Purpose

The purpose of this procedure is to describe the setup, measurement, and reporting procedures for the absorbed-dose certification of customer-irradiated NIST transfer dosimeters.

Scope

NIST provides transfer standards in the form of sets of calibrated alanine pellets packaged in polystyrene. The sealed, packaged dosimeters are sent to the customer for irradiation to nominal, agreed–upon absorbed dose levels in a prescribed geometrical arrangement. The unopened packaged dosimeters are then returned to NIST to be measured and evaluated and the results reported in the form of an absorbed-dose certificate. The absorbed dose range that is suitable for use with these transfer dosimeters is 20 Gy to 100 kGy.

Definitions

Absorbed dose to water: the energy absorbed from ionizing radiation per unit mass of water: 1 J/kg = 1 Gy.

Dosimeter batch: quantity of dosimeters made from a specific mass of material with uniform composition fabricated in a single production run under controlled conditions, and having a unique identification code.

Electron Paramagnetic Resonance (EPR): the process of resonant absorption of microwave radiation by paramagnetic ions or molecules in the presence of a static magnetic field.

Equipment

Essential Equipment	Calibration Method	Calibration Frequency	Location
^{60}Co Gamma-Ray Sources	Comparison to Vertical Beam Source	Determined by control charts	Irradiation Facilities
Bruker EMXmicro EPR, ER 070; SN: 807095	Dosimeter Check Standard Measurement	As needed	H023
Bruker ECS 106 EPR, B-E 25; SN: 25 89 436	Dosimeter Check Standard Measurement	As needed	B0020
Bruker Benchtop EPR e-scan, SC0160	Dosimeter Check Standard Measurement	As needed	B0020
Microbalance	External Service	Annual	H023

Bruker EPR systems use commercial software, WinEPR, to simplify bridge tuning, resonator calibration, and data collection.

Health & Safety Precautions

Radiation safety
The ^{60}Co sources used for system calibration are housed in secure areas. Radiation safety, trainings are provided by the NIST Gaithersburg Radiation Safety Division.

Magnetic field safety
A Gaithersburg Office of Safety, Health and Environment survey of the vicinity of the EPR spectrometers determined that the magnetic field strengths are below actionable limits. However, as an extra precaution the room entrance has magnetic field warning signs; individuals with pacemakers should avoid rooms containing electromagnets associated with EPR spectrometers.

Procedures

1. *Dosimeter Batch evaluation and testing*

The evaluation testing provides data to assess influence quantities that may have significant effects on the performance of a dosimetry system. Data from all tests shall be recorded in the Dosimetry System Databook.

1.1 Records should include a correlation between the unambiguous pellet identifier, its batch, and the container from which it was removed. The pellets will be stored in labeled containers.

1.2 Pellet Mass Test

1.2.1 Select and weigh pellets to the nearest 0.0001 g.

1.2.2 Plot a histogram of the mass distribution.

1.2.3 Determine the mean, standard deviation, and relative standard deviation (RSD) of the pellets measured.

1.2.4 RSD Acceptance Level: ≤ 10 %

1.3 Alanine-EPR Response Variation

1.3.1 Irradiate 4 pellets to each of the prescribed doses: 0.025 kGy, 0.200 kGy, 1.00 kGy, 10.0 kGy, and 40.0 kGy.

1.3.2 Measure the EPR response (see Section 4) of the individual pellets.

1.3.3 Determine the mean, standard deviation, and relative standard deviation of the measured pellets grouped by prescribed absorbed dose.

1.3.4 RSD Acceptance Level: ≤ 1 %

1.4 Dose fractionation

1.4.1 Irradiate six pellets (groups 3A & 3B) to 1.0 kGy, wait 1 hour then irradiate the six pellets to an additional 1.0 kGy, remove three pellets (group 3B), wait 1 hour then irradiate the group 3A pellets to an additional 1 kGy, wait overnight (~20 hours), then irradiate group 3B to an additional 1.0 kGy.

1.4.2 Irradiate three pellets (group 3C) to 3.0 kGy.

1.4.3 Irradiate six pellets (groups 30A & 30B) to 10 kGy, wait 1 hour then irradiate the six pellets to an additional 10 kGy, remove three pellets (group 30B), wait 1 hour then irradiate the group 30A pellets to an additional 10 kGy, wait overnight (~20 hours), then irradiate group 30B to an additional 10 kGy.

1.4.4 Irradiate three pellets (group 30C) to 30 kGy.

1.4.5 After a 24 h wait period from the last irradiation, measure the absorbed dose for all pellets.

1.4.6 Determine the mean, standard deviation, and relative standard deviation of the pellet groups measured, and compare fractionated doses to continuously applied doses.

1.4.7 RSD Acceptance Level: ≤ 2 %

1.5 Post-irradiation time dependence

1.5.1 Irradiate six pellets, three to 1.0 kGy and three to 10 kGy.

1.5.2 Measure the absorbed dose approximately every other day for 2 weeks.

1.5.3 Plot the signal of the measured pellets as a function of time. Determine the mean, standard deviation, and relative standard deviation for the stabilized signal. Determine the time necessary for the signal to stabilize.

1.5.4 RSD Acceptance Level: ≤ 2 %

1.6 Irradiation temperature coefficient

1.6.1 In the dewar irradiation geometry, irradiate pellets to 10 kGy at each of three irradiations conditions: ambient; 20 °C higher than ambient; and 20 °C lower than ambient.

1.6.2 Measure the EPR response of the individual pellets.

1.6.3 Compute the resultant temperature coefficient (slope of the percent change, relative to the predicted value at the ambient temperature, in response versus the irradiation temperature) and compare this value to the accepted value.

1.6.4 Computed temperature coefficient Acceptance Level: ≤ 30 %

1.7 Batch mean

1.7.1 Irradiate simultaneously (co-located) two pellets from the previous batch with two pellets from the batch undergoing evaluation to each of the following doses: 1.0 kGy and 10 kGy.

1.7.2 Measure the EPR response (not absorbed dose) of the individual pellets.

1.7.3 Determine the mean of the pellet groups and compute the percent difference in response between the batches.

1.7.4 Batch response difference Acceptance Level: ≤ 20 %

2. Instrument maintenance

EPR Spectrometers are operated and maintained according to the manufacturer’s guidelines. Significant maintenance activities are recorded in the EPR spectrometer log book.

2.1 Record major maintenance activities in the EPR spectrometer log book.

2.2 As necessary, or before each new calibration curve is measured, the quartz sample tube should be cleaned.

2.2.1 Soak a long stick cotton swab with methanol/water mixture (a few drops of water in 1 mL to 2 mL methanol) and insert into the sample tube to clean the pellet resting area. Allow the swab to remain inserted for 5 hours to 7 hours.

2.2.2 Draw a vacuum until sample tube is dry. This step may take 1 day to 2 days to be complete.

2.2.3 Maintain a log of the laboratory conditions, such as temperature and humidity. Long-term trends will be reviewed in a control chart.

3. Dosimeter system calibration

Once a batch of pellets has been characterized and passed all acceptance criteria, a calibration curve shall be established.

3.1 Irradiate dosimeters to specified doses as detailed in RPD Procedure 11.

3.1.1 Selection of dose range of interest (Dose minimum is denoted as Dmin and the Dose maximum is denoted as Dmax).

3.1.2 To determine the minimum number of dose points, the equation Q = log(Dmax/Dmin) should be used. If Q is equal to or greater than 1, calculate 5 × Q, and round this up to the nearest integer value. If Q is less than 1, then 5 dose points may be sufficient.

3.2 Measure pellets

3.2.1 After all irradiations are completed, measure the pellets as described in Section 4.

3.3 Analyze the measurement data.

3.4 Record the calibration curve and any supporting information in the Dosimetry System Databook

4. *Customer-irradiated absorbed-dose certification for alanine pellets*

4.1 Upon receipt of a shop.nist.gov order, calibration service staff will evaluate whether the calibration service can be completed. If accepted, the calibration service staff will change the status to “Accepted” within the e-commerce platform. Calibration service staff will log the order in the Electronic Calibration Log Book with a unique HD number. After confirmation from the e-commerce platform concerning the payment status, the customer will be notified of the status by the calibration service staff.

4.1.1 An Electronic Test Folder (ETF) is created for record maintenance of the calibration order. Store all relevant documents from the e-commerce platform in the ETF. Start a new paper file (HD folder) to hold all printed documents until they can be digitized into the ETF and destroyed.

4.2 Mail dosimeters for requested test (service) numbers with an instruction letter to the customer (Appendix A). This step is not applicable to service code 49030C.

4.2.1 Each dosimeter consists of four alanine pellets in a polystyrene vial or in a disc, upon customer request [2].

4.3 After receiving the returned customer dosimeters, verify that irradiator and irradiation information (target dose, temperature, etc.) on instruction letter has been provided by customer and reconcile the dosimeters returned with the list cited in the accompanying documents.

4.3.1 Customer letter for service code 49030C must contain the lot/batch number for the dosimeters provided.

4.4 Opening only one vial at a time, remove pellets from vials, unambiguously labeling each pellet consecutively (top to bottom) as each one is removed from the vial.

4.4.1 An additional sequential mark is placed on the service code 49030C pellets as a visual aid.

4.4.2 The pellets will be stored in labeled containers with appropriate labeling.

4.4.3 Weigh pellets and input masses into Excel spreadsheet. Create Excel spreadsheet to record data from measurements.

NOTE: Empty vials are cleaned by immersing in ethanol with agitation, allowing them to remain immersed overnight, then dried in a fume hood overnight. Service code 49030C vials are not cleaned by NIST; they are returned to the customer.

4.5 Operate EPR Spectrometer

4.5.1 Turn on magnet cooling water chiller.

4.5.2 Turn on magnet.

4.5.3 Check that the micrometer on the ruby reference device is at set value.

4.5.4 Logon to the EPR computer using the appropriate login credentials.

4.5.5 Tune spectrometer.

4.5.5.1 For ECS106 Press F5/F3. Once the standby light changes from red to green, use the right arrow key to change to tune mode.

4.5.5.2 With a pellet in the EPR sample tube, use the page-up key to perform the auto-tune procedure at least twice and allow approximately one hour for the spectrometer to warm up, then run the auto-tune procedure once more.

4.5.5.3 For the EMX, select the autotune option under the microwave dialogue box.

4.5.5.4 Open VBS code for data collection.

4.6 Ensure that the spectrometer is operating at an expected level of reproducibility (<1 %) by recording alanine pellet and ruby spectra at regular intervals.

4.7 Excel spreadsheet setup

4.7.1 Verify that the Parameter worksheet contains the EPR Spectrometer parameters matching those of the corresponding calibration file.

4.7.2 The measurement worksheet includes the date, vial number, pellet number, pellet mass, alanine signal max/min peak height and ruby signal max/min peak height, peak-to-peak amplitude, and mass-ruby normalized signal amplitudes (response).

4.7.3 The summary worksheet includes the company name, date, calibration function and the corresponding solution formula, coefficients of the calibration curve being used, the calculated mass-ruby normalized signal (from the measurement worksheet), the calibration temperature and temperature coefficient, and the customer-reported irradiation temperature and estimated dose (from the customer instruction letter).

4.7.4 The summary worksheet calculates the irradiation temperature corrected response and absorbed dose.

4.8 EPR measurement

4.8.1 The mean response and RSD are calculated for each group of four pellets within a vial. Check the RSD for each grouping, perform an outlier test and/or repeat measurements as needed. The mean response is the value used to calculate the absorbed dose.

4.8.1.1 An increasing pellet response trend that exceeds a 1 % RSD across the stack of four alanine pellets in the vial is considered to be a significant absorbed dose gradient. In this case, the absorbed dose shall be calculated and reported for each pellet.

4.8.2 The dose determination for service code 49030C is preceded by an analysis of the check standard dose repeatability and alanine pellet anisotropy.

4.8.3 Determine the mean response and RSD for the pre- and post-customer pellet measurements of the four check-dose pellets. A dose value is interpolated and the pre- and post-check standard dose deviations from the established absorbed dose must agree within 1 %. If the deviation percentages differ by 1 % or more, the measurement session must be repeated. Note that the absolute deviation from the established absorbed dose can be greater than 1 %.

4.8.4 The mean response and ruby-normalized alanine signal anisotropy is calculated for each customer dosimeter. If any dosimeter has an anisotropy difference greater than 1 %, that dosimeter must be remeasured. If repeated measurements continue to exceed 1 %, a special comment should be appended to the certification report.

4.8.5 Calculate dose by using the coefficients from the applicable calibration curve (refer to Dosimetry System Databook).

4.9 Above 5kGy, the Dose Rate Effect (DRE) may be evident. Check standard dosimeters irradiated to > 5 kGy with < 1 Gy/s will be adjusted using an experimentally determined DRE. DRE-adjusted Check standard dosimeters can be used to establish EPR performance but all calibration curves above 5 kGy shall be completed with higher dose rates (> 2 Gy/s).

4.10 For service code 49030C and for doses below 200 Gy, an additional step is added to adjust for the check-dose-offset value.

4.10.1 When the calibration curve is created, a 25 Gy reference dose value is established to relate all future check-dose measurements to the calibration curve. That value is the interpolated dose from the fitted equation derived from the mean response of the 25 Gy dosimeter group of the calibration set.

4.10.2 The average dose value of the pre- and post-check standard dose is calculated. The difference of that average check standard dose value to the previously established reference dose value is then calculated (in Gy). This difference is recorded as the dose-offset value for the measurement session and is added/subtracted from each customer pellet calculated dose.

4.10.3 Uncertainty analysis is modified, if needed.

4.11 Check the spreadsheet cell links/functions and entered data for accuracy.

4.11.1 Print copies of data, and insert in Transfer Dosimetry Databook

4.11.2 Copy Transfer Dosimetry Databook pages and insert into HD folder

4.12 Report and test closure

4.12.1 A checklist, Appendix B, for HD irradiation services is filled out and included in the ETF.

4.12.2 Create an “Absorbed Dose Measurement Certificate” report from a template. Include an annotated draft of the certificate in the ETF checking the company information, order number and Transfer Dosimetry Databook references (footnote), and the final dose values into the report template (see Appendix C)

4.12.3 The preparer sends the ETF and the electronic certificate for review. They are sequentially routed to the reviewer, Group Leader and Division Chief (as designated on the certificate) for review and an electronically certified signature.

4.12.4 The certificate with the electronically certified signatures is returned to the preparer. The preparer submits the report to the e-Commerce platform and notifies the Calibration Administrative Staff of the completion of the work. The order status changes to “Completed”. Upon customer request, the preparer may send the electronic certificate by email or/and send a printed copy of the electronically signed certificate.

4.12.5 The Administrative Staff will change the order status to “Closed”.

5. Quality control

5.1 Absorbed-dose check standards

Approximately every month, or as needed, dosimeter pellets are irradiated to the following doses: 0.025 kGy, 0.20 kGy, 1.0 kGy, 10 kGy, and 40 kGy as detailed in RPD Procedure 11. These check standards are routinely measured ~24 hours to 72 hours after irradiation, as well as prior to service measurements. Data from these check standards are archived in working spreadsheet files for reference availability. A control chart is updated and included into the ETF. Check standard dose measurements that measure outside of set limits must be resolved through re-measurement, repetition of the check standard process, or a complete recalibration of the dosimetry system.

5.2 Transfer dosimetry controls

Each set of transfer dosimeters shipped to a customer is paired with a control vial that is packaged separately and marked “Do Not Irradiate”. Control vials contain pellets of the same type that have been previously irradiated to a calibrated dose. These dosimeters are typically check standards that have exhibited good stability after repeated measurements. A continuous history of these data is recorded. Any nonconformance shall be reported; action to be taken is at the discretion of the calibration staff.

5.3 International comparisons

Upon mutual agreement, dosimetry comparisons are performed with the high-dose calibration facility of the National Physical Laboratory of the United Kingdom. Dosimeters from each facility are exchanged, measured, and the results compared. The RPD participates in larger international comparisons, such as those organized by the BIPM, when available (approximately every ten years) [3, 4]. These data are summarized in the High-Dose International Comparisons Databook.

6. Traceability

6.1 Dose rate transfer

The SI unit of absorbed dose is the gray (Gy). For this service, the Gy is realized through water calorimetry measurements in the Vertical Beam ^{60}Co Source. These measurements are transferred to the lowest dose rate Gammacell calibration source a by source-rate ratio measurements using alanine dosimetry. Similarly, the source-rate ratio from the lowest dose rate Gammacell is then transferred to the higher dose rate Gammacell and GR420 irradiators. These transfer measurement protocols are described in NIST SP250-44 [5]; the traceability scheme was later modified [6].

Determination of Uncertainties

The basis for the determination of uncertainties associated with High-Dose calibrations is the *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results* [7]. The purpose of this section is to explain the derivation of the various components of uncertainty for absorbed-dose certification. Examples of the values for the uncertainty components are listed in Appendix D.

Water Calorimetry: uncertainty from realization of the Gy [8].

Source Ratio Data: uncertainty from source dose-rate transfer (water calorimetry rate to high-dose calibration source rate) through ratio measurements.

Field Uniformity: radiation field uniformity within a dosimeter volume.

Environmental Effects: temperature control during irradiation.

Timer: uncertainty of timer readout relative to shortest irradiation time interval.

Decay Correction: half-life correction factor uncertainty.

Mass: uncertainty of microbalance relative to pellet mass.

Repeatability and Reproducibility: standard deviation of replicate pellet measurements.

Interspecimen Contamination: cross contamination of pellets during the measurement process.

Ruby Correction: uncertainty resulting from EPR spectrometer fluctuations during the time interval between the alanine pellet measurement and the reference (ruby) measurement.

System Drift: uncertainty arising from temporal EPR spectrometer response fluctuations.

Temperature Correction: uncertainty from alanine dosimeter temperature coefficient measurement.

Calibration Curve: fit uncertainty from alanine dosimeter calibration curve.

Additional uncertainties are applied to irradiations in electron beams and ^{137}Cs, or for absorbed dose to silicon conversions.

References

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4. McEwen, M.R., Sharpe, P.H.G., Pazos, I.M., Miller, A., Pawlak, E., Ninlaphruk, S., Zhang, Y., Kessler, C. 2022 Supplementary comparison CCRI(I)-S3 of standards for absorbed dose to water in Co-60 gamma radiation at radiation processing dose levels, Metrologia, 59, 06012.
5. Radiation Processing Dosimetry Calibration Services and Measurement Assurance Program, Humphreys, J.C., Puhl, J.M., Seltzer, S.M., McLaughlin, W.L., Desrosiers, M.F., Bensen, D.L., Walker, M.L. 1998 NIST Special Publication 250-44.
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Records

Record	Contents/Purpose	Location
Electronic Calibration Log Book	Login all tests to obtain test folder number	In the High Dose folder
Dosimetry System Databook	Records dosimetry system calibrations and dosimeter batch characterization	245/ B0020
Internal Calibrations	Source ratio measurements and data analysis	245/ B0020
EPR Spectrometer User Log Book	Usage and maintenance records	245/ B0020

Record	Contents/Purpose	Location
Transfer Dosimetry Databook	Records all transfer dosimeter certification data	245/ B0020
High-Dose International Comparisons Databook	Interlaboratory measurement comparison data summaries	245/ B0020

Filing and Retention

All paper copies of customer files are stored in the test folder for that service until they can be digitized and stored in ETF at which time it can be destroyed. The ETF is stored in OneNote. All customer-related electronic files are stored in the “High Dose” folder on the shared network drive.

The RPD Quality Manager shall maintain the original and past versions of this RPD Procedure.

Appendix A – Sample Transfer Letter

June 20, 2021

HD0000

Ms. Gray
RAD Sterilizers

Return Shipments to:
NIST High-Dose Service
Building 245
100 Bureau Drive, Stop 8460
Gaithersburg , MD 20899-8460
USA

Dear Ms. Gray,

Enclosed are the alanine transfer dosimeters that you requested for irradiation in your facility. There are six vials for irradiation (9901-9906), each filled with four alanine pellets from the batch T030901. The other vial (#44) is a control and should not be irradiated. Do not open the vials. The useful life of the dosimeters is approximately 30 days from the date of receipt at your facility. If dosimeters are not used within this time frame, please contact NIST for further instruction. Please complete the table on the following page and return it with the dosimeters.

Dosimeter	**Date(s) of irradiation**	**Target Dose, kGy (approximate)**	**Average Irradiation Temperature (°C)**
9901			
9902			
9903			
9904			
9905			
9906			
Control Vial (#44)	**DO NOT IRRADIATE**	**0**	

How would you like for us to identify your irradiator on the certificate?

Any other information you wish to be noted on the certificate?

Sincerely,

Calibrations Technician
Dosimetry Group
Physical Measurement Laboratory
PHONE: 301-975-xxxx FAX: 301-869-7682 E-MAIL: caltech@nist.gov
Enclosures

Appendix B – QM Checklist for 49020C and 49030C

NIST ID:
Date:

Checklist for 49020C and 49030C:

____ The Spectrometer was set up with the spectral parameters that were used for the corresponding calibration curve.
  ____ ECS106
  ____ EMX
____ The spectral parameters were noted in the Excel spreadsheet.
____ The pellet masses are paired correctly with the corresponding pellet number.
____ The Excel spreadsheet reflects the appropriate NIST ID, company name, irradiation temperatures, etc.
____ The Excel spreadsheet reflects the appropriate file names and dates for both the data file and calibration file.
____ The correct calibration curve coefficients were used in the dose calculation and noted on the spreadsheet.
____ All mathematical calculations embedded in cells have been checked for accuracy and correct cell linkage.
____ The appropriate correction factors were applied (i.e., temperature, dose-to-water, dose-to-silicon, ^{137}Cs, etc.) to the calculated dose.

Signed by: ______________________________ Date: ____________

Appendix C – Example Certificate

National Institute of Standards and Technology

Absorbed-Dose Measurement Certificate

NIST Service Identification Numbers 49020C and 49022C

IRRADIATOR
MDS Nordion Gammacell XXX

CUSTOMER
RAD Sterilizers
7 Electron Avenue
Mega Rad, LA 99817

ATTN: Ms. Gray
Reference: PO # 5678

Measurements made by Ileana M. Pazos

Report reviewed by Lonnie Cumberland

Report approved by
Michael G. Mitch, Leader
Dosimetry Group

Approved by
James M. Adams, Chief
Radiation Physics Division
Physical Measurement Laboratory
For the Director of the National Institute of Standards and Technology

Information on technical aspects of this report may be obtained from Ileana M. Pazos, NIST, 100 Bureau Drive Stop 8460, Gaithersburg, MD 20899, 301-975-4121, ileana.pazos@nist.gov.

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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NIST DB 2000/000
July 23, 2021
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Transfer dosimeters were sent to RAD Sterilizers for irradiation in their facility. The dosimeters were NIST alanine pellets of FWT batch T030901; four each in a polystyrene vial. The dosimeters were analyzed on July 8, 2021, using a Bruker EMXmicro spectrometer. Dose interpolations are based on a NIST calibration of batch T030901 alanine dosimeters performed January 1, 2021 and include the influence of the customer-reported irradiation temperature. The results are summarized in the following table.

Dosimeter Identification	Absorbed Dose kGy(H_2O)
9901	0.325
9902	0.678
9903	0.989
9904	1.21
9905	2.22
9906	3.25

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

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UNCERTAINTIES AND RELATED FACTORS IN HIGH-DOSE MEASUREMENTS

Absorbed Dose Evaluations Based on Use of Mailed Alanine Pellet Transfer Standard Dosimeters Irradiated Using ^{60}Co

(Expanded uncertainty: ± 1.8 % at a 95 % confidence level)

The customer's use of NIST-certified transfer standard dosimeter measurements to determine their radiation-source dose rate is subject to limitations and precautions described in the letter accompanying the dosimeters. The customer must follow the prescribed procedures carefully in order to ensure that the results obtained from the transfer dosimeters are valid. The uncertainty value cited above may be assumed as long as suitable care is exercised. That value does not include uncertainty in the customer-reported irradiation temperature or non-uniformity in the customer's irradiation field.

The absorbed dose in water evaluation is based on NIST alanine pellet dosimeters that are traceable to primary standard water calorimeter measurements and are corrected by certain modifying factors (such as the geometry attenuation factor and source decay factor). The absorbed dose value(s) given in this report can be used to check the accuracy of customer measurement systems and to verify the capabilities of those systems to both transfer and maintain traceability of measurement results. The absorbed dose value(s) relate only to the dosimeters in this report.

A detailed list of the various sources of uncertainty and estimates of the magnitude of those uncertainties that make up the overall uncertainty given above may be obtained through the Internet (https://www.nist.gov/programs-projects/basic-metrology-high-dose-dosimetry-uncertainty-tables) or by requesting this information from NIST. The uncertainties are divided into two types: A and B. Type A uncertainties are those evaluated by statistical methods, often associated with random effects. Type B uncertainties are those evaluated by other means, often associated with systematic effects.

Type A Uncertainties
The combined standard uncertainty evaluated by statistical methods is ±0.66 % at an approximate level of confidence of 68 %.

Type B Uncertainties
The combined standard uncertainty based on scientific judgment is estimated to be ±0.59 % at an approximate level of confidence of 68 %.

Expanded Uncertainty
The Type A and Type B uncertainties have been combined in quadrature (the square root of the sum of the squares) and multiplied by a coverage t-factor of 2.05 to yield an expanded uncertainty of ±1.8 % at an approximate level of confidence of 95 %.

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Appendix D- Example Uncertainties Table for Transfer Dosimetry Service

High-Dose Alanine Response, Far West / Gamma Service Alanine Pellets

Uncertainty Source	**Type A (%)**	**Type B (%)**
Repeatability and Reproducibility	0.30	
Mass Determination	0.20	
Interspecimen Contamination		0.10
Ruby Correction		0.05
System Drift		0.10
sqrt(sum)	0.36	0.15

Alanine Pellet Dosimeter Transfer Dose(water), Gamma/X-Ray, >100 Gy

Uncertainty Source	**Type A (%)**	**Type B (%)**
Alanine Dose Rate (GC207 Center)	0.25	0.55
Alanine Response	0.36	0.15
Temperature Correction		0.10
Dose Rate Effect		0.10
Calibration Curve	0.50	0.10
sqrt(sum)	0.66	0.59
combined in quadrature		0.89
t-factor for 45 d.f at 95.45 %		2.06
Expanded Uncertainty at 95.45 % conf.		**1.8**