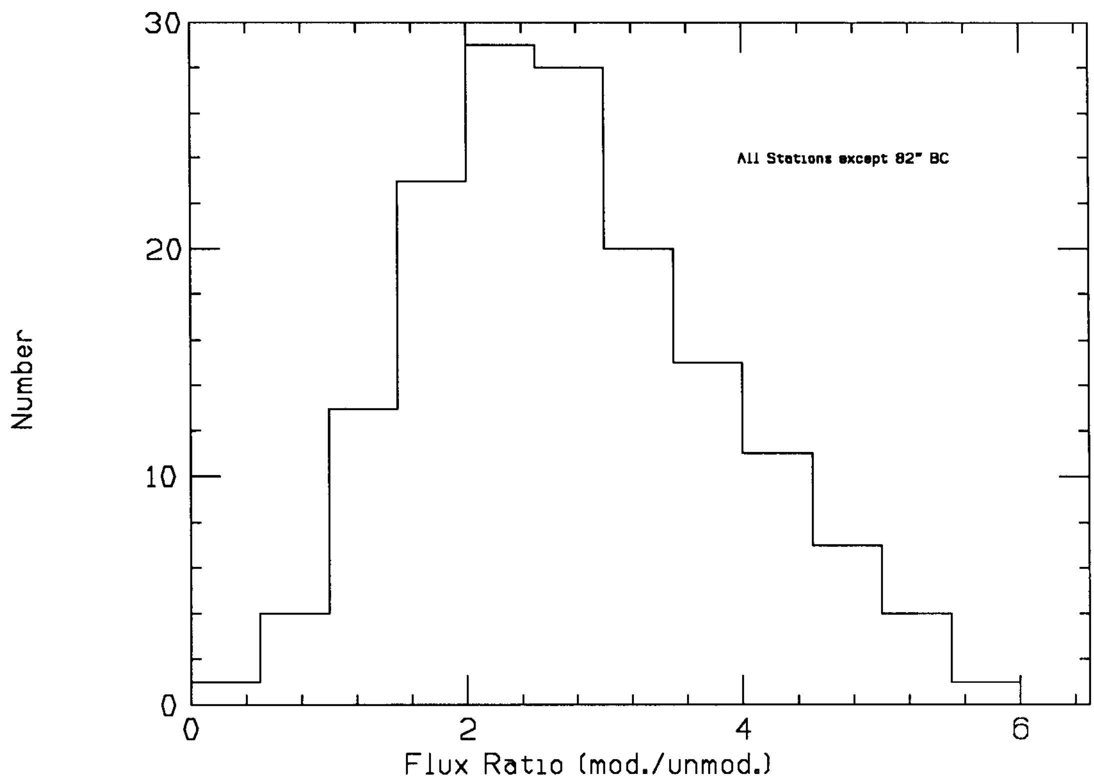

Figure 5. Frequency of moderated/unmoderated neutron ratios.

Thus, the ratio of moderated-to-unmoderated fluences doesn't vary greatly anywhere in the research area where neutron doses greater than 40 mrem/yr are present.

4. TLD Calibration

Next, the response of the wallet TLD to these same radiation fields must be determined. Unhappily, the fluence rates aren't great enough anywhere in the research area to use these fields themselves for calibration purposes, and so a substitute radiation environment was created.

Some years ago, it was thought that the moderating effect of the body for fast neutrons might give a response to a thermal neutron detector (a Li-6 disc) proportional to the dose received by the body (a 'simple' albedo dosimeter). The response of a bare Li-6 disk to a fast neutron fluence from PuBe neutrons was determined as a function of paraffin thickness behind the TLD, analogous to a TLD worn near the human body [4]. Fig 6 shows the result, about 1.3 nC/mrem for paraffin thicknesses greater than 2 inches.

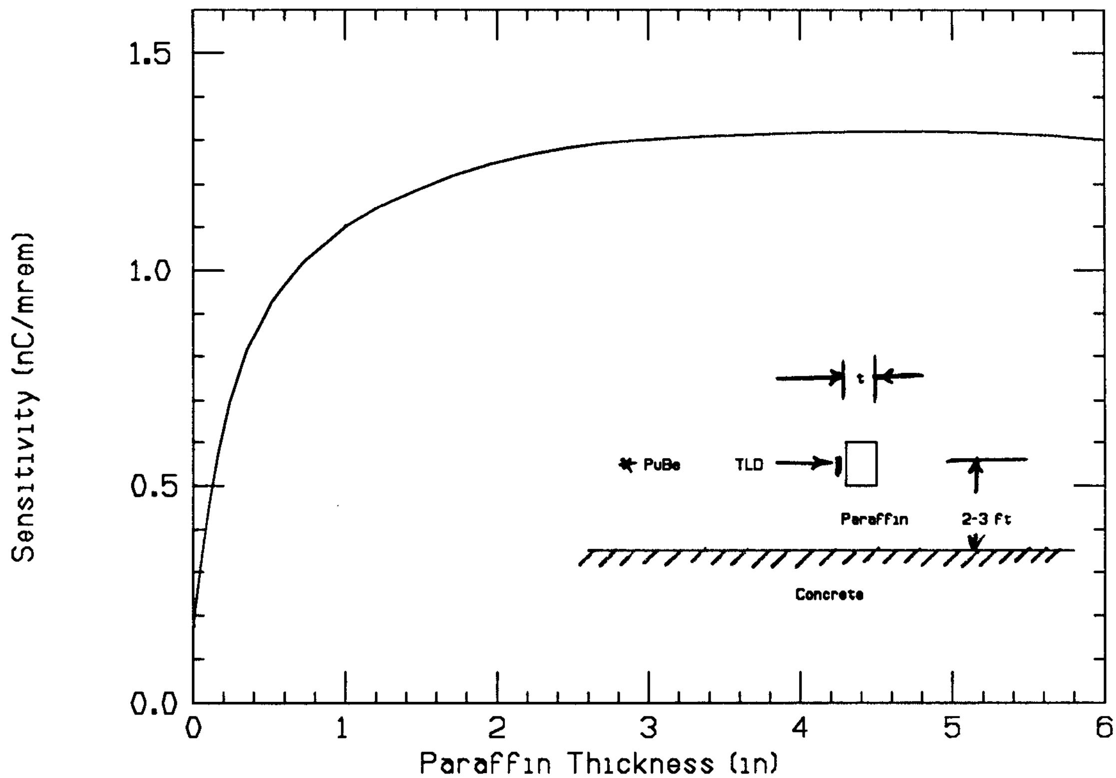

Figure 6. TLD sensitivity as a function of paraffin thickness.

In this measurement, the fluence ratio of moderated/unmoderated was later determined to be 50:1. If this were analogous to a wallet TLD worn in the research area, then the TLD would always need to be in close proximity to the body to be accurate; *i.e.*, it would act as an "albedo" dosimeter measuring thermal neutrons generated within the body and which were then reflected. However, this isn't the same neutron field as measured in the research area. The moderated-to-unmoderated fluence ratio of 50:1 for this geometry meant that there were very few neutrons being thermalized by the surrounding environment and thus the Li-6

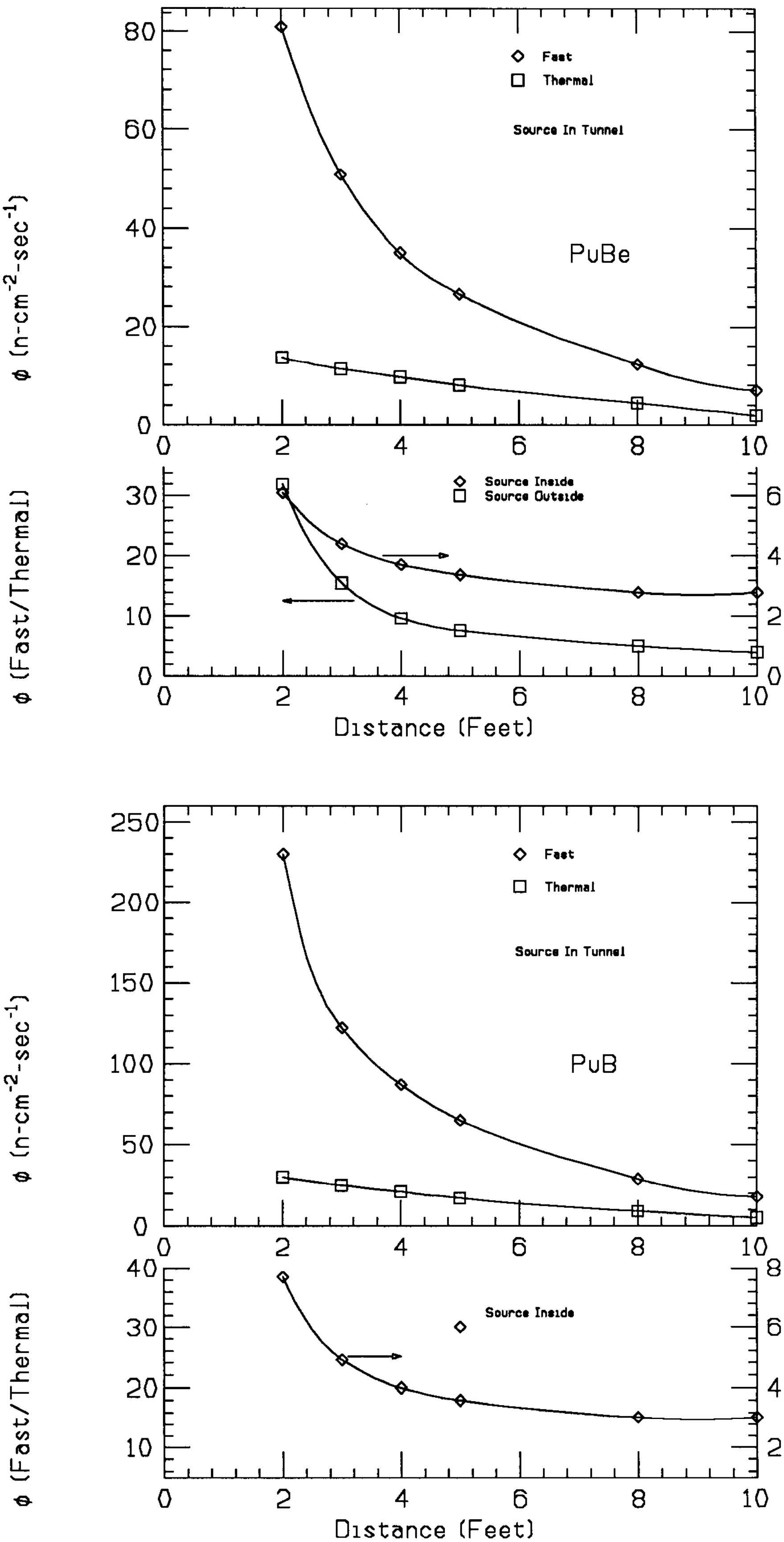

Fig. 7a-b. Mapping of Tunnel Neutrons.

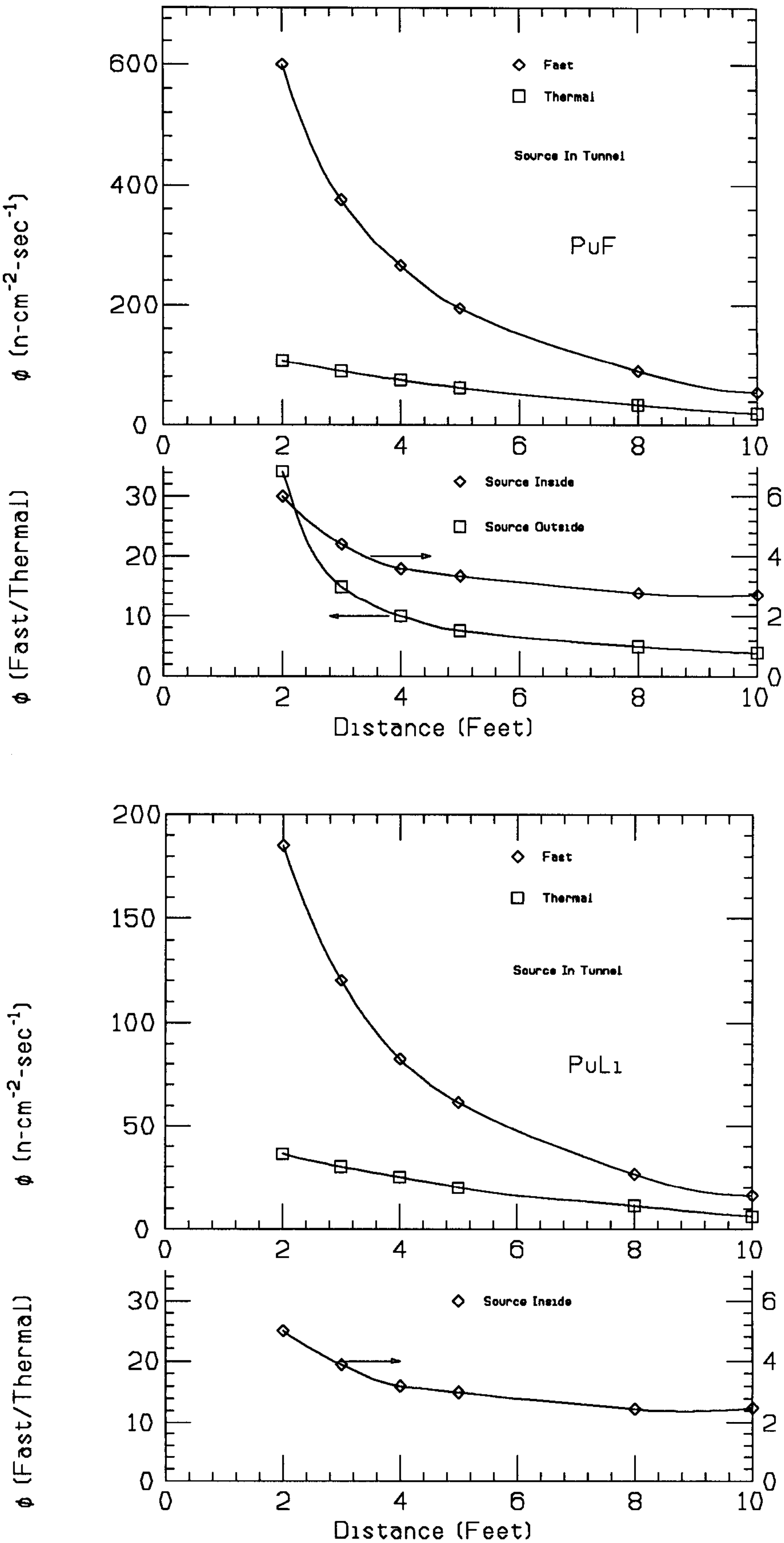

Fig. 7c-d. Mapping of Tunnel Neutrons.

was able to measure thermal neutrons generated within the body itself. This would not be the case in the research yard where there is already a relatively large thermal neutron field.

In order to achieve ratios close to 1.5:1 to 10:1 such as are found in the research yard, the neutron source was moved inside a concrete tunnel where the thermal neutron component would be enhanced. Two tunnels were used. The first had a cross section of about 4.5 m by 3 m, whereas the smaller had a cross section of about 0.92 m by 1.5 m. Fluences as measured by the moderated and unmoderated detectors for four different sources are shown in Figs 7a-d. The sources, PuBe, PuB, PuF and PuLi were chosen to give different average neutron energies and would point out any sensitivity to neutron spectrum. Average energies, as measured with combination moderated BF_3 and proton recoil counters, varied between about 250 keV and 3.5 MeV. Pairs of LiF discs, moderated and unmoderated, were then exposed in these fields and a calibration factor derived from the numbers.

To determine the effect of the body on the response of the Li-6 disc to these neutron fields, the discs were placed on contact and at varying distances from a 30 cm water-filled polyethylene cylinder. The presence or absence of the water phantom had no effect, from which we conclude that the presence of thermal neutrons from the radiation environment in the moderated/unmoderated range of 2:1 to 10:1 masks any effects of the thermalizing of neutrons by the body.

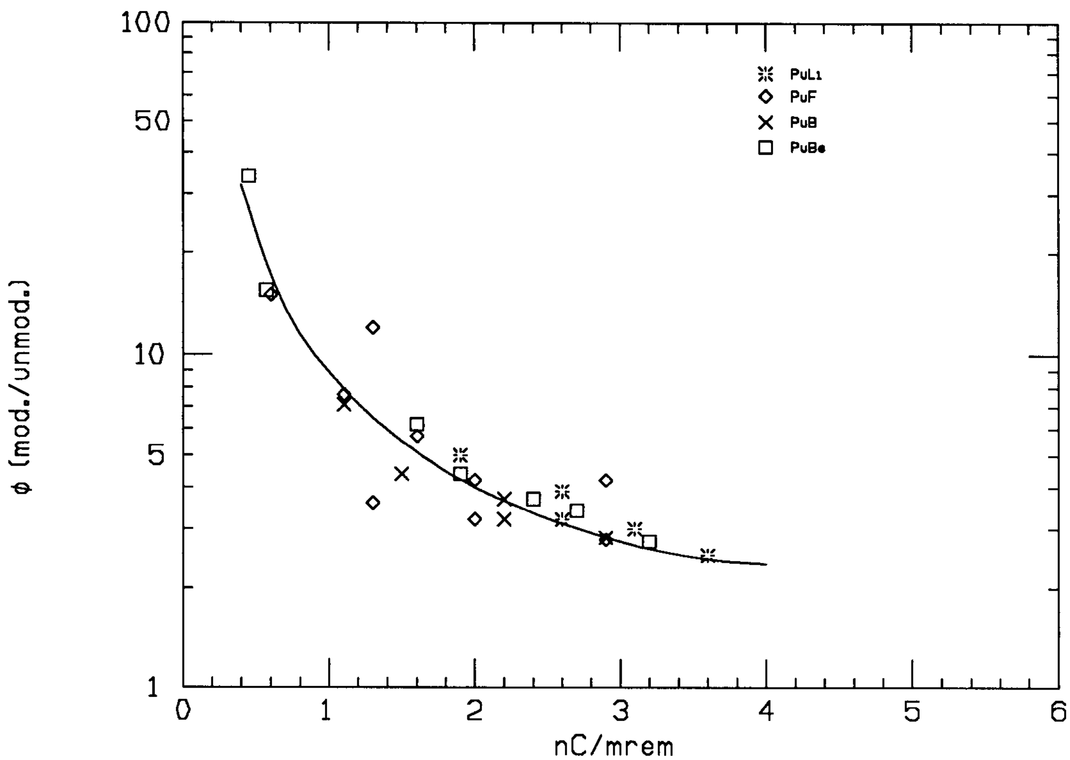

Figure 8. Sentitivity of TLD's versus mod./unmod. fluence ratios.

5. Discussion

Fig. 8 shows the results of the tunnel calibrations for all sources. If the average mod./unmod. number at SLAC of 2.75 were used, then the conversion would be 3 nC/mrem. Thus for example, a 100 nC net signal on the Li-6 disc (*i.e.*, after subtraction of the photon component as determined by a companion Li-7 disc) would be ascribed a 33 mrem dose using this calibration factor. However, it has always been SLAC policy to be conservative, and thus a lower conversion factor is in order. One choice might be to use the 90% point (mod./unmod.) of 4.4, which corresponds to a conversion factor of 1.8 nC/mrem. The same 100 mV signal then would be ascribed a dose of 55 mrem, which is 67% greater than the value derived from the average. We have chosen to be even more conservative than this, however. Since 1971, SLAC has conservatively used 1 nC/mrem, which means the same 100 mV would be ascribed a dose of 100 mrem.

Using such a conservative conversion factor means that the doses recorded are probably higher than actually received by at least a factor of two, and perhaps even a factor of 3. In Fig 9, we have inscribed the relative occurrence of mod./unmod. ratios onto the calibration curve of Fig 8.

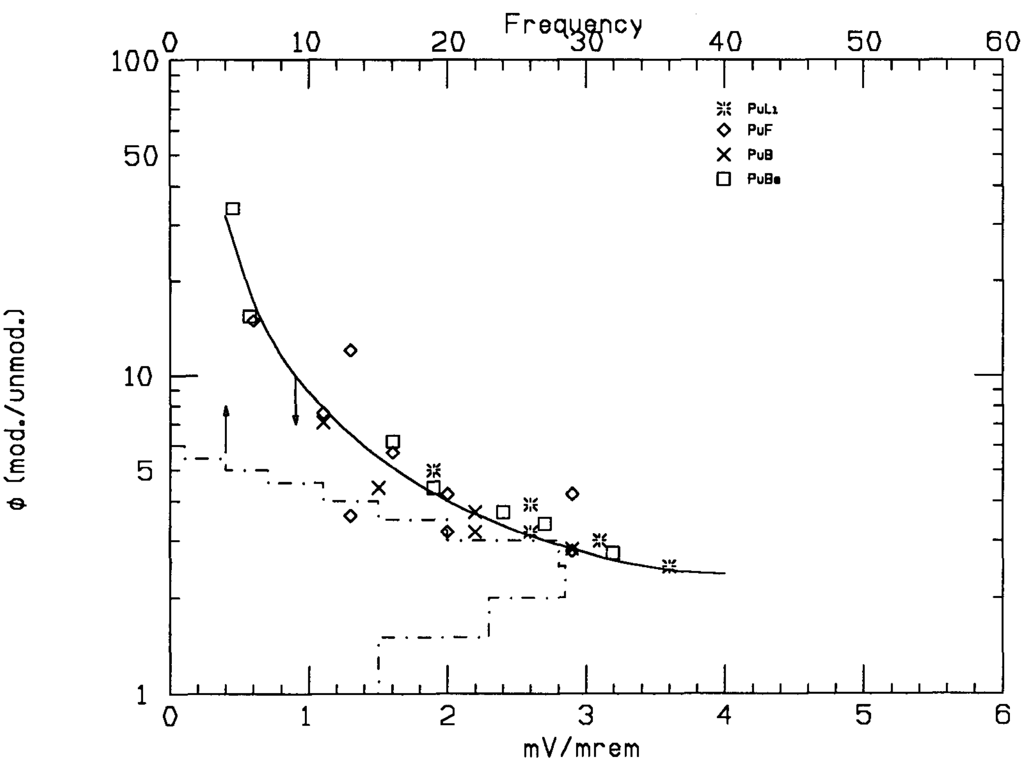

Figure 9. Sentitivity of TLD's versus mod./unmod. fluence ratios with Research Area ratios inscribed.

How important has this conservatism been? Table 1 gives the SLAC neutron doses by year from 1974 through 1985 as measured by the TLD method. A number of interesting points can be seen from this table. First, except for 1974, less than 6% of the badges issued showed neutron doses above 40 mrem for the year. In the same period, less than 7% of the badges showed photon doses greater than 40 mrad. The n/γ ratios varied from about 0.5 to 2.7, with the average about 1.5. Second, the percentages have remained more-or-less constant over the years.

Since 1975, it has been difficult simply by analyzing the data to determine the difference between radiation workers (quarterly badged) and occasionally exposed (annual badged) personnel. The average dose is < 100 mrem/yr in both populations. This is due in part to a shift in experimental requirements toward colliding $e^+ - e^-$ beams in place of high intensity fixed-target physics. There is therefore less induced radioactivity in targets and beam dumps (which were primary sources of personnel exposures).

Table 1
Annual Neutron and Photon Doses.

Year	Number	mrem/yr neutron		% Total	mrad/yr photon		% Total	Ratio
	Issued	0-40	$40 < D < 500$	> 40	0-40	$40 < D < 500$	> 40	n/γ
1974	1445	1320	125	8.7	1386	59	4.1	2.1
1975	1577	1496	81	5.1	1546	31	2.0	2.6
1976	1626	1559	67	4.1	1549	77	4.7	0.87
1977	2085	1990	95	4.6	2040	45	2.2	2.1
1978	2567	2459	108	4.2	2492	75	2.9	1.4
1979	3081	2913	168	5.5	3019	62	2.0	2.7
1980	4148	4116	32	0.8	4120	28	0.7	0.8
1981-2	1815	1762	51	2.8	1772	38	2.1	1.3
1983	2577	2447	130	5.0	2470	107	4.2	1.2
1984	2445	2328	117	4.8	2371	74	3.0	1.6
1985	2517	2432	85	3.4	2355	162	6.4	0.5

REFERENCES

1. L.D. Stephens and A.R. Smith, Fast-Neutron Surveys Using Indium-Foil Activation", UCRL-8418 (1958).
2. M. Awschalom and A.R. Smith, Fast-Neutron Surveys Using Indium-Foil Activation", UCRL-8418 (1958).
3. J.B. McCaslin, A.R. Smith, L.D. Stephens, R.H. Thomas, T.M. Jenkins, G.J. Warren and J.W. Baum, "An Intercomparison of Dosimetry Techniques in Radiation Fields at Two High-Energy Accelerators", Health Physics 33, (1977) 611
4. G. Svensson, Internal memo, 1971.