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RESULTS OF ORNL MEASUREMENTS MADE DURING THE INTERNATIONAL NEUTRON DOSIMETRY INTERCOMPARISON MARCH 19—30, 1973

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OAK RIDGE NATIONAL LABORATORY

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RESULTS OF ORNL MEASUREMENTS MADE DURING THE INTERNATIONAL NEUTRON DOSIMETRY INTERCOMPARISON - MARCH 19-30, 1973

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1.0 BACKGROUND

The Radiation Research and Development Section of the Health Physics Division at ORNL participated in the International Dosimetry Intercomparison (INDI) on March 19 through 30, 1973, at the Brookhaven National Laboratory. The intercomparison measurements were made at the Radiological Research Accelerator Facility (RARAF) which is operated by Columbia University. Several laboratories participated, however only the results of the ORNL group are included in this report.

At the RARAF a 4-MeV Van de Graaff accelerator was used to produce neutrons of several different energies. The reactions used were $^3H(d,n)^4He$ to produce 15.4-MeV (± 4%) neutrons, $^2H(d,n)^3He$ to produce 5.55-MeV (± 7%) neutrons, and $^3H(p,n)^3He$ to produce 2.12-MeV (± 5%) neutrons. In addition, a nominal 2-mg californium-252 source was used. The measurements included both neutron and gamma-ray kerma in air for each of the sources described above and absorbed dose in a water-filled phantom for the 15.4- and 5.55-MeV neutrons.

2.0 EXPERIMENTAL DETAILS

The experimental arrangement at the accelerator is shown pictorially in Fig. 1 and schematically in Fig. 2. The phantom was an open-topped Lucite cube filled with distilled water and having outside dimensions of 30 cm and walls 0.64 cm thick.

The primary normalization channel was an ionization chamber placed 5 cm from the accelerator target and directly in line with dosimeters used in the measurements. This ionization chamber was operated by the RARAF personnel who provided the normalization data from the chamber approximately two weeks after completion of the measurements. A secondary normalization was provided by a precision long counter located along the center line of the experiment 200 cm from the accelerator target. Information from this counter was not provided to participants. All results were to be expressed in terms of monitor counts obtained from the primary normalization channel.

All tissue kerma rates in free air were measured at the 30-cm position. In the case of the ^{252}Cf measurements, the source was placed at the position normally occupied by the accelerator target. Doses in the phantom were measured at depths of 5, 10, and 20 cm corresponding to distances of 25, 30, and 40 cm, respectively, from the target.

Gamma-ray kerma and absorbed-dose-rate measurements were made using a "Phil" Geiger counter[1] as shown in Fig. 3. A lithium shield was used

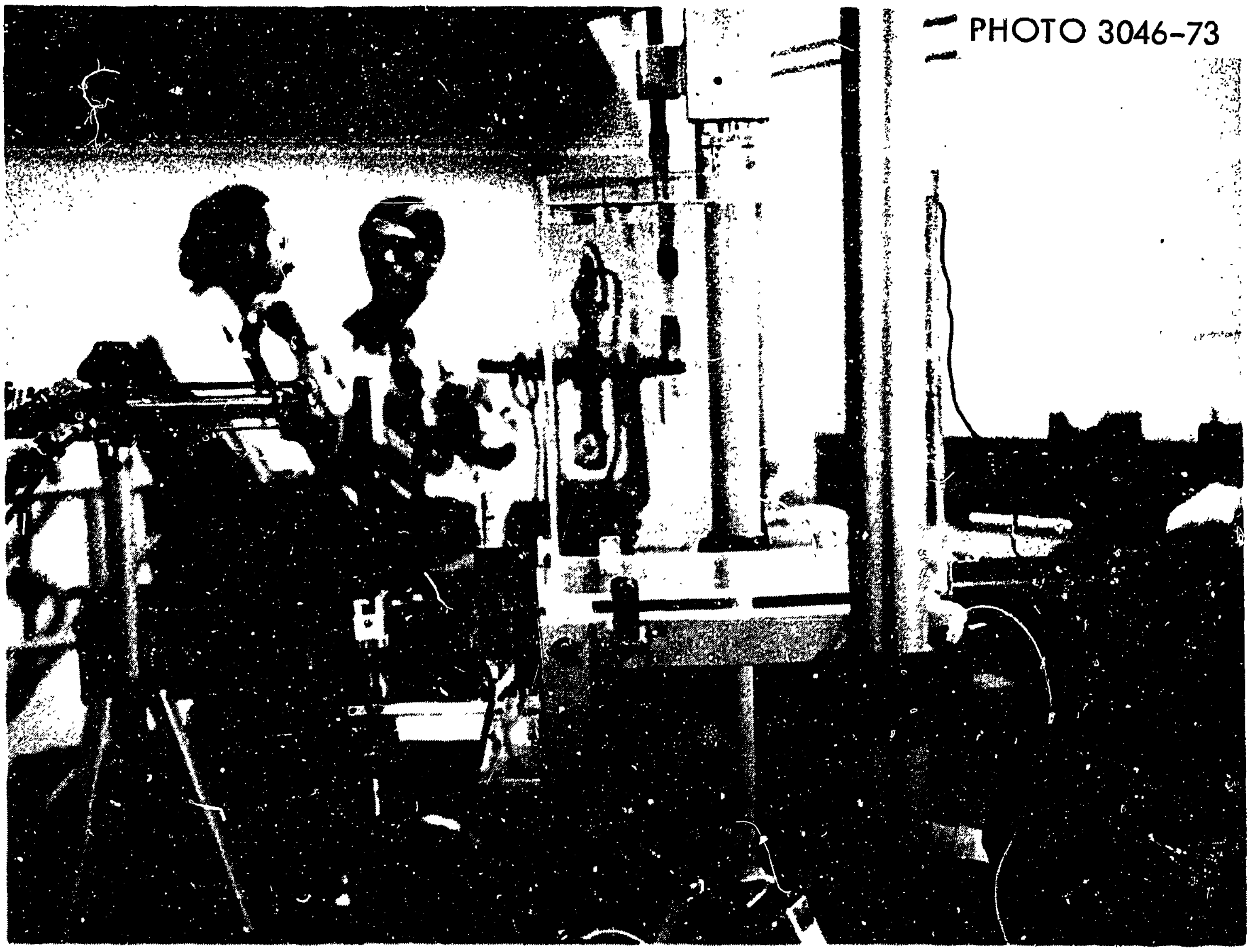

Fig. 1. Experimental Arrangement Showing a "Phil" Detector Located at the 30-cm Position in the Phantom

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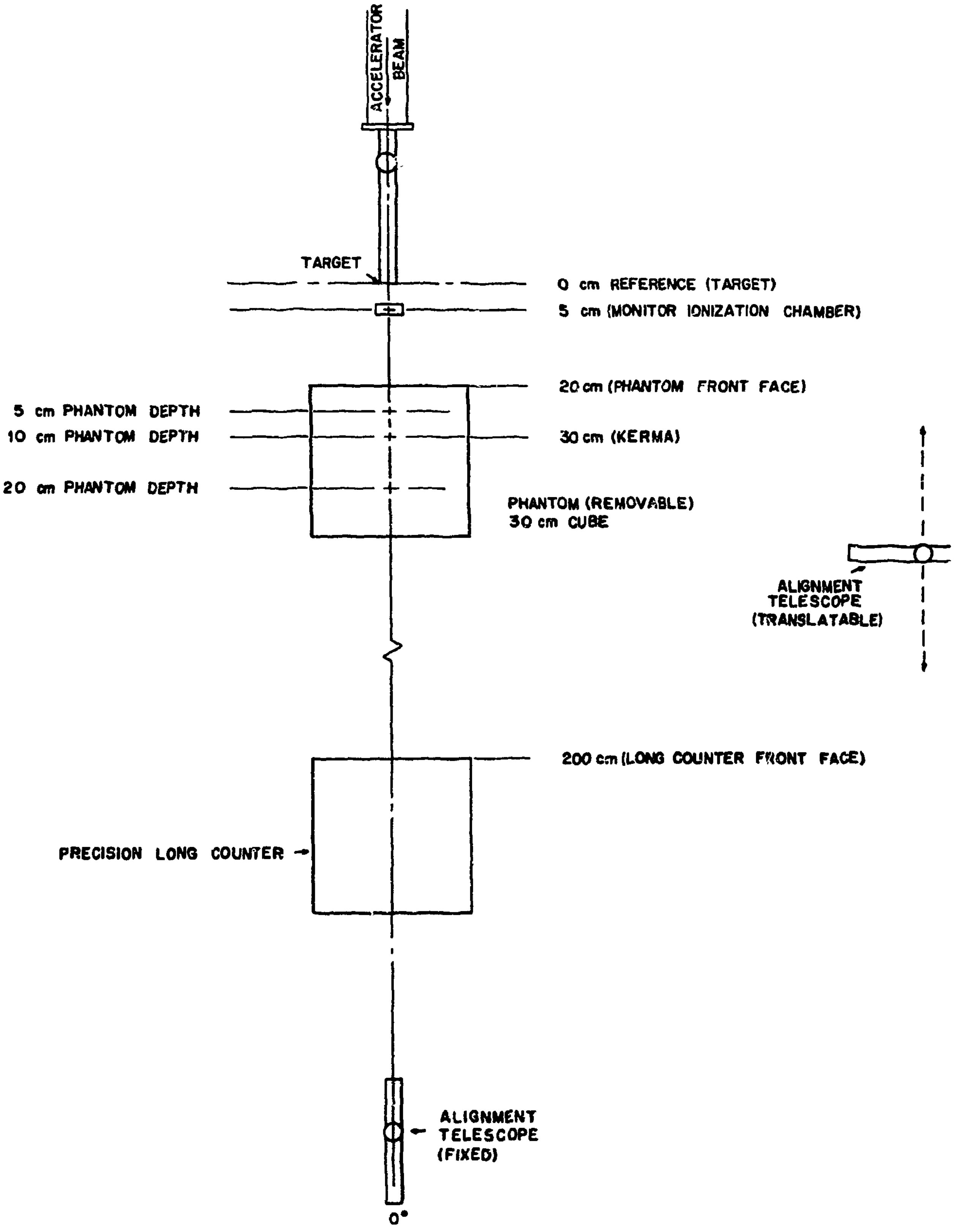

Fig. 2. Intercomparison Apparatus Arrangement, Top View

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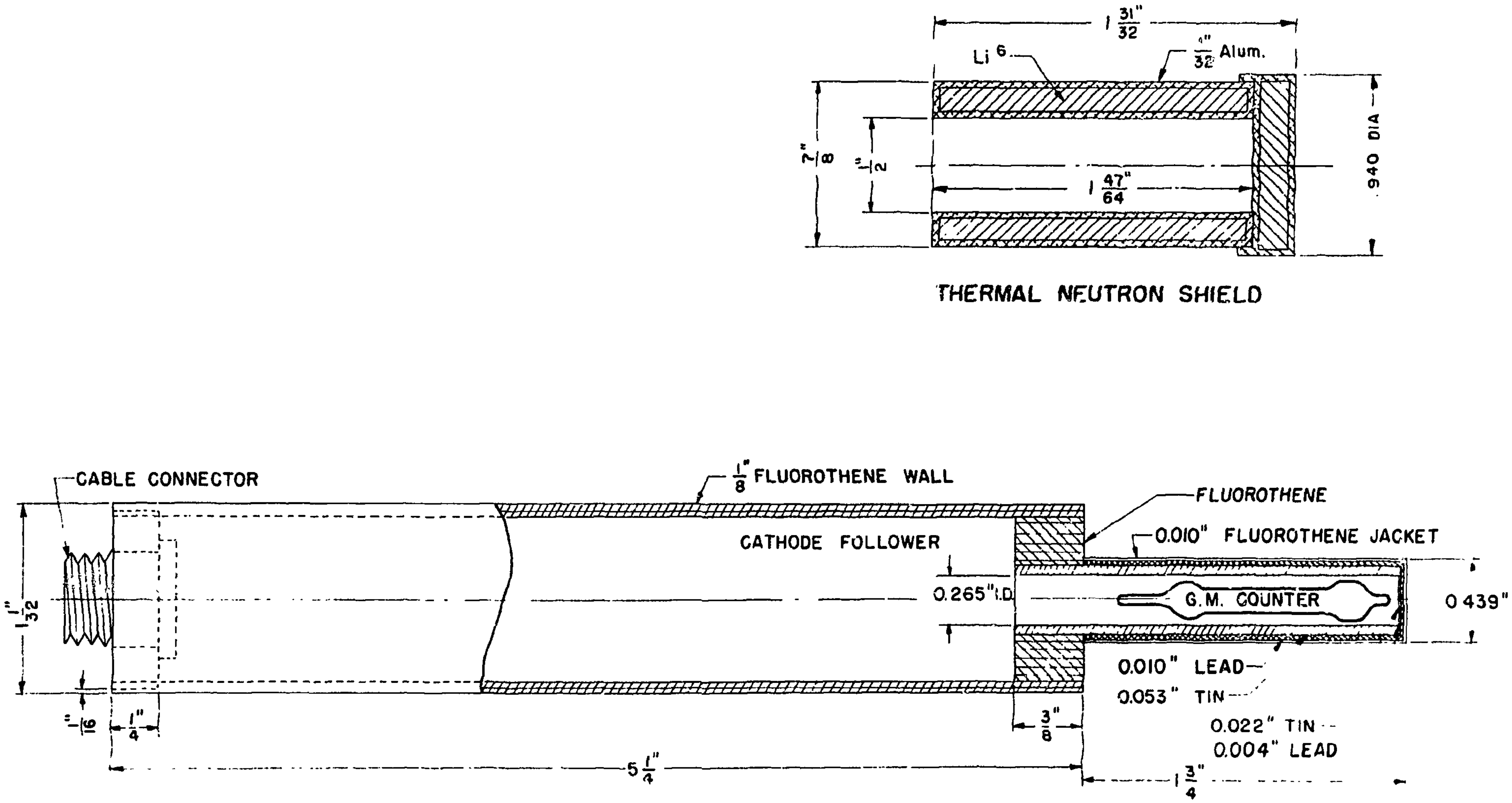

Fig. 3. Schematic Diagram of the "Phil" Geiger Counter

to reduce the thermal neutron response of the counter. This dosimeter was used because of its relative insensitivity to fast neutrons and because its size made it convenient for measurements within the phantom. The pulses from the Geiger tube were inverted and shaped with a preamplifier and recorded with a scaler-timer. The pulse rate from the counter is directly proportional to the absorbed dose or kerma in tissue.[2]

Neutron kerma and absorbed dose rates were measured with an in-phantom Hurst proportional counter[3] as shown in Fig. 4. The detector was operated with the instrumentation shown in the block diagram in Fig. 5. The absorbed dose is proportional to the size and number of pulses; therefore, the pulse height distribution from the detector was obtained with a 128-channel analyzer and recorded on paper tape for subsequent computer analysis.

3.0 DATA ANALYSIS

3.1 Gamma Measurements

The Phil Geiger counter was calibrated using both the ^{137}Cs source provided by RARAF and a ^{60}Co source from ORNL. Both sources had been calibrated previously by the National Bureau of Standards. Using an exposure-to-dose conversion factor of 0.956, the calibration with the ^{60}Co source gave 4.301×10^3 counts/mrad, while the ^{137}Cs source gave 3.800×10^3 counts/mrad. The difference of 13.1% could not be explained. Upon return to ORNL, the Geiger counter calibration was checked with two

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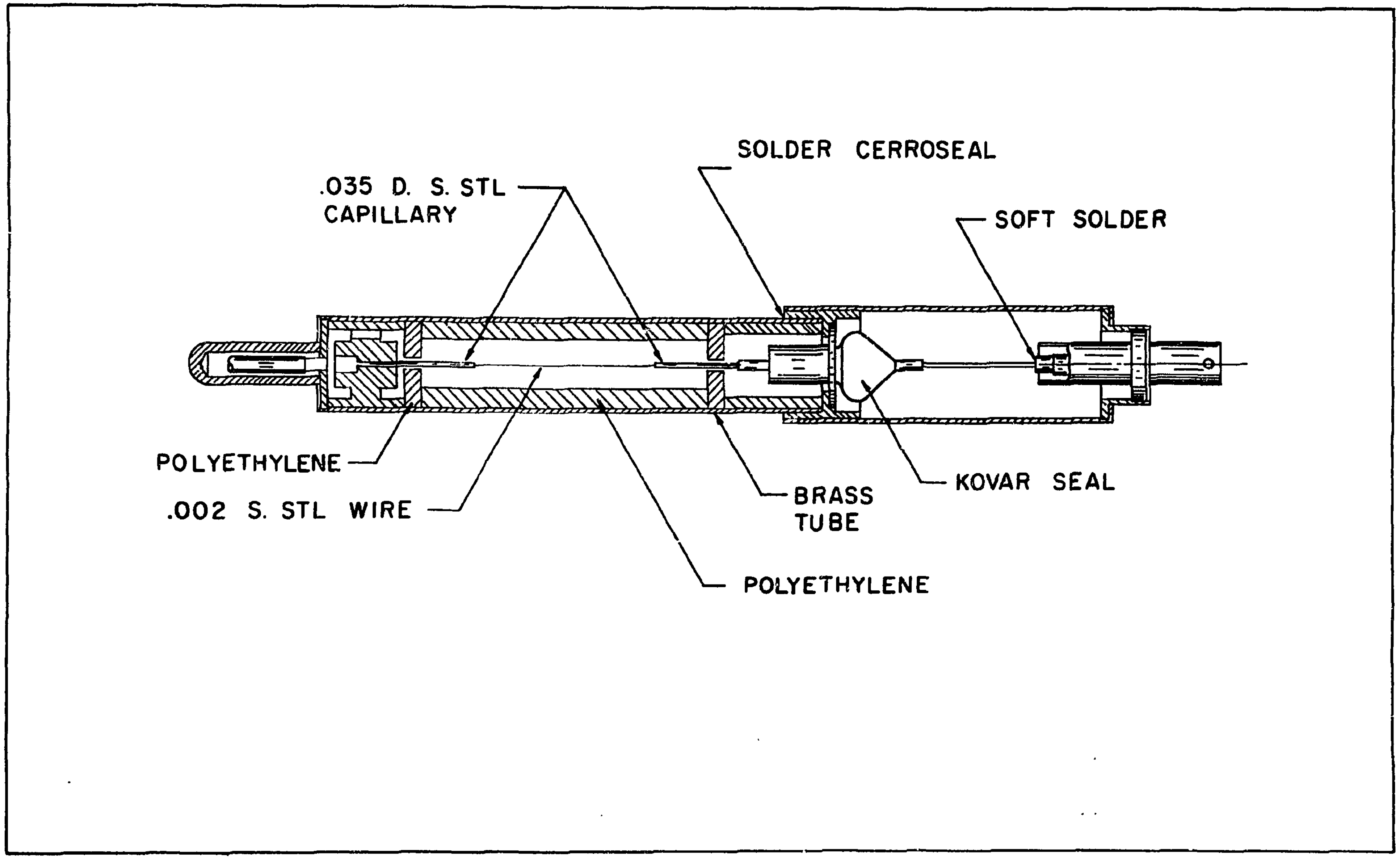

Fig. 4. Schematic Diagram of the Hurst Proportional Counter

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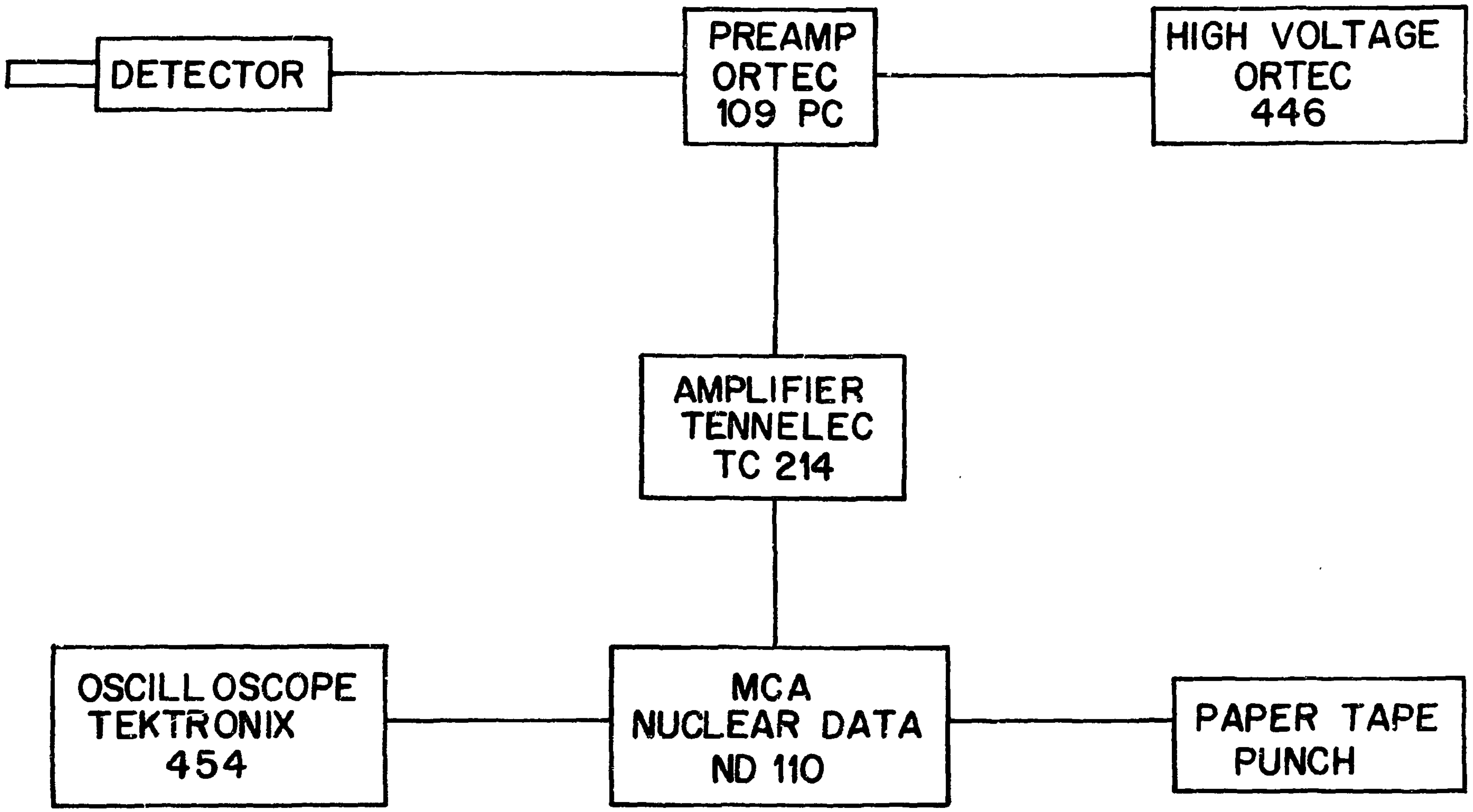

Fig. 5. Instrumentation Used with Hurst Proportional Counter

additional sources, a ^{137}Cs source and a ^{60}Co source. These calibrations agreed quite well with the previous ^{60}Co calibration.

The gamma data were analyzed using both calibrations; however, we shall report only the results for the original ^{60}Co calibration. The results can be normalized easily to the RARAF ^{137}Cs source by multiplying the gamma dose by 1.131.

At least three runs were made for each experimental setup, i.e., for each air and phantom position used for each source energy. In addition, a background measurement was made with the beam on the beam stop. Total counts for each run were recorded, a correction was made for counting losses due to the dead time of the Geiger counter, the background was subtracted, and finally the corrected net counts were divided by the calibration factor to yield the kerma or absorbed dose for each run. The ionization chamber monitor count for each run was eventually supplied by RARAF personnel. Total kerma or absorbed dose for each run was divided by the monitor count, and these results were averaged for each experimental position to provide the normalized kerma or absorbed dose. An exception was the ^{252}Cf measurements where no monitor was provided and the results were simply the measured kerma rate.

No corrections were made for detector geometry. The Geiger tube, being sufficiently small, was assumed to be a point detector located as accurately as possible at the desired distance from the source using the geometrical center. The Geiger tube in its shielded configuration does have an angular dependence; however, no correction was made since the spatial dependence of the radiation field around the detector was not known.

3.2 Neutron Measurements

Pulses from the Hurst counter were recorded using a multichannel analyzer that had a paper tape readout. The paper tape was read into a PDP-10 computer for analysis.

The pulse height distribution from the Hurst counter was due largely to neutron interactions; however, gamma radiation contributed to the low energy end of the spectrum. In order to determine only the neutron response, the computer program incorporated a stripping routine. The portion of the pulse height distribution due solely to neutrons was fitted with an exponential function using a least squares technique. Using the empirically derived function, it was possible to extrapolate to the low-energy end of the spectrum to yield an estimate of the neutron response in the gamma sensitive region. The result of this calculation was a modified pulse height distribution representing only the neutron response.

Using the modified pulse height distribution, the product of the counts in each channel and the channel number were taken and summed for the whole spectrum.

The counter was calibrated using an AmBe neutron source that had been standardized by NBS in terms of neutron yield, nominally 1.27×10^7 n/sec. This source produces a first collision dose rate of 1.46 mrad/hr at 1 m.

The calibration factor was determined by dividing the known dose from the calibration source by the weighted sum of the modified pulse height distribution as described above. The dose or kerma for each run was obtained by multiplying the weighted sum of the modified pulse height distribution for that run by the calibration factor.

Small corrections were applied to the measured dose or kerma for inverse square effects and angular dependence. The detector was placed with its geometrical center placed at the point where measurements were desired. An inverse square correction over the length of the chamber was made. Also, an angular dependence correction was made for the accelerator irradiations based on information provided by RARAF (see Appendix) on the relative kerma rate as a function of angle or distance off the central axis. The ^{252}Cf source was assumed to be isotropic, and only inverse square corrections were applied to the measurements of that source. These correction factors are listed in Table 1.

From two to four runs were made for each experimental setup. These runs were taken using different gain settings on the detector amplifier. In general, good agreement was obtained at the different gain settings and an arithmetic average of the measurements was used.

Table 1. Correction Factors Used with Hurst Proportional Counter

Energy	Position	Correction Factor		
		Inverse Square	Angular Dependence	Combined
15.4 MeV	30 cm in air	0.9964	0.9943	0.9907
	25 cm in phantom	0.9952	1.0	0.9952
	30 cm in phantom	0.9964	1.0	0.9964
	40 cm in phantom	0.9982	1.0	0.9982
5.55 MeV	30 cm in air	----	----	0.9872[a]
	25 cm in phantom	----	----	0.9688[a]
	30 cm in phantom	----	----	0.9770[a]
	40 cm in phantom	----	----	0.9926[a]
2.12 MeV	30 cm in air	0.9964	0.9857	0.9822
^{252}Cf	30 cm in air	0.9964	1.0	0.9964

[a]Only combined correction factors were calculated for the 5.55-MeV neutrons based on formulae given by RARAF (see Appendix).

4.0 EXPERIMENTAL RESULTS

The results of our measurements are presented in Table 2. With the exception of the ^{252}Cf source measurements, all results have been normalized to the RARAF ionization chamber monitor count.

5.0 ERROR ANALYSIS

Owing to the elaborate alignment system used by RARAF, it is doubtful if any significant error could be assigned to uncertainty in detector position. Any error in detector position should be consistent and would likely produce the same error in the measurements of all participants.

Corrections for inverse square effect and angular dependence of the field were 1% to 3% in magnitude. The error associated with these corrections is probably less than 1%. The angular dependence of the detectors themselves could introduce another error of as much as 5%.

Our detector calibrations were based upon the knowledge of source strengths. The sources carried NBS certification of ± 3% for the ^{60}Co source and a ± 2% for the AmBe source. There is an uncertainty of ± 5% in the flux-to-dose conversion factor for the AmBe source.[4] In addition, the statistics associated with the counting of these standard sources gives a 1% to 2% error in the count. The calibration error is thus ± 3.6% for the Phil counter and ± 5.7% for the Hurst counter. Counting statistics associated with the actual measurements all gave less than 1% standard deviation.

Table 2. Results of Measurements

Neutron Source	Position	Kerma or Dose (rad/monitor count x 10^7)		
		Neutron	Gamma	Total
15.4 MeV	30 cm in air	4.095	0.1592	4.254
	25 cm in phantom	4.581	0.5167	5.098
	30 cm in phantom	2.736	0.3938	3.130
	40 cm in phantom	0.9781	0.1963	1.174
5.55 MeV	30 cm in air	3.700	0.2328	3.933
	25 cm in phantom	5.075	0.4418	5.517
	30 cm in phantom	2.375	0.3347	2.710
	40 cm in phantom	0.4928	0.1586	0.641
2.12 MeV	30 cm in air	3.356	0.0549	3.411
^{252}Cf	30 cm in air	2.863[a]	1.699[a]	4.562[a]

[a]The californium measurements are in rad/hr.

For the Phil counter, no corrections were made for the neutron response of the detector. For the measurements in free air, the correction would be less than 0.5%;[1] however, in the phantom, it could be slightly higher due to the presence of thermal neutrons. It is estimated that in the worst case, the error in gamma dose would be less than 1% from this effect. Also, no corrections were made in the Phil counter data for the under-response of the detector for low-energy photons. The energy compensating shield reduces the detector response below about 200 keV.[1] The error from this source is estimated to be 5% in the case of phantom measurements and 1% in the case of measurements in air.

The correction applied to the Hurst counter for its gamma response assumes an exponential distribution of pulses in the low-energy end of the spectrum. This fitting technique could lead to errors of as much as 5%, depending upon the neutron spectrum and the level of associated gamma radiation.

In summary, it is estimated that the gamma measurements in the phantom should have an error of $\pm$ 8% and those in air should have an error of $\pm$ 6%. The error associated with the neutron measurements is $\pm$ 9%.

APPENDIX

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NEUTRON DOSIMETRY INTERCOMPARISON: KERMA RATE

VARIATIONS WITH ANGLE

$^{3}H(p,n)^{3}He$

Bombarding Energy - 3.0 MeV

Target No. 3HT-21

Object Size for Energy Spread Calculation - 0.01 cm

Beam Spot Diameter - 0.60 cm

Neutron Energy at Zero Degrees = 2.12 MeV $^{+5\%}_{-5\%}$

Angle (Degrees)	Neutron Energy (MeV)	Relative Kerma Rate
0.0	2.12	1.0000
0.5	2.12	0.9987
1.0	2.12	0.9962
1.5	2.12	0.9935
2.0	2.12	0.9907
2.5	2.12	0.9879
3.0	2.12	0.9851
3.5	2.12	0.9822
4.0	2.12	0.9794
4.5	2.11	0.9764
5.0	2.11	0.9735
5.5	2.11	0.9705
6.0	2.11	0.9675
6.5	2.11	0.9645
7.0	2.11	0.9615
7.5	2.11	0.9584

(continued)

Angle (Degrees)	Neutron Energy (MeV)	Relative Kerma Rate
8.0	2.10	0.9553
8.5	2.10	0.9522
9.0	2.10	0.9491
9.5	2.10	0.9459
10.0	2.09	0.9417
10.5	2.09	0.9352
11.0	2.09	0.9279
11.5	2.09	0.9205
12.0	2.08	0.9131
12.5	2.08	0.9057
13.0	2.08	0.8985
13.5	2.07	0.8911
14.0	2.07	0.8836
14.5	2.06	0.8761
15.0	2.06	0.8687
15.5	2.06	0.8687
16.0	2.05	0.8612
16.5	2.05	0.8462
17.0	2.04	0.8386
17.5	2.04	0.8311
18.0	2.04	0.8236
18.5	2.03	0.8160
19.0	2.03	0.8085
19.5	2.02	0.8009
20.0	2.02	0.7927
20.5	2.01	0.7829
21.0	2.01	0.7725
21.5	2.00	0.7623

(continued)

Angle (Degrees)	Neutron Energy (MeV)	Relative Kerma Rate
22.0	1.99	0.7527
22.5	1.99	0.7437
23.0	1.98	0.7343
23.5	1.98	0.7249
24.0	1.97	0.7156
24.5	1.97	0.7062
25.0	1.96	0.6968
25.5	1.95	0.6875
26.0	1.95	0.6781
26.5	1.94	0.6687
27.0	1.93	0.6594
27.5	1.93	0.6500
28.0	1.92	0.6406
28.5	1.92	0.6313
29.0	1.91	0.6222
29.5	1.90	0.6126
30.0	1.89	0.6021

NEUTRON DOSIMETRY INTERCOMPARISON: KERMA RATE VARIATIONS WITH ANGLE

$^{3}H(d,n)^{4}He$

Bombarding Energy - 0.6 MeV

Target No. 3H T-20

Object Size for Energy Spread Calculation - 0.01 cm

Beam Spot Diameter - 0.6 cm

Neutron Energy at Zero Degrees = 15.49 MeV $^{+3\%}_{-5\%}$

Angle (Degrees)	Neutron Energy (MeV)	Relative Kerma Rate
0.0	15.49	1.0000
5.0	15.49	0.9997
10.0	15.47	0.9995
15.0	15.44	0.9994
20.0	15.41	0.9967
25.0	15.36	0.9940
30.0	15.31	0.9913

NEUTRON DOSIMETRY INTERCOMPARISON: KERMA AND DOSE VARIATIONS AS A FUNCTION OF TRANSVERSE DISPLACEMENT

$^{2}H(d,n)^{3}He$

Bombarding Energy = 2.550 MeV

Target No. (^{2}H) D-7

Cavity Diameter for Relative Response Measurements - 6 mm

Beam Spot Diameter = 6 mm

Neutron Energy at Zero Degrees = 5.55 MeV $\pm$ 5%

X = Transverse Displacement, cm

$R_k = \frac{\text{tissue kerma at X}}{\text{tissue kerma on axis}}$ $R_d = \frac{\text{tissue dose at X}}{\text{tissue dose on axis}}$

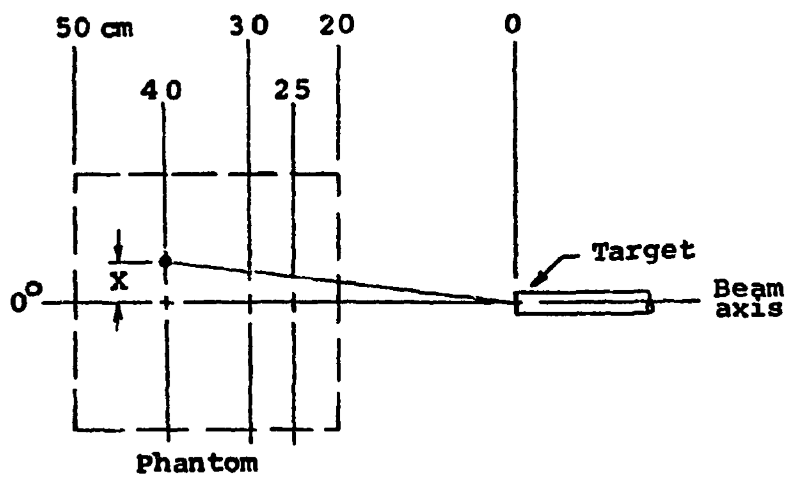
Least Squares Fit of R as a Function of X

30 cm from target, in air:
$R_k = 1 - (4.3 \times 10^{-3})X^2.$

25 cm from target, 5 cm deep in 30-cm cube water phantom:
$R_d = 1 - (1.4 \times 10^{-2})X - (3.6 \times 10^{-3})X^2.$

30 cm from target, 10 cm deep in 30-cm cube water phantom:
$R_d = 1 - (0.9 \times 10^{-2})X - (3.3 \times 10^{-3})X^2.$

40 cm from target, 20 cm deep in 30-cm cube water phantom:
$R_d = 1 - (2.5 \times 10^{-3})X^2.$



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