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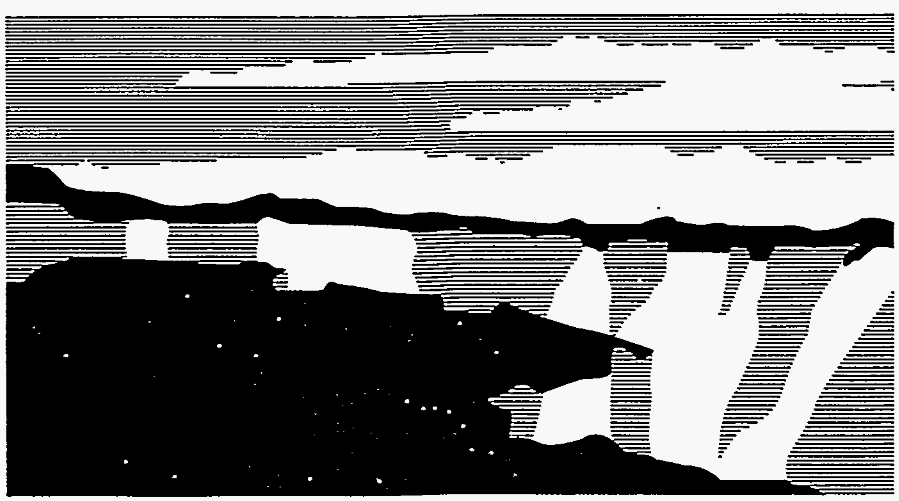

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DISCLAIMER

USING RESPONSE CHARACTERISTICS OF NEUTRON MEASUREMENT DEVICES TO IMPROVE NEUTRON DOSIMETRY

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Abstract - Recent administrative restrictions on personnel dose equivalent have resulted in increased pressure to more accurately report the neutron component without the traditional conservative added factors which sometimes inflate the reported values. Improvements include a new albedo neutron dosimeter which is capable of some limited energy discrimination. Also, additional emphasis has been placed on improving field measurements using traditional survey instrumentation and specialized spectroscopic techniques such as tissue equivalent proportional counters, Bonner spheres, and a modified 9" to 3" ratio technique. Improvements in these techniques along with a better understanding of the response of the TLD system have resulted in substantial reduction in the reported dose equivalent by improving the accuracy of the dosimeter system.

The response characteristics of the TLD system and other instrumentation are obtained through modeling with the Monte Carlo code MCNP-4A. Neutron fields in work areas are initially characterized with Bonner spheres. Routine updates are accomplished using a modified 9" to 3" ratio technique. These measurements are then used to predict the response of the TLD system when worn in that area. Correction curves are derived for the principal spectrum with various fractions of moderated or reflected neutrons. Work assignments are tracked through a database systems which is used to determine the principal spectrum that results in the neutron dose equivalent . The energy discrimination capability of the TLD system is used with the correction curve to derive an average correction appropriate to the readings of the dosimeter thus giving an energy corrected dose equivalent for the individual.

INTRODUCTION

Improved neutron dose equivalent measurement for individuals at Los Alamos National Laboratory (LANL) has become an increased priority due to lower administrative restrictions on personnel doses, increased workloads involving exposure to neutrons, and general improvements in quality control and ALARA implementation. Personnel dosimeters must be small and reliable. It is also desirable to have a system that is economical on an individual basis and easy to maintain. For the most part, the TLD-based dosimeter meets all of the requirements except that the system is not very accurate for the measurement of the neutron dose equivalent. Specifically, the neutron fluence-to-dose equivalent conversion factors increase dramatically with increasing neutron energy while the response of the TLD decreases rapidly with increasing energy (Figure 1). The advent of the albedo dosimeter[2] improved the response characteristics dramatically but is still far from dose equivalent. A neutron dosimeter that responds to both direct and albedo neutrons has been in use at LANL for many years. It has been necessary to derive correction factors for each work area such that the response of the dosimeter can be corrected based upon the individual work assignment. The factor, referred to as the Neutron Correction Factor (NCF), must be updated each time the person changes job assignments or the facility is modified because the neutron spectrum in the work area can change significantly. It should be obvious that the potential for error in such a system is significant. It is therefore a standard practice to overestimate the NCF so that the reported dose equivalent is greater than the actual dose equivalent. This would improve the likelihood that a person would be removed from a work assignment before the radiation dose becomes high enough to result in a biological response. Unfortunately, due to lower administrative control levels the over reporting of the dose equivalent is no longer considered an acceptable practice.

In an effort to improve the existing system without modification to the procedures or equipment, additional Bonner sphere measurements were made in some of the highest dose rate areas and in lower dose rate areas with high occupancy. Time-motion studies were conducted to evaluate the average exposure each individual received in each neutron field. These studies resulted in significant decreases in the applied NCFs and a corresponding lowering of the reported doses. The primary problem was that job assignments were changed frequently, sometimes more than once a day. Hence, the unacceptable possibility remained that a person could receive a significant exposure in a field with a higher correction factor while still assigned a lower value. The design of a new combination beta/gamma/neutron dosimeter with four TLD elements available exclusively for neutron measurement has been underway for several years. Prototypes have been tested in the laboratory and in the field. During 1994, the neutron component of the reported radiation dose equivalent for all of LANL was 75% of the total dose. This resulted in a decision to move up deployment of the new design prior to its formal acceptance as the dosimeter of record. During this interim period, the new design is neither used for determination of the neutron dose equivalent nor of the neutron correction factor, at least not as a stand alone device. However, it is used as a quasi-transfer instrument between the NCF measurement and the TLD dosimeter-of-record algorithm. The application of this technique provides an interesting look at some of the techniques used in neutron personnel dosimetry.

INSTRUMENT RESPONSE CHARACTERIZATION

In order to use the current design of the Bonner sphere system available at LANL, it was necessary to derive the response functions of the nine different detector configurations as a function of neutron energy. Each detector response was estimated by modeling the geometry using the LANL Monte Carlo code MCNP. The resulting response functions were very similar to those published by Mares, et.al.[3]. The unfolding techniques used were similar to those in the SPUNIT unfolding code developed at Pacific Northwest Laboratories[4]. The actual unfolding was accomplished in a computer spreadsheet and used a combination of the unfolding algorithms in SPUNIT and in SAND II[5]. A basic test of the system was made using bare and D_2O-moderated ^{252}Cf. The response was consistently about 90% of the calculated values. This was consistent with the expected wall effect in the detectors which was not included in the model. Measurements made in work areas resulted in neutron spectra which were consistent with the well known spectra of the sources present with appropriate variations according to room size and shielding.

An additional technique applicable to the determination of the NCF is the modified 9"-to-3" ratio system. This technique, derived by Hankins[6] uses a 9" rem ball to determine the dose equivalent. Another detector, referred to as a 3" ball, was used to derive the relative response of an albedo dosimeter. (It should be noted that neither the 9" nor the 3" detectors are standard 9" (22.86 cm) or 3" (7.62 cm) moderators but are called by those names since they were derived from those types of detectors. Hence the name "modified 9"-to-3" ratio system.") The technique as developed is not directly applicable to NCF measurements at LANL since the dosimeter-of-record is not an albedo dosimeter, i.e., it does not use a cadmium or boron filter to reduce the response to direct thermal neutrons. In order to use this technique, the BF_3 detector used in both the 9" and 3" detectors was also used without moderator, with and without a cadmium cover. Therefore, for each measurement location, four detector measurements were made. Again, the response curves were derived using MCNP and checked against the ^{252}Cf sources. In this case, however, unfolding of the neutron spectrum was not necessary. The NCF can be derived using a linear combination of the responses to estimate the dose equivalent response and the TLD response separately. The ratio of these two values is then the desired NCF.

The response of the TLDs was also calculated using MCNP. The response curves of the three different sets of TLD-600/TLD-700 pairs is shown in Figure 2. The design of the new dosimeter holder is shown in Figure 3. The response of the new dosimeter elements in the subject work areas can be derived directly from the Bonner sphere results or measured in the field.

DERIVATION OF NCFs

Neutron correction factors were initially derived in all of the subject work areas using the derived spectra from Bonner sphere measurements and the modified 9"-to-3" ratio technique. The ratios of the elements were also derived from the spectra using the calculated response curves. Spot checks were made with the prototype dosimeters to ensure the system was giving reasonable results. The NCF is defined as the dose equivalent per neutron relative to the dosimeter response per neutron, as given by:

$$NCF = \frac{\sum \phi_i H_i}{\sum \phi_i R_i}, \qquad (1)$$

where ϕ_i is the neutron fluence in the *i*th energy group, H_i is the neutron dose equivalent conversion factor for the *i*th group, and R_i is the response of the dosimeter for the *i*th group. It is important to note that neutron fluences are additive but NCFs are not. This means that the calculation of the NCF does not depend upon the number of fields the person is exposed to but only upon the sum of the fluences from those fields. Unfortunately, the results of Equation 1 are not a smooth function or even a unique function with changing neutron spectra. One can use a crude approximation however, in assuming that, for a given source, as the amount of moderation by hydrogenous material increases, the average dose equivalent per neutron decreases at a rate that is related to the increase in the response of the thermally-sensitive TLD dosimeter. The NCF then gets smaller as the numerator of Equation 1 decreases and the denominator increases. For one type of moderator material, this function is not linear but is unique and monotonic. By similar argument, it can be seen that the ratio of the direct thermal neutron element response over the albedo element response increases with increasing moderation, again a function that is not linear but is unique and monotonic. Therefore, a mathematical fit to the data can provide a tool to obtain a reasonable estimate of the NCF.

Data obtained from one specific work area are given in Figure 4. The goal is to use the measured NCFs in each work area in combination with the ratio measured by the new dosimeter to obtain an appropriate average NCF for the old dosimeter design. Therefore, the NCFs for the old dosimeter are plotted as the abscissa vs the ratio from the new dosimeter on the ordinate to obtain a function for a given work area. The multi-room area in Figure 4 contains mostly fission sources with a few (α,n) sources in one section of the area. The curve is not the best fit to the data but a conservative estimate that represents an upward bound on the data. The calibration point for bare Cf is shown for comparison.

To insure the values derived from the above method are valid for application to assessment of the dose-of-record, continuing measurements are made with the Bonner sphere spectrometer and the modified 9"-to-3" ratio. It has been observed that the curve is no longer valid when the source is mostly shielded by iron or concrete. When a source is shielded by a substance such as iron, the spectrum from that combination must then be considered as the source spectrum and the measurements repeated for various amounts of additional moderation by hydrogenous materials.

CONCLUSIONS

Significant improvements have been made in the assessment of personnel neutron dose equivalents by use of a combination of spectral measurements and more complex neutron dosimetric techniques. By using neutron field measurements to obtain information about the response characteristics of the neutron dosimeters, the dosimeters have been capable of transferring spectral correction factors for limited work areas. The basis for these improvements has been the capability to derive a detailed neutron-energy response for all of the devices using Monte Carlo modeling.

The correction factors currently applied are still overestimates. As additional field data is obtained, the conversion curve will be lowered to a more accurate representation of the data. The weakness in the technique is related to the fact that each type of neutron source requires a different curve and if an individual is exposed to several different types of sources, there is no means to determine the most applicable curve.

Other techniques are being explored that could result in improved neutron dose equivalent measurement for individual personnel. Supplemental dosimeters based on track-etch techniques are currently being developed. A system based on NTA film has been in use for many years in areas which have very high-energy neutron fields. It is hoped that a system based on a combination of the new TLD dosimeter and a track-etch dosimeter will result in a dose equivalent response in all of the neutron fields encountered at LANL.

REFERENCES

1. International Commission on Radiological Protection, *Data for Protection against Ionizing Radiation from External Sources: Supplement to ICRP Publication 15,* ICRP Publication 21 (1971).
2. Hankins, D.E. *A Small, Inexpensive Albedo-Neutron Dosimeter*, Los Alamos Scientic Laboratory Report LA-5261 (1973)
3. Mares, V., Schraube, G., and Schraube, H. *Calculated Neutron Response of a Bonner Sphere Spectrometer with ^{3}He Counter*, Nucl Inst and Meth, **A307**, 398-412 (1991).
4. Brackenbush, L.W., and Scherpelz, R.I. *SPUNIT, A Computer Code for Multisphere Unfolding*, Pacific Northwest Laboratory Report PNL-SA-11645 (1983).
5. McElroy, W.N., Berg, S., Crockett, T., and Hawkins, R.G. *A Computer-Automated Iterative Method for Neutron Flux Spectra Determination by Foil Activation*, Air Force Weapons Laboratory Report AFWL-TR-67-41, Vol 1 (1967)
6. Hankins, D.E. *The Effect of Energy Dependence on the Evaluation of Albedo Neutron Dosimeters*, IN Proc. 9th Mid-Year Topical Symp of the Health Physics Society, Denver, Co. (1975).

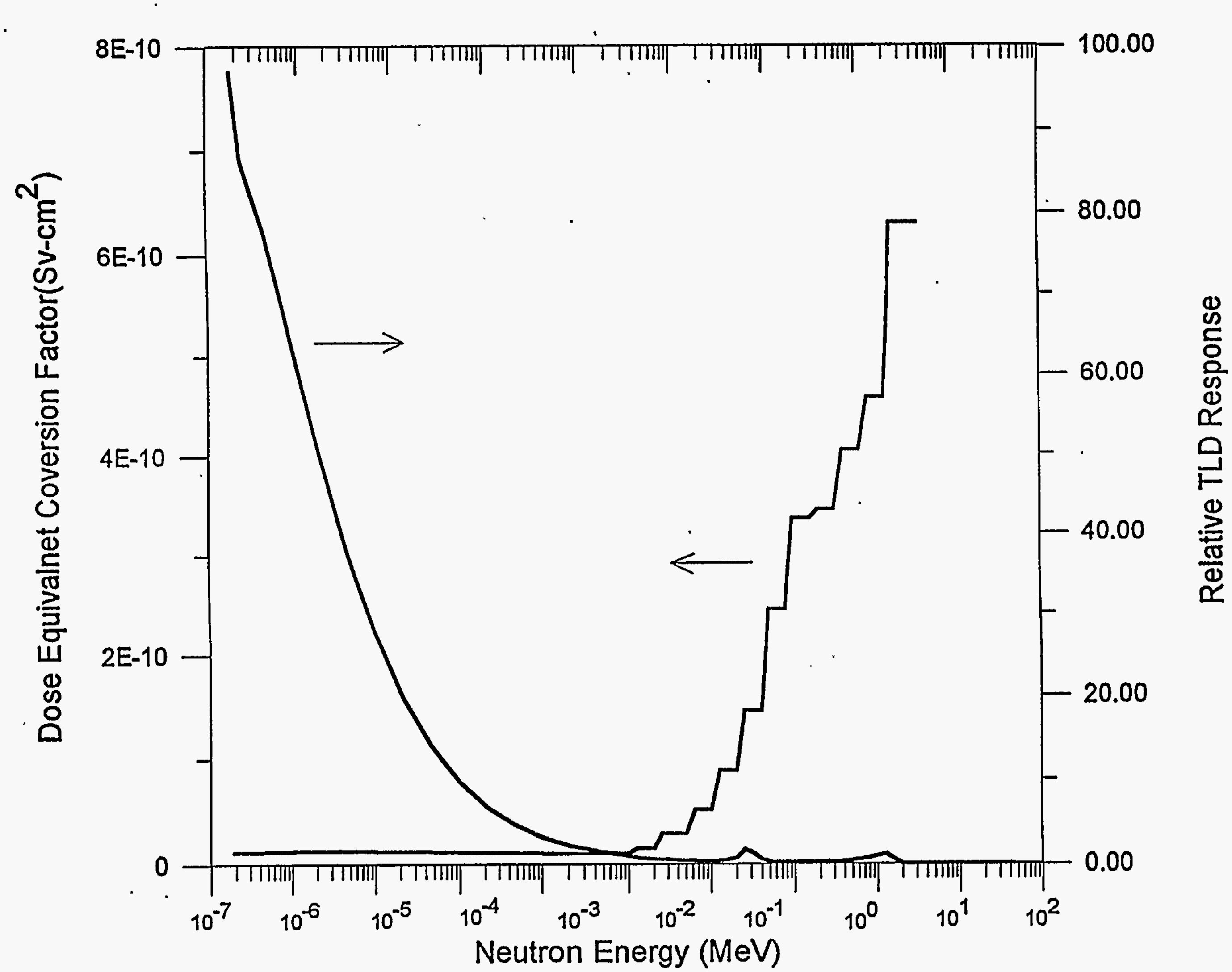

Figure 1 Comparison of ICRP-21 dose equivalent conversion factors with calculated response of a bare TLD chip in air.

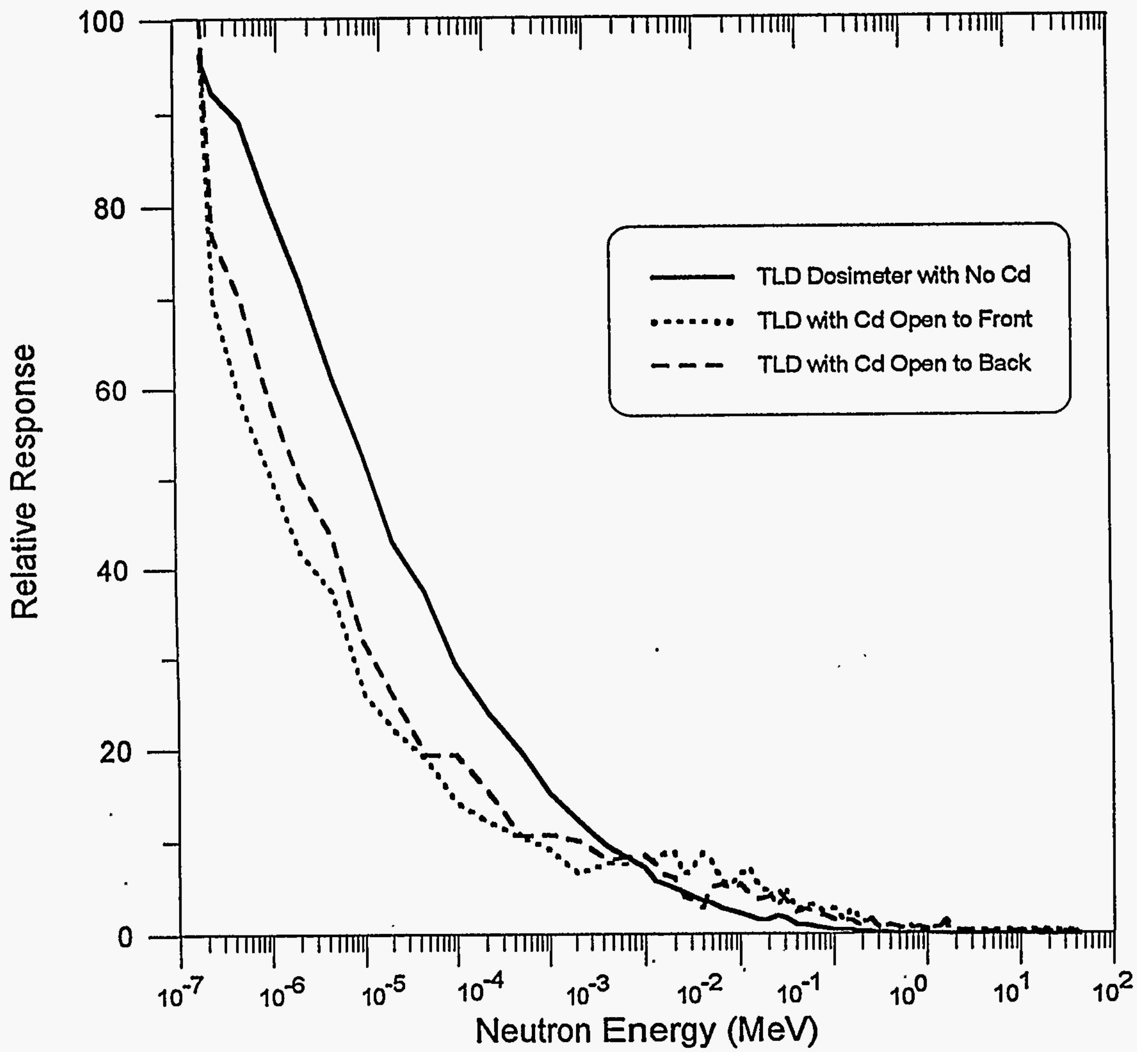

Figure 2 Relative Calculated responses of the old dosimeter style with no cadmium compared to the response of the new Harshaw/Bicron Type 8823 Dual-Card Dosimeter with cadmium box.

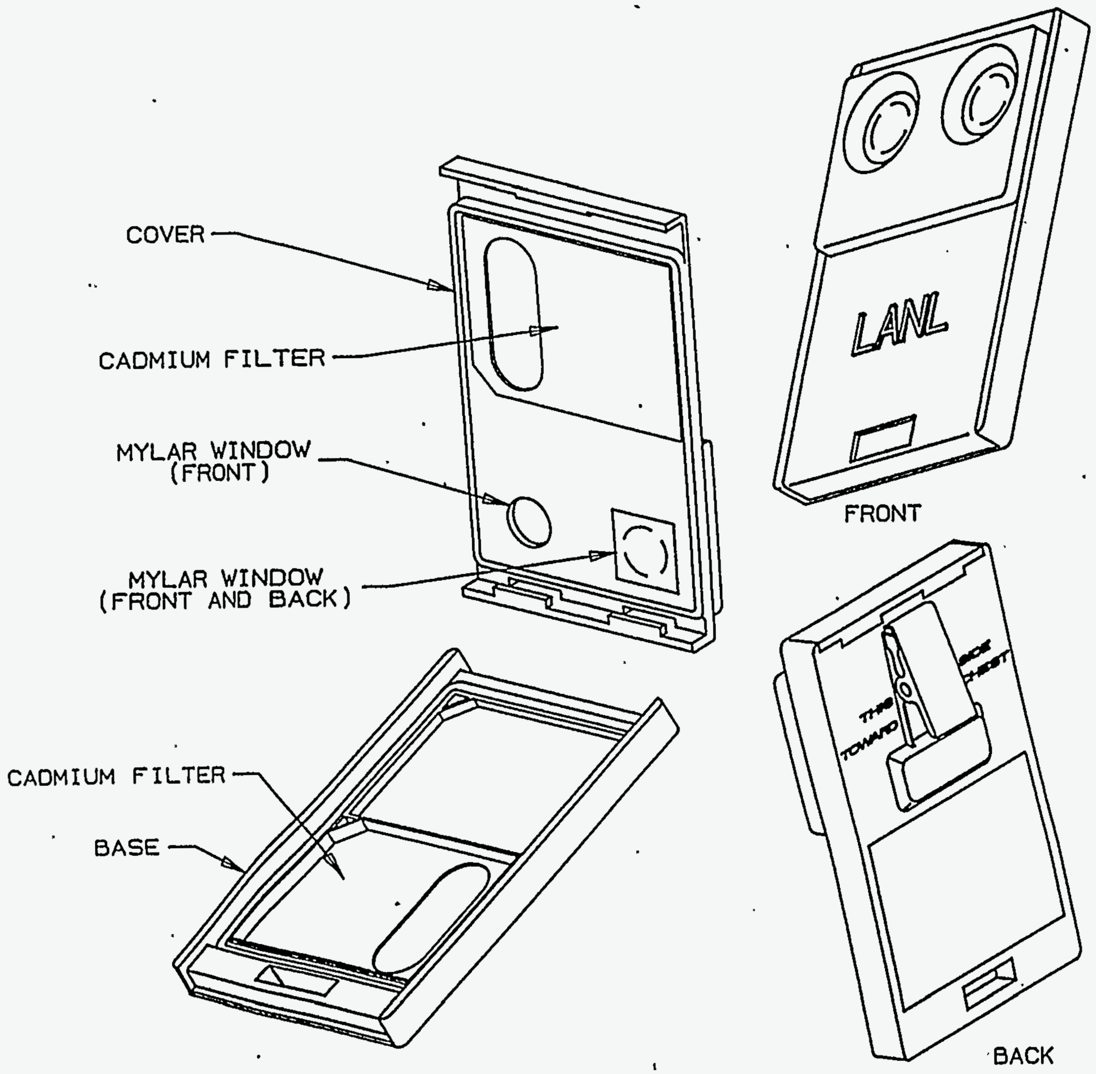

Figure 3 Physical design of the new Harshaw/Bicron Type 8823 Dual-Card Dosimeter showing openings over and under TLD-600/700pairs.

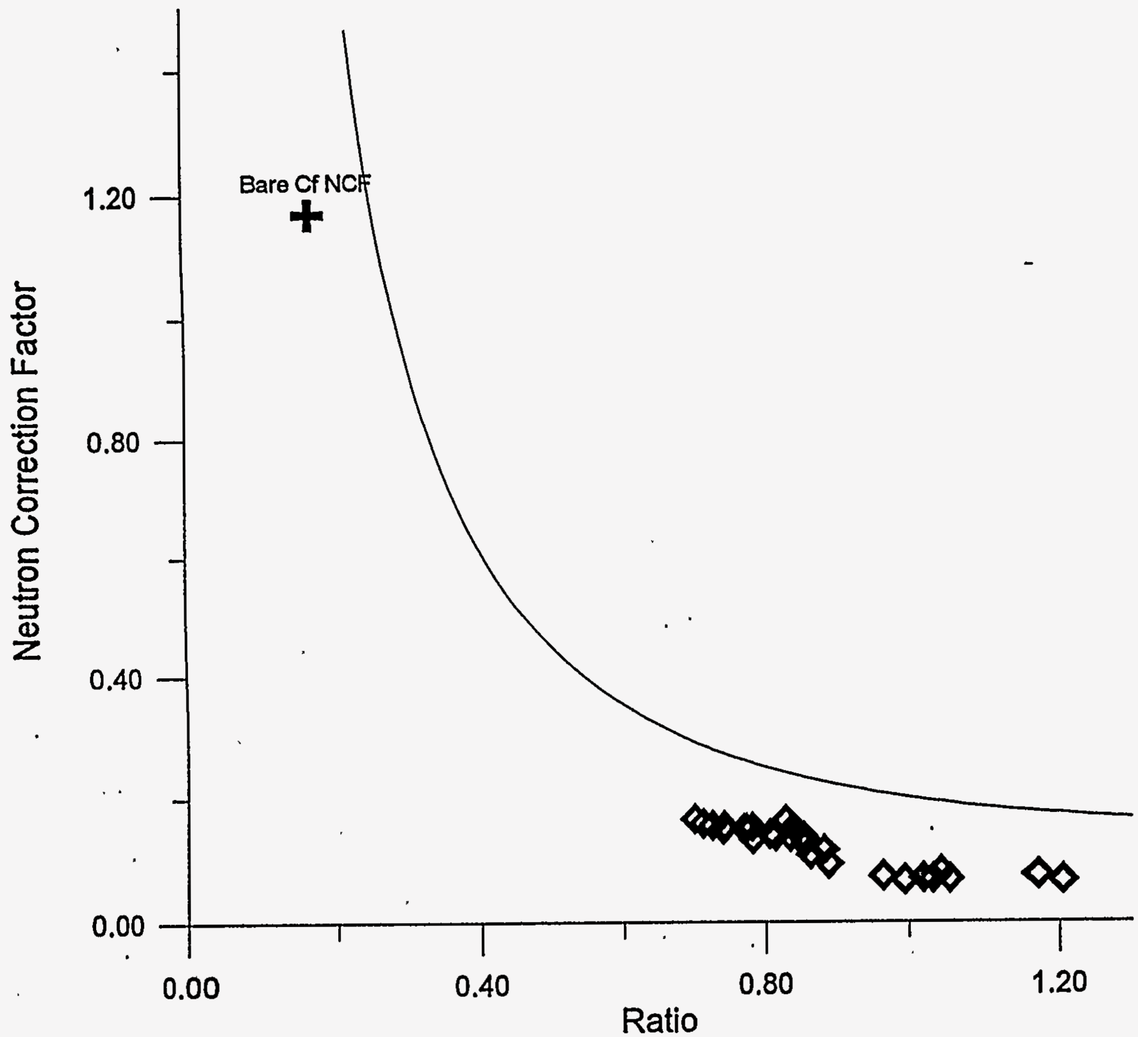

Figure 4 Measurement Data from one work location showing variation of NCF for old style dosimeter as a function of the ratio of elements in the new style. Calibration point with bare ^{252}Cf is shown for comparison purposes.