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BIOLOGICAL AND CLINICAL DOSIMETRY

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BIOLOGICAL AND CLINICAL DOSIMETRY

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BIOLOGICAL AND CLINICAL DOSIMETRY

ABSTRACT

Several major dosimetric intercomparisons were carried out during the last year. At the National Institute of Radiological Sciences, Chiba-shi and the University of Tokyo, Tokyo, Japan, calorimetric and ionimetric intercomparisons of dose were performed. Similar measurements were also carried out at the Lawrence Berkely Laboratory, Los Alamos, and Harvard. The measurements of the thermal defect for A-150 plastic were completed and an average value of $(4.1 \pm 0.3)\%$ was found. Preliminary measurements using a cryogenic calorimeter were carried out at Lawrence Livermore National Laboratory. The first measurement of the event size distribution for 20-MeV neutrons was carried out at Ohio University and an interesting difference between the measurement and theoretical calculations was found. The measured fraction of events due to alpha particles was found to be significantly lower than the fraction predicted by the calculation of Caswell and Coyne.

BIOLOGICAL AND CLINICAL DOSIMETRY

INVESTIGATORS TIME & EFFORT ON PROJECT

The principal investigator has devoted approximately 15% of his time and the co-principal investigator approximately 50% of his time to the projects described herein. These percentages are not expected to change during the remainder of the current term.

I. SUMMARY

Our research during the last year has yielded measurements of the product of the stopping power ratio between chamber wall and gas $S_{w,g}$ and W_n , the average energy expended per ion pair formed in methane-based tissue-equivalent (TE) gas, in a number of radiation beams. Several significant developments in the technology of calorimetric dosimetry were achieved. In addition, unique microdosimetric measurements were carried out.

The major research accomplishments of this year were as follows:

- 1) Intercomparison of TE ionization chamber measurements to the Sloan-Kettering (SKI) TE calorimeter at two neutron therapy facilities in Japan.
- 2) Calorimetric intercomparison at Hammersmith Hospital and the Gray Laboratory.
- 3) Intercomparison of TE ionization chamber measurements in the charged particle radiotherapy beams at Lawrence Berkely Laboratory, the Los Alamos Meson Physics Facility, and the Harvard Cyclotron Laboratory.
- 4) Preliminary measurements of the kerma in carbon for 15-MeV neutrons were carried out at the Lawrence Livermore National Laboratory.
- 5) Measurements of the thermal defect for A-150 plastic were completed.
- 6) The first measurement of the event-size distribution for a 20-MeV neutron beam was carried out.

II. CALORIMETRIC DOSIMETRY

A. Neutron Dosimetry Intercomparison in Japan

During April of 1980, an international dosimetry intercomparison was carried out at The National Institute of Radiological Sciences, (NIRS) Chiba-shi and the University of Tokyo (UT), Tokyo, Japan. Participants included Joseph McDonald and I-Chang Ma of our Laboratory, K. Kawashima, T. Hiraoka and K. Hoshino of NIRS and A. Ito of UT. Measurements of absorbed dose per monitor unit in the clinical neutron beams were made using the SKI portable tissue equivalent calorimetric system and a variety of ionization chambers. The equipment, techniques, and methods of dose computations in Japan are slightly different than in the U.S., therefore, this intercomparison provided an opportunity to evaluate the difference that might exist in dosimetry.

Our chambers were calibrated at the Memorial Regional Calibration Laboratory which is one of the U.S. counterparts of the Japanese secondary standards laboratory. The measurements of exposure using the Memorial calibrated chambers and the NIRS-calibrated chambers were in agreement to better than one per cent. UT agreement to about one per cent was also found.

At NIRS, TE ionization chambers have been designed and constructed of a TE plastic mixture similar to A-150 plastic. This same mixture was used at UT to construct a spherical ionization chamber similar to the IC-17 chamber. Agreement of exposure measurements demonstrates that although the dosimeters are not identical and are constructed of a slightly different plastic, the measurements were still consistent.

The computation of neutron dose in Japan is also carried out differently than in the U.S. The U.S. Neutron Dosimetry Protocol (1) has been developed from material outlined in ICRU Report 26 (2) and then the experience of the Fast Neutron Dosimetry Physics Task Group. In Japan, neutron dosimetry seems to follow closely the methods of ICRU Report 26. In spite of small differences in physical parameters used and methods used to compute dose, the agreement in the final computation of neutron dose was good, with about 2-3%.

Results of our measurements at the National Institute of Radiological Sciences are shown below:

⁶⁰Co Measurements Free-in-air
10 x 10 cm field at 80 cm SAD

<u>Chamber</u>	<u>IC-17</u>	<u>IC-18</u>	<u>T-2</u>
HV	+250	+250	+250
Gas	TE	TE	TE
Set Exposure for 2 min.	86.8	86.8	86.8 (R)
Measured Response	2.983×10^9	2.322×10^{10}	5.404×10^9 (R/C)
Memorial	2.995×10^9	2.305×10^{10}	5.415×10^9

Neutron Beam Free in air
11.4 x 11.4 cm field at 200 cm SAD

<u>Chamber</u>	<u>IC-17</u>	<u>IC-18</u>	<u>T-2</u>
Electrometer	NIRS	NIRS	NIRS
W_n/W_e	1.064	1.064	1.064
S_n/S_e	1.00	1.00	1.00
A-150 Dose per mu	67.34	66.64	67.16 (rad)

Neutron Beam in Phantom
11.4 x 11.4 cm field

<u>Chamber</u>	<u>PPC</u>	<u>IC-17</u>	<u>T-2</u>	<u>PPC</u>	<u>IC-17</u>
Electrometer	NIRS	NIRS	NIRS	NIRS	NIRS
SAD	200	200	200	175	175 (in air)
W_n/W_e	1.064	1.064	1.064	1.064	1.064
S_n/S_e	1.00	1.00	1.00	1.00	1.00
A-150 Dose per mu	62.75	62.64	62.67	86.24	81.51
Calorimeter Dose/mu		63.58		82.78	

Estimated Uncertainty for Calorimeter $\pm 2.5\%$

Note: Displacement Correction for IC-17 taken as 0.97.

The following results were obtained at the University of Tokyo.

^{60}Co Free in Air
10 x 10 cm field at 80 cm SAD

<u>Chamber</u>	<u>IC-17</u>	<u>T-2</u>	<u>IC-17</u>	<u>T-2</u>
HV	+250	+250	+250	+250
Gas	Air	Air	TE	TE
Electrometer	IMS Keithley Model 602			
Exposure Calibration	3.461	6.242	2.965	5.340
Memorial Calibration	3.504	6.334	2.995	5.414 $(\times 10^9 \text{ R/C})$

Estimated Uncertainty $\pm 2\%$
Response Ratio Air/TEG = 1.17

Neutron Beam Free in Air
10 x 10 cm field at 80 cm SAD

<u>Chamber</u>	<u>T-2</u>	<u>T-2</u> (build-up cap)	<u>IC-17</u>
Corrected Response	4.163	4.179	7.359 $(\times 10^{10} \text{ C/mu})$
W_n/W_e	1.062	1.064	1.064
S_n/S_e	1.00	1.00	1.00
A-150 Dose/mu	2.262	2.271	2.210

Estimated Uncertainty $\pm 3.5\%$

Neutron Beam
5 cm deep in A-150 plastic phantom

<u>Chamber</u>	<u>SKI Parallel Plate</u>	<u>IC-17</u>
Corrected Response	5.128×10^{-10}	$6.402 \times 10^{-10} \text{ (C/mu)}$
W_n/W_e	1.064	1.064
S_n/S_e	1.00	1.00
A-150 Dose/mu	1.824	1.865
Calorimeter A-150 Dose/mu	1.852	

B. Neutron Dosimetry Intercomparison in England

During this report period, we also carried out an intercomparison of calorimetric and ionimetric dosimetry at the Hammersmith Hospital neutron therapy facility in London, England. Ionization chamber measurements were carried out in the neutron beam and comparisons were made to the calorimeter. Agreement between all the measurements was within about 2%, giving confidence to the techniques used by the participants.

Participants included physicists from the following organizations:

Medical Research Council, Cyclotron Unit, Hammersmith Hospital,
London (MRC)
Western General Hospital, Edinburgh (WGH)
Memorial Sloan-Kettering Cancer Center, New York (SKI) and
CENDOS

The conditions of the intercomparison were as follows:

Neutron beam: d(16.7 MeV) + Be.

Field Size: 10 cm x 10 cm.

TSD: 135 cm.

T.E. gas: Supplied by M.R.C.

Measurement Conditions: 1) 2.3 cm deep in T.E. phantom block for comparison with calorimeter (SKI).

2) In air.

Dosimeters 1) SKI Parallel plate 0.8 cc T.E. chamber.

2) WGH Exradin T2 0.5 cc T.E. chamber.

3) MRC Exradin T2 0.5 cc T.E. chamber.

Polythene/air chamber (in air only).

Energy compensated Geiger Muller counter.

4) CENDOS Exradin T2 0.5 cc T.E. chamber.

E.G. & G. 1cc T.E. chamber)

TNO chamber) in air only

French chamber)

Gamma calibrations: 'Home' calibration factors used.

Physical data used by all participants:

$W_c : 0.95, (S_{m,g})_c : 1.00, (S_{m,g})_N : 1.00, K_m/K_t : 1.031$
 $\overline{WN}$

$k_T : 0.979, k_u : 0.007, h_u = h_T = 1.00$

RESULTS

MEASUREMENTS IN T.E. PHANTOM

INSTITUTE	CHAMBER	K(elect)	OBSERVED nc	CALIBRATION RAD/nc	R_T^1	R_U^1	D_N	D_G	D_T
SKI	Parallel Plate	1.003	0.2934	3.351	0.997	0.059	0.965	0.052	1.017
SKI	T2	1.003	0.1962	5.13	1.014	0.059	0.983	0.052	1.035
WGH	T2	1.000	0.1951	5.179	1.024	0.059	0.993	0.052	1.045
MRC	T2	0.992	0.1973	5.274	1.044	0.059	1.014	0.052	1.066
SKI	T2	1.003	0.1955	5.13	1.011	0.059	0.980	0.052	1.033
MRC	EG & G		0.3188	3.204	1.025	0.059	0.995	0.052	1.047
MRC	T2	0.992	0.1973	5.274	1.033	0.059	1.003	0.052	1.055
SKI	CALORIMETER								1.025
MRC	EG & G		0.3188	3.204	1.014	0.059	0.983	0.052	1.035

MEASUREMENTS IN AIR

INSTITUTE	CHAMBER	K(elect)	OBSERVED nc	CALIBRATION RAD/nc	R_T^1	R_U^1	D_N	D_G	D_T
MRC	Polythene	1.000	0.1291				0.919		
MRC	T ₂	0.991	0.1868	5.274	0.976	0.038	0.965	0.032	0.997
WGH	T ₂	1.000	0.1835	5.179	0.950	0.038	0.939	0.032	0.971
SKI	T ₂	1.003	0.1865	5.13	0.954	0.038	0.942	0.032	0.974
MRC	T ₂	0.991	0.1858	5.274	0.971	0.038	0.960	0.032	0.992
MRC	EG & G			3.204	0.956	0.038	0.994	0.032	0.976

A measurement of the absorbed dose and gamma-ray contaminant in the d(4) Be neutron beam at the Gray Laboratory, Northwood, England was also carried out. These measurements provided values of dosimetric parameters at a lower energy than previously available. (3-5)

Dosimetry measurement were carried out in a d(4)Be neutron field using tissue equivalent (TE) ionization chambers and a TE calorimeter in a TE plastic phantom. The photon dose fraction was measured using two types of Geiger-Mueller (G-M) dosimeters. Good agreement was found in the absorbed dose as determined by the use of three types of ionization chambers: spherical, thimble-shaped, and parallel plate. Measurements with the parallel plate chamber and the calorimeter yielded a value for the ratio of absorbed dose to specific charge, which is proportional to the product of the stopping power ratio for secondary charged particles in the chamber wall and gas, and W , the average energy expended in the gas per ion pair formed. The value of this ratio for the d(4)Be field studied was found to be 31.9 ± 0.7 . (2,8)

The total dose computed for each of the chambers in the phantom at a depth of 2.3 cm of A-150 plastic in terms of A-150 dose per monitor unit is as follows:

Graylab IC-17	=	0.1232	A-150 rad/mon unit
SKI T-2	=	0.1240	A-150 rad/mon unit
Graylab T-2	=	0.1233	A-150 rad/mon unit

C. Charged Particle Measurements in the U.S. and Japan.

The second tissue equivalent calorimeter developed in our laboratory specifically for measurements in charged particle beams was used for dosimetry intercomparison measurements at the Lawrence Berkely Laboratory, the Los Alamos Meson Physics Facility, the Harvard Cyclotron Laboratory and at the NIRS in Japan. In the U.S. most of the ionization chambers compared to the calorimeter were manufactured by Far West Technology (formerly by E.G. and G.). These were the thimble shaped type IC-18 chambers. The charged particle beams included: 900 MeV helium nuclei, 474 MeV/ μ carbon nuclei, negative pions, 160 MeV protons, and 70 MeV protons.

1. Pions

Absorbed dose is determined by the calorimeter directly; Q_p is measured by the ionization chamber and electrometer; M_g is determined by calibration of the ionization chamber on a ^{60}Co beam whose exposure calibration is traceable to NBS and by mechanical measurements of the chamber volume. The quantity of interest is the product of the average energy expended per unit charge in the gas cavity and the gas-to-wall conversion factor. This product is given by,

$$\frac{W_p \cdot (S_{w,g})_p}{e} = \frac{D_{w,p} \cdot M_g}{100 Q_p}$$

$D_{w,p}$ = absorbed dose in rads in the A-150 plastic chamber wall due to pions.

Q_p = measured ionization charge (C).

M_g = the mass of gas in the cavity (kg)

W_p/e = the average energy expended per unit charge in the gas cavity (J/C)

$(S_{w,g})_p$ = the gas-to-wall conversion factor

Since the gas-to-wall conversion factor, $(S_{w,g})_p$ is expected to be near unity the values for $\frac{W_p \cdot (S_{w,g})_p}{e}$ will be within a few percent

of the values for W_p/e . In this manner we have an experimental determination of a quantity which is difficult to calculate because of the lack of detailed information concerning the energy fluence of the multiplicity of charged particle types interacting with the cavity gas.

The following table show the experimentally determined values obtained for A-150 plastic and methane-based TE gas.

SKI RESULTS

$$\frac{W_p \cdot (S_{W,G})_p}{e}$$

<u>Particle</u>	<u>Position</u>	<u>1979</u>	<u>1980</u>	<u>Mean</u>
π^-	Plateau (um)		29.5 ± 0.6	29.5 ± 0.6
π^-	Peak (um)	29.7 ± 0.5	30.3 ± 0.8	29.9 ± 0.5
π^-	Proximal peak		30.4 ± 0.7	30.4 ± 0.7
π^-	Distal peak		30.2 ± 1.0 29.7 ± 0.9	30.0 ± 0.7
π^+	Plateau (um)	29.5 ± 0.4	28.9 ± 0.7 29.1 ± 0.8	29.3 ± 0.3
π^+	Peak (um)	28.3 ± 0.4	28.6 ± 0.9	28.4 ± 0.4

Notes:

um refers to an un-modulated Bragg-peak.

Errors are sd of the mean. Includes random errors only.

The results for the NBS graphite calorimeter and ionization chamber are shown below. It is interesting to note that the value for positive pions in the peak in both the SKI and NBS data is lower than that for the plateau. Intuitively, one would expect it to be higher. However, the ratio, peak-to-plateau is 0.969 for the SKI TE-TE system and 0.967 for NBS carbon-air system, leading one to think that this may not be an anomaly. The explanation for this effect is not clear at the moment.

NBS Results

<u>Particle</u>	<u>Position</u>	$\bar{W}_p \cdot (S_{w,g})_p$
π^-	Peak (um)	34.2 ± 0.4 (1.2%)
π^+	Plateau	33.4 ± 0.4 (1.2%)
π^+	Peak	32.3 ± 0.4 (1.1%)

Uncertainties include 1.1% systematic added in quadrature to random errors.

2. Heavy Charged Particles

Using the same technique as described for the case of pi-mesons, similar sets of the product of $S_{w,g}$ and $\frac{W}{e}$ were computed for measurements carried out at the Lawrence Berkeley Laboratory. Two measurement situations were considered. Measurements were carried out first in the entrance region, and then just a few cm beyond the spread at Bragg-Peak in the 900 MeV helium ion and 474 MeV/u carbon ion beams. The results are shown in the Table below.

A-150 Plastic and Methane-Based TE Gas

<u>Particle</u>	<u>Positron</u>	<u>$\frac{W}{e} (S_{w,g})$</u>
Helium Ions	Entrance	29.7 ± 0.5
Helium Ions	Peak	29.8 ± 0.5
Carbon Ions	Entrance	29.6 ± 0.7
Carbon Ions	Peak	29.4 ± 0.6

3. Protons

Similar measurements were also carried out at the Harvard cyclotron Laboratory for 160 MeV protons and at the National Institute of Radiological Sciences in Japan using 70 MeV protons. The results from Harvard are still being analyzed, but the 70 MeV results can be presented here. Due to time constraints, only one geometry was available; that was for the spread-out Bragg-peak.

A-150 Plastic and Methane-Based TE Gas

<u>Particle</u>	<u>Positron</u>	<u>$\frac{W}{e} (S_{w,g})$</u>
70 MeV proton	Spread-out Bragg-Peak	30.2 ± 0.7

D. Measurements at the d-T Source in Livermore

Experiments were carried out in a mono-energetic 14.9-MeV neutron beam at Lawrence Livermore National Laboratory, California, where a comparison was made using ionization chamber, calorimeter, and fluence based absorbed dose determinations. (9-12)

Absorbed dose in A-150 plastic irradiated by 15-MeV neutrons was measured using three dosimetric methods: an A-150 plastic calorimeter, A-150 ionization chambers, and activation of gold foils. The dose determinations by the calorimeter and ionization chambers agreed to better than 1%, while the activation method yielded a 3.5% lower dose. The agreement between the methods is better than expected from the estimated uncertainties.

SUMMARY OF RESULTS

Measurements of Absorbed Dose in A-150 Plastic ($\mu\text{Gy}/\text{Monitor Count}$)

<u>Geometry</u>	<u>Dosimeter</u>	<u>Total Dose</u>	<u>Neutron Dose</u>
Open	IC-17 Spherical Chamber	2.99	2.89
	Parallel Plate Chamber	(3.06)	(2.95)
	Gold Foil	-	2.79
In Phantom	Calorimeter	2.98	2.85
	IC-17 Spherical Chamber	(3.04)	(2.85)
	Parallel Plate Chamber	2.97	2.79
	Gold Foil	-	(2.22)

III. NEW CALORIMETER CONSTRUCTION

A. Spherical Calorimeter

The small spherical calorimeter described in our last progress report was modified to house a graphite absorber. The core diameter was one centimeter and the thickness of the adiabatic jacket surrounding the core was 2mm. These dimensions provide sufficient material for charged particle equilibrium and enough mass for reasonable thermal equilibrium.

This calorimeter was used to measure kerma in graphite irradiated by 15-MeV neutrons at Livermore. Unfortunately, when the measurements were attempted, there were problems with thermal regulation and large drifts were present. The data obtained were not good enough to obtain reasonable answers. The system is now being worked on and we hope to have the problem solved soon so that the experiment can be repeated.

B. Cryogenic Calorimeter

During this report period, initial testing of a prototype for a cryogenic calorimeter was carried out. The cryostat has some useful features as well as some disadvantages. The small size, rugged construction and built-in vacuum pump make it possible to maintain the absorber at 77 K with a minimum of equipment. However, the fact that the cryostat is stainless steel causes two problems. It introduces a scatter component which is difficult to evaluate, and it becomes radioactive when exposed to an intense fast neutron flux.

Measurements in our laboratory indicated that stability could be achieved within a few hours. Vacuum was well below 10^{-5} Torr, and the core thermistor resistance was at the proper value. The first field measurements were not successful.

The cryostat and ancillary equipment were brought to the 15-MeV neutron facility RTNS-I at Lawrence Livermore National Laboratory, Livermore, California. After successful pump down and equilibrium at 77 K overnight, the absorber was lowered away from the nitrogen reservoir into the irradiation positron. Stability was never achieved after this time leading us to suspect that some internal damage was sustained during transit.

The unit is now being inspected and tested for the cause of this problem, and a second unit is also being worked on. The cause of the problem is not clear at present, but there is no reason to suspect that the unit will not work as planned.

IV. THERMAL DEFECT MEASUREMENTS

Measurement of the Thermal Defect for A-150 Plastic

The quantity of deposited energy not resulting in the production of heat in irradiated A-150 plastic was measured calorimetrically. Several plastic samples, molded at different laboratories, were studied to determine whether differences in thermal defect existed. In addition, samples deliberately molded at extremes of temperature and pressure were used. Irradiations were carried out using protons accelerated to energies of 0.5, 1.7, and 4.0 MeV, and helium -3 ions of 4.0 MeV. It was found that there were no measurable differences in thermal defect for A-150 samples prepared at different laboratories or with different molding methods. No dependence on particle energy or type or accumulated absorbed dose could be discerned over the ranges used in these experiments. The average value of the thermal defect found for A-150 plastic irradiated by the aforementioned charged particles was $(4.1 \pm 0.3)\%$.

The Table below includes the values obtained using helium -3 ions; and the computed average value. The absence of dependence upon ionization density is evident since the initial LET of the 4 MeV protons was approximately 9 keV/ μm , whereas the 4 MeV helium -3 ions had an initial LET of about 90 keV/ μm .

In order to test the system and to test the hypothesis that the aluminum face of our absorber had no thermal defect, it was compared to platinum and gold. To our knowledge, there is no mechanism at room temperature which would allow for a thermal defect in either gold or platinum. Energy storage in these materials at room temperature is virtually zero.

The values of gold relative to aluminum for protons or helium -3 ions is essentially zero. In addition, the response to radiation was nearly identical to that observed using an equal amount of electrical power from the calibration heater.

The value of $(4.1 \pm 0.3)\%$ for the thermal defect of A-150 plastic irradiated by the charged particles employed in this experiment is probably appropriate to other types of radiations since the ionization densities of the charges particles employed covered a larger range, and the thermal defect did not change by an amount larger than the measurements.

Experimentally Determined Values for Thermal Defect
for
A-150 Plastic

<u>Particle</u>	<u>Thermal Defect</u>
0.5-MeV protons	$(3.2 \pm 0.3)\%$
1.7-MeV protons	$(4.6 \pm 0.6)\%$
4.0-MeV protons	$(4.0 \pm 0.3)\%$
4.0-MeV helium -3 ions	$(3.2 \pm 0.3)\%$

Average Value = $(4.1 \pm 0.3)\%$

(n = 25)

IV. MICRODOSIMETRIC MEASUREMENTS

Measurements of event-size distributions in lineal energy were carried out using nearly monoenergetic neutrons whose principal energies were 8, 20, and 25-MeV. The commercially produced spherical A-150 plastic walled proportional counter employed (E.G. & G. LET- $\frac{1}{2}$), was filled to a pressure of approximately 33 Torr with propane based tissue equivalent (TE) gas, thereby stimulating an effective counter diameter of approximately 1 μm . Neutrons were produced by bombarding a small tritium gas cell with 9.0-MeV protons, 3.95-MeV and 8.11-MeV deuterons, yielding approximately 8, 20, and 25-MeV neutrons, respectively. The neutron energy spectra were measured using conventional time-of-flight techniques. (22)

The fraction of gamma-rays present in these neutron fields was estimated from the time-of-flight spectra and the dose due to events below about 20 $\text{keV}\cdot\mu\text{m}^{-1}$ recorded by the proportional counter. The event-size distribution measured for 20-MeV neutrons was compared to recent theoretical calculations by Caswell and Coyne and the value of $\bar{y}_D$ for this energy was measured to be 106 $\text{keV}\cdot\mu\text{m}^{-1}$ assuming a 1 μm effective site diameter. The measured distribution revealed more detail in the region from 100 to 500 $\text{keV}\cdot\mu\text{m}^{-1}$, where the proton and alpha edges are clearly visible and distinct. In addition, the measured spectrum contained significantly fewer events due to alpha particles than the calculated spectrum. (19-21)

The event-size distribution for 20-MeV neutrons, in a 1 μm simulated cavity is shown in Figure 1 along with the calculation of Caswell and Coyne. The value of $\bar{y}_D$ for the measured distribution was found to be 106 $\text{keV}\cdot\mu\text{m}^{-1}$, whereas the calculated value for $\bar{y}_D$ is 125 $\text{keV}\cdot\mu\text{m}^{-1}$. The measured distribution reveals more detail in the region between 100 and 500 $\text{keV}\cdot\mu\text{m}^{-1}$, where the proton and alpha edges are both resolved. The number of events due to densely ionizing charged particles in this region is less than the calculation.

20 MeV neutrons $d = 1 \mu\text{m}$

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PUBLICATIONS AND PRESENTATIONSMANUSCRIPTS:

1. "Calorimetric and Ionimetric Dosimetry Intercomparisons, I: U.S. Neutron Radiotherapy Centers", J. McDonald, I. Ma, J. Liang, J. Fenmaa, M. Awschalown, J. Smathers, R. Graves, L. August and P. Shapiro (accepted for publication, Medical Physics, 1980).
2. "Calorimetric and Ionimetric Dosimetry Intercomparisons, II: d-T Neutron Generator at the Antoni van Leeuwenhoek Hospital" J. McDonald, I. Ma, B. Mijnheer and J. Zoetelief (accepted for publication, Medical Physics, 1980).
3. "Some Characteristics of Commercial Ionization Chambers", J. McDonald, I. Ma and J. Liang., Proc. Workshop on Ionization Chambers for Neutron Dosimetry, Rijswijk, The Netherlands, Sept. 1979.
4. "Displacement Correction Factor for TE Ionization Chambers" J. McDonald, I. Ma and J. Liang, Proc. Workshop on Ionization Chambers for Neutron Dosimetry, Rijswijk, The Netherlands, Sept. 1979.
5. "Comparison of Dose Determinations for 15-MeV Neutrons", J. McDonald, H. Barschall and R. Howell (submitted to Medical Physics, 1980). *Removed*
6. "Measurements of the Thermal Defect for A-150 Plastic", J. McDonald and L. Goodman (submitted to Physics in Medicine and Biology, 1980). *Removed*
7. "Neutron Dosimetry Intercomparisons at the National Institute of Radiological Sciences", Joseph C. McDonald and I-Chang Ma, SKI Internal Report, Chiba-shi, Japan, 1980.
8. "Neutron Dosimetry Intercomparison at the Institute for Medical Sciences", Joseph C. McDonald and I-Chang Ma, SKI Internal Report, University of Tokyo, Tokyo, Japan, 1980.

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1. "Calorimetric Dosimetry in Neutron and Charged Particle Beams". J. McDonald, I. Ma and J. Laughlin, Eur. J. Cancer, Supplement Pergamon Press (Oxford) 159-160, 1979.
2. "Absorbed Dose Measurements Using Parallel Plate Polysytrene Ionization Chambers in Polystyrene Phantoms", J. Holt, A. Buffa, D. Perry, I. Ma and J. McDonald. Int. J. Rad. Oncol. Bio. Phys. 5:2031-2038, 1979.

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PRESENTATIONS

John S. Laughlin

1. Invited Presentation on Recent Advances in Medical Physics, University of Tokyo, Tokyo, Japan, March 1980.

Joseph C. McDonald

2. Invited Seminar, "Calorimetric Dosimetry" at the Physikalische Technische Bundesanstalt, Braunschweig, W. Germany, Nov. 1979.
3. "Neutron Dosimetry Intercomparison Measurements using a TE Calorimeter" presented at Hammersmith Hospital, London, England, Nov. 1979.
4. "Microdosimetric Measurements and Their Implications for Radiological Research" Seminar at Ohio University, Jan. 1980.
5. Invited Presentation, "Recent Advances in Calorimetric Dosimetry", Presented at Radiation Research Society Meeting, New Orleans, May, 1980.
6. Seminar on Mammography Dosimetry at the Radiation Effects Research Foundation, Hiroshima, Japan, April, 1980.