Characterization Of MOSFET Response To The Xoft AXXENT™ X-ray Brachytherapy Source

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ABSTRACT

Purpose:To study the response characteristics of MOSFET dosimeters in the energy range of the Xoft Axxent™ Electronic Brachytherapy system. These devices can be used to measure skin dose in breast HDR treatments. While MOSFETs have flat energy response at energies above 1 MeV, at the lower energies relevant to this device (up to 50 keV) spectral dependence is anticipated. Therefore it is important to characterize the response to the source, both bare and filtered by varying amounts of absorber to simulate different source-to-skin distances.

Method and Materials:The Thomson-Nielsen MobileMOSFET dosimetry system was characterized with respect to a calibrated air ionization chamber for a Xoft Axxent™ X-ray Source operating at 50 kVp. A sequence of aluminum absorbers was introduced to study how changes in the spectrum due to filtering affect the cross calibration of the MOSFETs. The Thomson-Nielsen system supports continuous readout at 10 second intervals while under irradiation, allowing detailed comparison of the time series of dose readings, and an evaluation of the real-time capabilities of the system.

Results:Thomson-Nielsen MOSFETs had excellent linearity, with deviations throughout irradiation up to 14 Gy on the order of 3% or less. Changes in calibration as a function of absorber thickness were observed, and can be characterized by degree of change per fraction of attenuation.

Conclusion:Thomson-Nielsen MOSFET dosimeters provide skin dose measurement capability with accuracy on the order of 3 to 5%, providing corrections are applied to account for the distance from source to skin. Without these corrections the errors will be on the order of 10% in clinical use, where significant filtering will always be present from the balloon and skin. For a bare source with no filtering, the variation could be as large as a factor of two.

INTRODUCTION

- Metal Oxide Semiconductor Field Effect Transistor (MOSFET) dosimeters are increasingly being used to provide *in-situ* and *in-vivo* dose measurements, typically in external beam radiation treatments. Xoft, Inc. is currently studying the use of MOSFETs to measure skin dose during fractions of HDR breast brachytherapy treatment in early human trials of its Axxent™ Electronic Brachytherapy System. The Axxent™ system consists of a miniature x-ray source operating at up to 50 kVp and 300 μA, a set of inflatable balloon applicators, and a portable control console.
- MOSFET dosimeters are typically used with electron or photon radiation in the range above 1 MeV, where it is known that the energy response is very nearly flat, and the devices are linear with dose. The physics of the device is such that at energies in the Xoft spectrum, the response is considerably greater per unit dose. It is also a function of x-ray energy within the spectral range, which means that the response will depend on the details of the source spectrum as it is filtered by passing through material (tissue). As a means of measuring skin dose, where the source to skin distance will vary with patient and therefore the spectrum will as well, it is essential to determine the degree to which the MOSFET calibration constant is modified.
- There is a scarcity of MOSFET data for low energy sources. In a recent paper Kinhikar, et al., presented results for 192-Ir with Sicel OneDose MOSFET dosimeters. In the same paper, sensitivity was reported to be 10% higher in the 192-Ir energy range (average energy 380 keV, range 136 to 1060 keV) compared to the nominal MeV range.
- Bower and Hintenlang reported on MOSFET linearity and sensitivity at diagnostic x-ray energies using Philips Maximus C850 x-ray system with operating voltages from 40 to 140 kVp.
- The purpose of the current investigation is to study the response characteristics of MOSFET dosimeters in the lower energy range of the Xoft Axxent™ Electronic Brachytherapy System. Specifically we look at the linearity with dose as a function of filtering of the source, and how the resulting calibration or proportionality constant changes with degree of beam filtering. Results on short term noise for systems supplying near real time readings is also presented, which is relevant to potential future real-time dose control applications.

References:

Bower MW and Hintenlang DE. “The Characterization of a Commercial MOSFET Dosimeter System for Use in Diagnostic X-Ray”, *Health Physics* 75, 197-204 (1998).

Kinhikar RA, Sharma PK, Tambe CM, and Deshpande DD. “Dosimetric Evaluation of a New OneDose MOSFET for the Ir-192 Energy”, *Phys. Med. Biol.* 51, 1261–1268 (2006).

METHODS

- The Thomson-Nielsen MobileMOSFET dosimetry system was characterized with respect to a calibrated air ionization chamber for a Xoft Axxent™ HDR X-ray Source operating at 50 kVp.
- A sequence of aluminum absorbers (0.5 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 mm) was introduced into the beam path to study how changes in the spectrum due to filtering affect the cross calibration of the MOSFETs.
- The source was encased in a steel jacket with a hole near the anode to define the beam and eliminate scattered radiation.
- The ionization chamber (Exradin Model A600) was mounted in a radiation-shielded tank at a distance of 100 mm from the source. The chamber was connected to a PTW UniDos E electrometer operating in current mode, which was integrated via a serial port into a PC-based data acquisition system. A custom LabVIEW program acquired the readings twice per second and provided the calculations necessary to determine dose rate and integrated dose.
- Two MOSFET detectors (#1 and #2) were mounted in the plane of the ion chamber window with one on either side of the centerline. The Thomson-Nielsen system supports continuous readout of both MOSFETs while under irradiation through their remote reader unit. The MOSFETs were read out by a Thomson-Nielsen supplied program at the minimum 10 second intervals.
- Collected data was exported from the LabVIEW and Thomson-Nielsen programs to a spreadsheet for comparative analysis.

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RESULTS

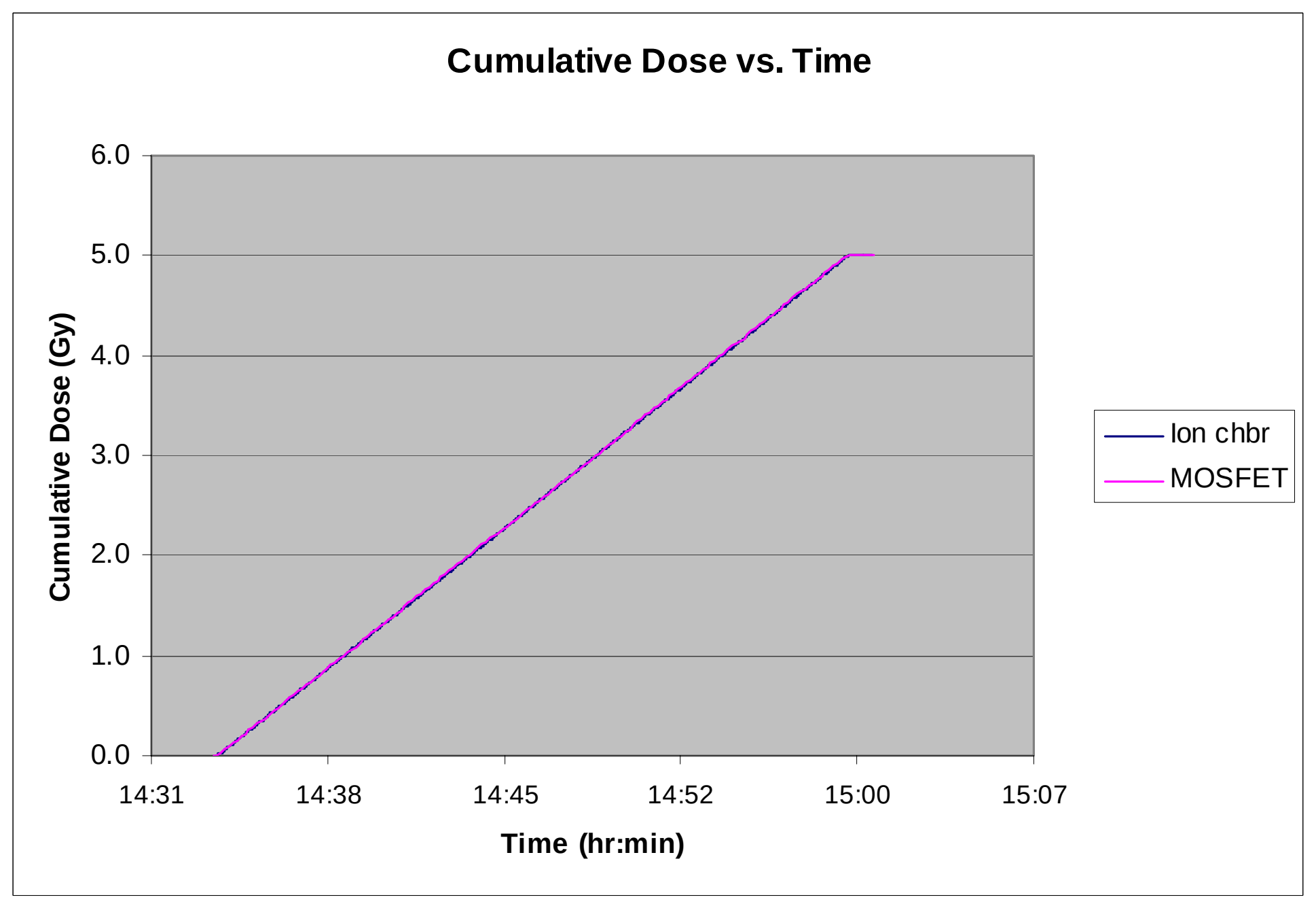

Figure 1. Integrated dose vs. time for the A600 ion chamber and Thomson-Nielsen MOSFET dosimeter, using a best fit calibration constant to scale the MOSFET readings. A dose of 5 Gy was delivered to both devices for this measurement.

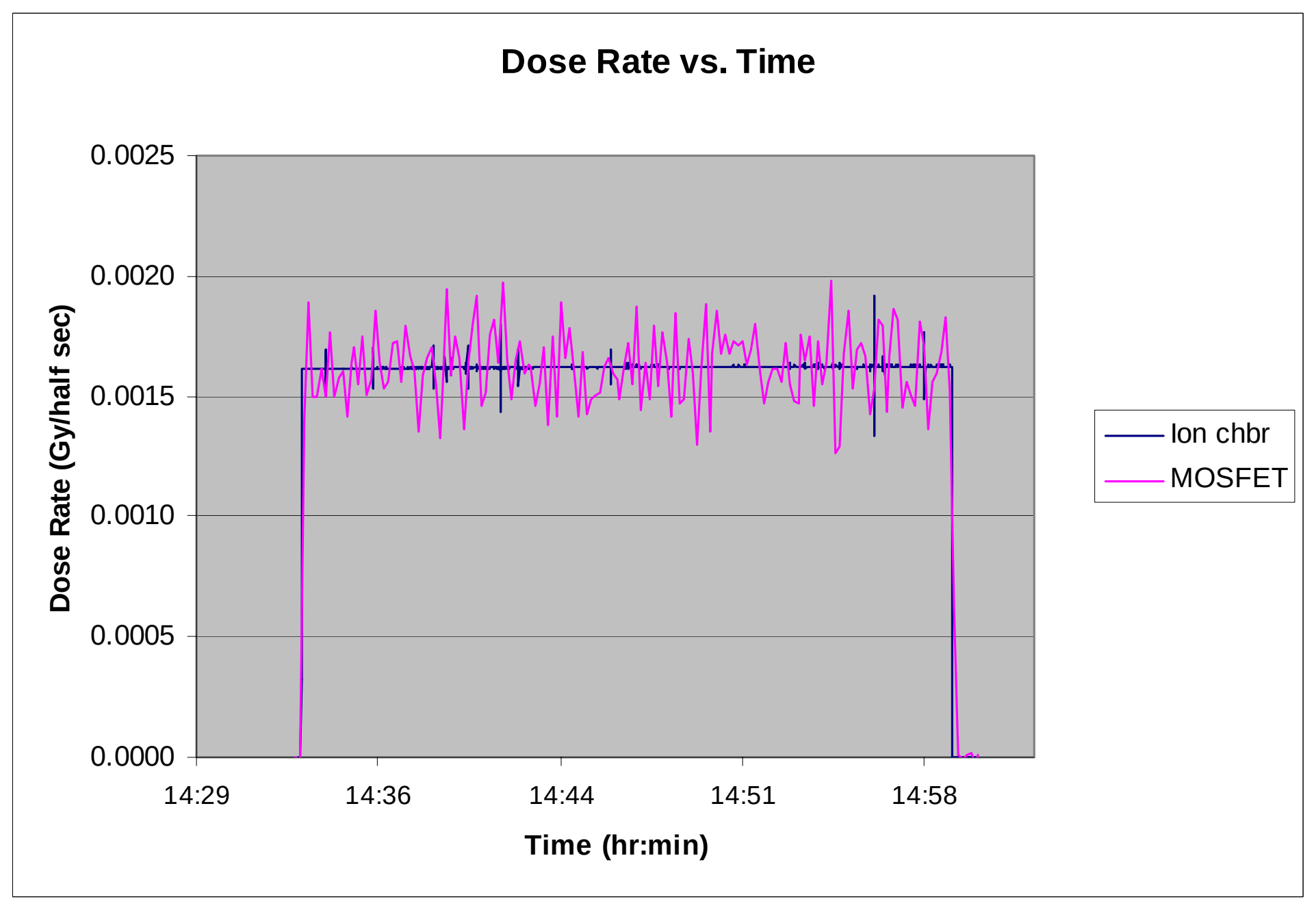

Figure 2. Dose rate vs. time for the A600 ion chamber and Thomson-Nielsen MOSFET dosimeters.

- Data taken with various amounts of aluminum absorber present showed MOSFET noise increasing with absorber thickness, up to about 20% with 3.5 mm present, at which point the signal level had dropped by 90%. The increase in noise is to be expected as the signal strength drops. With no absorber the change in MOSFET threshold voltage is approximately 10 mV per 10 second reading, dropping to 2 mV when the maximum absorber thickness of 3.5 mm Al is present. Longer time periods than the system-minimum 10 seconds used here, will provide larger signals and therefore lower noise.
- The calibration slope in Gy/mV also decreases exponentially with absorber thickness, as seen in **Figure 3**. Presumably the decrease is due to filtering of the lowest energy x-rays, which have the largest MOSFET response per unit dose. For this source at 50 kVp, 1 mm of aluminum has similar absorption to 10 mm of water. In clinical use for skin dosimetry in breast brachytherapy, the Xoft source will be surrounded by a balloon with 15 to 25 mm water thickness, plus tissue thickness on the order of 10 mm. Thus the slope changes only slowly in the region of interest, beyond about 25 mm water, equivalent to about 2.5 mm of aluminum.
- How the slope changes with filtering can be conveniently characterized by plotting slope versus absorber attenuation ratio, determined from the ion chamber readings. The attenuation ratio is defined as the signal strength with a given absorber to that with no absorber. This is shown in **Figure 4** for MOSFET #1. A linear fit gives good agreement, with a standard deviation of residual errors of 1.6% for MOSFET #1 and 4.5% for MOSFET #2. The clinical region of interest has attenuation ratios in the range from below 0.09 to about 0.13. For measuring skin dose, if the absorption of the balloon plus tissue is known, for example from a calculation based on imaging input data, a correction could be applied to a nominal calibration constant to improve accuracy. Without any correction the constant changes by about 6% over the stated range. With corrections this should be reduced by at least half.

- **Figure 1** shows integrated dose versus time from the ion chamber and MOSFET over a range of 5 Gy. The MOSFET raw readings take the form of a threshold voltage. The values were multiplied by a single calibration constant that gave best agreement with ion chamber readings. In this case there was no filtering of the X-ray Source, so there was a substantial low energy (< 20 keV) spectral component, and the dose rate was quite high (0.4 cGy/sec). The two data series track each other very closely.
- The high degree of linearity is attributable both to the inherent response of the MOSFET and to a very constant x-ray source output. As the individual data points are acquired at different times, it is most straightforward to calculate the difference between the ion chamber and MOSFET readings graphically. With this approach one can estimate a maximum deviation less than 3%.
- The dose rates vs. time, corresponding to the data in Fig. 1 are shown in **Figure 2**. Dose rate was recorded directly for the ion chamber and calculated from the differences between successive readings from the MOSFET. The noise on the individual 10 second MOSFET readings is characterized by a standard deviation of about 9% in this example.

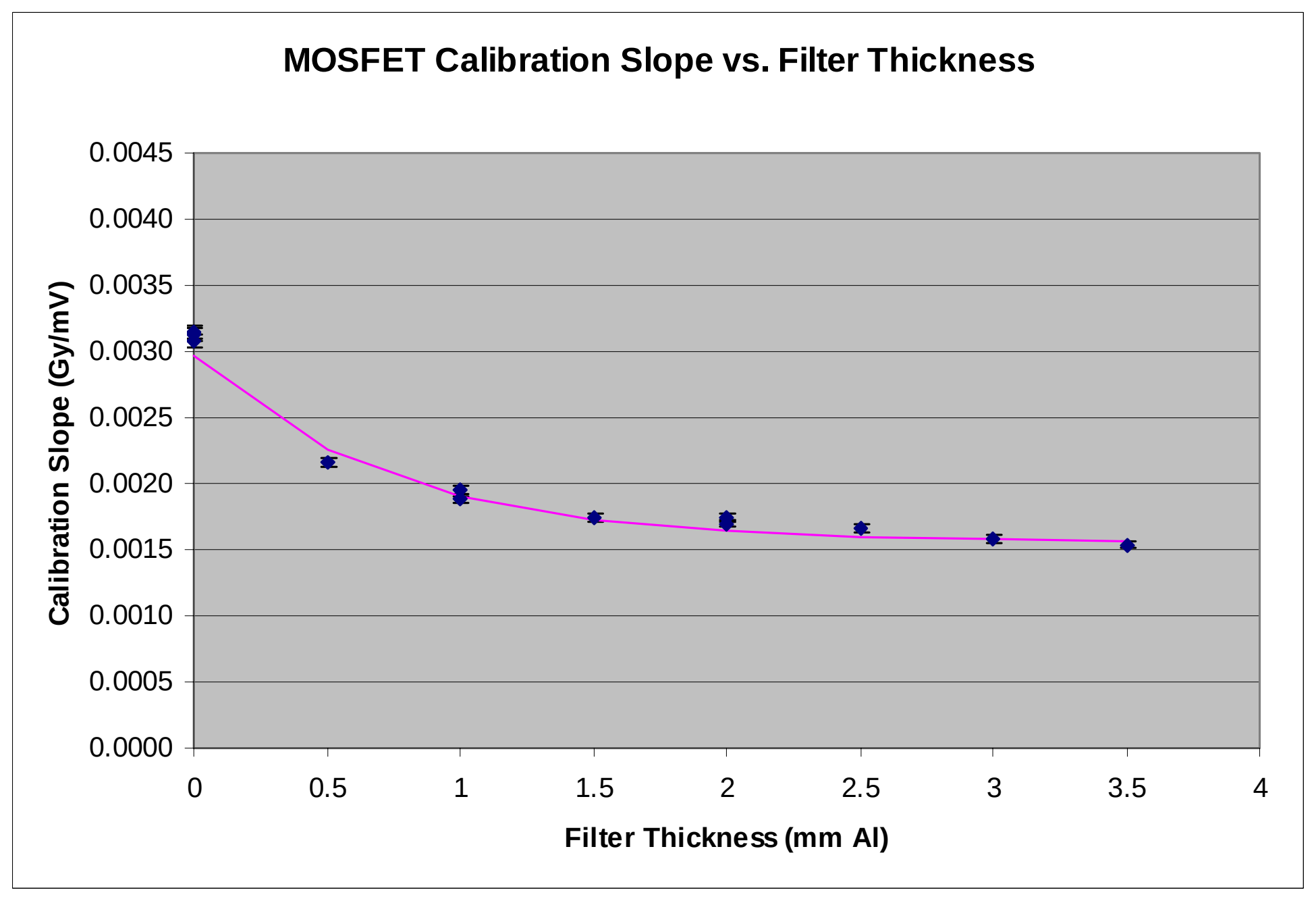

Figure 3. Slope of MOSFET dose response as a function of absorber thickness at 50 kVp for MOSFET #1. The line represents a simple exponential decay function. Bower and Hintenlang reported a sensitivity of 0.0011 Gy/mV for a filter thickness of 2.7 mm Al with a test configuration similar to the present one.

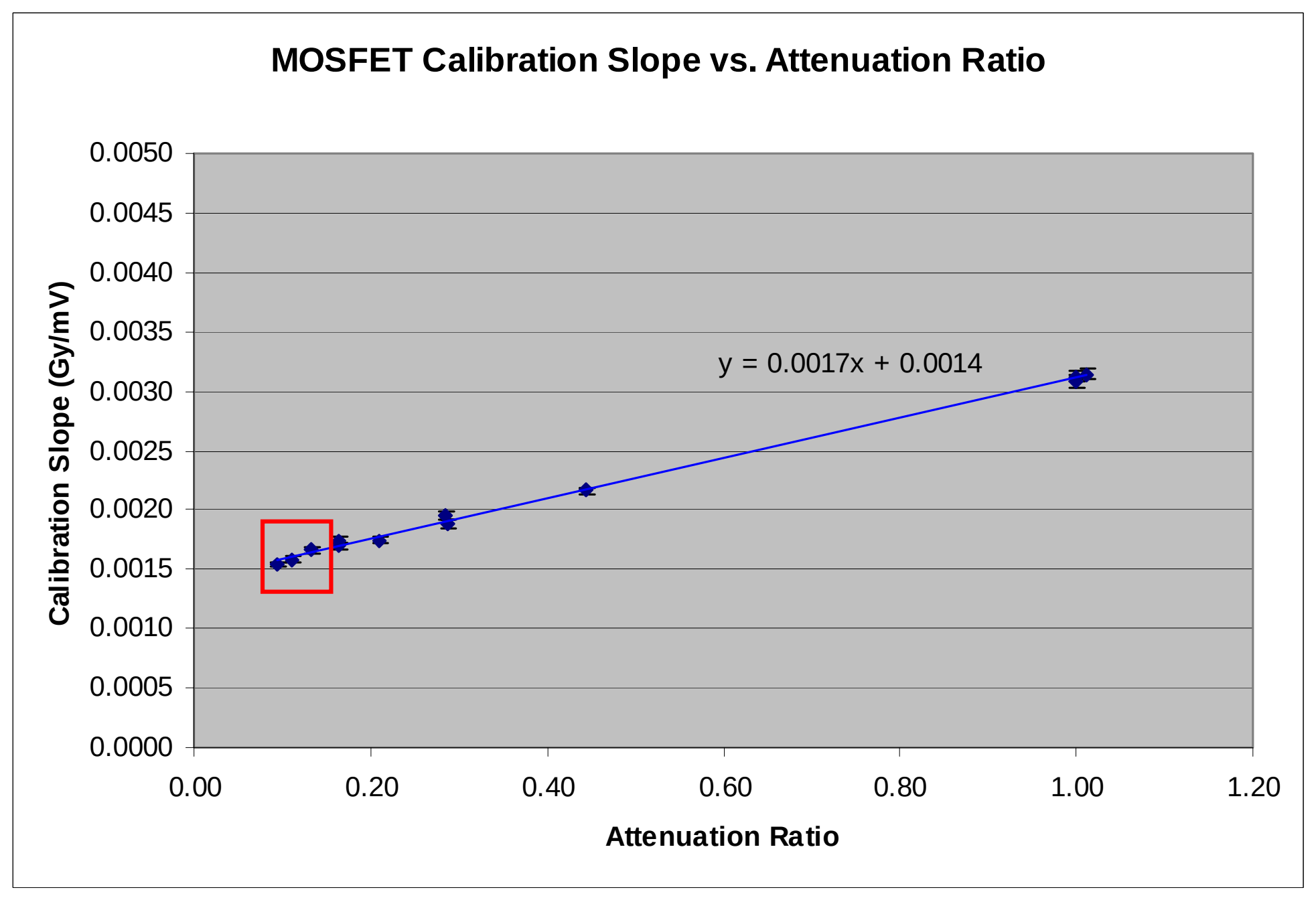

Figure 4. MOSFET calibration slope as a function of absorber attenuation ratio; with no absorber the ratio is 1.0. For this data from MOSFET #1, the standard deviation of the points about the linear fit is 1.6%. For MOSFET #2, the standard deviation was 4.5%. The red box outlines the clinically relevant area.

CONCLUSIONS

- Thomson-Nielsen MOSFET dosimeters can provide breast brachytherapy skin dose measurement capability for the Xoft Axxent™ source, with an accuracy on the order of 3 to 5%, providing corrections are applied to account for the distance from source to skin.
- Without these corrections the errors in clinical use may be as much as 10%.

Study Funded by Xoft