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DOE RADIOLOGICAL CALIBRATIONS INTERCOMPARISON
PROGRAM: RESULTS OF FISCAL YEAR 1989

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SUMMARY

Calibration measurements for personnel dosimetry purposes must be both accurate and consistent with national standards. In order to satisfy these requirements, the following methods are usually employed. In one case, a radiation source is sent to the National Institute of Standards and Technology (NIST)^(a) for calibration and is returned to the laboratory to be used as a local standard. Another method involves the calibration of an instrument, such as a precision ionization chamber, by NIST. After calibration, this instrument is then used to measure the exposure rate delivered by radiation sources at the laboratory. Such calibrations by NIST are essential, but they do not provide a complete check on the quality of the calibrations that are carried out by the individual laboratory. Additional assessments are necessary to assure the quality of such measurements. When laboratory staff are asked to carry out measurements with calibrated instruments and report results for evaluation, they are participating in a measurement quality assurance (MQA) program. Such a program tests not only the quality of the equipment but also the ability of the staff to correctly use and interpret the results obtained with the equipment. The NIST operates an MQA program with a selected number of calibration laboratories, including Pacific Northwest Laboratory (PNL); however, NIST tests only x-ray and gamma-ray measurements. The U.S. Department of Energy (DOE) intercomparison program was designed specifically to include x-ray, gamma-ray, beta, and neutron calibrations for personnel dosimetry purposes. This program serves a need that is not being met by NIST, and it provides documentation of the accuracy and uniformity of the radiological calibrations carried out in DOE facilities.

In Fiscal Year 1989, the instrument sets were used to intercompare calibration fields associated with ^{137}Cs , ^{60}Co , ^{90}Sr , $^{241}\text{AmBe}$ and ^{252}Cf . The results of the delivered-to-measured exposure rate and absorbed dose rate ratios were 1.00 ± 0.01 for photon measurements, 1.01 ± 0.01 for TLD measurements, 1.00 ± 0.02 for neutron measurements and a ratio of 1.03 for beta measurements. From the excellent agreement shown here it is evident that the radiological calibration intercomparison program is achieving its objective.

(a) Formerly the National Bureau of Standards.

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INTRODUCTION

The objectives of the intercomparison program are to 1) provide standard measurement techniques that allow U.S. Department of Energy (DOE) laboratories to assess and improve the accuracy of radiological calibration sources, 2) provide a basis for recommending improvements in calibration techniques and units generally applicable to all DOE facilities, and 3) provide a forum addressing existing and potential problems related to radiological calibrations by holding periodic workshops.

To meet the objectives, a program under the DOE Laboratory Accreditation Program (DOELAP), was initiated during Fiscal Year (FY) 1986 to routinely compare radiological calibrations. The program is managed and operated by Pacific Northwest Laboratory (PNL).^(a) Two sets of intercomparison instruments are made available to DOE laboratories on a monthly basis, and one secondary beta source set is made available to DOE laboratories on a bimonthly basis. Participants in the program used the instruments to perform dose or exposure measurements on their calibration sources, or they used the beta sources to irradiate the instruments that calibrate their standards. The results of the measurements were forwarded to PNL for tabulating and comparing to calibration values established by PNL for the various instruments and beta sources. Participation by the DOE laboratories was voluntary; submission of measurement results was also voluntary, even though strict confidentiality was maintained regarding the originator of the results.

To compare measurements from a wide variety of sources, four instruments were selected for inclusion in the instrument set: 1) a thin-walled ion chamber with build-up cap to measure the exposure rate from x-ray and gamma-ray sources, 2) a tissue equivalent ionization chamber to measure the absorbed dose rate from neutron sources, 3) a Geiger-Mueller (GM) counter to estimate the absorbed dose rate for photons in mixed neutron/gamma fields, and 4) an extrapolation ionization chamber to measure the absorbed dose rate from beta sources.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

In addition, a set of beta point sources was provided, including a 2-mCi (74-MBq) $^{90}\text{Sr}/^{90}\text{Y}$ source, a 0.5-mCi (18.5-MBq) ^{204}Tl source, and a 14.5-mCi (536.5-MBq) ^{147}Pm source. The set also included an irradiation jig and a shutter with a controller/timer.

Participants performed the desired measurements and irradiations, and returned the sets and results to PNL. The instruments were operationally checked and sent to the next participant. The measurement results were compared to PNL values and reported to each participant. This annual report summarizes the operation, results, problems, and improvements in the program.

The DOE benefits from the operation of the program in several ways:

- The accuracy and credibility of radiological calibration are improved by frequent measurement and intercomparison.
- Common problems of a general nature are identified, allowing a DOE-wide approach in solving problems related to radiological calibrations.
- A radiological calibration workshop is planned to be held approximately every 2 years. This provides a forum in which to address the impact of proposed regulations on calibrations, such as changes in the neutron quality factor and changes resulting from the impact of calibrations on regulations, e.g., the DOELAP performance results.
- The results and conclusions of this project directly support the DOELAP operational program and certain DOELAP research tasks.

This report presents the FY 1989 results of the radiological calibrations intercomparison program. Included are discussions regarding the intercomparison operation, the equipment used (i.e., the particular instrument set and/or the beta source set), and relevant calculations. Solutions to problems and improvements in the program are suggested, and conclusions are then introduced.

INTERCOMPARISON PROGRAM OPERATION

The intercomparison program makes the instrument sets and beta source set available to the greatest number of participants possible during the fiscal year. The operation of the program is described below in chronological sequence.

1. An invitation to participate in the intercomparison is sent annually to those people at DOE laboratories who are primarily involved in performing or managing radiological calibrations. The invitation contains a short history of the intercomparison and a participation request form.
2. When a participation request form is received from a participant, the requested instrument set or beta set is scheduled as specified on the form. If a particular intercomparison set is unavailable at the requested time, the participant is notified in order to reschedule the intercomparison set.
3. Letters are sent to participants verifying the scheduled use of the intercomparison sets. The expected arrival of the set will occur during the second week of the scheduled month of participation.
4. The participant uses the intercomparison set on the calibration sources of his choice. At the conclusion of the measurements or irradiations, the set is returned to PNL so that its expected arrival occurs during the last week of the month after it was sent. Thus, the length of time the intercomparison set is available to the participant is approximately 6 weeks.
5. Results of the measurements or irradiations are reported to PNL where those results are compared to reference values. These comparisons and the calculational methods are then reported back to the participant as soon as possible.

At any time during the sequence, the participant may decide that the results are suspect and should not be reported. Because participation is voluntary, the use of the reported data has been left in the control of the participant. All results, however, are strictly confidential between the PNL intercomparison program manager and the participating laboratory.

EQUIPMENT DESCRIPTION

The equipment used in the DOE Radiological Calibrations Intercomparison Program includes two complete sets of intercomparison instruments and one set of secondary standard beta sources. The components of each set are described in the following sections.

INSTRUMENT SET

The instruments used in the intercomparison were the same as those used for the pilot intercomparison program. These particular instruments were chosen for maximum flexibility of dose measurement from a variety of radiological sources, for their precision and stability, and for their simplicity of use and familiarity to the participants. The combination of the scalar/ratemeter and the GM counter previously used in FY 1988 was replaced by a separate counter/timer and high voltage power supply. This replacement was made because of complications with the previous combination due to the modifications made to make the separate components compatible. Also, in FY 1989 thermoluminescent dosimeters (TLDs) were incorporated for intercomparison.

The chambers are calibrated using ^{137}Cs in the PNL calibration facility. The exposure rates of the ^{137}Cs source are traceable to the National Institute of Standards and Technology (NIST) by means of transfer standards (ionization chambers). The electrometer is calibrated using a picoampere source, which is traceable to NIST from the Hanford Engineering Development Laboratory Calibration Program. The instruments are listed and their purposes are described in Table 1. The instruments are shown in Figure 1 and a description of each is provided below.

Electrometer

The electrometer is a Keithley Model 614 multifunction meter capable of measuring integral charge between 10^{-8} and 10^{-11} coulombs (C) and voltages between 10^{-4} and 20 volts (V). It can operate on 110 V(ac) or on its integral battery pack.

TABLE 1. Equipment Contained in the Intercomparison Instrument Set

<u>Equipment</u>	<u>Purpose</u>
Electrometer	Measure and record integral charge from ionization chamber measurements.
Thin-walled ion chamber	Measure exposure from photon calibration sources.
Tissue equivalent ion chamber	Measure total absorbed dose from neutron calibration sources. Can also be used to calibrate photon fields above 500 keV.
Geiger-Mueller (GM) counter	Measure the component of dose resulting from photons created by a neutron calibration source.
Extrapolation ion chamber	Measure the dose rate from beta calibration sources at 7 mg/cm ² .
Thermoluminescent dosimeters	Measure photon and/or neutron dose by intercomparing with PNL TLD response.
Counter/timer	Record integral pulses from the GM counter.
High-voltage power supply	Supply high voltage (+500 V) to the GM counter.
Battery high-voltage power supply	Provide a stable bias voltage in 50-V steps from 0 to ± 300 V for use with ionization chambers.

FIGURE 1. DOE Intercomparison Program Instrument Set

The input/output connector is a triaxial connector. In addition, a triaxial-to-coaxial (triax-to-coax) adapter is provided, allowing the user to use low-noise coaxial signal cables for the ionization chambers. A 75-ft coaxial signal cable is also supplied in the instrument set.

The front panel of the Keithley electrometer is illustrated in Figure 2. The electrometer has been modified by the inclusion of a "run/hold" switch that "freezes" the display and allows timed measurements.

Thin-Walled Ionization Chamber for Photon Measurements

The ionization chamber chosen for photon measurements is a Capintec Model PM-30 air equivalent ion chamber (AEIC). The chamber is constructed of air equivalent conducting plastic and has an active volume of 28 cm³. The response of the instrument for measuring exposure is nearly independent of the energy of the incident photons from 20 keV to a few MeV. Exposure rates are measurable from approximately 100 mR/h to 10 R/min. A Lucite buildup cap is provided so the chamber can be used for high-energy photons (¹³⁷Cs and ⁶⁰Co). Without the buildup cap, the chamber may also be used to measure exposure rates from x-ray beams. The connector is a triaxial-BNC-type that

FIGURE 2. The Keithley Electrometer, Front Panel

connects to a shop-built cable splitter. The connections on the cable splitter are BNC for the signal and MHV for the high voltage.

Tissue Equivalent Ionization Chamber for Neutron Measurements

The ionization chamber chosen for neutron measurements is a Far West Technology (FWT) Model IC-80 tissue equivalent ionization chamber (TEIC). The 80-cm³ spherical chamber is constructed of A-150^(a) tissue equivalent plastic and is usually operated with ambient air as the fill gas, rather than tissue equivalent counting gas. The signal output connector is a BNC-type, and the high-voltage connector is an MHV-type. The chamber is operated using 300-V high voltage. The signal is directed to the electrometer by means of a low-noise coaxial signal cable and a coax-to-triax adapter. The instrument is used in conjunction with a GM counter for neutron measurements and measures total absorbed dose. The TEIC can also be used for calibrating photon fields with energies above approximately 500 keV. The GM counter, because of its low sensitivity to neutrons, is used to measure the absorbed dose from photons.

Geiger-Mueller Counter

The GM counter chosen to measure the photon contribution of absorbed dose in a neutron field is an FWT model GM-2 energy-compensated GM counter. The detector is a 0.48-cm-diameter GM tube with an active volume of 0.12 cm³. The fill gas is neon, quenched with a halogen-quenching agent. The tube wall is an iron chromium alloy. The detector housing is aluminum and includes an energy-flattening shield to eliminate the normal low-energy photon response characteristic. The photon energy response of the GM counter is $\pm 10\%$ from 70 keV to 2 MeV. The signal output through a BNC-type connector is routed to a read-out device (scaler) through the coaxial signal cable. The counter is operated at +500 V. The scaler and high-voltage power supply for the GM counter were supplied as part of the intercomparison set.

Extrapolation Ionization Chamber for Beta Measurements

The chamber chosen for determining dose rates from beta sources is an FWT Model EIC-1 tissue equivalent plastic extrapolation ionization chamber. The device is a parallel-plate-type ionization chamber with a continuously

(a) ICRU Report 26 (1977).

variable volume from approximately 0.1 to 1.4 cm³. The front entry window has a density thickness of 6.9 mg/cm². The collecting electrode was modified by the manufacturer from a 1-cm to a 2-cm diameter to increase the sensitivity. The output is routed through a BNC connector to the electrometer using low-noise coaxial signal cable and a coax-to-triax adapter. The recommended high voltage is 50 V per revolution of the outer wall of the chamber (one revolution increases the gap approximately 1 mm).

Thermoluminescent Dosimeters

The TLDs included in the instrument set consist of both Harshaw ⁷Li (photon sensitive) and ⁶Li (photon and neutron sensitive) chips arranged in Hanford-type personnel badges with ten chips per badge. This Hanford-type badge consists of five different chip locations, each location having a specific filtration associated with it to allow for in-depth study of a particular radiation field, including both deep and shallow doses. These badges are to be irradiated on a phantom and the given dose equivalent (in millirem) reported to PNL.

Counter/Timer

The EG&G Ortec model 871 counter/timer used in conjunction with the GM counter simply counts the number of input pulses received during the counting period. It features an eight-decade light-emitting diode (LED) display and an internal timer, which will take counts for the preset time period, zero, and then count again automatically, giving the operator enough time to record the number of counts. The counter/timer plugs into a nuclear instrumentation module (NIM) bin.

High Voltage Power Supply

The high voltage power supply used to supply the bias for the GM counter is an Ortec model 456H. This stand-alone power supply is capable of supplying up to 3000 volts. Both MHV and SHV output connectors are located in back of the instrument.

Battery High Voltage Power Supply

The battery high voltage power supply is a box containing a 300-V battery. A switch is included to select either "polarity" or an "off" position.

A range switch allows selected voltages from 0 to 300 V in discrete steps of 50 V. At the "zero" voltage setting, probe connectors have been installed to allow for a voltage check underload. The output connector is a coaxial MHV connector.

Procedures

Operating procedures detailing the description and use of the instruments are included in each instrument set. The procedures are updated several times during the year to clarify and address specific characteristics of each measurement. Included in the procedures are graphic illustrations of the electrical connections for each instrument.

SECONDARY STANDARD BETA SOURCE SET

The secondary standard beta source set (referred to as the beta set in this report) consists of three beta-emitting sources and an irradiation apparatus, shown in Figure 3. The set, Model BSS.1, was purchased from Amersham and includes a 2-mCi (74-MBq) $^{90}\text{Sr}/^{90}\text{Y}$ source, a 0.5-mCi (18.5-MBq) ^{204}Tl source, and a 14.5-mCi (536.5-MBq) ^{147}Pm source. The sources are secured in a lead pig (for shipping) inside a Department of Transportation (DOT)-7A overpack. For irradiations, a source is removed from the pig using that is part of the set. Other equipment includes beam-flattening filters, reference-distance rods, a jig stand, and instructions for use. The same set is designed to follow the specifications for the Series 1 source set of the International Standardization Organization (ISO) standard on beta dosimetry, ISO 6980 (ISO 1984).

The dose rates of the sources have been determined using a Physikalisch-Technische Bundesanstalt (PTB)-type extrapolation ionization chamber, calibrated with a similar beta secondary standard set at PNL, which was calibrated at the PTB and checked under the MQA program between PNL and NIST. Reference dose rates are taken to be at a depth of 7 mg/cm^2 and a distance of 30 cm from the source for $^{90}\text{Sr}/^{90}\text{Y}$ and ^{204}Tl . The dose rate from ^{147}Pm is referenced to a depth of 7 mg/cm^2 in tissue, at a distance of 20 cm from the source. The dose rate is also normalized to standard temperature (22°C), pressure (760 mm Hg), and humidity (45%) to allow for differences in the delivered dose rate resulting from absorption of the beta particles by air (Pruitt 1985).

FIGURE 3. DOE Intercomparison Program Secondary Standard Beta Source Set

CALCULATIONS

Participants in the intercomparison program are requested to deliver a known exposure rate for x-ray and photon fields, a known tissue absorbed dose rate for a beta field, or a known neutron tissue kerma rate for neutron fields. The associated signals are recorded on the supplied data sheets and reported to PNL. The signals are then used to calculate the appropriate quantity, and ratios of the delivered quantity to the measured result are determined. Those ratios are reported to the participant in a letter. The calculations used to determine dose and dose equivalent quantities from the measurements and beta source irradiations are given below.

INSTRUMENTS

The signal-to-dose or dose equivalent calculations for the instrument measurements are described in this section.

The photon measurement results are determined by using the following equation:

$$X = Q \cdot C_{tp} \cdot C_e \cdot C_\gamma \quad (1)$$

where X = the integral exposure in R (coulombs/kg)

Q = the net collected charge in coulombs

C_{tp} = the correction for temperature/pressure

C_e = electrometer calibration factor

C_γ = the PNL calibration constant.

For the beta measurements, the standard extrapolation chamber formula from Appendix C of ISO Standard 6980 (ISO 1984) is used:

$$\dot{D}_t = S_{T,A} \cdot \frac{W}{e} \cdot \frac{1}{b\rho_A} \cdot \left(\frac{dI}{dx} \right)_{x \rightarrow 0} \quad (2)$$

where $\dot{D}_t$ = the absorbed dose rate to tissue at 7 mg/cm² in rad (Gy)

$S_{T,A}$ = the ratio of the average mass collision stopping powers of striated muscle tissue and of dry air (obtained from ICRU 37 [1984])

$\frac{\bar{W}}{e}$ = The quotient of the mean energy, $\bar{W}$, expended in dry air per ion formed and the elementary charge, e

b = the effective area of the collecting electrode

ρ_A = the density of air at standard temperature and pressure (STP)

$\left(\frac{dI}{dx}\right)_{x \rightarrow 0}$ = the limiting value of the quotient of the corrected mean ionization current, I , produced in the chamber by the chamber depth as this chamber depth x approaches 0

I = the mean collected ionization currents (corrected to STP conditions) for positive and negative bias voltages.

For the FWT extrapolation chamber, the area of the collecting electrode is approximately 3.14 cm². The ratio of $\bar{W}/e = 33.85$ (joules/ coulomb). The air density, ρ_A , is 0.001197 g/cm³ at 22°C (295 K) and 760 mmHg (101.3 kPa). No further corrections are applied to adjust the signals for effects listed in Appendix C of ISO 6980 (ISO 1984).

The neutron measurements require two detectors: a tissue equivalent plastic ionization chamber for total (gamma plus neutron) absorbed dose and a GM counter for gamma absorbed dose. It is assumed that since the TEIC measurements are performed in air and the chamber wall is thick enough to create charged particle equilibrium for up to 20-MeV neutrons, the absorbed dose and kerma are equal. The following calculation for absorbed dose rate in tissue is taken from International Commission on Radiation Units and Measurements (ICRU) Report 26, Neutron Dosimetry for Biology and Medicine (1977), and from American Association of Physicists in Medicine (AAPM) Report 7, Protocol for Neutron Beam Dosimetry (1980). The first step is to calculate the response of the tissue equivalent chamber (Equation [3]) and GM counter (Equation [4]):

$$\dot{R}_T = \dot{Q} \cdot C_T \quad (3)$$

$$\dot{R}_U = \dot{N} \cdot C_U \quad (4)$$

where $\dot{R}_T$ = the response of the tissue equivalent ionization chamber from neutrons and photons ($\text{rad} \cdot \text{sec}^{-1}$)

$\dot{Q}$ = the average current from the tissue equivalent ionization chamber corrected for air density and electrometer calibration ($\text{coulomb} \cdot \text{sec}^{-1}$)

C_T = the ionization chamber calibration constant ($\text{rad} \cdot \text{coulomb}^{-1}$)

$\dot{R}_U$ = the response of the GM counter from photons ($\text{rad} \cdot \text{sec}^{-1}$)

$\dot{N}$ = the average pulse rate collected using the GM counter ($\text{pulses} \cdot \text{sec}^{-1}$)

C_U = the GM calibration constant ($\text{rad} \cdot \text{pulse}^{-1}$).

In order to calculate a neutron absorbed dose rate to tissue, two assumptions are made about the GM counter. First, response of the GM counter is assumed independent of photon energy (e.g., the number of pulses per roentgen is equivalent for photons with different energies over a wide range of energies). The energy response of the counter quoted by the manufacturer is 1.00 ± 0.10 for photons with energies between 0.07 and 2.0 MeV.

The second assumption is that the response of the GM counter to neutrons is negligible. Ongoing work at the PTB indicates that the neutron response (pulses per rad, tissue absorbed dose) is less than 2% of the photon response for small commercially available GM tubes.

The neutron absorbed dose rate in tissue is then calculated by:

$$\dot{D}_n = (\dot{R}_T - \dot{R}_U) \cdot \frac{(S_{w,g})_N}{(S_{w,g})_c} \cdot \frac{\bar{W}_N/e}{\bar{W}_c/e} \cdot \frac{K_N}{M_c} \cdot A_{w,c} \cdot f_{t,c} \quad (5)$$

where $\dot{D}_n$ = neutron absorbed dose rate in tissue ($\text{rad} \cdot \text{sec}^{-1}$)

$(S_{w,g})_x$ = ionization chamber gas-to-wall absorbed dose conversion factor for the secondary charged particles created by the neutron field ($x = N$) or by the calibration source ($x = C$)

$\bar{W}_x/e$ = average energy required to create an ion pair in the chamber gas by secondary charged particles created by the neutron field ($x = N$) or by the calibration source ($x = C$)

K_N = neutron kerma factor ratio for ICRU muscle tissue relative to A-150 tissue equivalent (TE) plastic

M_C = quotient of mass energy absorption coefficients for ICRU muscle tissue to A-150 TE plastic for the photons from the calibration source

$A_{w,C}$ = attenuation and scattering correction factor for the calibration source for the TE chamber of equilibrium wall thickness

$f_{t,C}$ = ICRU muscle tissue exposure-to-dose conversion factor for the photons from the calibration source.

The parameters in the absorbed dose calculation are dependent on the neutron energy spectrum of the neutron field and on the calibration source. Because ^{137}Cs is the calibration source, the values in Table 2 have been adopted.

To get from the measured neutron absorbed dose (D_n) to neutron dose equivalent (H_n), a quality factor (Q) was used. The Q value for unmoderated Cf was obtained from Alekseev et al. (1985), and the Q value for AmBe was obtained from Nachtigall (1967).

THERMOLUMINESCENT DOSIMETERS

The two identical sets of TLD badges include one set to be exposed to a source or sources at the participating laboratory and another set to be exposed at PNL to NIST-traceable sources of the same type. Both TLD sets are read out at PNL and controls are used to subtract out background and transit dose. The actual dose equivalent given the TLDs by the participating laboratory is calculated using a calibration obtained at PNL by measuring the TL chips' visible photon output (in coulombs [c]) per given dose equivalent (rem). This calibration (in c/rem) is obtained for each of the five different

TABLE 2. Values for Parameters of Absorbed Dose Calculations Using Equation (5)

Parameter	Value	Reference
$(S_{w,g})_N$ (A-150/air)	~1.17	AAPM Report No. 7 (1980)
$(S_{w,g})_c$ (A-150/air)	1.14	AAPM Report No. 7 (1980)
$\bar{W}_C/e$ (air)	33.85 (J/C)	ICRU 31 (1979)
$\bar{W}_N/e$ (air)	~35.5 (J/C)	AAPM Report No. 7 (1980)
K_N	~0.96	AAPM Report No. 7 (1980)
M_C	0.998	Hubbell (1982)
$A_{w,c}$ (A-150) (chamber wall = 0.32 cm)	~0.99	AAPM Report No. 7 (1982)
$f_{t,c}$	0.961	Hubbell (1982) AAPM Report No. 7 (1980)

TLD positions on the badge; each position having two TL chips and a different filtration associated with it.

BETA SOURCES

The delivered doses from the beta sources in the secondary standard beta source set are calculated according to Böhm (1986):

$$D = \dot{D}_r \cdot t \cdot C_Z \cdot C_A \cdot C_F \quad (6)$$

where D = the delivered dose in rad (Gy)

$\dot{D}_r$ = the reference dose rate at 7 mg/cm², the reference distance at the reference calibration date

t = the irradiation time

C_Z = the exponential decay correction to the source strength

C_A = the air density correction to the dose because of temperature and pressure variations

C_F = the air density correction to the dose because of humidity variations.

The values of C_Z and C_F currently adopted for the beta sources are contained in Table 3. In addition, the delivered doses are corrected for variations in air density, C_A , in Table 4, using the following algorithm from Pruitt (1985):

$$D = D_0 (1 + ax + bx^2) \quad (7)$$

where D = reference dose at 22°C (295 K) and 760 torr (101.3 kPa)

D_0 = the delivered dose

a, b = coefficients listed in Table 4

$x = 1 - r/r_0$

r = air density during the irradiation

r_0 = air density at the reference temperature and pressure.

TABLE 3. Parameters Used to Calculate the Absorbed Dose from the DOE Intercomparison Beta Sources

Source	C_Z	C_F
$^{90}\text{Sr}/^{90}\text{Y}$	$\exp(-6.66 \times 10^{-5} t) (a)$	1.0
^{204}Tl	$\exp(-5.024 \times 10^{-4} t)$	1.0
^{147}Pm	$\exp(-7.248 \times 10^{-4} t)$	$1.02 \exp(-4.37 \times 10^{-4} RH) (b)$

(a) t is time (in days) that has elapsed between the calibration date and the irradiation date.

(b) RH is the relative humidity in percent.

TABLE 4. Parameters Used to Calculate the Air Density Correction, C_A

Nuclide	Nominal Activity (MBq)	Reference Depth (mg/cm ²)	Coefficients Used in Eq. (7)	
			a	b
^{147}Pm	518	7	3.54	19.79
^{204}Tl	18.5	7	0.13	-0.33
$^{90}\text{Sr}+^{90}\text{Y}$	74	7	-0.05	-0.18

MEASUREMENT RESULTS

During FY 1989, five laboratories requested the intercomparison instrument sets and two laboratories requested the secondary standard beta set. Of the five participants who requested the instrument set, two were unable to do the measurements as scheduled due to unavailability of facilities and staff, and one participant scheduled for October of FY 1990. Hence, results will be published for that participant in the FY 1990 annual report. Of the two participants who requested the secondary standard beta set, one scheduled for November of FY 1990 and one participant was unable to receive the sources due to the absence of the correct radiation materials license.

The instruments were used to intercompare calibration fields associated with ^{137}Cs , ^{60}Co , ^{90}Sr , $^{241}\text{AmBe}$, and ^{252}Cf .

The results of the photon measurements are summarized in Tables 5 and 6. The average and one standard deviation of the delivered-to-measured exposure rate ratios was 0.998 ± 0.013 for ion chamber measurements and 1.01 ± 0.01 for TLD measurements. The results indicate excellent agreement.

The results of the TLD intercomparisons are summarized in Table 6. The average and one standard deviation of the delivered-to-measured deep dose ratios was 1.01 ± 0.01 . This shows that this TLD intercomparison method works well for gamma rays.

TABLE 5. Summary of Gamma Ray Intercomparison Results Using Ionization Chambers

<u>Participant</u>	<u>Source</u>	<u>Chamber</u>	<u>Ratio Delivered/Measured</u>
A	^{60}Co	TEIC	1.006
	^{60}Co	AEIC	1.006
	^{137}Cs	AEIC	1.011
B	^{137}Cs	TEIC	0.987
	^{137}Cs	AEIC	<u>0.981</u>
Average			0.998
One Standard Deviation			0.013

TABLE 6. Summary of Intercomparison Results Using Thermoluminescent Dosimeters

<u>Participant</u>	<u>Source</u>	<u>Deep Dose Ratio Delivered/Measured</u>
A	^{60}Co	1.00
B	^{137}Cs	<u>1.02</u>
Average		1.01
One Standard Deviation		0.01

The results of the neutron measurements are summarized in Table 7. Here, the measured neutron absorbed dose (as measured by the participant) was obtained using the TEIC/GM system and Equation (5). The calculated neutron absorbed dose was obtained by multiplying the measured neutron fluence by the fluence-to-dose conversion factors for AmBe (Nachtigall 1967) and Cf (Schwartz and Eisenhauer 1982). The measured dose equivalent values were obtained by multiplying the measured absorbed dose by quality factors found in Nachtigall (1967) and Alekseev et al. (1985). All values in Table 7 include room scatter contribution. The average and one standard deviation of the calculated-to-measured neutron absorbed dose and dose equivalent rate ratios were 1.00 ± 0.02 and 1.08 ± 0.10 , respectively.

TABLE 7. Summary of Intercomparison Results for Neutron Absorbed Dose Rate Measurements

<u>Participant</u>	<u>Source</u>	<u>Technique</u>	<u>Neutron Absorbed Dose Calculated/Measured</u>	<u>Neutron Dose Equivalent Calculated/Measured</u>
A	^{252}Cf	TEIC/GM	1.01	1.15(a)
B	$^{241}\text{AmBe}$	TEIC/GM	<u>0.98</u>	<u>1.01(b)</u>
Average			1.00	1.08
One Standard Deviation			0.02	0.10

-
- (a) Using a Q factor of 9.5 for measured dose equivalent.
 (b) Using a Q factor of 8.0 for measured dose equivalent.

Participant B used the FWT extrapolation chamber to measure the absorbed dose rate from a ^{90}Sr source (see Table 8). The agreement was very good, showing that for high-level beta sources (9 to 10 rad/h), this small chamber is adequate for intercomparisons.

A summary of the program's results since it was initiated in FY 1986 is tabulated in Table 9. The results for all participants for each category were averaged. The results are given as a ratio of PNL's reference values and the participants' measured values. In almost all categories steady improvement in intercomparison results can be seen.

TABLE 8. Summary of Intercomparison Measurements Using the FWT Extrapolation Chamber

<u>Participant</u>	<u>Source</u>	<u>Ratio Delivered/Measured</u>
B	^{90}Sr	1.03

TABLE 9. Summary of Intercomparison Results (Reference/Measured) Since FY 1986

<u>Fiscal Year</u>	<u>Data Received^(a)</u>	<u>Beta</u>	<u>X-ray</u>	<u>Gamma</u>	<u>Neutron</u>	<u>Secondary Standard Beta Set</u>		
						<u>^{90}Sr</u>	<u>^{204}Tl</u>	<u>^{147}Pm</u>
1986	6/9	-	-	1.14 ± 0.19	4.55 ± 0.05	1.02	1.12	0.63
1987	10/15	-	-	1.01 ± 0.04	2.16 ± 0.94	1.01 ± 0.07	1.15 ± 0.21	1.09
1988	6/10	1.02	1.00 ± 0.01	0.99 ± 0.10	1.45 ± 0.55	-	-	-
1989	2/4	1.03	-	1.00 ± 0.01	1.08 ± 0.10	-	-	-

(a) Ratio of participants who reported data and total number participating that fiscal year.

FY 1989 PROGRAM IMPROVEMENTS

There were two major improvements made for the FY 1989 program. First, the Bicron scalar/ratemeter used in FY 1988 for GM counter measurements was replaced by a separate Ortec counter/timer and an Ortec high voltage power supply. This replacement was made because of complications encountered when the Bicron/GM system was modified to make the two compatible. Feedback from the program participants and the measurements taken proved that this replacement was indeed an improvement. Second, a set of TLDs consisting of both ^7Li (photon sensitive) and ^6Li (photon and neutron sensitive) chips was added as an additional intercomparison method. These TLDs, together with the different filtration used, reveal much more about the particular source spectra, including both deep and shallow doses. As can be seen in the measurement results section, this intercomparison method worked well.

Another improvement in FY 1989 was the accurate measurement of the extrapolation ionization chambers' (EICs') active areas. This measurement improved beta dose rate measurements of one chamber by approximately 3%.

FY 1989 PROGRAM PROBLEMS AND SOLUTIONS

Two problems were encountered in the program during FY 1989:

1. The Far West Technologies 80-cc TEIC, which was used in conjunction with the GM counter for neutron measurements, was found to be underresponding to ^{252}Cf neutron spectrums by a factor of approximately 1.5.
2. Measurements of the response of the GM counters revealed a considerably larger photon rate dependence below 500 mR/hr than was originally thought.

To salvage the participants' neutron data, the factor by which the TEIC was underresponding was measured and the participants' data was corrected. To prevent this problem, in FY 1990 the 80-cc will be replaced by a 1000-cc TEIC filled with TE methane. This 1000-cc TEIC has been tested and found to be considerably more accurate, giving a dose equivalent rate for the PNL ^{252}Cf source that agreed within 9% of the NIST value and giving an absorbed dose rate within 6% of the calculated value.

To correct the GM dependence problem, calibrations were obtained for the GM counters at photon fields below 100 mR/hr and these were used to correct the participants' data. In the future, calibrations will be used that are obtained in a photon field whose rate more closely matches the rate of the gamma component of the participants' neutron source.

Future plans include the possible replacement of the TEIC/GM neutron measuring system with a tissue equivalent proportional counter (TEPC) system. The TEPC will measure direct absorbed dose from fast neutrons. It is possible that the neutron measurement intercomparisons could be further improved by implementing the convenient Quam Pocket REM Meter. Neutron measurements of NIST's and PNL's ^{252}Cf sources with this instrument gave dose equivalent values that agreed within 2% of the expected values. This compact instrument would be very convenient for neutron intercomparison measurements.

CONCLUSIONS

The program continues to benefit the DOE community by improving radiological calibrations. The intercomparison sets allow comparison of radiological calibration sources to NIST standards. Also, because the reference sources for calibrating the intercomparison instruments are the same as the DOELAP calibration sources, the calibrations are further linked to DOELAP and dosimeter calibrations.

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