TECHNICAL MEMORANDUM

NOTICE: This document is version controlled and was produced as a part of the GEX Information Program which requires that all Series 100 documents be reviewed periodically to maintain currency and continuity of information. Appropriate Technical Memorandum are used to provide information detail in support of the Product Data Sheets as well as GEX Recommended Procedures and to provide technical information in support of GEX Marketing documents.

REVISION HISTORY: Expanded range of energies for the Risø aluminum wedge is used to 20 MeV. Added descriptive detail in the discreet point section to elaborate on method for determination of depth in aluminum

HIGH ENERGY ELECTRON BEAM ENERGY DETERMINATION THROUGH DEPTH DOSE DISTRIBUTION

RELEASE DATE: August 1, 2007

ENERGY ANALYSIS USING EXTRAPOLATED RANGE MEASUREMENTS

Range measurement is an established technique for energy estimation of electron beams. In principle this technique recreates a profile of energy deposition in respect to depth for a given homogenous absorber. It is applicable in an energy range from about 50 keV to 20 MeV for industrial radiation processing uses. In practice, dosimeters are either positioned at discreetly varying depths in a solid absorber such as aluminum, graphite, polymeric material, or a strip of dosimeter material is placed continuously through the absorbing medium (strip of film). The energy deposition profile is then reconstructed by means of an amplitude signal (relative response or absorbed dose) from the dosimeter. A typical wedge or step-wedge device employs either a strip of thin radiochromic film that is analyzed by means of a scanning device, or an array of individual radiochromic films, so that each of the dosimeters in the array is precisely positioned corresponding to a distinct depth in absorber material. The most commonly employed wedge material is aluminum.

At low energies encountered in radiation processing applications (approximately 50-500 keV), a multi-layer arrangement (stack) of very thin radiochromic dosimeter films of uniform thickness becomes a depth-dose absorber device in itself. The discussion of this document is limited to the determination of electron beam energies in the range of 2.0 MeV to 20 MeV which is the validated range of the Risø aluminum wedge.

Regardless of the implemented methodology, the analysis of measurements is always the same. A range parameter of the energy deposition profile is functionally correlated to the energy parameter of the electron beam. Typically such a correlation, before it is accepted for general use within a specific users group, is a subject of thorough discussion and approval by an expert review panel. In the case of the industrial radiation processing industry, ISO/ASTM Standard Practice 51649 is applicable and contains approved and recognized functional energy vs. range relationships and is used by GEX as a reference document.

GEX has developed and validated three standardized methods for electron beam energy analysis for beam energies between 2.0 MeV and 20 MeV. These methods use off-the -shelf products to provide conformance with the accepted industry practices described in ISO/ASTM 51649 and its Annexes. These methods utilize either an aluminum wedge or a stack of aluminum plates that are manufactured and certified by Risø National Laboratory. The methods have been intercompared with reproducible agreement between the methods demonstrated within ±0.1 MeV. Each method may be utilized for measurement of energies between 2.0 and 20 MeV with approximately the same level of confidence and reproducibility.

METHODS

The first method uses a wedge card dosimeter array with a certified Risø Aluminum Wedge and an automated software program to estimate electron beam energies using discreet dosimeter points. The wedge card array consists of 30 consecutively numbered 1.0 cm square radiochromic film dosimeters mounted on precision die-cut centers. The automated measurement software integrates directly with a spectrophotometer for absorbance data transfer directly to the energy measurement worksheet in the GEX WINdose for Excel software. A second method uses a stack of Risø certified aluminum plates with pairs of individual radiochromic film dosimeters hand mounted on each plate. The individual dosimeters are also measured and reported using the GEX WINdose for Excel software program. A third method involves the use of the certified Risø aluminum wedge with a continuous strip of radiochromic dosimeter film in conjunction with a standard flatbed scanner and computer with special continuous scan software (RisøScan).

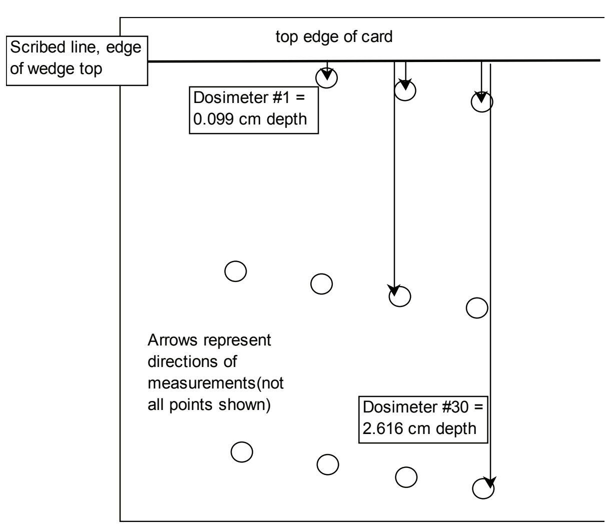
Each method requires use of a fixture that secures the aluminum wedge or aluminum plate stack perpendicular to the beam during the irradiation process.

DISCRETE DOSIMETER - ALUMINUM WEDGE METHOD

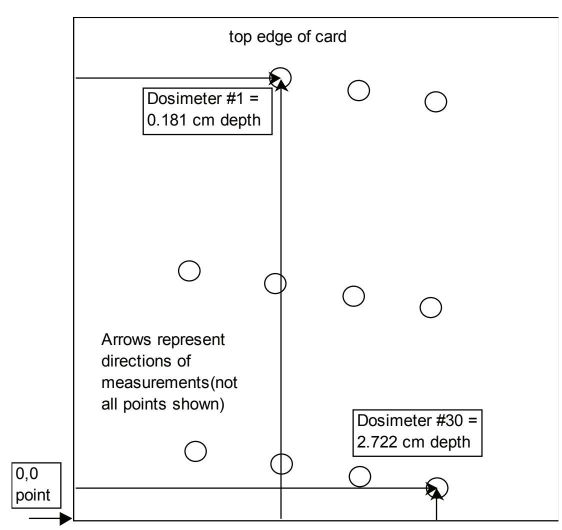
This technique uses an array of discreet radiochromic film dosimeters placed at progressively greater depths in the wedge (in the form of the GEX B3110 Wedge Card Array) and assigned an origin of reference coordinate system, to which, the positions of the centers of all dosimeters are measured. The B3110 Wedge Card was designed for use with the S5100 WINdose for Excel software B3110 Template that incorporates the energy formulae of the ISO/ASTM 51261 document. The Wedge Card array also contains die-cut holes that mount over the wedge posts to assure proper alignment onto the wedge.

This discrete point method has been cross validated over a number of reproducible experiments using different electron beam systems against the continuous strip method. The results show good agreement with a maximum difference of 0.1 MeV. The Y-coordinate in the plane of a card, is multiplied by sin (16°) – (the tilt angle of the card) giving the Z-coordinate of any given point. Finally, all calculated Z-coordinates are subtracted from the full thickness of the wedge to determine the depth in aluminum. The full thickness of the wedge was measured at 1.175" or (29.85 mm). The diagrams below, detail the set of coordinates for the first and the last point on the Wedge Card using two different reference points for determining the depth in aluminum. The first, titled the Risø Method utilizes a scribed line at the tip of the wedge as the starting reference that leaves off the portion of the wedge (0.82 mm) removed when the wedge is cut into two pieces. The second, titled the GEX Method, accounts for this missing portion of the wedge that was milled away when the wedge was cut by using the bottom base of the wedge as the reference or 0,0 coordinate.

Risø Method



GEX Method



The extra 0.082 mm associated with the GEX Method results in slightly higher energy estimates (on the order of 0.3 MeV for a 10 MeV beam). Using the base of the wedge as the reference point in the GEX method is recommended because it is more consistent and eliminates the bias that is inherent in the Risø method.

The starting depth using the Risø method is 0.099cm while the starting depth using the GEX method is 0.181cm, with all remaining depth points begin at the measured interval which is the same in either method.

Per Note A3.10 in ISO/ASTM 51649 (entire note is given at the end of this document), the purpose of determining and monitoring beam energy is for quality assurance and control of the irradiation facility energy. Since both methods are valid, a Risø wedge user simply chooses and establishes one of these methods and then simply uses the same method consistently.

The WINdose for Excel software program provides direct absorbance measurement data transfer to the worksheet and plots a depth dose curve and uses built in Microsoft Excel functions to establish the X intercept and slope (final determination of the points to be used for the slope are user adjustable) and applies the appropriate formulae of the ISO/ASTM 51649 document to estimate $E_{average}$ and E_p energies.

Extrapolated Range (cm)
Slope -20.31 Y-Intercept 46.73

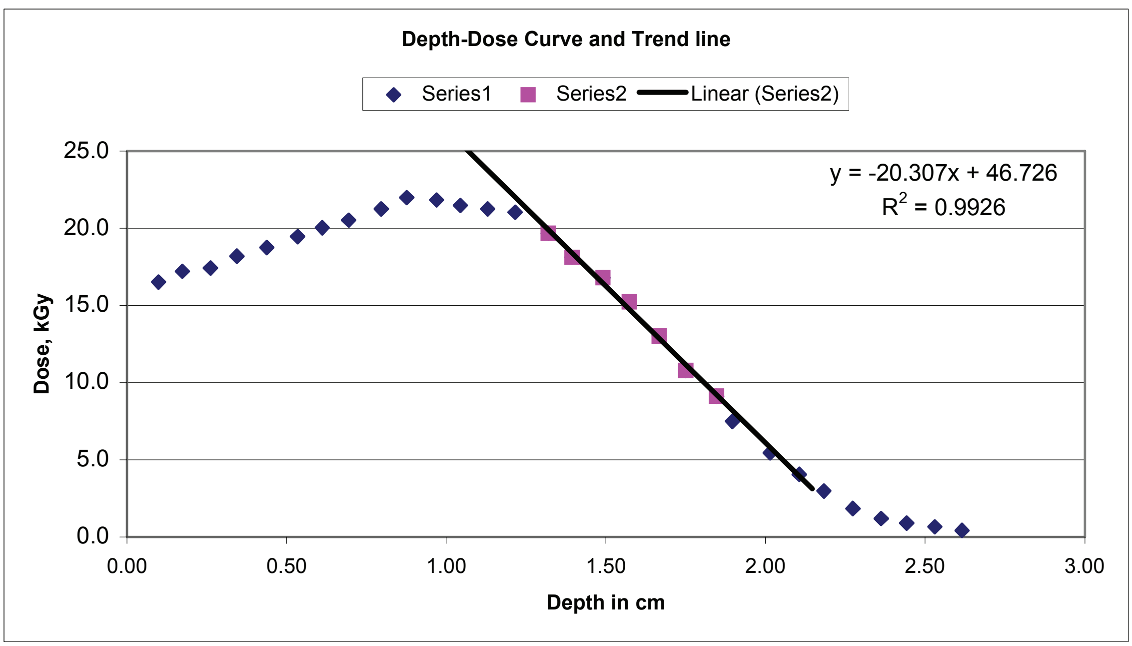
R50	Rex	Rp
1.76	2.30	2.28

The fitted series (Slope & Y intercept, and the Trend line on the chart) default to the 15th through 21st dosimeters only. The data ranges should be adjusted by the user to incorporate more or fewer data points appropriate to the energy being tested.

Extrapolated Electron Energy Per ASTM E1649
monoenergetic beam 10-50 MeV

Ea	Ep
10.76	11.65
Formula X3.19	Formula X3.18

Correction for density of aluminum: 0.986

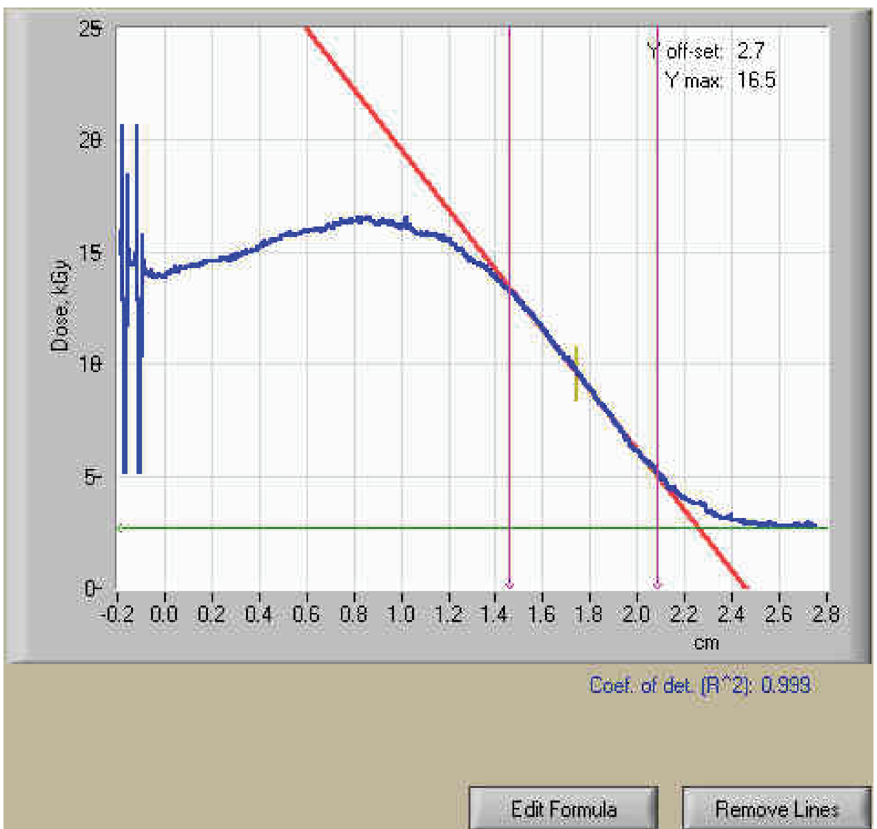


CONTINUOUS STRIP - ALUMINUM WEDGE METHOD

This method uses a pre-cut strip of radiochromic film (GEX # B3307) that is analyzed after irradiation by means of continuous scanning measurement using the (GEX #S5200) RisøScan software and standard PC flatbed scanner. This method is accomplished by placing and securing the pre-cut film strip in the wedge, then aligning the reference point measurement start line across the edge of the top piece of the wedge. The RisøScan software plots a depth dose curve and requires the operator to select the reference X and Y axes offsets that provide measurement set points. The software automatically determines the "best" slope and corresponding intercepts used to determine the energies.

Care is required in order to consistently align the measurement start point on the film strip with the top edge of the wedge. This method allows the user freedom to vary the X and Y reference points and adjust the slope as well.

Following irradiation, the film strip is scanned into the computer as an image file. The RisøScan software allows importation of the file and provides a depth dose profile curve with manipulation tools to allow selection of the start point of the scan along with selection of the slope area to be used. The program uses these selections to establish the X intercepts and applies the appropriate formulae of the ISO/ASTM 51649 document to estimate $E_{average}$ and E_p energies.



Results

	Value, cm	Formula	Energy, MeV	
R50	1.75	6.2*x	10.82	Average energy
Rex	2.26	5.09*x+0.2	11.70	Most probable

DISCRETE DOSIMETER ALUMINUM PLATE STACK METHOD

This approach uses a stack of equal thickness aluminum plates certified by Risø with pre-numbered pairs (with A and B IDs) of GEX #B3002 dosimeters that are hand mounted at the center of each of the plates. Following irradiation, the films are read sequentially using the same software described in the discrete dosimeter wedge method above. The final determination of the points to be used for the slope is also user adjustable.

Extrapolated Range (cm)

Slope -22.69 Y-Intercept 51.33

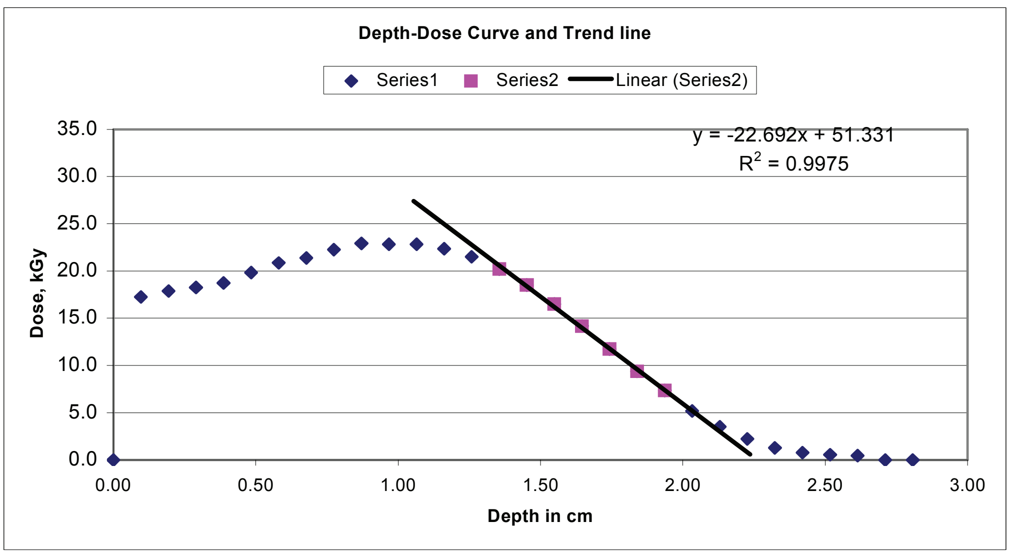
R50	Rex	Rp
1.76	2.26	2.24

Extrapolated Electron Energy Per ASTM E1649 monoenergetic beam 5-25 MeV

Ea	Ep
10.83	11.54
Formula X3.19	Formula X3.18

The fitted series (Slope & Y intercept, and the Trend line on the chart) default to the 15th through 21st dosimeters only. The data ranges should be adjusted by the user to incorporate more or fewer data points appropriate to the energy being tested.

Correction for density of aluminum: 0.994



COMPARISON OF THE METHODS

While each of the methods provides a simple and reproducible standardized means of electron beam energy estimation, each has advantages and limitations over each other.

Method	Discrete Dosimeter Wedge	Discrete Dosimeter Stack	Dosimeter Strip Wedge
Technique Requirements	easy to learn and use - prepackaged die-cut cards auto secure and align over fixed posts of wedge	user time intensive to set up -requires hand placement with small pieces of tape needed to secure individual dosimeters	requires user skill - positioning and placement of film strips to align and secure
Test Preparation Time	< one minute	15 - 20 minutes	2 - 3 minutes
Measurement Report Time	10-15 minutes	15-20 minutes	5-10 minutes
Technical Considerations	uses routine dosimeters and batch calibration - only 6-9 discrete data points used for determination of the energy slope	uses routine dosimeters and batch calibration - uses 2 replicates per point but only 7-9 data points used for energy slope determination	scanner/computer calibration requires a separate calibration from the routine dosimeter batch calibration

CONCLUSIONS

Three methods have been developed and validated for high electron beam energy measurement in high energy (2.0-20 MeV) electron beam facilities that provide a means of compliance with accepted and published industry practices (ISO/ASTM 51649). Each method provides a standard means of energy measurement using certified energy fixtures from Risø, off-the-shelf application specific dosimeter products, and validated software.

The three methods are well documented and technically supported. Each method when used in accordance with the recommended protocol supplied with the standard products and software has been demonstrated to provide highly reproducible energy measurement results.

NOTE X3.10 ISO/ASTM 51649 - "As noted throughout this appendix, there may be differences in the energies determined through the use of the various equations presented in this appendix. It is most appropriate to use these equations and energy measurement techniques for quality assurance and control of the irradiation facility energy, provided the same equations and techniques are consistently used. In this way, the precision of energy at the facility can be determined. Accurate determination of energy may be difficult because of the imprecision of the equations with regard to the electron beam."