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COMBINATION TLD/TED DOSE ASSESSMENT

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COMBINATION TLD/TED DOSE ASSESSMENT

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During the early 1980s, an appraisal of dosimetry programs at U.S. Department of Energy (DOE) facilities identified a significant weakness in dose assessment in fast neutron environments. Basing neutron dose equivalent on thermoluminescence dosimeters (TLDs) was not entirely satisfactory for environments that had not been well characterized. In most operational situations, the dosimeters overrespond to neutrons, and this overresponse could be further exaggerated with changes in the neutron quality factor (Q). Because TLDs are energy dependent with an excellent response to thermal and low-energy neutrons but a weak response to fast neutrons, calibrating the dosimetry system to account for mixed and moderated neutron energy fields is a difficult and seldom satisfactory exercise. To increase the detection of fast neutrons and help improve the accuracy of dose equivalent determinations, a combination dosimeter was developed using TLDs to detect thermal and low-energy neutrons and a track-etch detector (TED) to detect fast neutrons. By combining the albedo energy response function of the TLDs with the track detector elements, the dosimeter can nearly match the fluence-to-dose equivalent conversion curve.

Several track detectors were evaluated early in the program through efforts at the Lawrence Livermore National Laboratory, the University of Connecticut at Storrs, and the University of California at Berkeley in addition to Pacific Northwest Laboratory (PNL).[a] It became clear very quickly that the polymer CR-39 had neutron detection characteristics superior to other materials tested. The CR-39 track detector is beta and gamma insensitive and does not require backscatter (albedo) from the body to detect the exposure. In its early formulation, the background signal (tracks per unit area) of CR-39 was relatively high and inconsistent. Changes by the material manufacturer and by the polymer caster significantly reduced the

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background and greatly improved the background consistency and response of CR-39. Experiments suggesting that the radiation-sensitive sites in the CR-39 occurred in the polymer's carbon/oxygen bonds led to attempts to further improve the detector material. Several materials were copolymerized with CR-39 to try to increase the number of damage sites and increase the neutron sensitivity. Certain materials showed promise but did not constitute a practical improvement over CR-39 alone.

The exposed CR-39 is processed using a strongly basic solution at elevated temperatures. The original prototype processing equipment consisted of single cell chambers, an audio-oscillator, and a step-up transformer. Advances in the cell design eventually led to a multi-chamber design increasing the number of samples that could be simultaneously processed to multiples of 24. A power supply specifically tailored to the needs of the electrochemical process greatly reduced the variability of results from one processing batch to the next. Chemical and electrical parameters were extensively evaluated to identify those providing the highest neutron response without increasing the background above acceptable levels.

One of the issues in using a combination dosimeter is how to make use of the information from each element to interpret the neutron dose equivalent. Efforts were begun to develop a generic algorithm using both components and basing them on a common ^{252}Cf calibration point. The algorithm was then tested using other sources and actual Hanford Site dosimetry data.

These efforts identified major theoretical limitations. Figure 1 illustrates the approximate normalized responses as expressed by mathematical expressions of the TLD and TED components. A summary curve mockup of the two responses is nearly flat and illustrates how well these two elements are complementary in neutron energy detection. The TLDs detect most neutron exposures, but their sensitivity falls off above the low-energy range. Track detectors with polyethylene radiators have a threshold around 100 keV. The use of the TEDs provides a reasonably clear estimate of the dose from fast neutrons. When exposed to a low-energy source, the TEDs will detect essentially nothing. In Figure 2, the approximate energy response of each element is demonstrated in relation to the ^{252}Cf bare energy spectrum.

Although each system can be calibrated to sources of interest, the responses from the two systems cannot be directly related to each other.

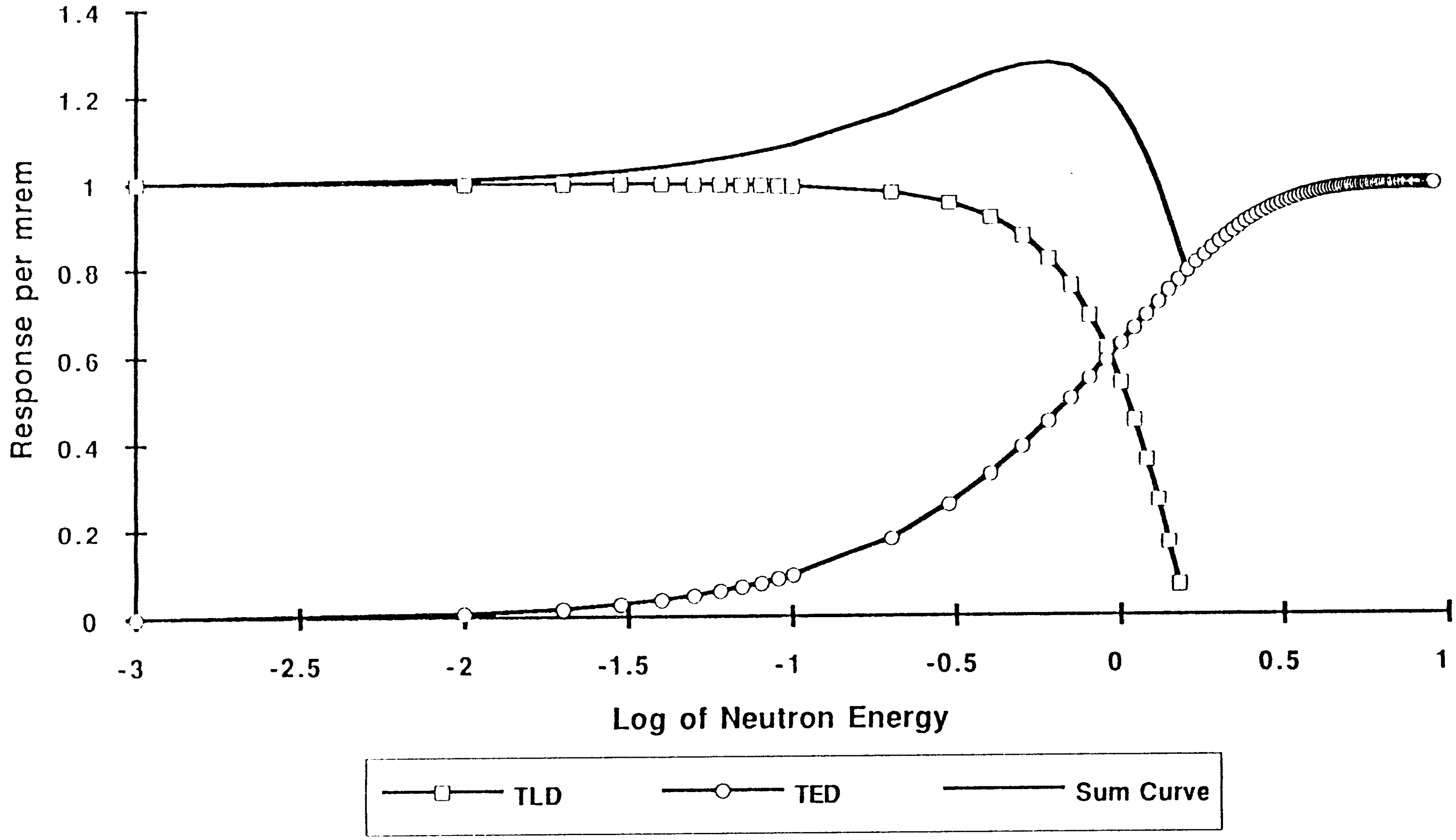

Figure 1. Relative Energy Response of TLDs and TEDs (Modeled and Normalized)

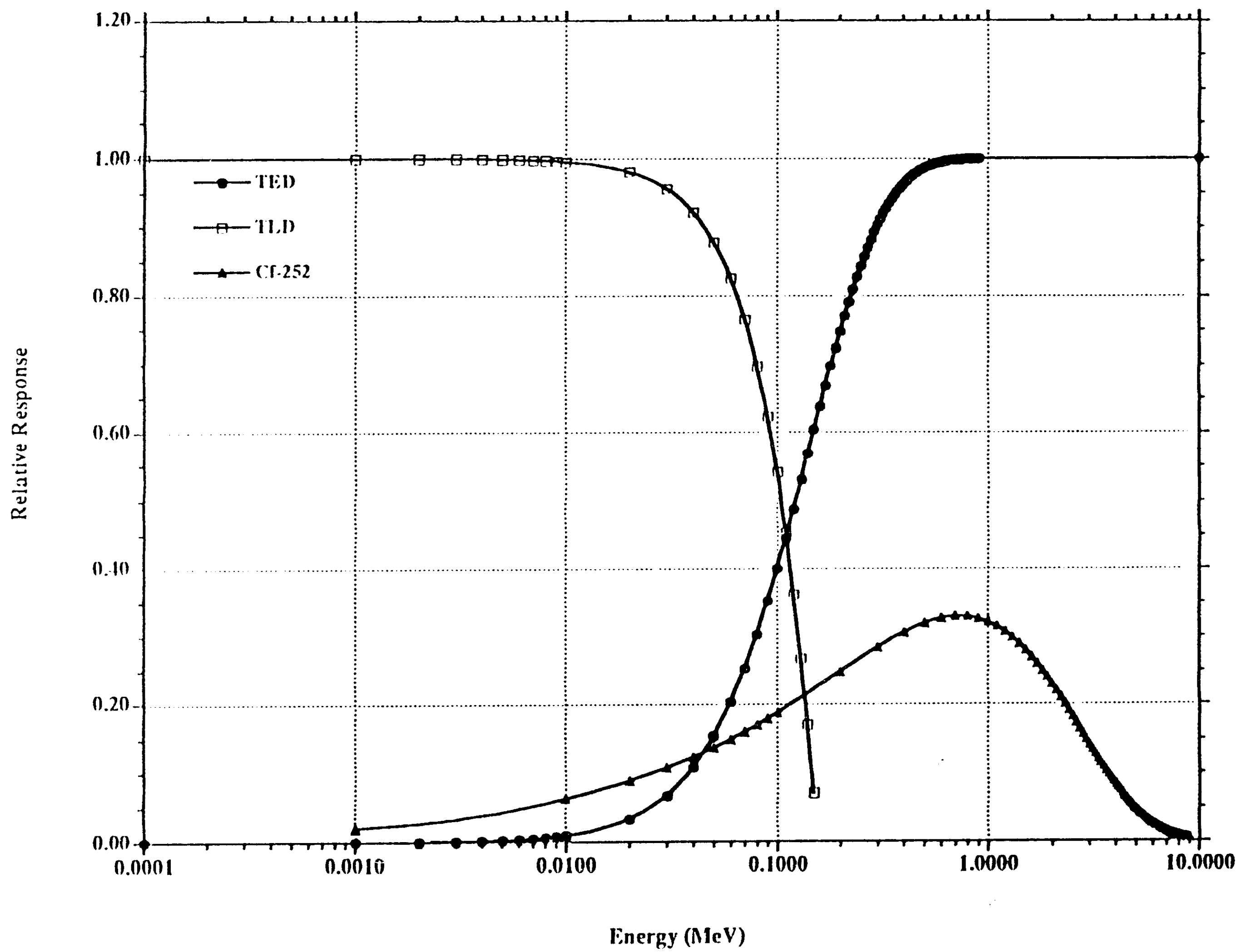

Figure 2. Relative Energy Response of TLDs and TEDs in Relation to the ^{252}Cf Spectrum (Modeled and Normalized)

Because TLDs continue detection at high energies, though at a much reduced rate, accurate dose assignment through the use of the two elements still requires spectrum characterization. This complicates the effort to use the data in a useful algorithm. The problem is primarily one of detection limits and sensitivities. Because of the dramatic energy response reduction of the TLDs and the threshold response of the TEDs at low energies, simultaneous equations to evaluate slow and fast neutron responses cannot be satisfactorily applied. Unless one assumes all TLD response is less than 100 keV for calculational purposes, it is very difficult to design an algorithm for varying or unknown neutron fields.

The current recommendation for making use of the combination dosimeter is to use both where a wide energy spectrum exists and to base the fast neutron dose on the CR-39 detectors. Whether this response should be added to the TLD dose depends on spectral information that may not be available. Although use of a TLD/TED combination provides additional energy information, it does not completely address energy bins that are important to the assignment of Q. Most of the TLD dose will fall into the proposed quality factor category 5 which includes energies of less than 10 keV. The Q of 10 for the 10- to 100-keV range is best detected with the TLDs. Probably all the TED response at most facilities will fall within the 20 factor energy range. If we are willing to apply a factor of 10 to all TLD-detected dose and 20 to the TED response, the combination dosimeter will support this conservative approach with few improvements.

If we are not willing to assign dose equivalent based on these two ranges alone, the potential exists for using an element capable of detecting the 10- to 100-keV range more accurately. This component uses CR-39 but with a boron radiator. When used with a filter to eliminate thermal energies, this detector is capable of bridging the "intermediate" energy gap. The polyethylene radiator makes use of the (n,p) interaction. The boron radiator functions through the (n,α) interaction. In fact, it appears possible to cover the 10- to 100-keV range as well as higher energies with this single element if track size is used to discriminate the (n,α) from the (n,p). Unfortunately, efforts to take this material from the laboratory into field situations are currently sidetracked.

A number of other efforts have been completed or are continuing. The combination dosimeter was initially seen as an "interim" system. Because the TED component has repeatedly demonstrated its value, it is likely to be used until a suitable replacement is developed. Because the TED processing and readout systems are labor intensive, a number of approaches to reduce time and cost have been pursued. One of these possibilities is to find a method of direct readout (without processing or with minimal processing) of damage sites in the plastic detectors. None of the optical and electronic processes tried to date have been capable of identifying such damage. However, several laser reading techniques are being evaluated, and it is expected that positive results may be obtained following a short etch procedure to initiate track formation.

Use of the TED methodology for dosimeters sent in for DOE's Laboratory Accreditation Program (DOELAP) certification requires certain procedural considerations and documentation of parameters. Some of these include:

- Ensuring that the equipment for developing and reading out the TEDs is appropriate for the system.
- Testing each batch of detector material for sensitivity and consistency to accept or reject the batch.
- Providing procedures and establishing appropriate operating conditions for
    - transferring sample identification to ensure accurate records
    - consistent and proper etch chamber assembly
    - consistent etchant normality and identified limits on solution reuse
    - consistent etching parameters of temperature, voltage, frequency, time, and pre- and post-etch preparations
    - recovering from electrical failure or chamber leakage
- Writing procedures and assigning responsibility for proper readout including:
    - proper sample cleaning preparations
    - warmup, if necessary, and calibration of track counting system to assure reproducibility
    - proper sample positioning and exposed/processed sample setup
    - readout magnification established and a minimum readout area (suggested 0.10 cm^2)
- Evaluating stability of the track reader and checking periodically as determined by the evaluation.

- Ensuring that technicians understand the operating conditions and critical functions of processing and readout equipment as identified above.

- Checking background track readings of samples from batch according to an established procedure before issuing TED.

- Calibrating control samples to an appropriate source for type or exposure or "normalize" to ^{252}Cf.

- Including calibration samples and background samples in every processing chamber.

- Packaging dosimeters to prevent contamination with unknown chemicals and away from direct exposure to ultraviolet rays.

As part of DOE's Personnel Neutron and Upgrade Program, we have been developing a CR-39 track detector over the past decade to address detection and measurement of fast neutrons. This technology has been used successfully by several DOE laboratories, vendors, and universities to better assess high-energy neutron exposures. Using CR-39 TEDs in combination with TLDs will now allow us to detect the wide spectrum of occupational neutron energies and assign dose equivalents much more confidently.

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