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DOE Radiological Calibrations Intercomparison Program: Results of Fiscal Year 1986

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J. C. McDonald**

May 1987

**Prepared for
the U.S. Department of Energy
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**Pacific Northwest Laboratory
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FOREWORD

The radiological calibration program is a fundamental part of the total radiation protection program. The quality of the radiation protection program is enhanced through the maintenance of radiological calibration standards at each laboratory that are accurately traceable to national standards and for which the capability for precise measurement verification exists. An intercomparison program for the measurement of radiological standards provides the opportunity for individuals at each laboratory to enhance their knowledge of radiological measurements and adds to the visibility of the importance of maintaining accurate radiological standards.

The goal of the Department of Energy (DOE) Intercomparison Program (developed by the DOE Office of Nuclear Safety) is the improvement of accuracy and precision for the measurement of radiological standards. The performance of the intercomparison measurements help identify areas requiring further attention by the participating laboratories. Communication between individuals responsible for maintaining radiological standards is increased. The measurement process allows individuals to use state-of-the-art calibration equipment which may be different from that employed at the participant's laboratory. The intercomparison measurements using the beta source set also makes available the standard set of sources specified in the international standard for beta dosimetry, ISO 6980.

Participation in this program by all DOE laboratories maintaining radiological standards is both welcomed and encouraged. We hope that the publication of the present and future annual reports will serve to both advertise and maximize its usefulness.

E.J. Vallario, Acting Director
Radiological Controls Division
Office of Nuclear Safety
U.S. Department of Energy

EXECUTIVE SUMMARY

The Department of Energy (DOE) Radiological Calibration Intercomparison Program was initiated in January 1986, under the research portion of the DOE Laboratory Accreditation Program. The program operates via the exchange of transfer standards, consisting of instrument sets and standard secondary beta sources.

There are two instrument sets and the scheduled use has been staggered such that one set is available for use during each month. One set of secondary standard beta sources is available for use bimonthly.

During the 1986 fiscal year, five laboratories used the instrument sets and three laboratories used the beta source set. Results were reported for all the measurements. The average and one standard deviation of the ratios of participant results to Pacific Northwest Laboratory (PNL) calibration values were 1.12 ± 0.17 for gamma measurements. Those ratios for the gamma measurements varied from 0.98 to 3.06. The larger differences of results from measurements performed at two facilities were directly attributable to unfamiliarity with the intercomparison instruments. The average and one standard deviation of the ratios of participant results to PNL calibration values obtained using the secondary ^{90}Sr beta source was 1.02 ± 0.05 , which is well within measurement uncertainties. The one participant who performed measurements using ^{147}Pm and ^{204}Tl sources obtained ratios of 0.68 and 1.11, respectively. No measurements were performed using neutron or x-ray sources.

The problems encountered during operation of the program stemmed mainly from user unfamiliarity with the equipment. To alleviate the problem, 1) procedures were upgraded, and graphics were included to illustrate the proper electrical connection of the equipment; 2) a training program was proposed to take place during the 1987 fiscal year for DOE intercomparison participants; 3) additional equipment was supplied in the instrument sets; and 4) changes were initiated to further simplify the connections and use of the equipment.

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DOE RADIOLOGICAL CALIBRATIONS INTERCOMPARISON PROGRAM:
RESULTS OF FISCAL YEAR 1986

INTRODUCTION

During the fiscal years 1984 and 1985, as part of the Technical Guidelines for the Radiological Calibration Project, the Pacific Northwest Laboratory (PNL)^(a) conducted a study to evaluate the feasibility of operating a routine program for the intercomparison of radiological calibrations performed at Department of Energy (DOE) facilities.^(b) The objectives of the intercomparison program are to provide standard measurement techniques that allow DOE laboratories to assess and improve the accuracy of radiological calibration sources; to provide a data base for recommending potential improvements in calibration techniques and units generally applicable to all DOE facilities; and to provide a forum addressing problems and potential problems relating to radiological calibrations.

In order to meet the objectives, a program under the DOE Laboratory Accreditation Program (DOELAP) research portion was initiated during the fiscal year 1986 to routinely compare radiological calibrations. A set of intercomparison instruments was made available to DOE laboratories on a monthly basis, and one Amersham^(c) secondary beta source set was made available to DOE laboratories on a bimonthly basis. Participants in the program utilized the instruments to perform dose or exposure measurements on their calibration sources or utilized the beta sources to irradiate instruments that comprised their laboratory standards. The results of the measurements were forwarded to PNL for tabulating and comparison to calibration values established by PNL for the various instruments and beta sources. The participation by the DOE

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- (a) PNL is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.
(b) McDonald, J. C., P. L. Roberson and F. M. Cummings. 1986. Intercomparison of Radiological Calibration Sources. A Pilot Study (Draft). Pacific Northwest Laboratory, Richland, Washington.
(c) Amersham Corporation, Arlington Heights, Illinois.

laboratories was voluntary. The submission of measurement results was also voluntary, even though the origin of the results was kept strictly confidential.

In order to compare measurements from a wide variety of sources, four instruments were selected for inclusion in the instrument set. The four instruments and their respective uses are 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.

In addition, a secondary standard set of beta sources 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 was provided. The set also included an irradiation jig and a shutter with a controller/timer.

Instrument and source sets were distributed to scheduled participants on a bimonthly basis. There were two instrument sets, and the scheduling was staggered such that one set was available each month.

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 with PNL values and reported to each participant. An annual report is being published to summarize the operation, results, problems, and improvements in the program.

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

- The accuracy and credibility of radiological calibration is improved by frequent measurement and intercomparison.
- Common problems of a general nature may be identified, allowing a DOE-wide approach to the solution of nagging problems in calibrations.

- A radiological calibration workshop is planned to occur every other year, providing a forum to address the impact of proposed regulations on calibrations, such as changes in the neutron quality factor, and the impact of calibrations on regulations, such as the DOELAP performance results.
- The results and conclusions of this program directly support the DOELAP operational program and certain DOELAP research tasks, such as the Calibration Good Practices Manual Task.

INTERCOMPARISON OPERATION

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

An invitation to participate in the intercomparison is sent to all participants annually. The invitation contains a short history of the intercomparison and a participation request form.

As participation request forms are reviewed, participants are scheduled to receive either the instrument set or the beta set as specified on the form. If the particular intercomparison set is unavailable at the desired time, the participant is called in order to schedule the desired intercomparison set at another time.

Letters are sent to prospective participants verifying the scheduled use of the intercomparison sets. A copy of the notification letter is included in each of the intercomparison sets which is sent to a participant so that expected arrival will occur during the second week of the scheduled month of participation.

At this time, the participant performs measurements or irradiations using 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 arrived. The elapsed time the participant has the intercomparison set is always greater than four weeks.

The results of the measurements or irradiations are reported to PNL where those results are compared with reference values. The comparisons and the calculational methods are reported back to each participant usually within six weeks of the time the results were reported to PNL.

At any time during the process, the participant may decide that the results are suspect and should not be reported. Since participation is

voluntary, the use of the reported data has been left in control of the participants. All results, though, are strictly confidential between the participating laboratory and the PNL intercomparison program manager.

EQUIPMENT DESCRIPTION

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

INSTRUMENT SET

The instruments used in the intercomparison were those used for the pilot intercomparison program operated under the Technical Guidelines for the Radiological Calibrations Project. The particular instruments were chosen for maximum flexibility of dose measurements from a variety of radiological sources, for their precision and stability, and for their simplicity of use and familiarity to the participants.

The specific pieces of equipment contained in each instrument set are listed in Table 1. The intended purpose of each instrument is also given in Table 1.

TABLE 1. Equipment Contained in the Intercomparison Instrument Set

<u>Piece of Equipment</u>	<u>Intended 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 kerma from neutron calibration sources
Geiger-Mueller counter	measure the component of dose due to photons created by a neutron calibration source
extrapolation ion chamber	measure the dose rate from beta calibration sources at 7 mg/cm ²
charge checker	provide a stable charge with which to check the electrometer operation

The chambers were calibrated using ^{137}Cs and ^{60}Co sources in the PNL calibration facility. The exposure rates of those sources were traceable to the National Bureau of Standards (NBS) via transfer standards (ionization chambers). The electrometer was calibrated using a picoampere source, which was traceable to NBS via the Hanford Engineering Development Laboratory Calibration Program. The instruments are shown in Figure 1. A description of each instrument follows.

Electrometer

This is a 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 105 to 125 Vac or on its integral battery pack. The display is 4-1/2 digits wide with the decimal point.

The instrument has a built-in high-voltage power supply consisting of five 67.5-V batteries. The user may select "+" or "-" polarity and the output

FIGURE 1. DOE Intercomparison Program Instrument Set

voltage may be varied in five equal steps between zero and the maximum voltage. The high voltage is transmitted on the two outer shields of the triaxial signal cable, thus providing additional shielding and lower signal-to-noise characteristics.

The input/output connector is a triaxial connector. A 75-ft triaxial cable is supplied in the set for using the electrometer with the Capintec Model PM-30 ionization chamber.^(a) In addition, a triaxial-to-coaxial (triax-to-coax) adapter is provided, allowing the user to employ low-noise coaxial signal cables for the other ionization chambers. A 75-ft coaxial signal cable is also supplied in the instrument set.

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

Thin-Walled Ion Chamber for Photon Measurements

The ionization chamber chosen for photon measurements is a Capintec Model PM-30. The chamber is constructed of air-equivalent-conducting plastic and has an active volume of 28 cm³. The response of the instrument for measuring air kerma is nearly independent of the energy of the incident photons from 20 keV to a few MeV. A Lucite[®] build-up cap is provided so the chamber can be used for high-energy photons (¹³⁷Cs and ⁶⁰Co). Without the build-up cap, the chamber may also be used to measure exposure rates from x-ray beams. The connector is a triaxial-BNC type which connects directly to the electrometer via a triaxial signal cable.

Tissue Equivalent Ionization Chamber for Neutron Measurements

The ionization chamber chosen for neutron measurements is a Far West Technology (FWT)^(b) Model IC-80 tissue equivalent ionization chamber. The 80-cm spherical chamber is constructed of A-150 tissue equivalent plastic and

(a) Capintec, Inc., Montvale, New Jersey.

[®] Trademark of the E.I. duPont de Nemours and Company.

(b) Far West Technology, Goleta, California.

FIGURE 2. The Keithley Electrometer a) Front Panel, b) Back Panel

is usually operated with ambient air as the fill gas instead of tissue equivalent counting gas. The signal output connector is a BNC type while the high-voltage connector is an MHV type. The chamber is operated using 300-V high voltage. The signal is directed to the electrometer via 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 as the ionization chamber and GM counter exhibit relatively high and relatively low sensitivities to neutrons, respectively.

Geiger-Mueller Counter

The GM counter chosen to measure the photon contribution of exposure in a neutron field was a FWT model GM-2 energy compensated GM counter. The detector is a small, 0.48-cm-diameter GM tube with an active volume of 0.12 cm^3 . The fill gas is neon, quenched with a halogen-quenching agent. The tube wall is a nonchromium alloy. The detector is enclosed in an energy flattening shield to eliminate the normal low-energy photon response characteristic. The 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 were not supplied as it was assumed that all participants would have ready access to these common pieces of laboratory apparatus.

Extrapolation Ionization Chamber for Beta Measurements

The chamber chosen for use in determining dose rates from beta sources was an FWT Model EIC-1 tissue equivalent plastic extrapolation ionization chamber. The device is a parallel-plate-type ionization chamber with a continuously variable volume from approximately 0.1 to 1.4 cm^3 . The front entry window has a density thickness of 6.9 mg/cm^2 . The collecting electrode has been modified by the manufacturer from a 1- to a 2-cm diameter to increase the sensitivity. The output through a BNC connector to the electrometer is achieved via the low-noise coaxial signal cable and coax-to-triax adapter. The recommended high voltage is 50 volts per revolution of the outer wall of the chamber (1 revolution = approximately 1 mm increase in gap).

Charge Checker

Also included in the instrument set was an electronic test circuit for verifying the stability of the electrometer. A mercury battery is employed to charge a polystyrene capacitor. Both of the components are very stable and produce a charge that is also quite stable with time. This charge pulse monitors the stability of the electrometer's response.

Procedures

A complete set of procedures detailing the description and use of the instruments was included in each set. The procedures were updated several times during the year to clarify and address specific characteristics of each measurement. Included in the procedures were graphic illustrations of the electrical connections for each technique.

SECONDARY STANDARD BETA SOURCE SET

The secondary standard beta source set (referred to as the beta set in this report) consisted of three beta-emitting sources and an irradiation apparatus as 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 the supplied source handling tool and is secured in the irradiation jig. The shutter of the jig is controlled using a microprocessor-based controller/timer 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 was designed to follow the specifications for the series 1 source set of the international 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 using a similar beta secondary standard set at PNL, which was calibrated at the PTB and checked using the measurement quality assurance program between PNL and the NBS. 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 . Reference

FIGURE 3. DOE Intercomparison Program Secondary Standard Beta Source Set

dose rates are taken to be at a depth of 7 mg/cm^2 and a distance of 20 cm for ^{147}Pm . Beta reference dose rates are further corrected to account for variations in air density because of altitude, according to the technique described by Pruitt (1985).

CALCULATIONS

Participants in the intercomparison program are requested to deliver 500 mR ($1.29 \times 10^{-4} \text{ C/kg}$) for x-ray and photon fields, 500 mrad (5 mGy) for a beta field, or 500 mrem (5 mSv) for neutrons; the participant is expected to

also supply the quality factor for neutron irradiations. The associated signals are recorded on the supplied data sheets and reported back to PNL. The signals are then used to calculate the appropriate quantity, and ratios of the measured quantity to the expected result are determined. Those ratios are reported back to the participant in a letter. The calculations which are 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 product of the measured charge, Q , the temperature/pressure correction, C_{tp} , and the calibration factor, C_γ .

$$X = Q \cdot C_{tp} \cdot C_\gamma$$

where X = the integral exposure in coulombs/kg (R)
 Q = the net collected charge in coulombs
 C_{tp} = the correction for temperature/pressure
 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.

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

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 tissue and of air

$\frac{\bar{W}}{e}$ = 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)

$(\frac{dI}{dx})_{x \rightarrow 0}$ = 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 zero.
 $(\frac{dI}{dx})_{x \rightarrow 0}$ is calculated from the slope of the function $I(x)$.

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 3.14 cm^2 . The ratio of $W/e = 33.85 \text{ eV/ip}$ (joules/coulomb). The air density, ρ_A , was taken to be 0.001197 g/cm^3 at 22°C (295°K) and 760 mmHg (101.3 kPa). No further corrections were applied to adjust the signals for effects listed in Appendix C of ISO 6980 (ISO 1984).

The neutron measurements required two detectors: a tissue equivalent plastic ionization chamber for total (gamma plus neutron) dose and GM counter for gamma dose. The calculation for absorbed dose was taken from International Commission on Radiation Units and Measurements (ICRU) Report 26, Neutron Dosimetry for Biology and Medicine (1977):

$$R_T = Q \cdot C_T$$

$$R_U = N \cdot C_U$$

where R_T = the response of the ionization chamber from neutrons and photons
 Q = the charge collected using the ionization chamber
 C_T = the ionization chamber calibration constant
 R_U = the response of the GM counter from photons
 N = the number of pulses collected using the GM counter
 C_U = the GM counter calibration constant.

The absorbed doses are then calculated by:

$$D_n = (R_T - R_U) \cdot K$$

and

$$D_\gamma = R_U$$

where D_n and D_γ are the neutron and photon absorbed doses in rad (Gy), respectively, and R_U and R_T are as previously defined, and

$$K = \frac{W_n}{W_\gamma} \cdot \frac{(S_{w,g})_n}{(S_{w,g})_\gamma} \cdot \frac{K_n}{K_\gamma}$$

where $\frac{W_n}{W_\gamma}$ = the ratio of energies necessary to create an ion pair by neutrons, n, and photons, γ

$\frac{(S_{w,g})_n}{(S_{w,g})_\gamma}$ = the ratio of gas-to-wall mass collision stopping power ratios for neutrons, n, and photons, γ

$\frac{K_n}{K_\gamma}$ = the ratio of kerma-factor ratios for neutrons, n, and photons, γ .

The factor K, which converts instrument response to absorbed dose in tissue, varies slowly with neutron energy. The values used to calculate K were adapted from the American Association of Physicists in Medicine (AAPM) Report No. 7 (1980). The ratio of the kerma factor for tissue equivalent plastic to International Commission on Radiation Units and Measurements (ICRU 1977) tissue (four element) was taken as approximately 1, which is generally valid for energies between 50 keV and a few MeV ($\pm 1\%$). The calculation of the conversion factor, K, is shown below using the values adapted for this study:

$$K = \left(\frac{35.5}{33.7}\right) \cdot \left(\frac{1.151}{1.139}\right) \cdot \frac{0.96}{1.0}$$

$$= 1.02$$

The measured responses were corrected for air density effects with 22°C (295°K) and 760 mmHg (101.3 kPa) as reference values for temperature and pressure, respectively.

The neutron dose equivalent was calculated as the product of the neutron absorbed dose and the neutron quality factor supplied by the participant.

Beta Sources

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

$$D = \dot{D}_r \cdot t \cdot K_Z \cdot K_L \cdot K_F$$

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

K_Z = the exponential decay correction to the source strength

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

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

The values currently adopted for the beta sources are contained in Table 2. In addition, the delivered doses are corrected for variations in air density because of altitude by the following algorithm from Pruitt (1985):

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

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

D_0 = the delivered dose

a, b = coefficients listed in Table 3

$x = 1 - \rho/\rho_0$

ρ = air density during the irradiation

ρ_0 = air density at the reference temperature and pressure.

TABLE 2. Parameters Used to Calculate the Absorbed Dose from the DOE Intercomparison Beta Sources

Source	K_Z	K_L	K_F
$^{90}\text{Sr}/^{90}\text{Y}$	$\exp(-6.66 \times 10^{-5} t)^{(a)}$	1.0	1.0
^{204}Tl	$\exp(-5.024 \times 10^{-4} t)$	1.0	1.0
^{147}Pm	$\exp(-7.248 \times 10^{-4} t)$	$150.2 \exp(-14.5 P/T)^{(b)}$	$1.02 \exp(-4.37 \times 10^{-4} RH)^{(c)}$

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

(b) P is pressure in kPa; T is the temperature in $^{\circ}\text{K}$.

(c) RH is the relative humidity in percent.

TABLE 3. Parameters Used to Calculate the Air Density Corrections for Altitude, $D = D_0 (1 + ax + bx^2)$ and $x = 1 - \rho/\rho_0$

Nuclide	Nominal Activity (M Bq)	Reference Depth ($\text{mg}\cdot\text{cm}^{-2}$)	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

RESULTS

During the seven months of fiscal year 1986 in which the program operated, five DOE laboratories participated in the DOE intercomparison program by performing measurements using the instrument sets. One of the laboratories participated twice, bringing the number of participants to six. Three DOE laboratories participated in the intercomparison by performing measurements using the secondary standard beta source set. Results of measurements and irradiations were received from eight of the nine participants. The one noncontributing participating laboratory experienced a malfunction of a measurement device during the time the beta set was at that laboratory. In order to assure that the set was returned on time, the laboratory returned the set without performing irradiations.

Calibration intercomparison measurements were performed using a variety of gamma sources and using one neutron source. None of the participants used instruments contained in the intercomparison instrument set to perform measurements in x-ray beams or in fields produced by isotopic beta sources.

The results of the photon measurements are summarized in Table 4. One result, an extrapolation chamber measurement on a ^{137}Cs source, yielded a ratio of the measured exposure rate to the expected exposure rate of 3.06. The cause of this unexpectedly high ratio is unknown, but other measurements on that source using fixed-volume ion chambers were in adequate agreement with the participant's calibration. As the program progresses in the next few years, only data from the appropriate instruments will be reported. This year, all the data are reported because the spread in the data indicates that some of the users are unfamiliar with the program and because errors generated by the tissue equivalent ion chamber and GM photon calibrations directly impact the neutron response of their instruments. In addition, the extrapolation chamber results point to difficulties in dose interpretation as some of the dose measured using this technique may be due to low-energy electrons generated by scatter air interactions.

The overall averages of the measured-to-expected ratios were 1.12 ± 0.17 . The distribution of the ratios is graphically presented in Figure 4. The

TABLE 4. Summary of Intercomparison Results from Photon Irradiations

<u>Participant</u>	<u>Source</u>	<u>Technique</u> ^(a)	<u>Ratio of Measured/Expected</u>
B	¹³⁷ Cs	PM-30	1.60
B	¹³⁷ Cs	TEIC	1.15
B	¹³⁷ Cs	EIC	3.06 ^(b)
C	¹³⁷ Cs	PM-30	1.31
C	¹³⁷ Cs	PM-30	1.43
O ^(c)	⁶⁰ Co	GM	1.03
D ^(c)	⁶⁰ Co	GM	1.07
D ^(c)	⁶⁰ Co	GM	1.01
D ^(c)	⁶⁰ Co	TEIC	1.02
D ^(c)	²²⁶ Ra	TEIC	1.08
E	¹³⁷ Cs	PM-30	Malfunctioned
E	¹³⁷ Cs	TEIC	1.06
E	¹³⁷ Cs	GM	1.06
D ^(d)	⁶⁰ Co	TEIC	1.02
D ^(d)	⁶⁰ Co	TEIC	1.05
D ^(d)	²²⁶ Ra	TEIC	1.05
D ^(d)	⁶⁰ Co	PM-30	0.98
D ^(d)	⁶⁰ Co	PM-30	1.00
D ^(d)	²²⁶ Ra	PM-30	1.03

(a) Techniques are designated as:

PM-30 = thin-walled ion chamber

TEIC = 80-cm³ tissue equivalent ion chamber

EIC = extrapolation ion chamber

GM = Geiger-Mueller counter.

(b) Not included in average.

(c) Initial measurements.

(d) Second set of measurements.

precision of the measurement ratios is such that the statistical population of the data may be considered to be similar to that observed in the intercomparison pilot study.^(a)

(a) McDonald, J. C., P. L. Roberson and F. M. Cummings. 1986. Intercomparison of Radiological Calibration Sources. A Pilot Study (Draft). Pacific Northwest Laboratory, Richland, Washington.

FIGURE 4. Distribution of Intercomparison Results from Gamma Irradiations

The data from the measurement on a $^{238}\text{PuBe}$ source resulted in a ratio of the measured dose equivalent to the expected dose equivalent of 4.55. The result is in disagreement with the agreement of neutron measurement results observed in the intercomparison pilot study.^(a)

The data from measurements performed using the secondary standard beta source set averaged 1.02 ± 0.05 for the participants who used the $^{90}\text{Sr}/^{90}\text{Y}$ source. One measurement was performed using dosimetry grade photographic film (ratio = 1.05) and another measurement was performed using an extrapolation chamber (ratio = 0.98). The participant who used the film could not obtain

(a) McDonald, J. C., P. L. Roberson and F. M. Cummings. 1986. Intercomparison of Radiological Calibration Sources. A Pilot Study (Draft). Pacific Northwest Laboratory, Richland, Washington.

results for the ^{204}Tl and ^{147}Pm irradiations. The participant who used the extrapolation chamber experienced a malfunction of the instrument causing him to shift to a fixed-volume instrument. The participant compared readings from irradiations using the intercomparison sources to readings from sources in an identical, albeit much older set. The ratios of measured-to-expected dose rate were 1.12 and 0.63 for the ^{204}Tl and ^{147}Pm irradiations, respectively. The distribution of the results is presented graphically in Figure 5. This part of the intercomparison project was not performed during the pilot study, so there is no comparison to earlier values.

FIGURE 5. Distribution of Intercomparison Results from Beta Irradiations

PROGRAM PROBLEMS AND IMPROVEMENTS

Several problems were encountered during the operation of the intercomparison program during fiscal year 1986. The specific problems and the implemented solutions and proposed improvements are listed below.

PROBLEM 1

The major problem encountered was user unfamiliarity with both the equipment and the procedures necessary to perform the intercomparison measurements.

FY-1986 Solution

- Procedures were upgraded and clarified by including graphics to illustrate the proper electrical connection of the equipment.

FY-1987 Improvements

- The connections will be improved to reduce the number of required signal cables to one, and the number of high voltage cables to one.
- Procedures will be upgraded and further clarified.
- A measurement training session for intercomparison participants is being proposed.

PROBLEM 2

Some participants complained of a lack of supporting equipment necessary to perform the measurements.

FY-1986 Solutions

- Towards the end of fiscal year 1986, PNL began to include a 0- to 3000-V high-voltage power supply (HVPS) in the instrument set.
- A larger number of cable adapters were included to increase the flexibility of the equipment.

FY-1987 Improvements

- Scaler/counters with built-in HVPSs have been purchased for use with the GM counter and will be incorporated into the instrument set.

- A battery pack that is capable of supplying high voltage to all three ion chambers will be included in the set. The battery pack has selectable polarity, discrete 50-V steps to a 300-V maximum, an MHV output connector, and a load circuit for battery checking.
- The number of cables will be reduced to two: one signal and one high-voltage. The adapters/connectors will be phased out over the year.

PROBLEM 3

Instabilities resulting from electrometer noise contributed to the imprecision of the measurements.

FY-1987 Improvement

- A Keithley Model 616 electrometer will be substituted for one of the Model 614 electrometers on a trial basis. If the stability improves, the Model 614 will be gradually replaced by Model 616 electrometers.

PROBLEM 4

The turnaround time for the beta source set was long primarily because of the problems encountered with the shipping of radioactive materials.

FY-1987 Improvement

- Pacific Northwest Laboratory will take a more active role to assure that the instrument sets are exchanged expeditiously. More frequent communications between PNL and the participating laboratory's technical contact and shipping department will help track the future shipment of the instrument sets.

CONCLUSIONS

Although most of the results from the participating laboratories indicated that measurements from high-energy-photon sources (such as ^{137}Cs and ^{60}Co) were in adequate agreement, several of the participants demonstrated that they were unfamiliar with the instruments and techniques employed in the intercomparison program. Lack of familiarity with equipment and techniques indicates a need for further training.

Of the 18 measurements that composed the results obtained using a number of detectors and a variety of sources, only one ratio of the measured dose to the expected dose was less than 1.0. This value indicates that many of the calibration exposure rates are high, i.e., slightly more exposure was delivered to the detectors than the participants expected. One impact of a high calibration exposure rate could be the addition of an inherent negative bias to dosimeter results. The additional bias could limit the acceptable precision of dosimeter results obtained during participation in the DOELAP.

Investigation of the data may lead the reader to conclude that some laboratories are performing inaccurate calibration; the authors, however, have concluded that is not the case. User unfamiliarity with the equipment and techniques, and the lack of a consistent definition of radiation beam characteristics throughout the DOE facilities are the primary reasons for the differences between the measured dose rates and expected dose rates. The primary value of the intercomparison program is that the magnitude of these differences between reference values and measurement results will be reduced as the intercomparison program continues. More data for the beta, neutron, and x-ray categories must be generated so that inherent problems in those areas can be addressed.

Other values of the intercomparison program to the DOE are the provision of a stable method for long-term evaluation of calibration techniques and the comparison of new techniques with older techniques. In addition, the implementation of new calibration techniques can easily be evaluated at several sites simultaneously.

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