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RAPID MEASUREMENT OF NEUTRON DOSE RATE FOR TRANSPORT INDEX

Robert L. Morris
BWX Technologies
Safe Sites of Colorado
Rocky Flats Environmental Technology Site
Golden, Colorado
(303) 966-6468
Robert.Morris@RFETS.gov

ABSTRACT

A newly available neutron dose equivalent remmeter with improved sensitivity and energy response has been put into service at Rocky Flats Environmental Technology Site (RFETS). This instrument is being used to expedite measurement of the Transport Index and as an ALARA tool to identify locations where slightly elevated neutron dose equivalent rates exists. The meter is capable of measuring dose rates as low as 0.2 μSv per hour (20 μrem per hour). Tests of the angular response and energy response of the instrument are reported. Calculations of the theoretical instrument response made using MCNP™ are reported for materials typical of those being shipped.

INTRODUCTION

Rocky Flats Environmental Test Site has approximately 2800 packages of Special Nuclear Material scheduled for shipment in fiscal years 2000 through 2002. For each of these packages, the Transport Index must be determined. One step in determining the Transport Index is measurement of the neutron dose equivalent rate 1 meter from the package. Historically, this measurement has been difficult to perform due to sensitivity and accuracy limitations of existing neutron remmeters. The Eberline WENDI-2 is a new, Los Alamos National Laboratory-designed, neutron dose equivalent meter with improved sensitivity and energy response compared with the conventional 9-inch remmeter. The WENDI-2 is similar to the original WENDI [1] with changes to enhance manufacturability and improve sensitivity. The original WENDI was never commercially produced. The first five WENDI-2's produced were purchased by Safe Sites of Colorado to expedite and improve measurement of the neutron dose equivalent. Use of the WENDI-2 in place of the conventional meter promises to save time and reduce personnel dose. When the neutron energy encountered during field measurements is significantly different from the calibration energy, the WENDI-2 provides a more accurate, less conservative estimate of dose equivalent.

TRANSPORT INDEX

Transport Index (TI) is a shipping concept that communicates the degree of control to be exercised by the carrier during transportation [2]. Emergency response personnel also use TI information during a response. For most shippers, the Transport Index is based on the total dose equivalent rate in mrem per hour at 1 meter, rounded up to the nearest 0.1 mrem per hour. For shippers of fissile material, the TI also describes the hazard of an accidental nuclear criticality.

A minimum TI based on criticality hazard, not dose rate, is set for each package type. TI values as low as 0.3 are allowable on many of the shipping containers used at RFETS if the total dose equivalent rate at 1 meter does not exceed this value. Instrument detection limits are needed for both gamma and neutron radiation that are less than the criticality TI, otherwise the reported TI may be higher than necessary. An overly conservative TI could limit the number of containers in a vehicle, which would increase shipping costs.

BASELINE TECHNOLOGY

Prior to 1998

Prior to 1998, neutron transport index measurements were made at RFETS using an Eberline NRD 9-inch remmeter operating in the ratemeter mode. Inadequate sensitivity and elevated background radiation in work areas made this an inaccurate and error-prone process.

Since 1998

In 1998, a new measurement procedure was implemented with the 9-inch remmeter operating in an integrated count mode. Background and sample count times necessary to achieve adequate sensitivity were selected based on the concept in Reference 3. A 10-minute background count is made at the measurement location, then the shipping container is moved to that location. A contact dose equivalent rate survey is performed to identify the point on the container where the highest neutron radiation level exists. A 10-minute count is taken 1 meter from the maximum point identified on the container surface. A net dose equivalent rate is calculated. This results in an adequately sensitive neutron measurement in the presence of a relatively high background. Background measurements are occasionally repeated as conditions change during a work shift.

The integrated measurement procedure introduced in 1998 is time consuming, requires several tedious arithmetic steps, and is costly in personnel dose. For both the background and signal measurements, the technician is required to convert the dose equivalent in 10 minutes to the dose equivalent rate per hour. Background is subtracted from the signal and the net value is added to the net gamma dose equivalent rate. This process takes 15 to 20 minutes per container. During that time many associated personnel, including packaging technicians, verification technicians, supervisors, and security guards, may be standing by in elevated radiation fields.

Complicating the picture is the inaccuracy of the 9-inch remmeter when measuring some neutron spectra. The 9-inch remmeter has a well-documented overresponse to moderate energy neutrons typical of those found in nuclear power plants [4]. In a test performed at RFETS, we found that a 9-inch remmeter calibrated to accurately respond to a bare californium-252 neutron source will over-respond by 130% to a D_2O-moderated californium-252 source. The average neutron energy being emitted by the shipping containers is somewhere between the two test conditions.

WENDI-2 TECHNOLOGY

The WENDI-2 design incorporates tungsten into the polyethylene moderator to enhance high-energy neutron response and to absorb neutrons in the energy range of 0.1 to 1.5 keV, resulting in improved agreement with the NCRP-38 [5] dose equivalent response function. The cylindrical design makes it possible to incorporate a high sensitivity pressurized cylindrical helium-3 thermal neutron detector at the centerline of the instrument. At 13.6 kg (30 pounds), the instrument is difficult to maneuver and is usually mounted on a cart. The WENDI-2 is manufactured as a "smart" instrument, meaning the calibration and display parameters are stored in a memory device packaged in the detector. It is designed for use with the Eberline E600 ratemeter, which enables several advanced features including automatic background subtraction and data logging.

Detection Limits

Observation of the response in the RFETS calibration facility, using the instrument in a ratemeter mode with a 60-second response time constant, suggests that it is possible to measure 0.2 μSv per hour (20 μrem per hour). Dose equivalent rates of 1μSv per hour (0.1 mrem per hour) are easily measured in the ratemeter mode. Testing has shown that the instrument response is linear to within 4% over the dose equivalent rate range of 10 μSv per hour (1 mrem per hour) to almost 40 mSv per hour (4 rem per hour). In fact, the dynamic range is probably wider, but limitations of the calibration facility prevented NIST-traceable testing at higher and lower dose equivalent rates.

Energy Response

The WENDI-2 was calibrated and tested in the RFETS low-scatter neutron calibration cell. When calibrated to accurately respond to a bare californium-252 neutron source, the WENDI-2 over-responds to a D_2O-moderated californium-252 source by 37%. MCNP™ [6] was used to calculate the energy response of the WENDI-2 to these two neutron spectra. Predicted values closely match the observed values.

Angular Response

The WENDI-2 was irradiated in a low-scatter room so that the neutrons impinged on the instrument at several different angles as illustrated in Figure 1. Table I shows the relative response with respect to the conventionally true value for irradiation using a bare californium-252 source and a D_2O-moderated californium-252 source.

Table I. Measured Angular Response of the WENDI-2 Calibrated to Bare Cf-252 then Irradiated with Bare and D_2O-moderated Cf-252.

Incident radiation angle	Bare Cf-252	D_20-Moderated Cf-252
90°	+16%	+81%
45°	0% *	+41%
0°	0%	+36%
-45°	-11%	+14%
-90°	+4%	+47%

* A value of 0% indicates agreement with the conventionally true value.

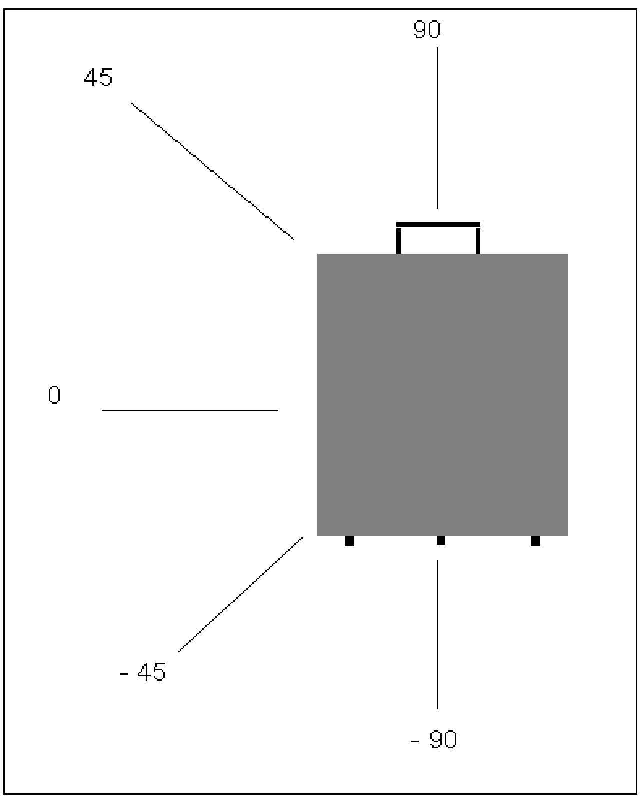

Fig. 1. Irradiation Geometry Used in Angular Response Test of the WENDI-2.

Transport Index Method Using the WENDI-2

The neutron TI method developed for use with the WENDI-2 with the E600 ratemeter uses the automatic background subtraction features of the E600. The background dose equivalent rate is established by selecting the BACKGROUND switch position. After pre-selected counting precision has been attained, or after 10 minutes have elapsed, the value is captured. This value is automatically subtracted from all subsequent measurements. The background measurement is reestablished occasionally as conditions change during a work shift.

As in the prior method, the container is moved to the measurement area and a contact dose equivalent rate survey is performed to identify the point on the container where the highest neutron radiation level exists. The WENDI-2 is located 1 meter from this point, and a 1-minute dose equivalent rate measurement is made using the E600 in the scaler meter mode. The net neutron dose equivalent rate is added to the net gamma dose equivalent rate to determine the radiation TI. This process takes approximately 5 minutes per container.

The same complement of technicians, supervisors, and security guards is present as in the baseline method.

CALCULATED BIAS IN TRANSPORT INDEX MEASUREMENTS

A theoretical study using MCNP™ was performed to determine accuracy of the neutron TI measurements for plutonium oxide and plutonium fluoride for the WENDI-2 and the 9-inch remmeter. The shipping container was crudely modeled as a DOT-17C drum (which resembles a 55-gallon drum) containing a point source of plutonium fluoride or plutonium oxide surrounded by a 1-cm-thick sphere of steel. The shielded source was assumed to exist at the center of the shipping container. The dose equivalent was calculated 1 meter from the surface of the container. The detectors (the WENDI-2 and the 9-inch remmeter) were accurately modeled based on design drawings of the instruments. For this calculation, both instruments are assumed to be calibrated to respond correctly, as defined by an idealized detector that follows the NCRP-38 [5] dose equivalent response curve, 1 meter from a bare californium-252 source. Table II shows the calculated energy response bias of the instruments when used to measure the TI. Both instruments provide acceptable accuracy for these measurements because the energy of the calibration spectrum is reasonably well matched to the field measurement conditions.

Table II. Calculated Bias in Neutron Transport Index of the WENDI-2 and the 9-inch Remmeter for Pu Oxide and Pu Fluoride Compared with an Ideal Detector. *

	WENDI-2	NRD 9-inch Remmeter
Plutonium Oxide	10%	15%
Plutonium Fluoride	2%	7%

* Both instruments are assumed to be calibrated to bare Cf-252. A positive bias indicates an overresponse with respect to the conventionally true value.

OTHER APPLICATIONS AT ROCKY FLATS

Special nuclear material consolidation at RFETS has resulted in frequent drum movements in a few facilities. The baseline approach for identifying areas where unacceptably elevated neutron doses equivalent exist is with an area TLD monitoring program. Area TLDs are replaced on a quarterly cycle, so it may be 3 months or more before an undesired effect of drum movements is recognized. This can result in unnecessary personnel dose. In one facility, a route has been established and measurement points marked with barcode labels. A technician uses the WENDI-2 to make an integrated dose equivalent measurement at each point until a pre-set counting precision is attained then log it in the E600 meter. Data are downloaded into a database program for trending and display. Aggressive monitoring has resulted in reduced personnel dose in administrative areas.

CONCLUSION

Approximately 2800 containers of special nuclear material remain to be shipped from RFETS, and each of these must have a TI measurement. A significant number of these shipments originate from areas where background dose rates exceed 10 μSv per hour (1 mrem per hour). Use of the WENDI-2 results in time savings of approximately 10 to 15 minutes for each container. Implementation of new procedures made possible by this instrument has resulted in improved accuracy and substantial savings in both cost and personnel dose. The greatly improved sensitivity of the WENDI-2 also makes it a valuable instrument for use in more general radiation protection applications, especially for identification of areas of low neutron dose rate where ALARA actions can further reduce personnel dose.

REFERENCES

[1] R. H. Olsher, Hsiao-Hua Hsu, A. Berverding, J. H. Kleck, W. H. Casson, D .G. Vasilik, R. T. Devine, "WENDI: A New Neutron Dose Equivalent Meter," LA-UR-99-1288 (1999).

[2] U. S. Department of Transportation, Title 49 Code of Federal Regulations, Subchapter C-*Hazardous Materials Regulations*, Part 173.403. Washington, D.C., Office of the Federal Register, National Archives and Records Administration.

[3] Handbook of Health Physics and Radiological Health, Third Edition. Figure 9.12 "Optimum Number of Counts for Minimizing Combined Counting Time When Percent Error is Assigned and Total-to-Background Ratio is Known" page 9-23. Williams & Wilkins. 1998. Baltimore, MD.

[4] G. W. R Endres, "Neutron Dosimetry at Commercial Nuclear Plants." U. S Nuclear Regulatory Report; NUREG/CR-1769, 1981.

[5] National Council on Radiological Protection and Measurements. 1971. "Protection Against Neutron Radiation." NCRP Publications; NCRP Report No. 38. Bethesda, Maryland.

[6] J. F. Breismeister, Ed., "MCNP – A General Monte Carlo Code for Neutron and Photon Transport," Version 4B2, LA-12625-M (March 1997).

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