Quality Assurance of Linear Accelerators Using Arrays of MOSFET Dosimeters: A Feasibility Study

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ABSTRACT

Comprehensive sets of measurements were performed to evaluate the accuracy and precision of metal oxide silicon semiconductor field effect transistor (MOSFET) dosimeters when acquiring dosimetry parameters of photon and electron beams. Parameters measured included reproducibility, energy dependence, field size dependence (FSD), percentage depth dose (PDD), off-axis factor (OAF), off-center ratio (OCR) and wedge profile (WP).

The AutoSense Dosimetry System model TN-RD-60 with twenty MOSFET dosimeters (Thomson-Nielsen Electronics LTD, Ottawa, Ontario, Canada) was used in this evaluation with the high voltage bias supply (TN-RD-22). Measurements were obtained with a dose of 100 cGy for calibration measurements and 50 cGy for all relative measurements. Experiments were performed in the 6 MV and 18 MV photon beams and the 6 and 16 MeV electron beams from a Clinac 21EX and a Clinac 2100C and also in the 6 MV photon beam from a Clinac 600CD. Several devices were made to facilitate measurements in air and in water. Measurements of FSD, PDD, and OAF were made with both an ionization chamber and MOSFET dosimeters under the same irradiation conditions. Measurements of PDD, OCR, OAF, WP were also compared to data obtained with a Welhoffer scanner WP700 beam data acquisition system and chamber array attachment. The percent standard deviation of MOSFET dosimeter calibration measurements was less than 2%. Measurements of PDD with MOSFET dosimeters were made for 6, 10, 20, and 30 cm square field sizes with a precision of 3%. Measurements of OCR, OAF and wedge profiles with MOSFET dosimeters also had a precision of 2-3%. Measurements of dosimetry parameters with MOSFET dosimeters such as PDD and FSD agreed with ionization chamber measurements to within 3%. Preliminary results show the feasibility of using arrays of MOSFET dosimeters to acquire simultaneously several point measurements to reassemble photon and electron beam dosimetry parameters.

INTRODUCTION

The American Association of Physicist in Medicine Task Group 40 and 45 reports recommend criteria for performance and quality assurance procedures for linear accelerators to meet the levels of accuracy and reproducibility recommended for radiotherapeutic dose delivery. A comprehensive quality assurance audit for photon beams includes precise ionization chamber measurements of beam output, calibration factors using the AAPM TG-51 protocol, output constancy, field size dependence (FSD), percentage depth dose (PDD) for different field sizes and depths, off-axis factors (OAF) in air or off-center ratios in water phantom, wedge factors (WF) and wedge profiles for different field sizes and depths, and mechanical checks. For electron beams measurements included output calibration for all energies, cone ratios (CR) and percentage depth dose. The accuracy of all ionization chamber measurements were believed to be between 1-2%. The Radiological Physics Center (RPC) criteria for acceptance of measurements for clinical use is 3% for output calibration and constancy checks, and 2% for all relative measurements (i.e., FSD, PDD, WF, OAF, and CR). The combined deviations from recommended criteria of all factors used in patient's MU calculations should be ±5%. The ICRU recommends that accuracy in the delivery of the absorbed dose to the target volume be within ±5%.

The aim of this paper is to determine if the accuracy and reproducibility of MOSFET dosimeter measurements meet the levels needed to monitor the dosimetric characteristics of linear accelerators. In this paper measurement of output, FSD, PDD, WF, beams profile for photon and electron beams are performed using a commercially available miniature MOSFET dosimeter in conjunction with the AutoSense Dosimetry System. On the basis of these measurements the feasibility of using MOSFET dosimeters for quality assurance of linear accelerators was determined.

MOTIVATION

- The RPC is presently monitoring about 1,300 megavoltage therapy facilities
- The RPC has a priority scheme for site visits based on:
  - Problem indicators (TLD).
  - The number of protocol-patients treated.
  - The on-site dosimetry review is a labor-intensive component of the QA program.

The large number of institutions monitored precludes frequent on-site visits.

MATERIALS AND METHODS

- Experiments were performed at 100 cm SSD in a Clinac 21EX and a Clinac 2100C for 6 and 18 MV photon beams and for 6 and 16 MeV electron beams and also in a Clinac 600CD for 6 MV photon beam.
- Measurements were made with a NEL 2571 ionization chamber and a Keithley electrometer model 602 modified by CNMC and repeated with MOSFET dosimeters under the same irradiation conditions.
- Output factors (cGy/MU) were calibrated at 5 cm depths for square fields of 6,10, 15, 20, and 30 cm^2 using the AAPM TG-51 protocol.
- Measurements were made in a water tank (30 cm x 30 cm x 30 cm) first with the ionization chamber and then with MOSFET dosimeters for the same field sizes and depths.

MATERIALS AND METHODS (cont.)

- A new AutoSense dosimetry system (model TN-RD-60) with 20 new MOSFET dosimeters (model TN-502RD) were used in the experiments.
- MOSFET dosimeters were used at the high sensitivity setting (i.e., high bias voltage setting).
- Each MOSFET dosimeter, voltage power supplies (TN-RD-22), and cable were tagged and identified during all experiments.
- An electro-mechanical vertical scanner was used to accurately setup the chamber and MOSFET dosimeters at different depths in the beam central axis.
- The MOSFET dosimeters were irradiated in water at 5-cm depth at 100 cm SSD.
- The output measurements were used to calibrate the MOSFET dosimeters.

MATERIALS AND METHODS (cont.)

- A device made of Solid Water (RMI, Gammex) was designed to hold one single MOSFET dosimeter at depth in water. (See Figures 1 and 2).
- Each MOSFET was irradiated at least three times with each photon energy.
- 100 MU was used for each calibration irradiation and 50 MU for all relative measurements .
- For each MOSFET dosimeter, the readings were averaged and the result divided by the dose determined previously by ionization chamber measurements to yield the calibration factor (mV/cGy).
- The percentage standard deviation of each group of three measurements was also determined.
- The calibration measurements for 6 MV and 18 MV photon beams are summarized in Table I and II respectively.

Measurements Performed

- MOSFET calibration, reproducibility and energy dependence.
- Field size dependence.
- Percentage depth doses for different field sizes and photon energies.
- Percentage depth doses for different electron energies.
- Photon open beam profiles.
- Off-axis factors in air.
- Off-center ratios in water.
- Wedge profiles and wedge depth doses.

AutoSense Dosimetry System

- **The AutoSense Dosimetry System is a computerized device for in-vivo patient dose verification.**
- **The AutoSense Dosimetry System uses four voltage power supplies and can measure signals from 20 MOSFET dosimeters (5 dosimeters per power supply) irradiated at the same time, and allows for remote data acquisition and storage.**

MOSFET Dosimeters Characteristics
(Metal Oxide-Silicon Field Effect Transistor)

- **Direct reading detector.**
- **Thin active area (<25 μm).**
- **Small size: 0.2x 0.2 mm by 1 mm thick.**
- **Signal is dose rate independent.**
- **Energy response within 2%-3%.**

MOSFET Dosimeters Characteristics (cont.)

- The sensitivity of MOSFET dosimeters is orientation-dependent. The MOSFET dosimeter has an isotropic response of ⌖2% for 360⌖.
- In all measurements in this paper the dosimeters faced the source, consequently the anisotropy of the response of the dosimeters was insignificant.
- Under full buildup irradiation conditions and high-sensitivity bias the MOSFET dosimeter sensitivity is 2.7 mV/cGy for a life span (total accumulated dose) of 20,000 mV.
- MOSFET dosimeter fading is less than 3% of 200 cGy when read within 15 minutes of exposure. (AutoSense Technical Manual).
- For this work all dosimeters were read within a minute of the irradiation.

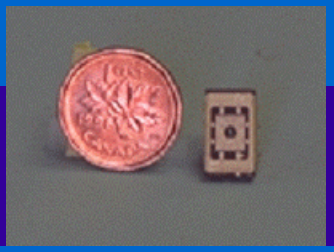
MOSFET Dosimeter Characteristics

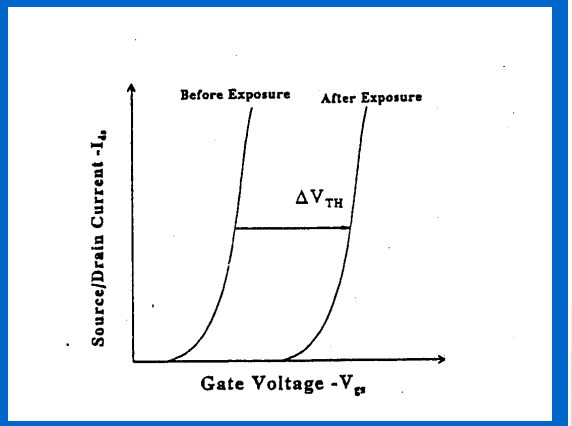
- **Stability (measure the response of the dosimeter to a given dose over time, and how frequently a new calibration is needed). Chuang et al. reported that under standard conditions of irradiation (10 cm^2, 1.5 cm depth, 100 cm SSD) MOSFET dosimeter consistency is ±3%. When converted to dose is 1.00 Gy ± 0.015 Gy.**

- **Linearity (dosimeter useful range), Chuang et al. reported that under standard conditions of irradiation MOSFET dosimeters are linear within 0.05 Gy to 4.2 Gy. Good linearity response from 30 cGy to 100 cGy is within 2%-3%.**

- **MOSFET dosimeter structure and characteristics have been described extensively in the literature (1-5).**

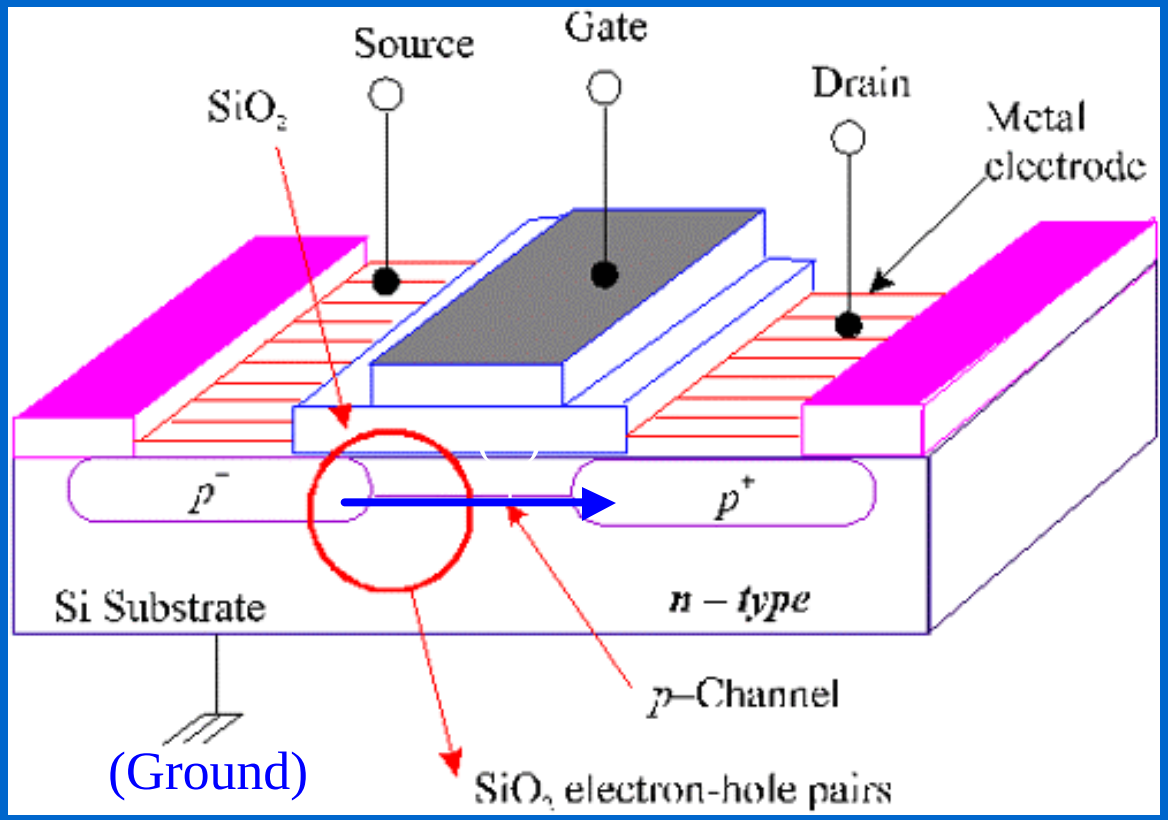
P Channel MOSFET Structure





ΔV_G ⟶ **Dose (cGy)**

$V_G(-)$

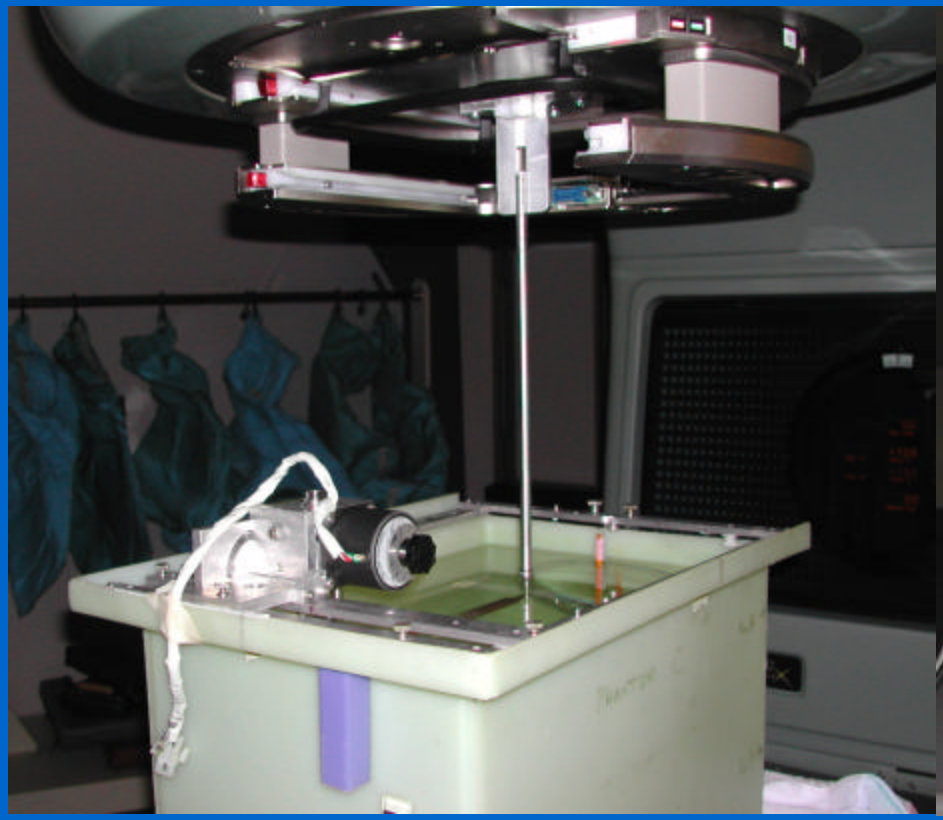


MOSFET Detector vs. Other Detectors

- **Reproducibility:**
  - **Better than TLD, worse than semiconductors.**
- **Temperature, dose rate and energy dependence:**
  - **Same as TLD, better than semiconductors.**
- **Immediate readout:**
  - **Same as semiconductors, better than TLD.**
- **Sensitivity:**
  - **Worse than TLD and semiconductors.**
- **Angular dependence:**
  - **± 2% under full buildup through 360 degrees rotation.**

Reference: P. Francescon, P. Scalchi, S. Cora, "Application of MOSFETs in radiotherapy dosimetry", 15th E.S.T.R.O. meeting, Vienna, 1996.

Fig. 1 Calibration of individual MOSFET at 5 cm depth in Water



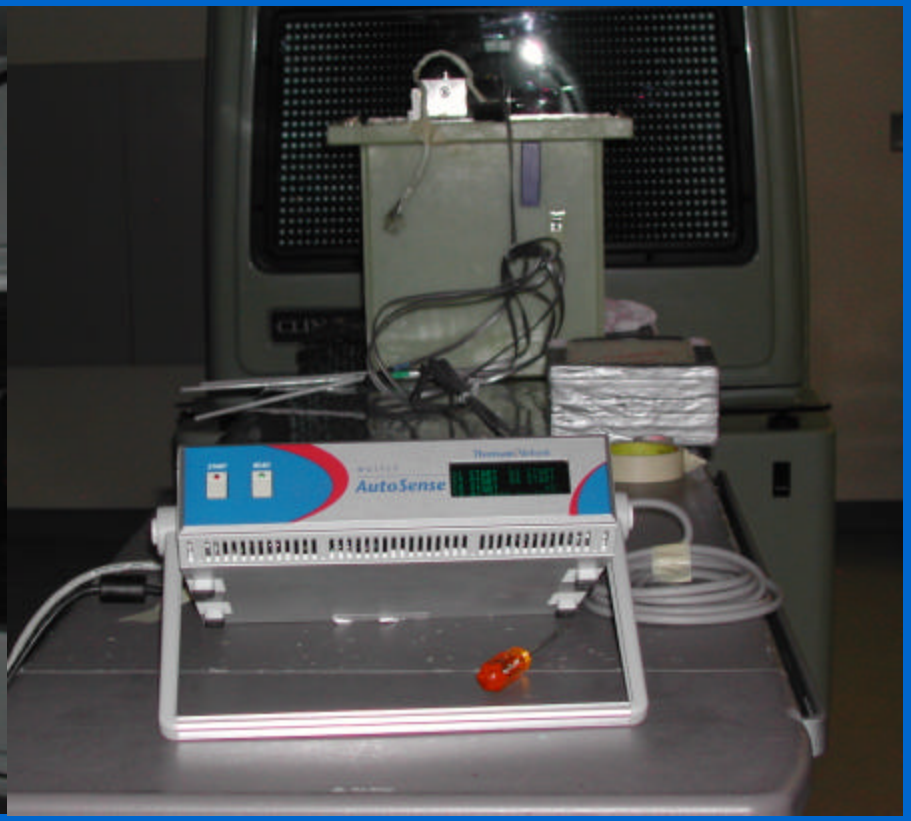


Table I. Calibration of Individual MOSFET 6 MV Photons

(5-cm depth in water, 10-cm x 10-cm field size at 100-cm SSD)

Rgd1	Rdg2	Rdg3	Average	STD	%STD	CF(mV/cGy)	CF1(cGy/mV)
276	266	268	270.0	5.3	2.0	2.89	0.346
276	268	272	272.0	4.0	1.5	2.91	0.343
271	269	268	269.3	1.5	0.6	2.89	0.347
269	267	269	268.3	1.2	0.4	2.88	0.348
268	270	273	270.3	2.5	0.9	2.90	0.345
275	272	272	273.0	1.7	0.6	2.93	0.342
274	275	270	273.0	2.6	1.0	2.93	0.342
269	271	272	270.7	1.5	0.6	2.90	0.345
272	270	267	269.7	2.5	0.9	2.89	0.346
267	266	260	264.3	3.8	1.4	2.83	0.353
270	273	271	271.3	1.5	0.6	2.89	0.346
270	272	270	270.7	1.2	0.4	2.89	0.347
277	274	274	275.0	1.7	0.6	2.93	0.341
276	269	278	274.3	4.7	1.7	2.93	0.342
280	277	279	278.7	1.5	0.5	2.97	0.337
289	283	281	284.3	4.2	1.5	3.03	0.330
274	267	271	270.7	3.5	1.3	2.89	0.347
272	273	269	271.3	2.1	0.8	2.89	0.346
267	267	266	266.7	0.6	0.2	2.84	0.352
261	270	266	265.7	4.5	1.7	2.83	0.353
			Average %STD		1.0		
			Average STD		2.5		

Table II. Calibration of Individual MOSFET - 18 MV Photons

(5-cm depth in water, 10-cm x 10-cm field size at 100-cm SSD)

MOSFET I.D	Rgd1	Rdg2	Rdg3	Average	STD	%STD	CF(mV/cGy)	CF1(cGy/mV)
A1	291	296	289	292.0	3.6	1.2	2.91	0.344
A2	297	297	295	296.3	1.2	0.4	2.95	0.339
A3	292	299	291	294.0	4.4	1.5	2.93	0.342
A4	294	296	297	295.7	1.5	0.5	2.94	0.340
A5	290	293	295	292.7	2.5	0.9	2.91	0.343
B1	298	300	303	300.3	2.5	0.8	2.99	0.334
B2	300	294	297	297.0	3.0	1.0	2.96	0.338
B2	292	292	291	291.7	0.6	0.2	2.90	0.344
B4	296	294	296	295.3	1.2	0.4	2.94	0.340
B5	289	288	285	287.3	2.1	0.7	2.86	0.350
C1	300	296	294	296.7	3.1	1.0	2.94	0.340
C2	295	294	294	294.3	0.6	0.2	2.92	0.343
C3	300	295	299	298.0	2.6	0.9	2.95	0.338
C4	299	300	294	297.7	3.2	1.1	2.95	0.339
C5	306	304	302	304.0	2.0	0.7	3.01	0.332
D1	312	312	313	312.3	0.6	0.2	3.10	0.323
D2	292	294	294	293.3	1.2	0.4	2.91	0.344
D3	299	295	292	295.3	3.5	1.2	2.93	0.342
D4	295	292	294	293.7	1.5	0.5	2.91	0.343
D5	289	287	289	288.3	1.2	0.4	2.86	0.350
				Average %STD		0.7		
				Average STD		2.0		

Table III. Reproducibility Data

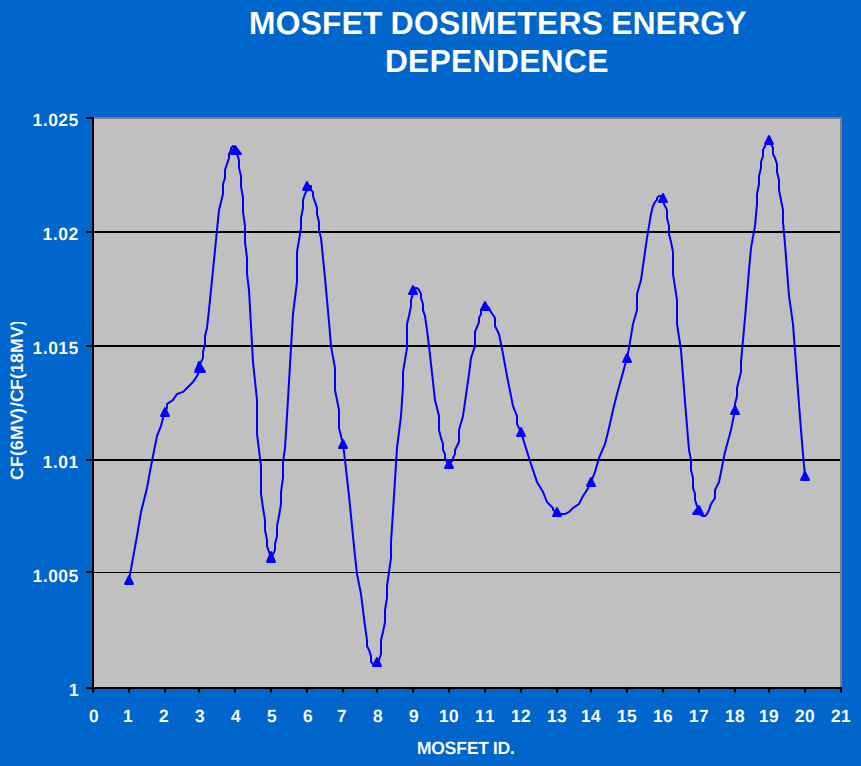
Field Size: 10 cm x 10 cm @ 100 cm SSD in a Water Phantom

6 MV Photons

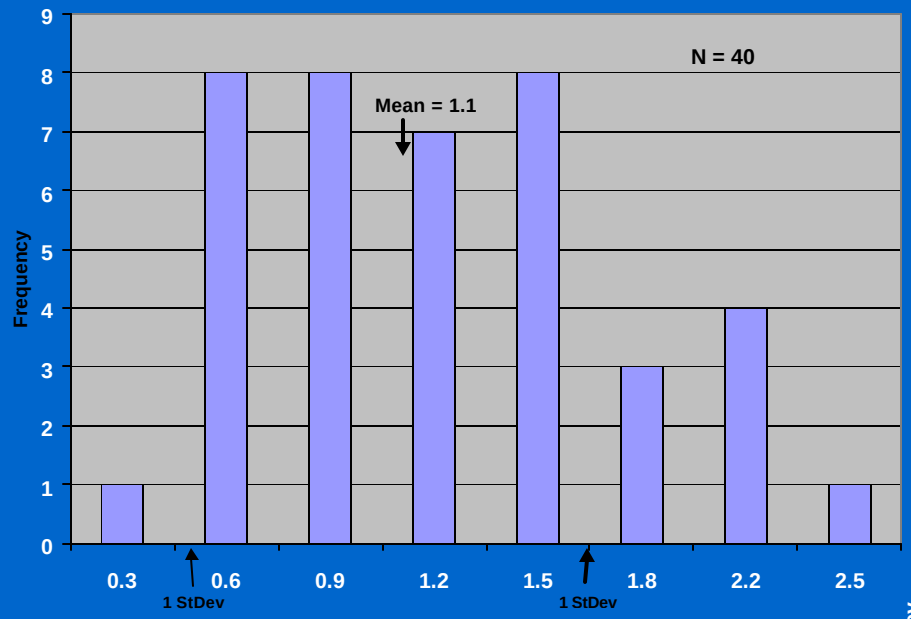
	C1	C2	C3	C4	C5
	353	323	327	312	316
	349	322	321	307	310
	354	314	321	310	311
	353	321	317	313	314
	349	315	323	316	313
	346	324	317	311	310
Average	350.7	319.8	321.0	311.5	312.3
STDEV	3.1	4.3	3.8	3.0	2.4
%STD	0.90	1.33	1.18	0.97	0.78

18 MV photons

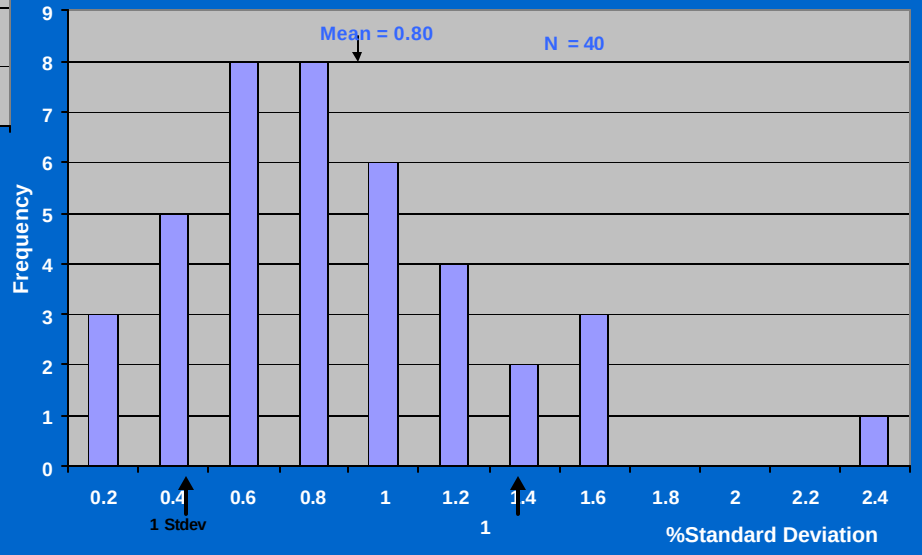
	C1	C2	C3	C4	C5
	328	305	307	300	295
	325	296	303	302	294
	325	298	307	296	298
	325	302	305	302	298
Average	325.8	300.3	305.5	300.0	296.3
STDEV	1.5	4.0	1.9	2.8	2.1
%STD	0.46	1.34	0.63	0.94	0.70



DISTRIBUTION OF UNCERTAINTIES

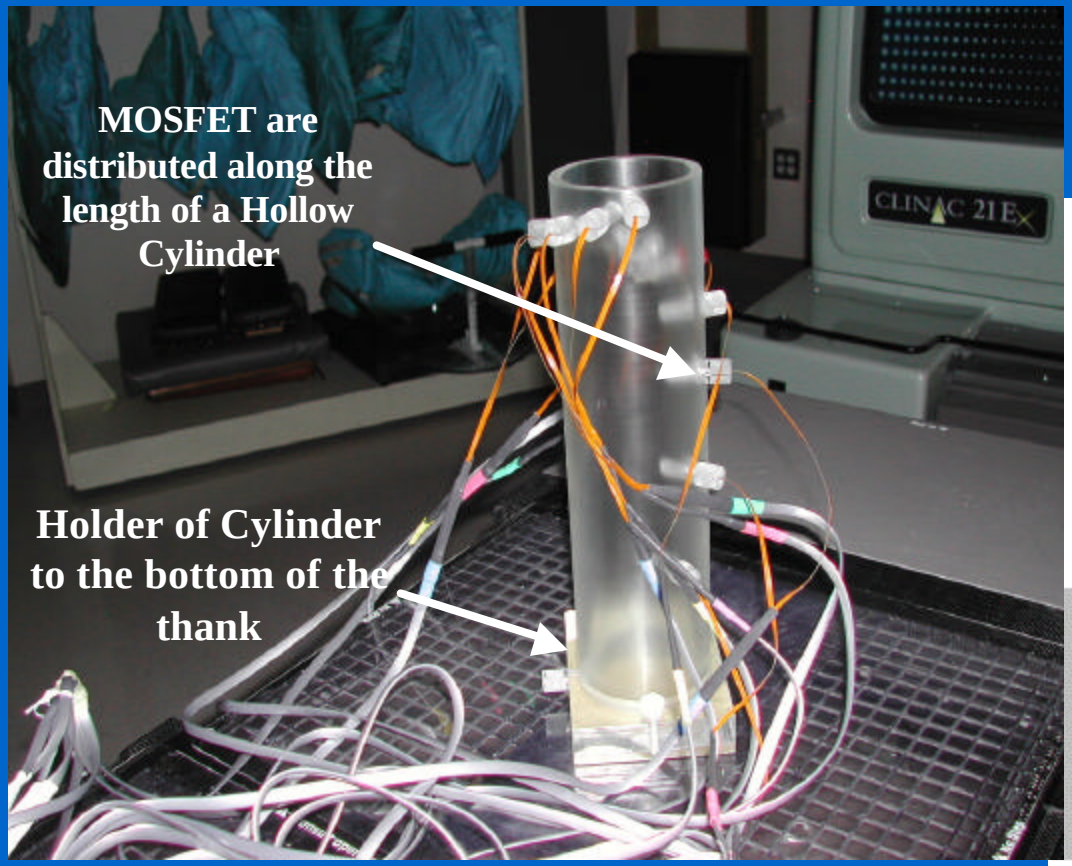


6 MV photons

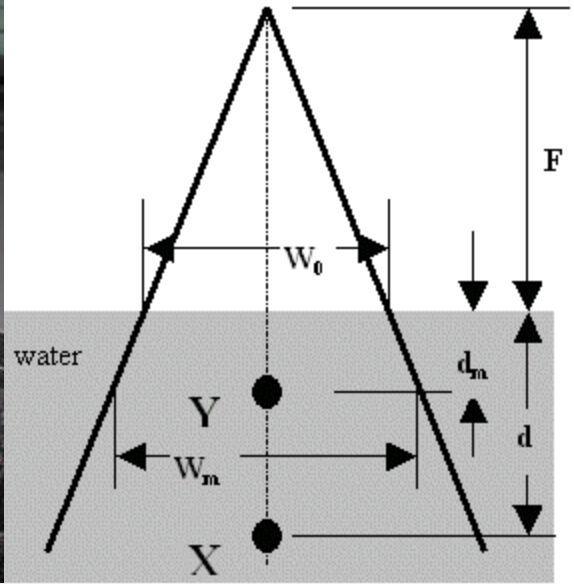


18 MV photons

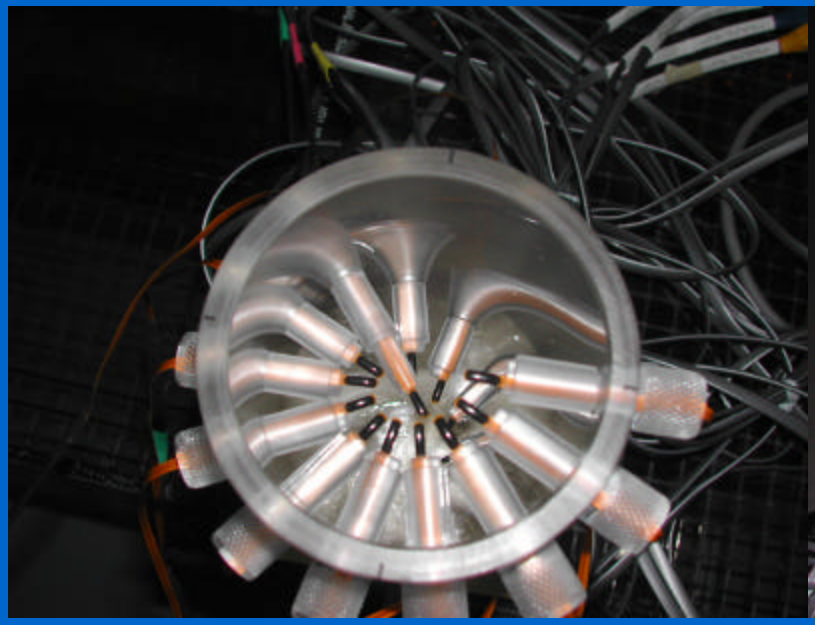
Percentage Depth Dose Measurement Device

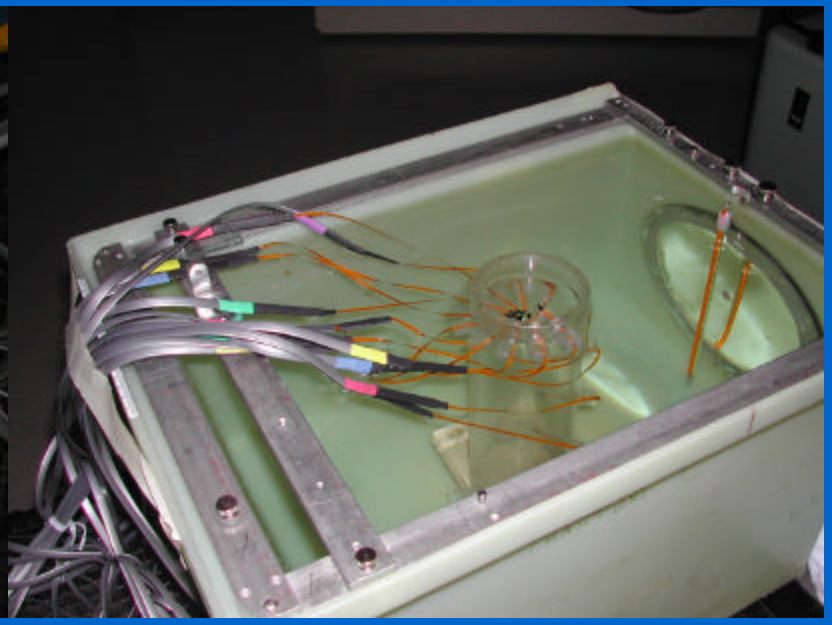


$$P(d, W_m, F, h\nu) = 100\frac{D_X}{D_Y}$$



Top View of MOSFET Dosimeter Array in the Cylinder and in the Water Tank





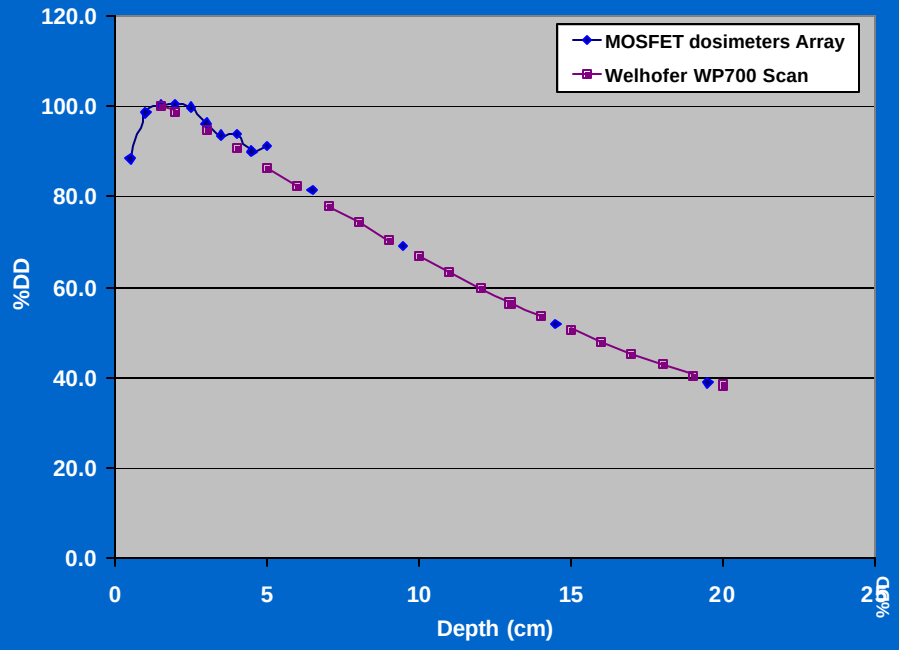
Field Size Dependence

F.S. (cm2)	Ionization chamber	MOSFET Dosimeter	6 MV photons MOSFET/Ion Chamber	Ionization Chamber	MOSFET Dosimeter	18 MV photons MOSFET/Ion Chamber
6	0.941	0.941	1.000	0.950	0.933	0.982
10	1.000	1.000	1.000	1.000	1.000	1.000
15	1.039	1.044	1.005	1.031	1.033	1.002
20	1.066	1.088	1.021	1.048	1.067	1.018
30	1.102	1.118	1.014	1.073	1.067	0.994

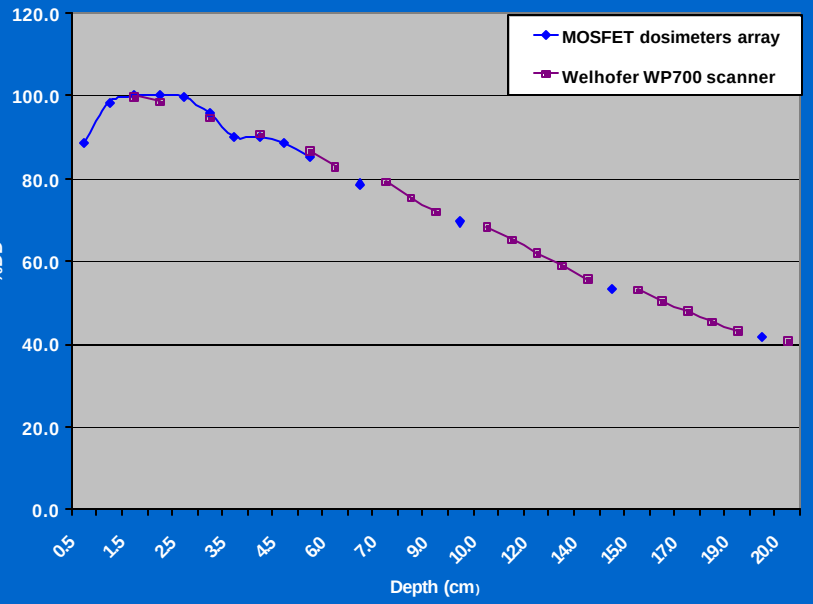
PDD-Welhofer Scan/PDD-MOSFET Array

Depth (cm)	Field Size (cm^2) 6	10	15	20	25
1.5	1.000	1.000	1.003	1.003	1.003
2.0	1.036	1.015	0.976	0.976	0.971
3.0	1.023	1.015	0.978	0.978	0.979
4.0	1.030	1.033	1.014	1.014	1.016
5.0	1.041	1.055	0.987	0.987	1.031

PDD- MOSFET Array vs. Welhofer WP700 scan



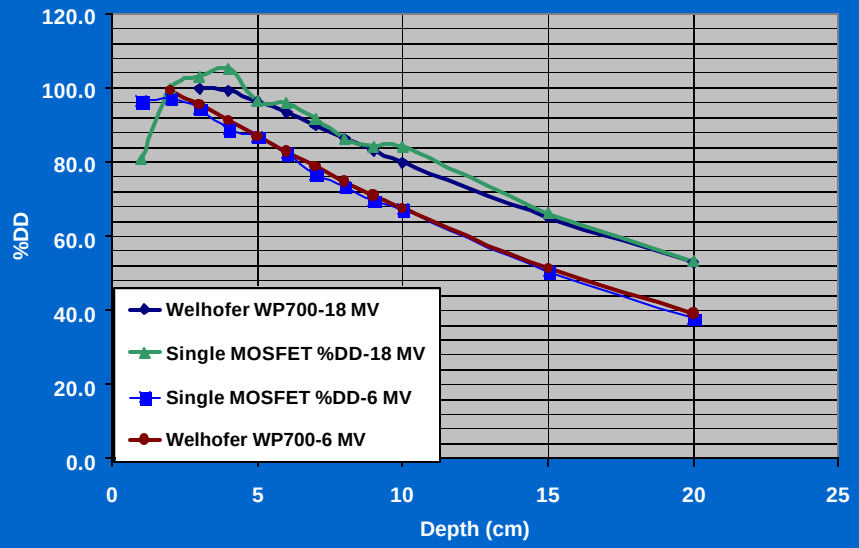
10 cm x 10 cm

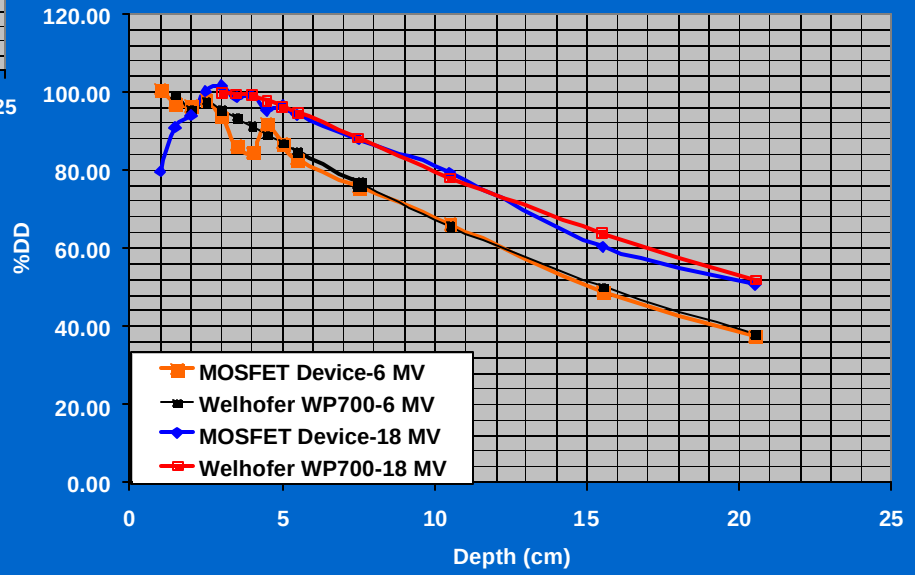


15 cm x 15 cm

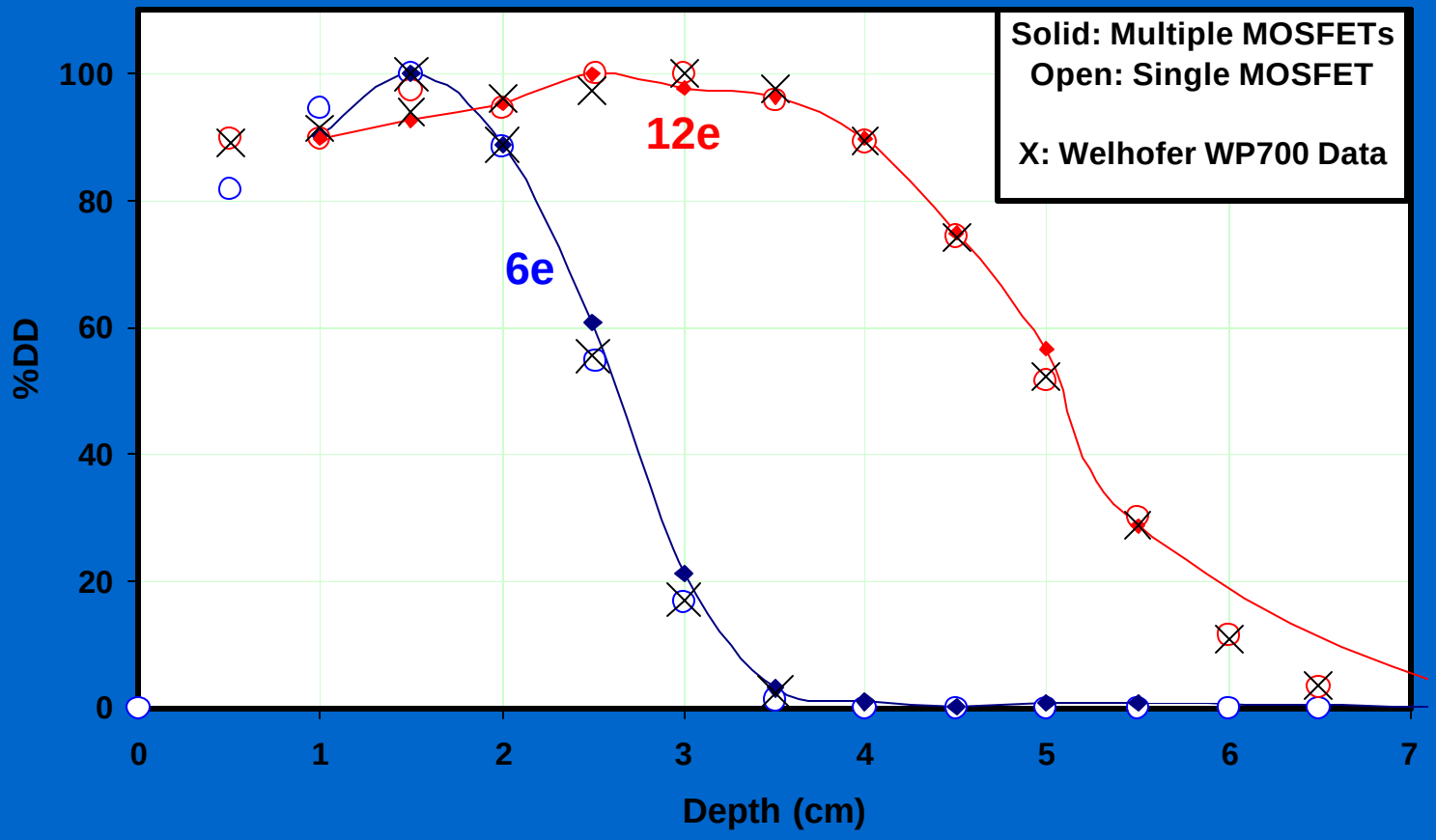
Percentage Depth Dose

Clinac 2100 10 cm x 10 cm field size

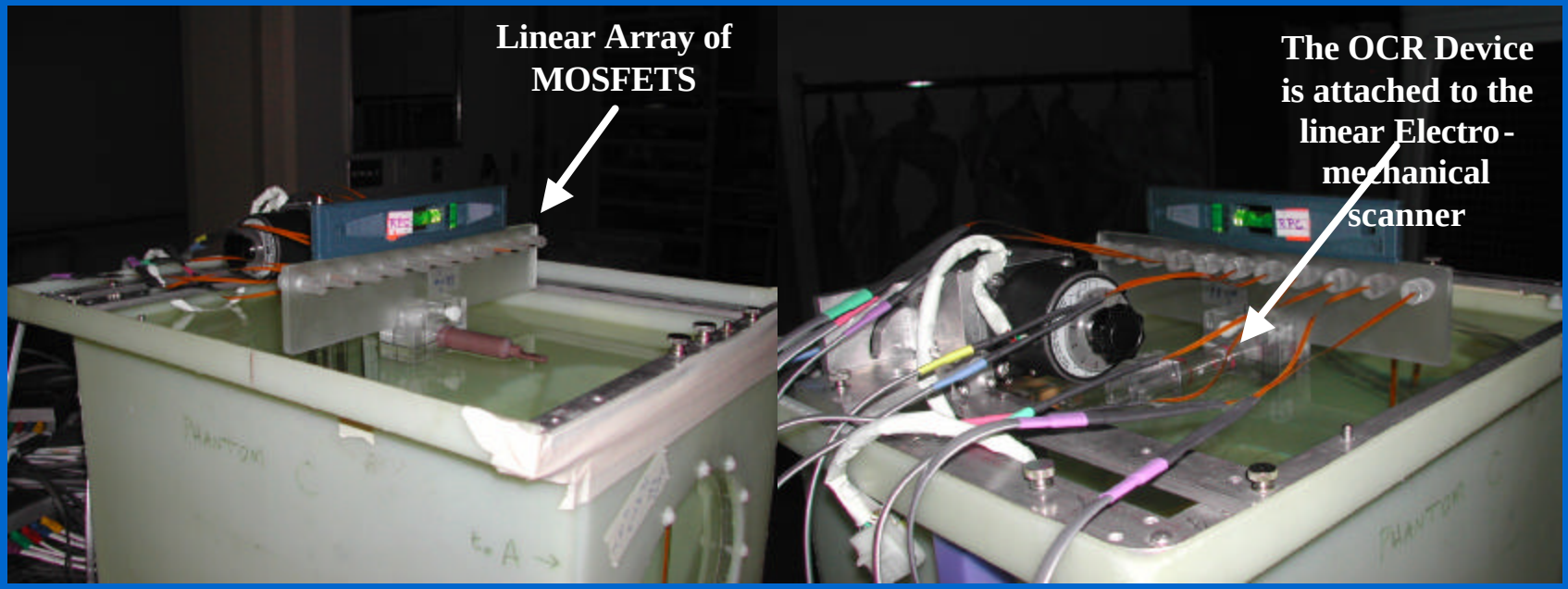




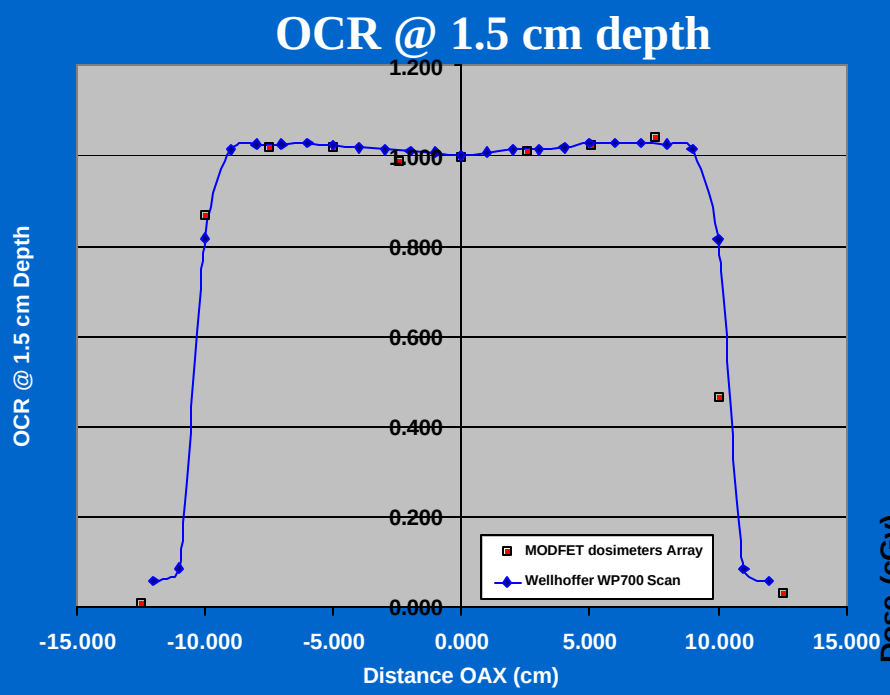
Percentage Depth Dose- Electrons

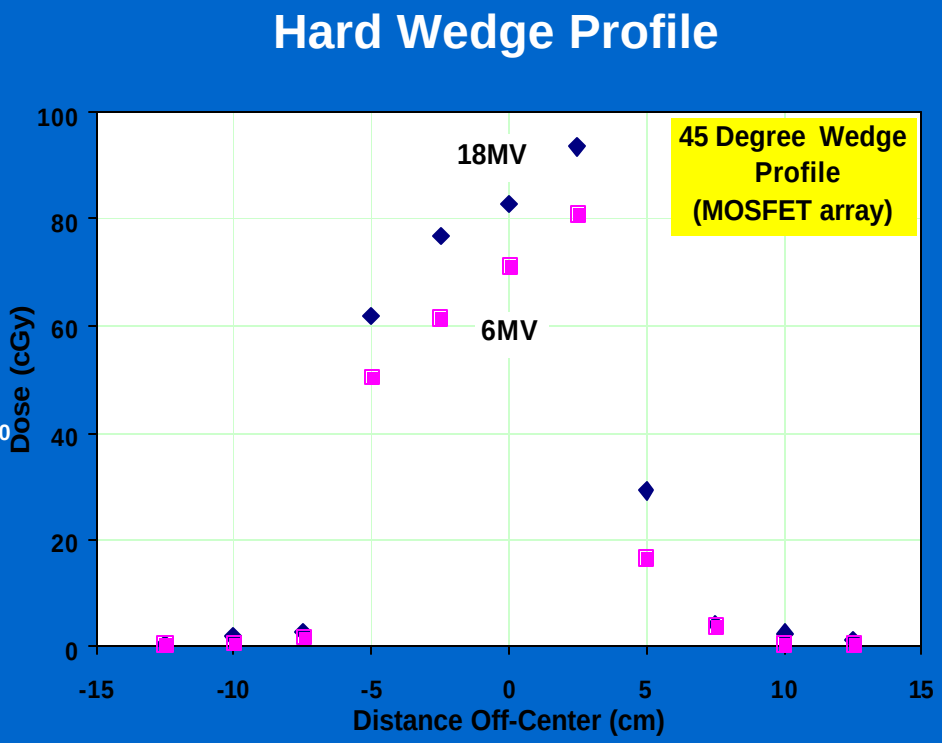


Device Used to Measure Off-Center Ratios (OCR)

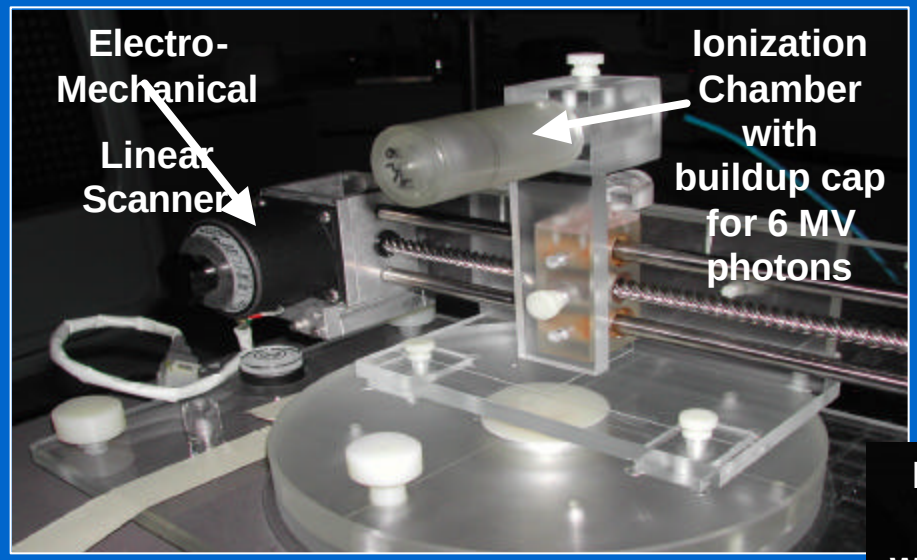


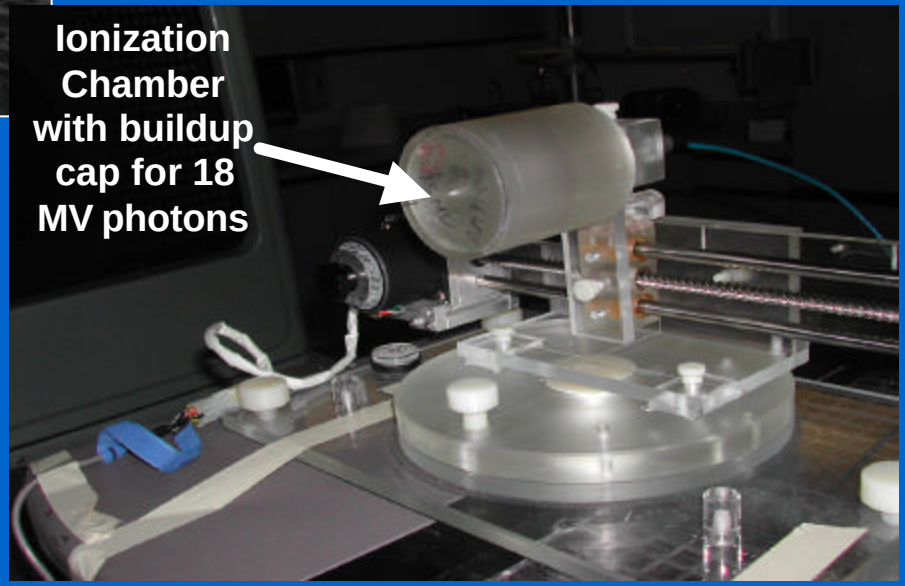
MOSFET dosimeter Array vs. Welhoffer WP700 Scan



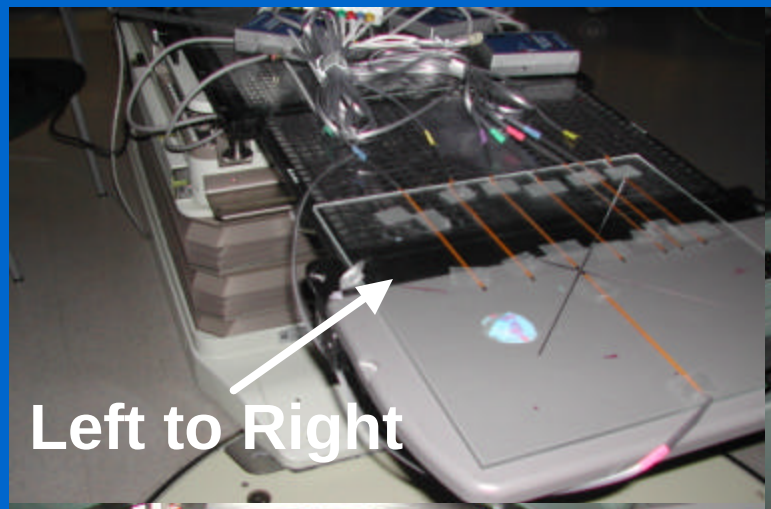


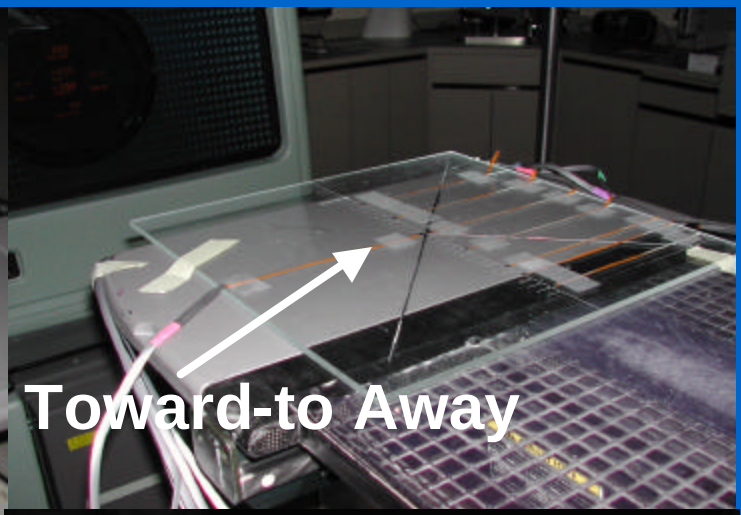
Device Used to Measure Off-Axis Factors in Air

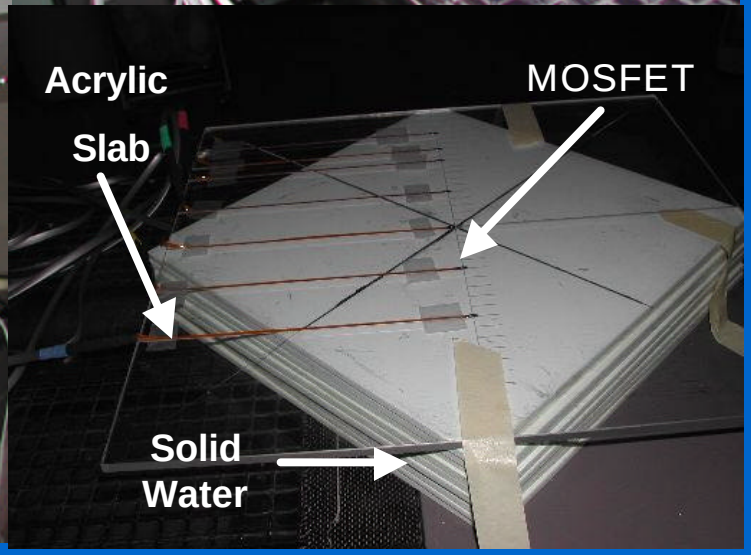




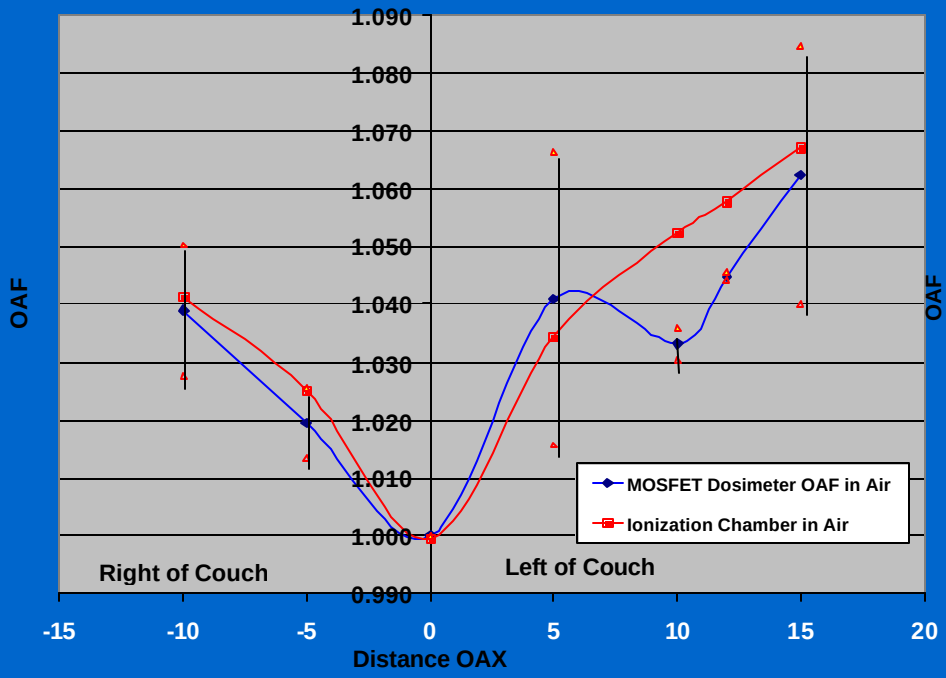
Device used to Measure Off-Axis Factors in Air



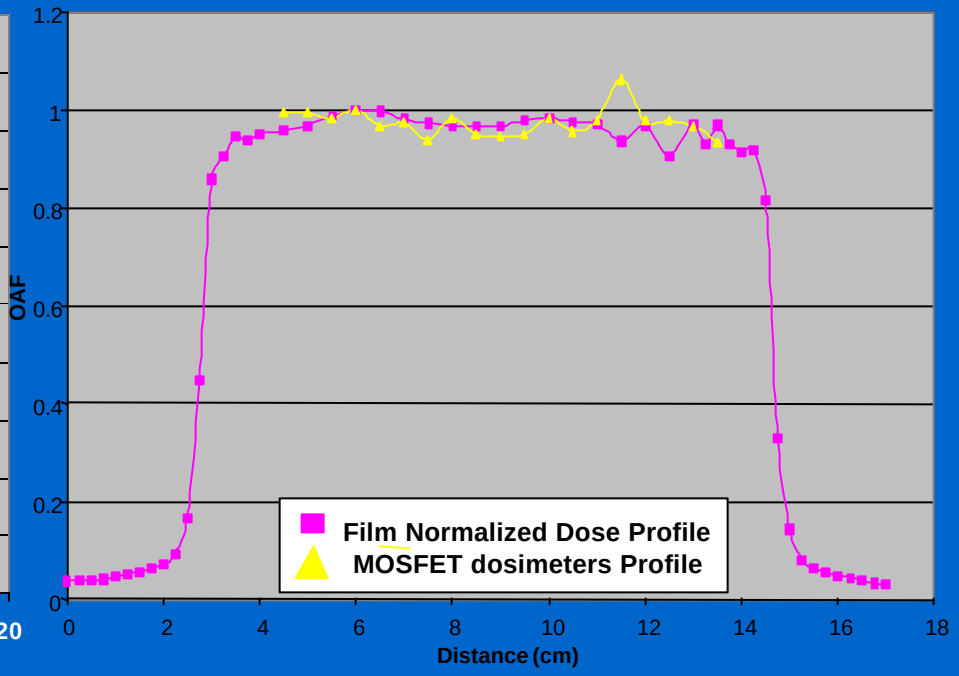




In Air Measurements



Off-Axis Factor MOSFET dosimeters
vs.
Ionization Chamber 6 MV photons



Film Normalized Dose Profile vs.
19 MOSFET dosimeters Profile

RESULTS

- The standard deviation of calibration measurements was within 1% to 1.5% of the mean.
-
- Measurement of PPD were made for 6, 10, 20, and 30 cm square field sizes. Results were within 3% of the mean.
- OCR, OAF, and wedge profiles were within 2% to 3% of the mean.

Conclusions

Preliminary results show the feasibility of using arrays of MOSFET dosimeters to acquire simultaneously several point measurements to reassemble photon and electron beam dosimetry parameters.

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