A Method for Establishing *e*-Traceability to NIST High-Dose Measurement Standards

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Abstract

A method for establishing electronic traceability, or *e*-traceability, of customer measurements to NIST high-dose measurement standards through the use of a measurement conversion factor (MCF) for Bruker e-scan instruments has been developed. The intent is that this factor will be incorporated into an Internet-based transfer dosimetry system, while still maintaining a reasonable and acceptable uncertainty for such a service. The method developed will define a relationship between measurements made on e-scan instruments at customer radiation facilities and the reference e-scan measurements made at NIST, and incorporate any uncertainty for this method into an overall uncertainty calculation for providing an electronic absorbed-dose certification service.

1. General

The National Institute of Standards and Technology (NIST) has been providing absorbed-dose certification services to private-industry radiation processors for years. This well-established, postal-based system can have a turn-around time of two to three weeks for a standard dose certification. To meet customer demand to improve turnaround time, yet maintain high accuracy and minimize uncertainties, an Internet-based system for remote dose certification of radiation sources using a compact EPR analyzer is being developed at NIST. The main concept of an *e*-certification transfer dosimetry service would be the same as a postal-based service; the where customer doses are certified by NIST and traceability is established. However, the major difference between the electronic and postal-based services is that during the certification event, there is no transfer of dosimeters between the customer and NIST, only information. This saves both time and money. The electronic-based service is based on three main elements: set-up, certification, and maintenance processes.

To perform the initial set-up of the service, the customer would subscribe to the NIST electronic service, and a calibrated set of dosimeters would be mailed to the customer facility. Through the guidance of the NIST *e*-certification software, the customer would measure the calibration set for the dose range that they wish to have certified. These data would be transferred electronically to NIST, and used to establish a measurement conversion factor (MCF) for that specific dose range. For the certification process, the customer would place a request for an absorbed-dose certification and measure their irradiated dosimeters in-house using their e-scan instrument. These initial measurements and dose calculations from the customer's e-scan would be transmitted electronically to NIST for review, and immediately a provisional certificate of absorbed dose would be issued to the customer. NIST would review the certification event data and verify that the software accurately calculated the absorbed dose. An official Absorbed-Dose Measurement Certificate would be issued to the customer. Maintenance processes for this *e*-certification service would consist of common quality practices, such as measuring check doses and maintaining dosimetry control charts.

By subscribing to this electronic service, the customer would be able to use NIST calibration curve coefficients and their MCF to calculate dose for their routine dosimetry measurements, as well as have access to NIST absorbed-dose certification measurements around the clock. This service has the potential to not only provide certified absorbed dose values in a time-efficient manner, but also to provide measurement consistency for the radiation processing community by disseminating national standards for high-dose dosimetry for use in day-to-day routine measurements.

2. Technical Details

The NIST *e*-certification service will establish an MCF to convert the measurements made on a customer's e-scan instrument to a value that can be used to determine dose from a calibration curve measured on the NIST reference e-scan instrument. This conversion factor will be specific to individual e-scan/insert combinations for each customer. Several potential methods were examined to derive an MCF by which traceability could be established and maintained through use of this electronic service.

The e-scan software utilizes a marker-only response history to monitor the performance and stability of the customer's e-scan instrument. These marker signals are unique to each instrument; different signal amplitudes will be obtained even when the same insert is used in different instruments. A ratio of this marker reading from different e-scan instruments could provide an MCF that could be used to equate measurements from one instrument to the other. Also tested were the Ratio of Ratios (RoR) and Linear Regression (LR) methods. For these methods, a standard calibration set was co-irradiated for each insert dose range for two e-scan spectrometers. One calibration set was measured only on the e-scan that served as a reference, and both sets were measured on the second "customer" instrument on the first day after irradiation, as well as on other days over an extended period.

The NIST reference e-scan calibration curve data were imported into the NIST calibration curve software (TableCurve 2D, Jandel Scientific) plotted versus the delivered absorbed dose. A third-order polynomial fit to the data was used to compute the reference calibration curve ratios, referred to in this work as "y-predicted ratios". This fit was used because it is already incorporated into the e-scan software as a fit method, and is recognized as representative of the entire dose range tested. For the RoR method, the customer's ratios were divided by the y-predicted ratios computed from the calibration curve function, and averaged to one final MCF. For the LR method, the customer ratios were plotted versus the y-predicted ratios. The MCF is the slope of the linear-fit applied to the data. In order to assess which method will most accurately and efficiently provide an MCF, each method was repeated several times on the measurement data from the respective day's measurements (MCF1, MCF4, etc.). MCF-values were computed based on the number of days after irradiation, to simulate postal time for a calibration set to reach the customer, and quantify how a delay in measurement might affect the MCF value and its associated uncertainty.

There was a ≈ 2 % decrease in the marker signal amplitude during an individual measurement session for the Marker-only method test. Data was also collected at the initiation of the measurement sessions on multiple e-scan instruments. There was no correlation between these measurements when the same insert was used on different e-scan spectrometers. The variability of the inserts, sensitivity fluctuations of the instruments, as well as the large uncertainty of the marker signal measurements allowed by the manufacturer, made this method for determining the MCF less than ideal.

The RoR and LR methods performed similarly, in that they both provided a reproducible means to calculate the MCF and both methods yielded nearly identical MCF values. There was no absolute reason to choose the RoR method rather than the LR method; however, the decision to apply one fit to the NIST calibration curve rather than apply a fit to each dataset (reference and customer) served as a means to distinguish the RoR method from the LR method. For the LR method a fit is applied to the entire measurement set, meaning that any outliers or near outliers (especially at the dose range extremes) could disproportionately affect the entire fit; whereas, the RoR method there is less interdependence on the data.

The absorbed doses for a set of test dosimeters were computed for each insert using the MCF derived using the RoR method for each individual calibration curve. The computed doses were plotted according to the percent difference from the absorbed dose. To minimize uncertainty and improve accuracy, the extreme dose points for each manufacturer-defined dose range were eliminated, and the measurements were recalculated to create the certifiable dose range. These data were also plotted showing the percent difference from the absorbed dose. From these data, it is apparent that adjusting the dose ranges will improve the uncertainty associated with these measurements. The new dose ranges were selected to avoid leaving gaps in between the adjacent dose ranges of the adjacent inserts and assure continuity between them (see Conclusions).

The Pellet Ulow (PU; 0.02 kGy - 0.5 kGy) insert computed doses were ± 4 % from the absorbed doses using the MCF for a single set of calibration curve data (Figure 1). By adjusting the manufacturer defined dose range to 0.03 kGy to 0.5 kGy for the NIST certifiable dose range, the percent difference from the absorbed doses was decreased to ± 3 % (Figure 2). The Pellet Xlow (PX; 0.05 kGy - 2 kGy) insert computed doses showed a trend of increasing deviation from the delivered absorbed dose in the lower end of the dose range, at approximately -10% for the lowest dose point (Figure 3). This trend further verifies the need to eliminate the extremes of the manufacturer-defined ranges. The certifiable dose range, 0.2 kGy to 1 kGy, computed doses with an overall ± 2 % difference from the absorbed dose (Figure 4). The computed doses for the other dose ranges deviated from the absorbed dose in the same manner as the PU and PX inserts, greater at the extreme dose points of the range. The Pellet High (PH; 3 kGy - 80 kGy) insert appeared to have the most reproducible responses of the pellet inserts. The Pellet Low (PL; 0.3 kGy - 10 kGy) insert and Pellet Vhigh (PV; 10 kGy - 200 kGy) insert MCF values were very different from all of the other inserts tested, and therefore the trend of the data when plotted were different from the other inserts as well. The film inserts, Film Low (FL; 0.5 kGy - 10 kGy), Film High (FH; 5 kGy – 80 kGy) and Film Xhigh (FX; 10 kGy – 200 kGy), showed a similar deviation of the computed doses from the absorbed doses for the respective dose ranges, approximately ± 4 % for the NIST certifiable dose ranges. However, the FX insert showed larger standard deviations for the highest dose points (140, 170 and 200 kGy), as those doses are nearer the saturation region of the response curve.

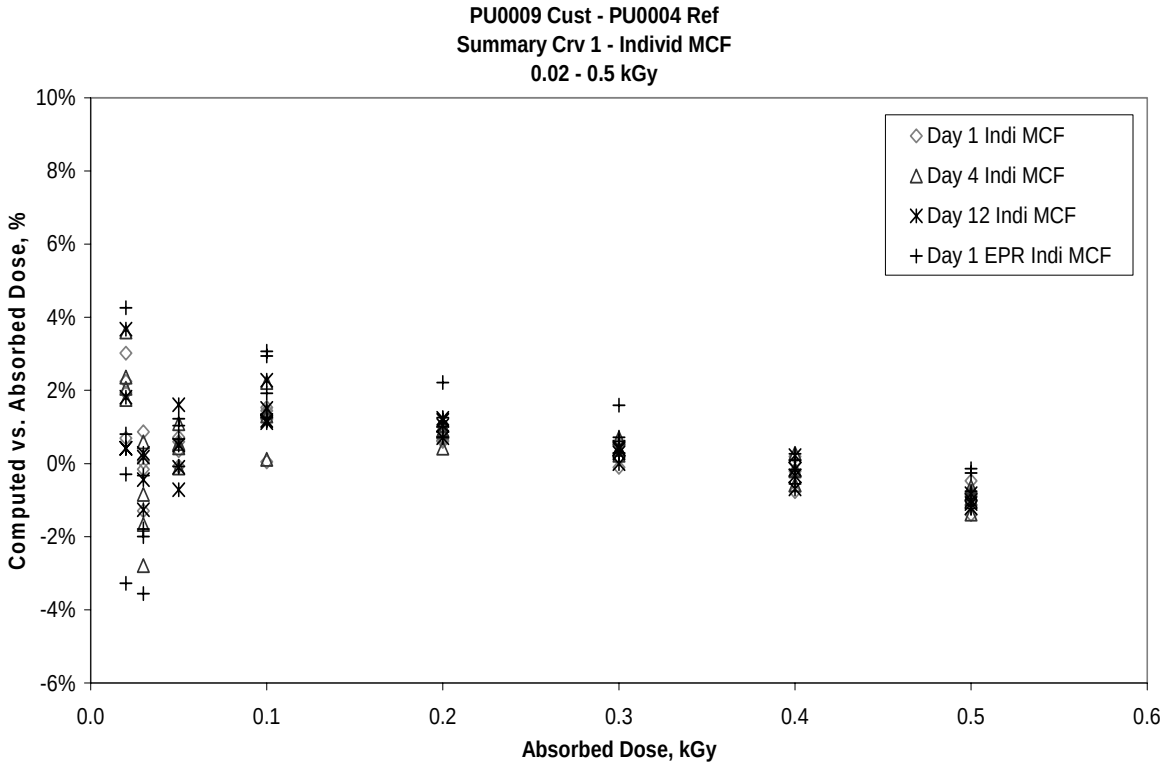

Figure 1 Percent difference of the computed dose from the absorbed dose for the PU dose range.

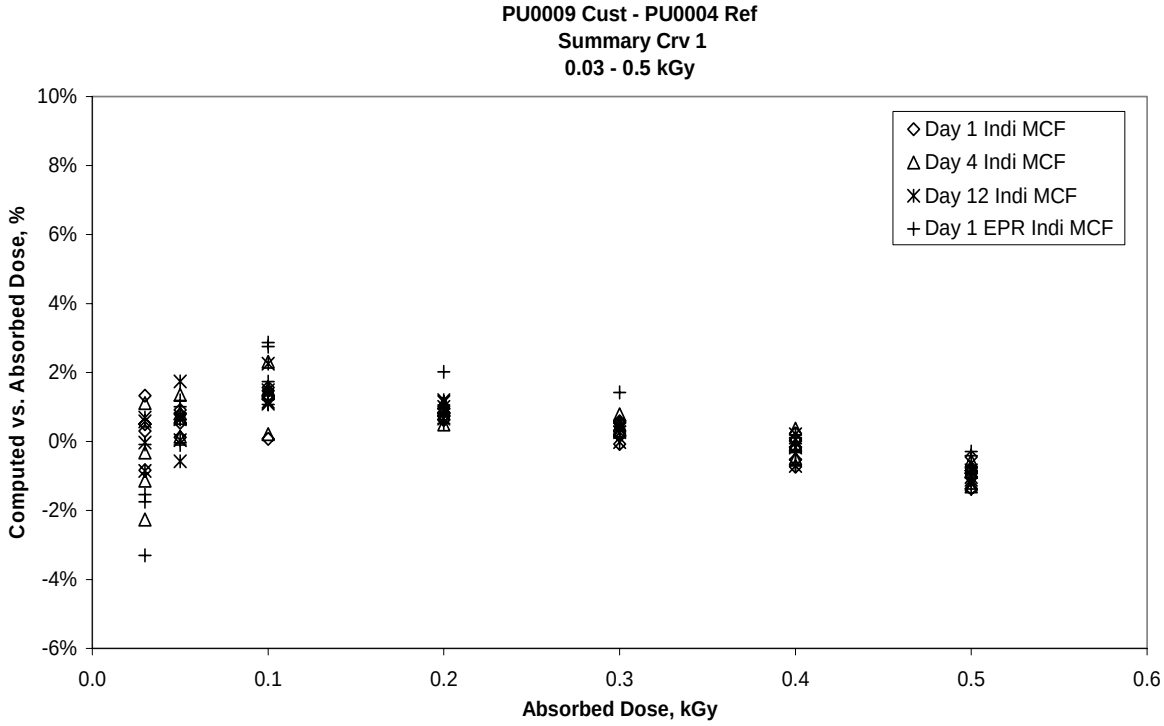

Figure 2 Percent difference of the computed dose from the absorbed dose for the certifiable PU dose range.

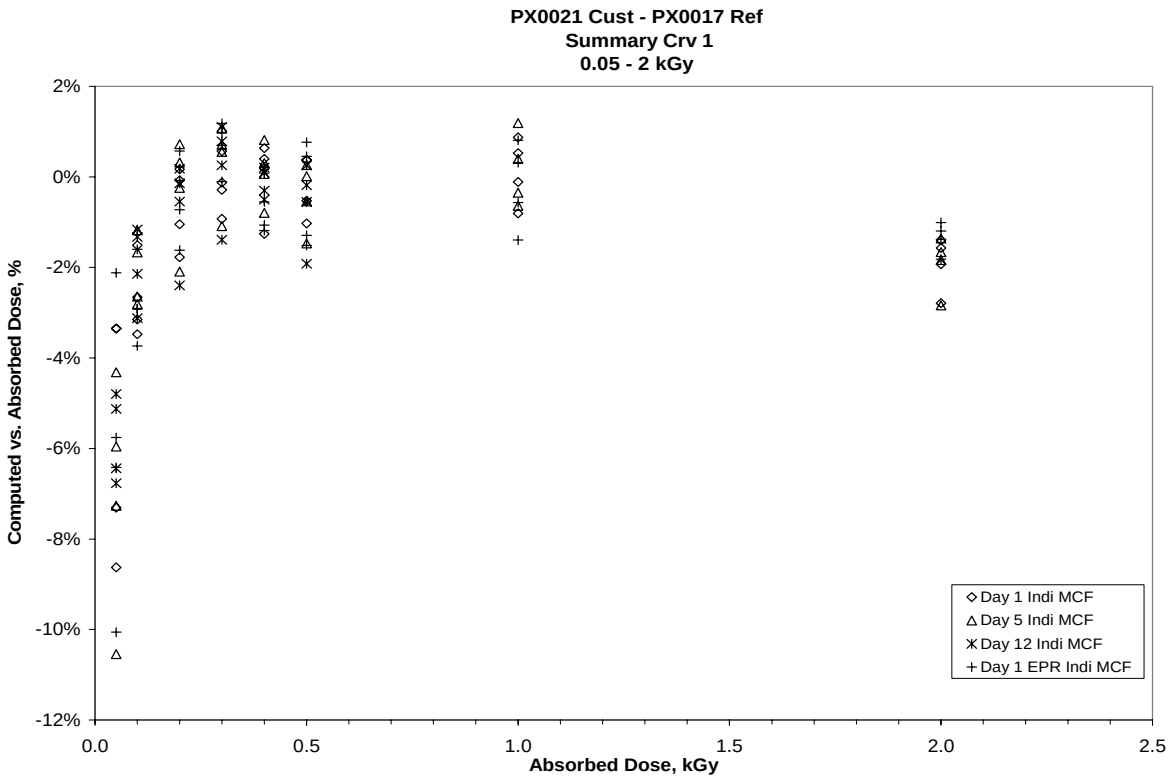

Figure 3 Percent difference of the computed dose from the absorbed dose for the PX dose range.

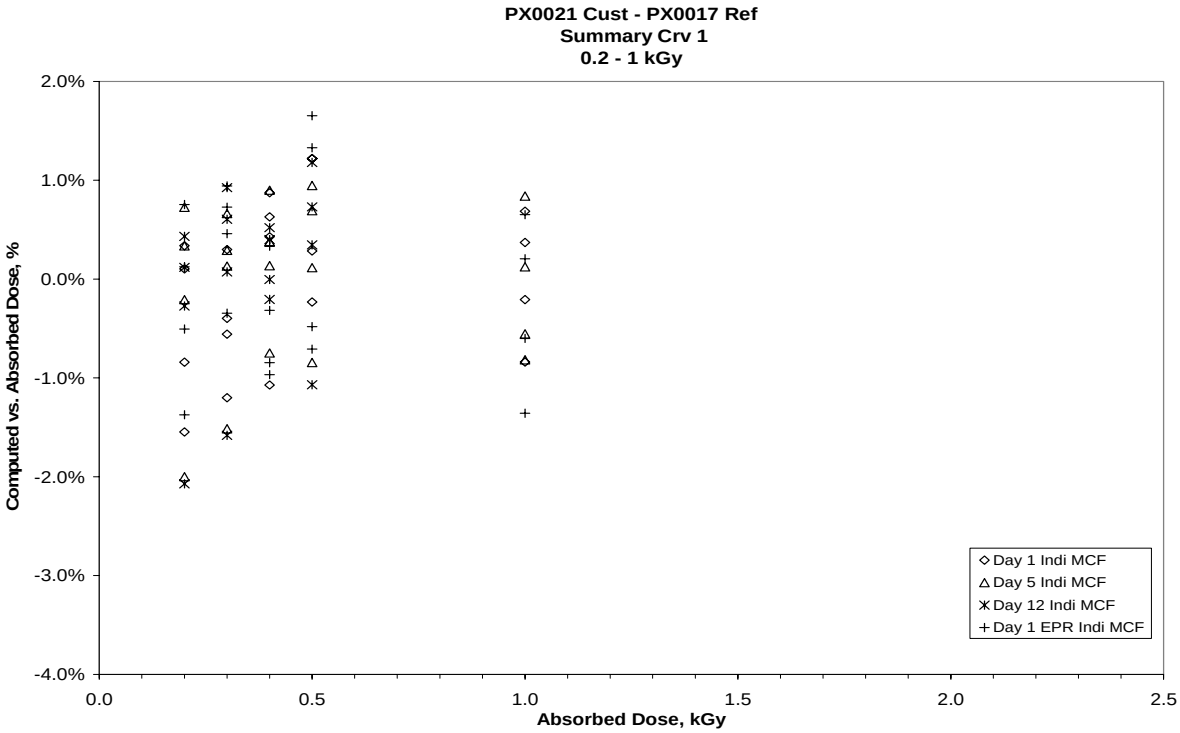

Figure 4 Percent difference of the computed dose from the absorbed dose for the certifiable PX dose range.

3. Conclusions

A measurement conversion factor (MCF) is an essential element of the NIST *e*-certification transfer dosimetry service. The method chosen to determine the MCF will be incorporated into the *e*-certification software; therefore, it is important to consider the accuracy and reproducibility of the method, as well as the ease and simplicity of incorporating the method into the e-certification software. The Marker-Only method showed too much variation to be considered further for determining the MCF. Based on the data collected and ease of use, the RoR method for calculating the MCF will be used in the continued development of the NIST *e*-certification project; also, each insert's manufacturer-defined dose range will be reduced by eliminating one or more dose points at the extremes of the range. Dose ranges were selected with consideration for maintaining a reasonable uncertainty, and such that the continuity between all inserts would be ensured.

Uncertainty values were calculated for each certifiable dose range. The expanded uncertainties for the current NIST transfer service are 3.0 % for doses 20 – 50 Gy, and 1.9 % for doses ≥ 200 Gy. The expanded uncertainty for the NIST *e*-certification service is estimated to be 6.0 % for the PU insert, and 4.7 % for the PX insert, at 95.45 % confidence level (Table 1). The estimated uncertainties for the other inserts are 9.1 % for PL, 6.0 % for PH and PV, 9.6 % for FL and 6.7 % for FH and FX.

Table 1. Summary of Current and Recommended Uncertainties.

Alanine Pellet Postal-based	Expanded Uncertainty
20 - 50 Gy	3.0 %
≥ 200 Gy	1.9 %
Alanine Pellet *e* -Cert Insert	**Expanded Uncertainty**
PU (20 - 500 Gy)	6.0 %
PX (200 Gy - 1 kGy)	4.7 %

Incorporating the MCF into the beta-testing for the NIST e-certification service will be a major element in continuing development of this electronic dose certification service. This will provide opportunity to further evaluate the reproducibility of the MCF performance over time. Overall expanded uncertainties could be improved by improving the measurement precision and reducing the day-to-day variation in the MCF. Some of this could be accomplished by adjusting the measurement parameters of the instrument. Future field testing and additional measurements made with other e-scan instruments and inserts could lead to further adjustments and may positively influence the uncertainties assigned to the respective dose ranges.

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