Purpose

The purpose of this procedure is to describe the setup, measurement and procedures for irradiating passive dosimeters such as Thermo-Luminescent Dosimeters (TLDs) in terms of air kerma using gamma-ray beams from the NIST ^{137}Cs and ^{60}Co sources.

Scope

This report describes calibration service 46020C. The document starts by describing the physical quantities air kerma and exposure and provides a brief background describing the rationale behind the irradiation process. It later describes the equipment and systems used and the procedures followed in performing the irradiations. The appendix includes a copy of a sample irradiation certificate.

Definitions and Background

Description of Service

The NIST Ionizing Radiation Division Radiation Interactions and Dosimetry Group receives passive dosimeters for irradiation to specified radiation levels. This service is assigned test number 46020C (for a single setup) and 46021C (for multiple setups). The total exposure or air kerma delivered is provided for each of the passive dosimeters irradiated.

The Quantities Air Kerma and Exposure

The quantity kerma characterizes a beam of photons or neutrons in terms of the energy transferred to any material. For the calibration service described in this document, consideration is limited to photon beams in air. Air kerma is the total energy per unit mass transferred from a photon beam to air. Air kerma, K_{air}, is the quotient of dE_{tr} by dm, where dE_{tr} is the sum of the initial kinetic energies of all electrons liberated by photons in a volume element of air, and dm is the mass of air in that volume element. Then

$$K_{air} = \frac{dE_{tr}}{dm}$$

The SI unit of air kerma is the gray (Gy), which equals one joule per kilogram; the special unit of air kerma is the rad, which equals 0.01 Gy.

The quantity exposure characterizes an x-ray or gamma-ray beam in terms of the electric charge liberated through the ionization of air. Exposure is defined as the total charge per unit mass liberated in air by a photon beam and is represented by the equation:

$$\boldsymbol{X} = \frac{\boldsymbol{dQ}}{\boldsymbol{dm}}$$

where *dQ* is the sum of the electrical charges on all the ions of one sign produced in air when all the electrons liberated by photons in a volume element of air, whose mass is *dm*, are completely stopped in air. The SI unit of exposure is the coulomb per kilogram (C/kg); the special unit of exposure, the roentgen (R), is equal to exactly $2.58\text{x}10^{-4}$ C/kg. The ionization arising from the absorption of bremsstrahlung emitted by the secondary electrons is not included in *dQ*. Except for this small difference, significant only at high energies, the exposure as defined above is the ionization equivalent of air kerma. The relationship between air kerma and exposure can be expressed as a simple equation:

$$\boldsymbol{K} = \boldsymbol{X}\ \ 2.58\cdot10^{-4}\left(\frac{\boldsymbol{W}}{\boldsymbol{e}}\right)\left(\frac{1}{1-\boldsymbol{g}}\right)$$

where *W/e* is the mean energy per unit charge expended in air by electrons, and *g* is the fraction of the initial kinetic energy of secondary electrons dissipated in air through radiative processes. The value currently accepted by the NIST for *W/e* is 33.97 J/C. The currently accepted *g* values for ^{60}Co and ^{137}Cs beams are 0.32 % and 0.16 %, respectively.

Characterization of the NIST Gamma-Ray Beams in Terms of Air Kerma

As of July 30, 2009 there are four NIST gamma-ray sources that produce the ^{137}Cs and ^{60}Co gamma-ray beams that are typically used for irradiating passive dosimeters in terms of air-kerma and exposure. The air-kerma rates and exposure rates at given distances are very well-known for all of these sources. The values for the air kerma and exposure at these distances are determined by using the primary standard instruments, which are a suite of graphite-wall, air-ionization, Bragg-Gray cavity chambers developed at NIST.

The value of the exposure rate measured with the primary standard instrument is decay corrected to provide the value of the exposure rate (and air-kerma rate) at a given distance from the source for any given date and time of the year.

Charts in each of the control rooms where the sources are located display the exposure rates for a given day and time of the year.

Generalities of the Irradiation of Passive Dosimeters in Terms of Air Kerma and Exposure

Passive dosimeters sent to the NIST are irradiated in terms of air kerma and exposure. The goal of the irradiation is to deliver a well-known value of exposure or air kerma to the dosimeters sent for irradiation. The value is reported to the customer in an "air kerma dosimeter irradiation certificate," a copy of which can be found in the appendix section of this report.

Equipment

Gamma-ray Sources

All sources are collimated. The location of each of these sources in Building 245 is listed in the table below, as are the nominal activities as of January 1, 1999.

Radionuclide	Activity (Bq)	Orientation
^{60}Co	1.3×10^{11}	Horizontal
^{60}Co	9.6×10^{09}	Horizontal
^{137}Cs	5.8×10^{12}	Horizontal
^{137}Cs	6.3×10^{11}	Horizontal

Console

In each of the irradiation facilities, there is a separate control unit for each source. The control unit is an electronic box, made in-house, that allows the operation of the sources. It mainly raises and lowers a cylinder containing the source. The console has a timer which can be set to the desired exposure time.

Reference Scale

In each room there is a metallic scale that is used to measure the distance between the source and the detector.

Other

There is a detector-alignment system consisting of a telescope, movable cart and a stand for positioning detectors at a fixed distance from the source, a laser for positioning the detectors along the beam-center-line, and an acrylic phantom.

Procedure

Communication with the Customer

The recommended procedure for requesting a NIST calibration service is outlined in the NIST Calibration Services Users Guide. In practice, however, customers request calibration services in a variety of ways. Typically, a new or first-time customer will establish contact with the Radiation Interactions and Dosimetry Group by telephone, letter, e-mail or fax requesting information regarding techniques offered, charges, backlog time, turnaround time, and shipping/mailing information. At this stage, there is generally an opportunity to discuss with the prospective customer appropriate qualities of radiation for the type of service being requested and methods of shipment to reduce the risk of damage. The customer is informed that a purchase order must be received at NIST before an official calibration is performed. The purchase order can be sent with the instrument to be calibrated or can be sent separately by fax, mail or e-mail. In addition to an authorization for payment, the purchase order should include a detailed description of the calibration request, including beam quality codes, dosimeter model and serial numbers, and the name and telephone number of a technical contact. If an incomplete purchase order is received, every effort is made to get a detailed description of the service requested.

Initiation of Paperwork and Inspection of Dosimeters sent to NIST for Irradiation

If the purchase order and the dosimeters are sent to NIST on the date agreed upon between the customer and the NIST contact, every effort is made to start the irradiation process as soon as possible. This process consists of two stages: one involves the handling of the paperwork and the other the handling of the dosimeters.

Regarding the paperwork, after a purchase order is received, a checklist, acceptance letter and a customer test folder are generated. A copy of the purchase order, the final copy of the irradiation certificate, the raw data and summary sheets and any documents of correspondence with the customer or the Measurement Services Division (MSD), Calibration Services Office are maintained, and the customer’s calibration-report folder is filed by the unique dosimetry group (DG) number. After copying the purchase order for the customer folder, the original purchase order, along with a request for a test folder, should be sent to the MSD. A test folder will be sent byMSD and will contain the original purchase order and appropriate forms. The test folder's unique number is used as one of the identifiers on the irradiation certificate.

Regarding the handling of dosimeters, dosimeters arriving for calibration are unpacked and inspected for damage. Shipping damage is reported to the NIST shipping department. When an instrument arrives in a state of disrepair that is obvious by visual inspection, the customer is notified, and a decision is made whether to return the instrument to the customer; if the repair is minor, NIST personnel may perform the repair.

<u>Source Setup in rooms B015 and B021</u>

1. Sign in using the logbook for operating the source. This logbook is located in room B019 for operating the sources located in rooms B021 and B015. Login the information requested in the logbook: date, operator name, time, shutter elapsed time, room, use, etc.

2. After filling in the logbook, get the key for unlocking the mechanical safe lock and unlock the source. **ATTENTION**: It is extremely important to unlock the source before operating it. Failure to do so can damage the source.

3. Turn on main power to console.

4. Enter the room to make sure no people are in it. Exit the room and close the door.

5. A check of the safety-interlock system and other visible indicators must be performed. The interlock system is checked by opening the source and later opening the door to the room containing the sources. The source must close immediately upon opening the door. This is verified only once at the start of the day.

6. The source is opened by first pressing the "Reset" Interlock button, then initializing the timer by pressing the "Initialize" button, and finally pressing the "Open" button. In the open position, radiation is present in the room. By pressing the "Close" button the source closes, and there is no radiation present in the room.

7. When opening the source for the first time on the day of measurement, also verify that the buzzer sounds (indicating the detection of radiation in the room).

8. After all safety checks outlined above have been performed, one can enter the room and set up the dosimeters for irradiation.

Preparation

1. Previous to setting up the dosimeters, they are grouped according to the total exposure they will receive.

2. The dosimeter type, models and serial numbers are written in a logbook dedicated to recording irradiation of passive dosimeters. The exposure rate is recorded, and the preset times are determined and written in the logbook (Log Book 966).

3. In determining the preset time, the timer offset must be taken into account by subtracting its value from the ideal preset time.

4. The timer offset can be measured by setting the timer for a given time, for example 60.00 seconds. The source is opened and when it stops the actual time is recorded. The timer offset is the difference between the actual time and the preset time. This is typically a fraction of a second for all of the sources.

5. Once the preset times for all the dosimeters are determined and recorded in the logbook, the dosimeters can be placed on the phantom inside the room after the steps outlined in the section entitled “Source Setup” have been followed.

Setup of Dosimeters

The irradiation of dosimeters using gamma-ray beams are performed by using a previously determined value of the air-kerma rate obtained by decaying the initial value to the date and time of the irradiation. The value of the air-kerma rate for a given distance from the source at a given date and time is displayed by a computer program and on wall charts.

For all customer irradiations, a NIST reference-class transfer ionization chamber is calibrated in the beam for quality assurance. The NIST chamber should have a previous calibration for the reference radiation qualities selected by the customer.

Irradiations are typically performed at a distance of 300 cm from the source. The setup of dosimeters is described in the following steps:

1. Each gamma-ray facility has a metallic scale that is used to set the source-to-detector distance. The source-to-detector distance is set by sighting the telemicroscope on the appropriate scale distance.

2. An acrylic phantom is placed on top of the table.

3. The height of the phantom is adjusted to the beam center-line using the laser beam associated with each source.
4. A mirror is placed on the rear face of the phantom that allows the laser beam to be reflected onto itself to ensure that the phantom is placed perpendicular to the photon beam.

5. The front face of the phantom is then centered in the telemicroscope-scale reticule.

6. A maximum of six passive dosimeters can be placed on the front face of the phantom using double sided adhesive tape. An effort is made in minimizing the gap between the dosimeter and the front face of the phantom. Ideally the dosimeter should be in direct contact with the phantom.

7. Once the dosimeters are mounted on the phantom, exit the room and close the door. The dosimeters are ready to be exposed.

8. Set the preset time on the console using the thumb switches. Make sure the range switch is set to the appropriate position for the given time.

9. Open the source.

10. Record the time the exposure started. The timer should be running at this time. The source will close automatically when it reaches the preset time.

11. Once the timer stops (the source is now closed), record the actual time in the logbook.

12. Calculate the total exposure delivered by multiplying the actual time by the exposure rate. Record this number in the data book.

13. Enter the room and remove the dosimeters. If there is a new batch of dosimeters, repeat the procedure described above.

14. Shut down the power to the console. Remove the key from the source and place it in the drawer in room B019. Sign out in the logbook. Turn all lasers off.

<u>Quality Control</u>

An in-house check of the irradiation system is performed by calibrating a NIST chamber at the same source-to-detector-distance where the dosimeters were placed. The NIST chamber must have a calibration history in order to be used for this purpose.

For all NIST reference-class chambers, a record is maintained of all calibrations, and the previous calibrations are compared with the current calibration to detect any trend or measurement discrepancy. The calibration histories for many NIST reference chambers are maintained in binders and/or are accessible electronically from the computer located in room B019. Any discrepancy arising with a NIST check chamber greater than 0.5 % gives rise to a thorough investigation of the calibration and irradiation systems previous to exposing the customer dosimeters.

Documentation/Irradiation Certificates/Storage

After the dosimeters have been irradiated, the irradiation certificate is generated. Currently, certificates are generated in Microsoft Word. Templates are available to simplify this procedure and to ensure consistency in the reporting format. A sample certificate is found in Appendix B.

The final copy of the irradiation certificate is reviewed and initialed by the preparer and an additional reviewer and then given to the Group Leader for review. After the Group Leader approves and initials the report, it is sent to the Division Office for approval. Upon return, two copies are made. The original is mailed to the customer, one copy is filed in the *customer DG folder*, and one copy is added to the *test folder*.

After all requested calibration work is completed, the fees are computed and NIST form 64 is generated using the ISSC database. Copies are filed in the test folder and the customer DG folder and the original is sent to the Administrative Officer for the Ionizing Radiation Division. The test folder is then signed and returned to the calibration program. The customer DG folder is filed in room C212. Shipping request forms are prepared after the Division Chief signs off on a calibration report and returns it to the Group office. The dosimeters are packed either in their original container or in a more suitable one if necessary.

The logbook containing the data mentioned in the Procedure section is also stored in room B019 but can be temporarily located in the office of the person writing the report.

Assessment of Uncertainties

The method of uncertainty assessment follows the NIST policy of expressing uncertainty, as outlined in the NIST Technical Note 1297. Conventional statistical estimates are given as standard deviations of the mean, and are designated as “Type A”, which can be considered to be objective estimates. All other uncertainty estimates, which are designated “Type B,” are subjective estimates, based on extensive experience. The “Type B” uncertainties are estimated so as to correspond to approximately one standard deviation. The Type A and Type B estimates are combined according to the usual rule for combining standard deviations, by taking the square root of the sum of the squares (the quadratic sum). The quadratic sum of the two types of uncertainties is then considered to be the combined uncertainty, which is in turn multiplied by the coverage factor of two (k=2) to give an expanded uncertainty. The uncertainty is considered to have the approximate significance of a 95 % confidence limit. Appendix A lists the details of the assessment of uncertainty in the air-kerma rates determined for the different gamma-ray beams. The details of the assessment of uncertainty in the irradiation of passive dosimeters are also listed in Appendix A.

Safety

The main safety consideration is radiation protection. As described below, every effort is made to avoid any possibility of radiation exposure, even though it would be highly unlikely that serious exposures could occur accidentally. All radiation areas in the building are marked with striped tape and dosimeters must be worn by all personnel in these areas. Radiation safety training and assessment services are provided by the NIST Health Physics Group.

Radiation Safety

All doors permitting access to the gamma-ray calibration ranges have interlocks as required by the Nuclear Regulatory Commission. A radiation detector with indicator lights and an audible signal is in each gamma calibration range. At each entrance to a gamma-ray calibration range, a set of two red lights indicates a "beam on" condition.

International Comparisons

International comparisons have been made with other National Metrology Institutes around the world. During these international comparisons, a reference class chamber is calibrated at both facilities, and the values of the calibration coefficients obtained at both institutions are compared. The reference section lists comparisons made in the last few years using the same ^{137}Cs and ^{60}Co gamma-ray beams that are used for the calibration service described in this procedure.

Filing and Retention

The Ionizing Radiation Division (IRD) Quality Manager shall maintain the original and all past versions of this IRD Procedure.

References

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3. NIST Calibration Services Users Guide 1998.

4. NIST Technical Note 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurements.

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8. M. O'Brien, R. Minniti and Stanslaus Alwyn Masinza, "Comparison between the NIST and the KEBS for the determination of air kerma calibration coefficients for narrow x-ray spectra and ^{137}Cs gamma ray beams," Journal of Research of the NIST, Volume 115, Number 1, January-February 2010.

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Appendix A: Uncertainty Analysis

Air-kerma Rate Uncertainty Analysis for Gamma Rays Shown in %

	Type A	Type B
Uncertainty components specific to a chamber		
charge	0.03	0.1
timing	0.04	0.1
volume	0.06	0.05
k_{sat}, loss of ionization due to recombination	0.01	0.05
axial nonuniformity		0.07
radial nonuniformity		0.01
stem scatter		0.05
Uncertainty components common to all chambers		
temperature		0.03
pressure		0.01
distance (axial)		0.02
air density		0.02
calculated humidity correction		0.06
k_{wall}, zero wall thickness		0.17
energy-absorption coefficient ratio		0.06
stopping-power ratio		0.57
W/e, ion pair energy		0.15
(1-g), radiative loss correction		0.02
quadratic sum	0.08	0.65
combined standard uncertainty	0.65	
expanded uncertainty (k = 2)	1.30	

Uncertainty analysis for Passive Dosimeters

	Passive dosimeters	
Uncertainty components	Type A	Type B
air-kerma rate	0.08	0.65
air density	NA	
charge	NA	
distance		0.01
humidity	NA	
leakage	NA	
radiation background	NA	
radial nonuniformity		0.02
recombination loss	NA	
scale reading	NA	
timing		0.1
quadratic sum	0.08	0.7
combined standard uncertainty	0.7	
expanded uncertainty	1.4	

Appendix B: Sample irradiation certificate

National Institute of Standards and Technology

Air Kerma Dosimeter Irradiation Certificate

FOR

The Nuclear Power Company
San Diego, California

Dosimeter Type: TLD Badge Model ABCD

Irradiations performed by Ronaldo Minniti

Report reviewed by Michelle O'Brien

Report approved by Michael G. Mitch

For the Director
National Institute of Standards and Technology
by

Lisa R. Karam, Chief
Ionizing Radiation Division
Physics Laboratory

Information on technical aspects of this report may be obtained from Ronaldo Minniti, National Institute of Standards and Technology, 100 Bureau Drive Stop 8460,Gaithersburg, MD 20899, (301)975-5586, ronnie.minniti@nist.gov. The results provided herein were obtained under the authority granted by Title 15 United States Code Section 3710a. As such, they are considered confidential and privileged information, and to the extent permitted by law, NIST will protect them from disclosure for a period of five years, pursuant to Title 15 USC 3710a(c)(7)(A) and (7)(B).
Report format revised: April 1, 2010.

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Air Kerma Dosimeter Irradiation Certificate

FOR

The Nuclear Power Company
San Diego, California

Dosimeter Type: TLD Badge Model ABCD

Badge Orientation: The front face was normal to the incident radiation.
Date of Exposure: March 30, 2009.
Beam Code: ^{137}Cs.
Air Kerma Rate: 1.08 E-5 Gy/s; ***Beam Radius:*** 62 cm.

TLD Identification		**Exposed on Phantom**	**Total Air Kerma (mGy)**	**Irradiation Distance (cm)**
Model	**Number**			
ABCD	1-6	YES	4.13	300
ABCD	7-12	YES	4.13	300
ABCD	13-18	YES	4.13	300
ABCD	19-24	YES	4.13	300
ABCD	25-30	YES	4.13	300
ABCD	31-36	YES	4.13	300
ABCD	37-40	YES	4.13	300

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Explanation of Terms

Air Kerma: The air kerma rate at the calibration position is measured by a free-air ionization chamber for x radiation and by graphite cavity ionization chambers for ^{60}Co and ^{137}Cs gamma radiation, and is expressed in units of grays per second (Gy/s). The gamma-ray air kerma rates are corrected to the date of calibration (from previously measured values) by decay corrections based on half-lives of 5.27 years for ^{60}Co and 30.0 years for ^{137}Cs. For a free-air ionization chamber with measuring volume V, the air kerma rate is determined by the relation

$$\dot{K} = \frac{I}{\rho_{\mathrm{air}} V} \frac{W_{\mathrm{air}}}{e} \frac{1}{1 - g_{\mathrm{air}}} \prod_i k_i ,$$

where

$I / (\rho_{\mathrm{air}} V)$ is the ionization current, measured by the standard, divided by the mass of air in the measuring volume

W_{air} is the mean energy expended by an electron of charge e to produce an ion pair in dry air, the value used at NIST is W_{air}/e = 33.97 J/C

g_{air} is the fraction of the initial kinetic energy of secondary electrons dissipated in air through radiative processes, the values used at NIST are 0.0032 for ^{60}Co, 0.0016 for ^{137}Cs and 0.0 (negligible) for x rays with energies less than 300 keV, and

$\Pi\ k_i$ is the product of the correction factors to be applied to the standard.

Air kerma in grays (Gy) is related to exposure (X) in roentgens (R) by the equation:

$$K = 2.58E - 04 \frac{W_{\mathrm{air}}}{e} \frac{X}{1 - g_{\mathrm{air}}} .$$

To obtain exposure in roentgens, divide air kerma in grays by 8.79E-3 for ^{60}Co gamma rays, 8.78E-3 for ^{137}Cs gamma rays, and 8.76E-03 for x rays with energies less than 300 keV.

Irradiation Distance: The irradiation distance is that between the radiation source and front face of the phantom.

Uncertainty: The expanded, combined uncertainty of the irradiation described in this report is 1.0%. The expanded, combined uncertainty is formed by taking two times the square root of the sum of the squares of the standard deviations of the mean for component uncertainties obtained from replicate determinations, and assumed approximations of standard deviations for all other uncertainty components; it is considered to have the approximate significance of a 95% confidence limit. Details of a typical uncertainty analysis are given in: P. J. Lamperti and M. O'Brien, "Calibration of X-Ray and Gamma-Ray Measuring Instruments", NIST Special Publication 250-58 (2001).

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Changes in NIST Air Kerma Primary Standards for Gamma-Ray Beams

The National Institute of Standards and Technology (NIST) has revised the primary standards for air kerma (and exposure) from ^{60}Co and ^{137}Cs gamma-ray beams. ***The new standards are effective 1 July 2003***. The changes are mainly due to the implementation of new wall corrections for the graphite-wall air-ionization chambers that serve as our primary standards for gamma-ray air kerma. A complete description of these changes can be found in reference [1,2]. In addition, the air kerma rates in our two therapy-level ^{60}Co gamma-ray beam facilities have been re-characterized through recent measurements using NIST primary-standard instruments. The result of these changes in standards is that the air kerma rates delivered by our various ^{60}Co and ^{137}Cs sources now have values roughly **1%** higher than before.

Calibration coefficients and calibration factors reported prior to 1 July 2003 for instruments sent to NIST for calibration in these beams should be modified or re-determined to account for these changes as described below.

Therapy-Level ^{60}Co Beams: Instruments that are regularly calibrated in our therapy-level ^{60}Co beams will receive a calibration incorporating the change in the standard when next sent back to NIST for calibration. No precise adjustment can be applied to the calibration coefficients reported previously because the irradiation conditions have been modified. Calibrations of instruments are now performed at distance of 1.0 m from the source with a collimator setting for a field of 10.0 x 10.0 cm^2, as recommended in most protocols.

Radiation-Protection-Level ^{60}Co Beams: If an instrument was calibrated at NIST prior to 1 July 2003 in one of our radiation-protection-level ^{60}Co-beam facilities, that calibration coefficient or calibration factor should be multiplied by **1.0105** to account for the change in the standard. Customers can contact Dr. Ronaldo Minniti at NIST (phone: 301-975-5586, e-mail: ronnie.minniti@nist.gov) to verify that their instruments were calibrated in the radiation-protection-level ^{60}Co facility prior to applying this adjustment.

^{137}Cs Beams: If an instrument was calibrated at NIST prior to 1 July 2003 in one of our ^{137}Cs-beam facilities, that calibration coefficient or calibration factor should be multiplied by **1.009** to account for the change in the standard.

If there are any questions regarding the changes in NIST gamma-ray air kerma standards or how they apply to your calibrations, please contact us at NIST.

References:

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