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L.A. Braby
K.L. Swinth
W.C. Roesch
LB

DATE November 10, 1967

TO H. M. Parker, Chairman
Human Subjects Committee

FROM W. E. Wilson, Manager
Radiological Physics Unit

SUBJECT REVIEW MEETING OF NEUTRON IRRADIATION AND SPERMATOGENESIS PROJECT IN COLLABORATION WITH DR. C. ALVIN PAULSEN OF UNIVERSITY OF WASHINGTON

This is a formal request for a committee meeting to discuss the status of the above mentioned research project.

Enclosed is a copy of the final report on the calibrations and dosimetry work on the facility at Walla Walla. Copies have also been distributed to other members of the committee.

BNWL-589

FAST NEUTRON MEDICAL RESEARCH FACILITY-DOSIMETRY*

By

K. L. Swinth and L. A. Braby

Instrumentation Section

and

Radiological Sciences Section

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PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

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ABSTRACT

Dosimetry measurements and calibrations have been made at the University of Washington's Fast Neutron Medical Research Facility. The facility is designed to deliver localized neutron doses of a few rads to the testes of volunteer subjects at 2.5 MeV and 14 MeV. Dose measurements were based on the use of tissue equivalent ion chambers. Dosimetry and shielding measurements show that doses accurate to ± 10% can be delivered to the volume of interest while maintaining safe dose levels outside the shield and to other portions of the subject.

TABLE OF CONTENTS

FIGURE CAPTIONS

Figure 1 Schematic representation of Medical Research Facility showing major hardware. As diagrammed the facility is set up to irradiate the testes from the front. To irradiate from the rear the positions of the spacer and bed are interchanged (rotate 180°). The subject kneels over the bed with the lower legs extending into notches in the sides of the spacer.

Figure 2 Overall view of the medical research facility. The positions of the BF_3 tube for monitoring at 2.5 MeV and 14 MeV are shown on the figure.

Figure 3 Calibration and location of ion chambers for use as a secondary monitor.

Figure 4 Dose to measured points in the volume of interest for 2.5 MeV neutrons.

Figure 5 Approximate position of the testes in the volume of interest.

Figure 6 Dose to measured points in the volume of interest for 14 MeV neutrons.

Figure 7 Dose to various locations (mrem) for 10 rads to the volume of interest. All measurements to the vertical section (A-A') are on the centerline of the target unless otherwise noted. Numbers on the floor plan represent dose rates two feet off the floor. (See Figure 2 for plan details)

Figure 8 Reference location for the irradiation vessel.

Figure Reference location for the indexing rod.

INTRODUCTION

This report describes and summarizes dosimetry measurements made on the University of Washington's "Fast Neutron Medical Research Facility". The facility is composed of a massive shield of water, concrete blocks, and lithium stearate, containing a neutron generator and an irradiation couch for a subject. The facility is designed to deliver low doses of 2.5 MeV neutrons, and much higher doses of 14 MeV neutrons to a small volume of interest (the testes) on a volunteer subject[1,2,3].

To selectively irradiate the volume of interest, it is necessary to use r^2 attenuation--thus irradiating with the volume of interest next to the source of neutrons. In order to produce uniform doses at small source to irradiation-volume distances, it is necessary to irradiate with one-half of the dose delivered from the front of the volume of interest and the other half from the rear. Figure 1 shows a schematic representation of the facility indicating the major pieces of hardware.

The volume to be irradiated is contained in a 5 by 7 by 10 cm plastic cup filled with warm water. This is done for two reasons: first, the warmth will cause descent of the testes, and second, the cup and testes will approximate a single tissue equivalent mass, thus making the dose distribution independent of variations from subject to subject. A temperature control circuit is used to regulate the temperature of the water to within 0.25° F.

Geometry control is important if reproducible doses are to be delivered. The testes are restrained within the plastic cup by a plastic insert forcing them against the surface of the cup facing the target. The front of the cup is referenced to the front of the table which is in turn referenced to an indexing rod (See Appendix). Both the table and the spacer are connected to the indexing rod by slide bolts, thus allowing positioning to within 1/16 of an inch and preventing uncontrolled movement. The trunk of the subject is not restrained during irradiation and is the only uncontrolled parameter.

The dosimetry is based on tissue-equivalent dosimetry methods although activation methods were used in the preliminary investigations[2,3]. Most of the measurements were made with air filled pencil chambers made of tissue-equivalent plastic[4]. These ion chambers were calibrated against a large volume tissue-equivalent ion chamber filled with tissue-equivalent gas. The calibration was done at the facility to assure calibration with the proper neutron spectrum. A large volume graphite ion chamber filled with CO_2 was used to estimate the contribution to the dose from gamma rays. Current through the large volume chambers was read continuously while the pencil chambers were pulse read[5].

A moderated BF_3 tube is used to give a continuous monitor of the dose delivered to the volume of interest. For irradiations at 2.5 MeV the BF_3 tube is located at the rear of the shield while for 14 MeV neutrons it was found that better performance occurred with the tube located near the front of the shield. Figure 2 shows the general positions for the monitor.

This monitor was calibrated during the dosimetry experiments, but should not be relied on exclusively as a standard during exposures due to variations caused by position changes of the subject. This is discussed in more detail in later sections. Tissue-equivalent ion chambers were used for the 2.5 MeV neutrons and sulfur pellets were used for the 14 MeV neutrons as supplementary monitors. The ion chambers are contained in holders affixed to the cup and the sulfur pellets are taped to the target holder.

For the purposes of dosimetry, an Alderson Research Remab phantom filled with a tissue-equivalent solution of water and sugar was used. The phantom contained approximately 30 liters of water and about 13.5 kg of sugar and 1 kg of gelatin in solution[6]. The phantom is articulated and contains a skeleton and dosimeter tubes so that dosimeters can be placed at various points of interest.

DOSIMETRY AT 2.5 MeV

DOSE MONITORING

Experiments were performed to investigate the effect on the monitor (BF_3 tube) of variation in the position of the phantom and the position of the table on which it rests. When the facility is set to irradiate the volume of interest from the front (See Fig. 1), the trunk of the subject is, effectively, between the target and the monitor. This is referred to as Position A. In this position moving the phantom's torso left or right caused a decrease of about 8% in the dose delivered to the volume of interest per unit monitor count when compared to the normal position. The torso was pivoted about a line through the testes with the head moving six inches left or right of the central position. Removing the right arm caused a decrease in the dose of about 3% per unit monitor count. Keeping the position of the volume of interest fixed with respect to the source of neutrons, it was found that moving the bed and phantom 2 3/4 inches toward the generator caused an increase of about 11% in the dose per unit monitor count. The position of the spacer located behind the bed had no observed effect on the dose per unit monitor count.

When the facility is set up to irradiate the volume of interest from the rear (Position B), it was found the position of the phantom's trunk had no observed effect on the dose to the volume of interest for a unit monitor count. In this position, the spacer is between the neutron source and the monitor and the neutron source is behind the subject. Removing the lower leg of the phantom, which rests in a notch in the spacer, caused a decrease of about 12% in the dose per unit monitor count. Holding the position of the volume of interest constant, but moving the spacer toward the generator one inch, caused an increase of about 5% in the dose per unit monitor count.

For an Alderson Research Remab phantom filled with a tissue equivalent solution[6] the calibration for the monitor is 106,000 counts per rad in Position A (irradiation from the front) and 100,000 counts per rad in Position B for primary neutrons of about 2.5 MeV. This is for an average dose of one rad to the volume of interest and in fixed positions as defined in the Appendix 1.

Since variations in the sensitivity of the dose monitor are likely to occur due to different body sizes and movement of the trunk, a second method of calibration was devised which is relatively unaffected by the phantom's position. During exposures pencil ion chambers affixed to the cup can be used to monitor the dose. A special holder is provided on the cup and the calibrations obtained for ion chambers in this position are shown in Fig. 3.

At first glance, one would expect chambers 1 and 2 to agree unless the dose center of the target did not coincide with the geometrical center. In general, one would not expect the dose center and geometrical center to agree, but it must be noted that the positions of the chamber are not exactly symmetric with the center of the target. This causes the apparent asymmetry in these calibrations. Using only the BF_3 monitor, an accuracy of about ± 10% in the average dose delivered to the volume of interest is feasible. The ion chambers will not improve upon the accuracy of the BF_3-determined doses, but serve as a secondary check.

DOSE DISTRIBUTION IN THE VOLUME OF INTEREST

Figure 4 shows the dose distribution for a typical irradiation of the volume of interest with the Remab phantom in the facility and with one-half the dose delivered from the front and one-half from the rear. Figure 5 shows the assumed position of the testes during an irradiation. These points were measured with pencil ion chambers as mentioned previously. It was assumed that the dose center and geometrical center were the same. This distribution represents an average dose of 0.98 rads to the volume of interest. The points show a standard deviation of 0.22 rads and range from 0.60 rads to 1.45 rads. This dose required an exposure time of about 50 minutes.

DOSE TO OTHER LOCATIONS IN THE PHANTOM

Dose to other points in the phantom were also investigated. The doses are shown in Table I.

TABLE I: Dose for a One Rad Dose to the Volume of Interest - 2.5 MeV

Location in Phantom[7]	Dose (mrad)
Eye	64
Base of Sternum	118
Prostatic Urethra	87
Trigone Area of Bladder	84
Anus	40
Rectum	59

In most cases, the doses are less than one-tenth the dose to the volume of interest. Most of the doses are approximately as expected. In the case of the eye and the base of the sternum, the doses are much higher than expected from calculations. The reason for the high readings is not known, but these points would be expected to agree more closely with the results for 14 MeV neutrons (Table 2). A second series of measurements confirmed that doses to various parts of the phantom were less than 100 mrad per rad to the volume of interest. Because of the unusually long exposure times needed, more accurate numbers were not obtained.

GAMMA CONTAMINATION

To estimate the contribution to the total dose delivered by photons, measurements were made with both a tissue equivalent flow chamber using tissue equivalent gas and a graphite chamber with carbon dioxide[8].

These measurements were then used to calculate the gamma contribution after the method of handbook 75[8]. For the 2.5 MeV neutrons the gamma contribution was determined to be about 0.4%.

DOSE OUTSIDE OF SHIELD

For generally occupied areas around the facility, measured dose rates were less than 0.5 mrem/hr for 2.5 MeV neutrons. Next to the entrance dose rates of 2 mrem/hr were obtained. This indicates that the dose rates around the shield are within safe limits when compared with the recommended limit of 100 mrem per week for continuous occupational exposure[9]. It should be pointed out that these measurements were made when the shielding was only partially assembled (door open and water tanks empty) and actual dose rates outside of the completed shield should be less than quoted above.

DOSIMETRY AT 14 MeV

DOSE MONITORING

For the 14 MeV neutrons it was found that the most reliable position for the BF_3 monitor was near the front of the shield (See Fig.2). A number of other positions were tried, but were unsuitable because of sensitivity to operating parameters or because of low or high count rates.

In Position A, it was found that moving the spacer two inches in or out from its standard position caused a change of about 14% in the dose delivered for a unit monitor count. Moving the torso or the right leg of the phantom caused errors of less than 2.5% in the dose per unit monitor count. We also found that removing the phantom and then placing it back in its standard position produced errors of as great at 5% in the dose per monitor count. In Position B, this error was about 7%; lateral movement of the phantom did not cause any significant change. For the Remab phantom filled with tissue equivalent solution it takes 172,000 monitor counts to deliver an average dose of 1 rad in the B position and 302,000 monitor counts for the same dose in the A position.

With the BF_3 monitor an accuracy of about ± 10% in the average dose delivered is feasible. As a second check sulfur activation can also be used to monitor the dose. One pellet can be positioned on the lower front of the cup and a second placed on the center of the target cap. For a calibration run using the Remab phantom, the sulfur pellet on the target cap gave a reading of 9.6 cpm/rad-gm while the one on the cup gave a reading of 1.07 cpm/rad-gm for irradiation Position A. In Position B, the sensitivity for the target cap was 17.6 cpm/rad-gm while the sensitivity for the cup was 2.07 cpm/rad-gm. The differences for the two positions probably reflect the changes in the scattered flux between the two positions. Ten minute counts were used in analyzing the sulfur pellets, which gave marginal reliability for low doses (<3 rads). For doses greater than 6 rads, 95% confidence limits of better than ± 10% were obtained for the pellets.

For low doses the accuracy of the calibration is limited to ± 10%. In these cases the BF_3 monitor may be more useful than the sulfur pellets.

DOSE DISTRIBUTION IN THE VOLUME OF INTEREST

Figure 6 shows the dose distribution in the volume of interest for a typical irradiation of the Remab phantom with one-half of the dose delivered from the front and one-half from the rear. These points were measured with the pencil ion chambers assuming the dose center and the geometrical center are identical. This distribution produced an average dose of 1.96 rads to the volume of interest. The points show a standard deviation of 0.34 rads and range from 1.21 rads to 2.59 rads. This exposure required a time of about five minutes. In general, the time required for a given exposure (i.e. dose rate) will depend on the age of the target and the operating parameters of the generator.

DOSE TO OTHER LOCATION IN THE PHANTOM

The dose to other locations for one rad delivered to the volume of interest in a typical irradiation of the Remab phantom are shown in Table II.

TABLE II: Dose for a One Rad Dose to the Volume of Interest - 14 MeV.

Location in Phantom[7]	Dose (mrad)
Eye	<5
Base of Sternum	59
Prostatic Urethra	73
Trigone Area of Bladder	82
Anus	40
Rectum	53
Middle of Back	14

The measured dose at other locations in the phantom is less than one-tenth the dose to the volume of interest, as expected from calculations. The dose to the location of the eye was less than the sensitivity of the ion chambers and so only an upper limit is given. The other numbers are accurate to about ± 10%.

GAMMA CONTAMINATION

The contribution to the total dose from photons was measured by the use of tissue-equivalent and graphite chambers after the method of Handbook 75[8]. By the use of this method a contribution of 7.4% was obtained. Earlier work with thermoluminescent dosimeters[3] indicated a contribution of 7.8% for a similar irradiation geometry for which the calculated γ-contamination was 7.5%.

DOSE OUTSIDE OF SHIELD

Dose rates and doses outside of the shielded facility were measured with both a De Pangher Double Moderator[10] and the standard radiation monitoring instrument used at Battelle-Northwest. The standard monitoring instrument is a scaled down version of the Double Moderator with a portable rate meter and is less sensitive than the larger De Pangher version.

Figure 7 shows the doses (mrem) delivered to various points of interest for 10 rads to the volume of interest as measured with the De Pangher Double Moderator. The doses shown are the average for both the A and B Positions; exterior dose rates being slightly higher (10%) in the B position. Dose rates are not given since the rapidly decaying output of a tritium target makes such information useless. All the numbers refer to operation with the water tanks filled and all of the shielding in place and with the phantom in the facility. All of the measurements were taken with the center of the dosimeter two feet off the floor unless otherwise noted. The critical measurements are those for the upstairs corridor and the clinic. These areas have unmonitored personnel and patients moving about. Because of the infrequent operation and limited usage of the neutron facility, the radiation level in adjoining rooms is considered safe. During exposure with 14 MeV neutrons it is recommended that operating personnel not remain in the room containing the shielded facility.

DISCUSSION

Phantom dosimetry results indicate that reproducible doses can be delivered to the defined volume of interest while delivering relatively low doses to other portions of the phantom and to people in adjoining rooms. The numbers presented are usually based on two or more separate readings in order to confirm all important measurements. Separate calibrations for the dose to the volume of interest made at different times at 14 MeV agreed to within 3.5%. This error includes both re-positioning errors and ion chamber errors. Dose variations within the volume of interest had a spread of ± 20% and ± 18% (standard deviation) for the two separate measurements. The accuracy of the dosimetry reported here is limited by the state-of-the-art and is estimated to have a 10% uncertainty in absolute calibration.

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APPENDIX

Since r^2 attenuation is used to control doses and since the moderated BF_3 monitor is affected by positioning errors, it is necessary that positioning be controlled and reproducible. Methods of restraint and referencing were established.

The testes are restrained within the irradiation vessel by a plastic insert and the irradiation vessel (cup) is referenced to the front of the table as shown in Fig. 8. The measurements used in calibrating the system are shown in Table 3.

Both the spacer and the table are restrained by slide bolts that fit into holes in an indexing rod. This rod has holes spaced one inch apart and can be adjusted to fractions of an inch by a screw which moves the entire rod. The fine adjustment of the rod is referenced by measurement with a meter stick as shown in Fig. 9. The holes in the rod are numbered consecutively. Table 3 shows the reference points used in calibrating the system with the phantom.

TABLE III: Reference positions

Geometry	Irradiation Vessel to Table	Index Rod Measurement	Index Rod Position Table	Index Rod Position Spacer
A	2"	3"	32	4
B	1 1/4"	2 17/32"	5	46

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FAST NEUTRON MEDICAL RESEARCH FACILITY

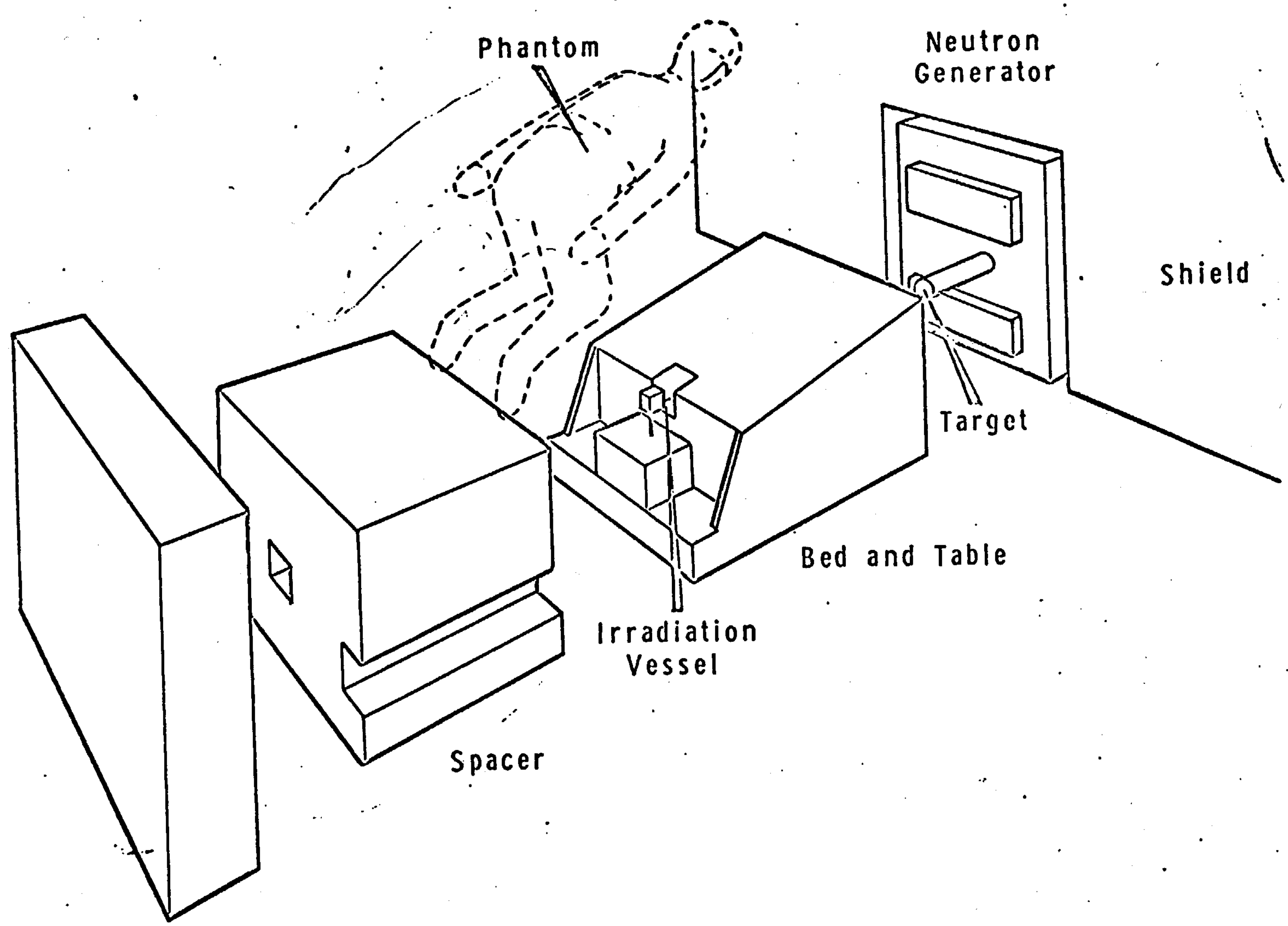

Figure 1

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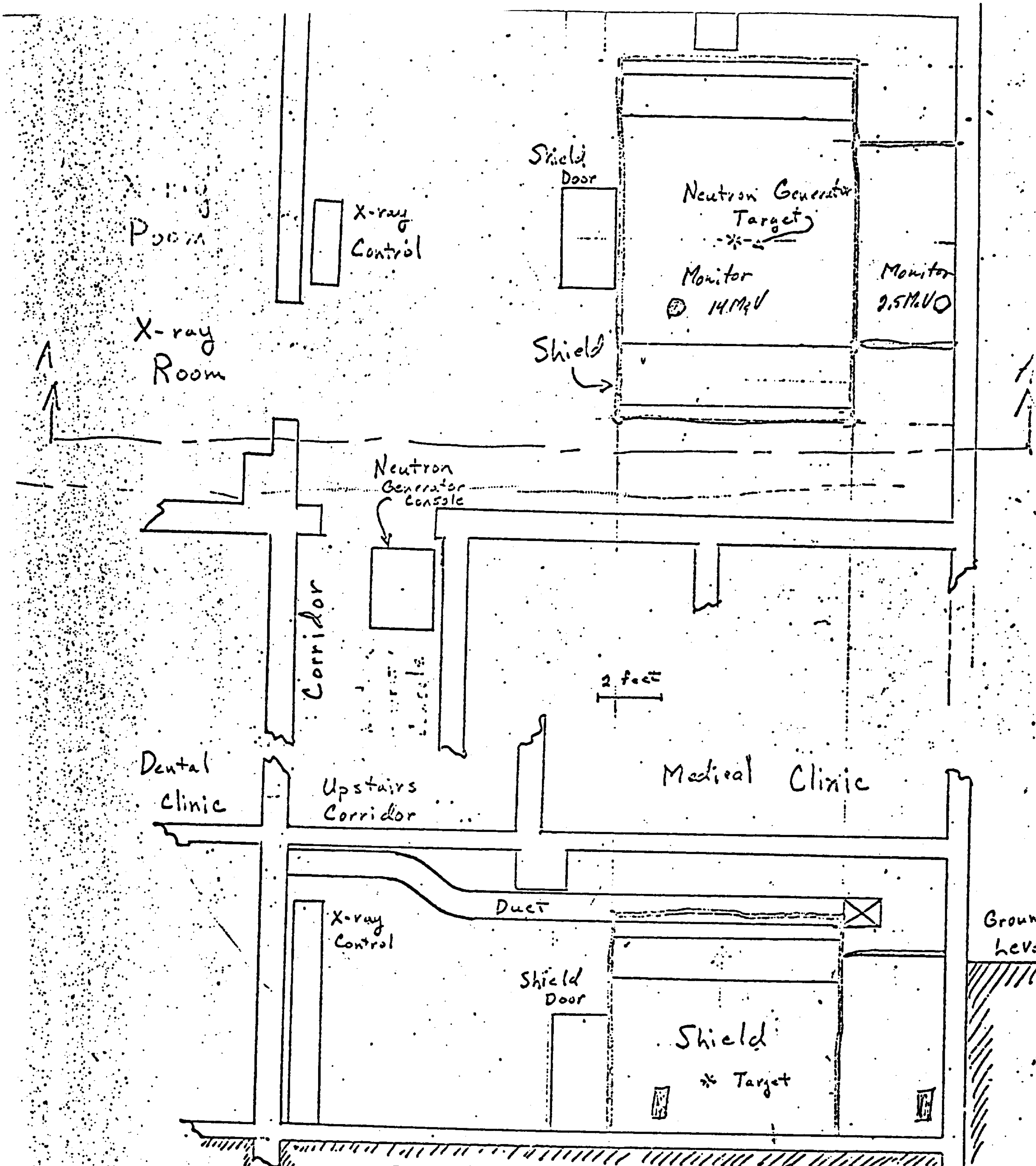

Section A-A'

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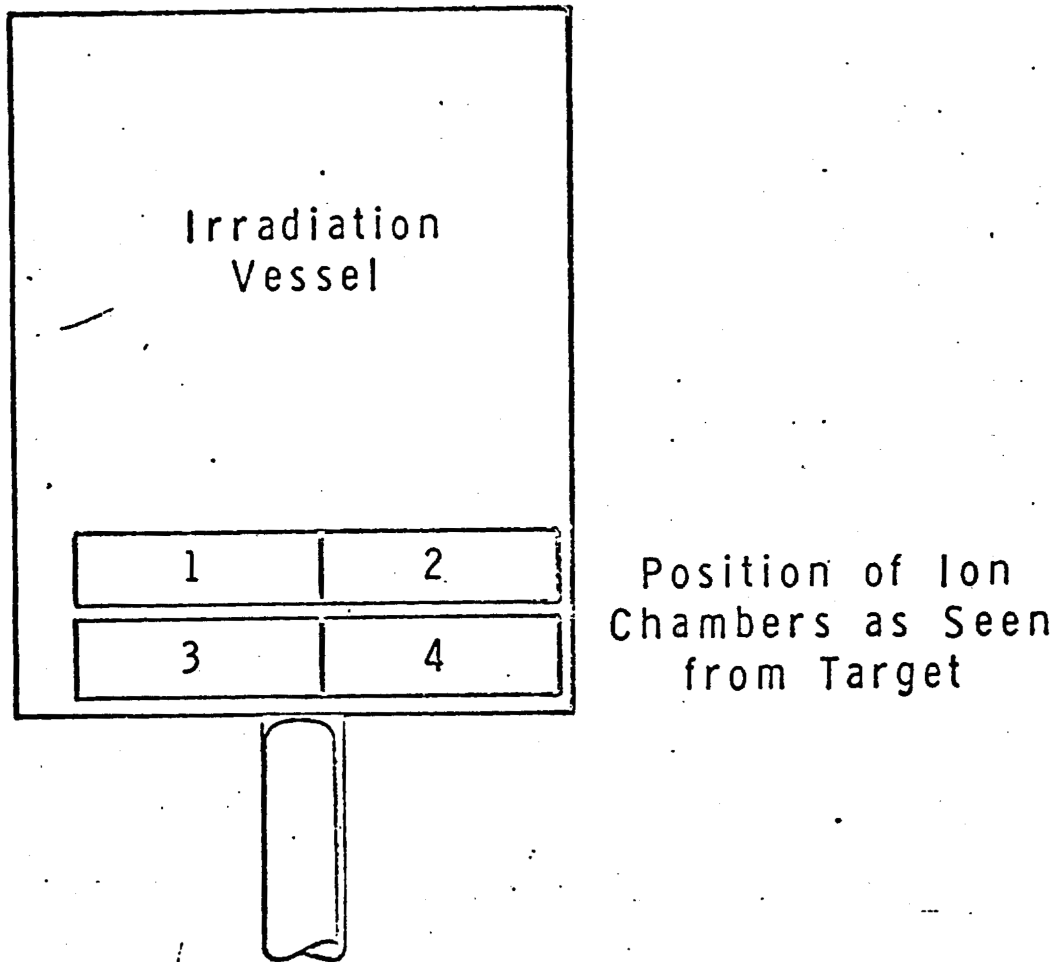
Fig 2



Chamber	Rads/Rad to the Volume of Interest	
	Position A	Position B
1	0.51	0.70
2	0.45	0.52
3	0.21	0.28
4	0.11	0.12

0008951

Figure 3

0.7

0.71	0.97	0.97	0.63
0.98	1.33	1.22	0.85
1.02	1.45	1.43	0.94
0.70	0.94	0.94	0.66

1.7

0.66	0.86	0.84	0.63
0.88	1.15	1.12	0.71
0.86	1.16	1.07	0.79
0.86	0.90	0.81	0.67

2.7

0.64	0.49	0.86	0.64
1.05	1.19	1.12	0.94
1.01	1.29	1.43	1.01
0.72	0.98	1.00	0.60

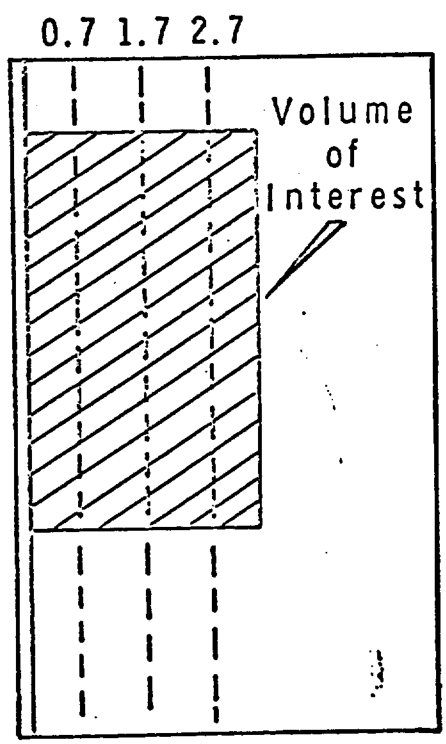


Figure 4

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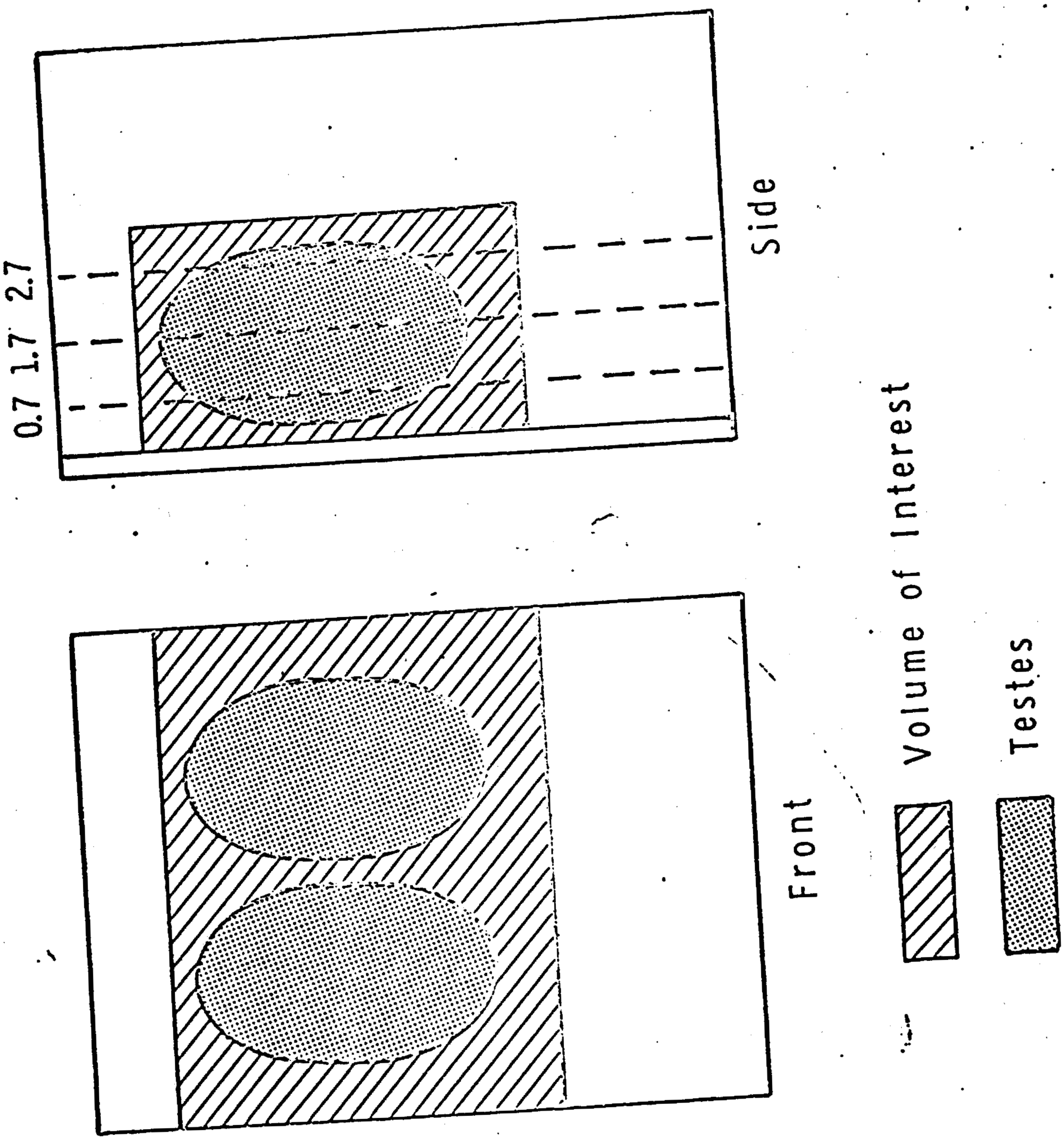

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Figure 5

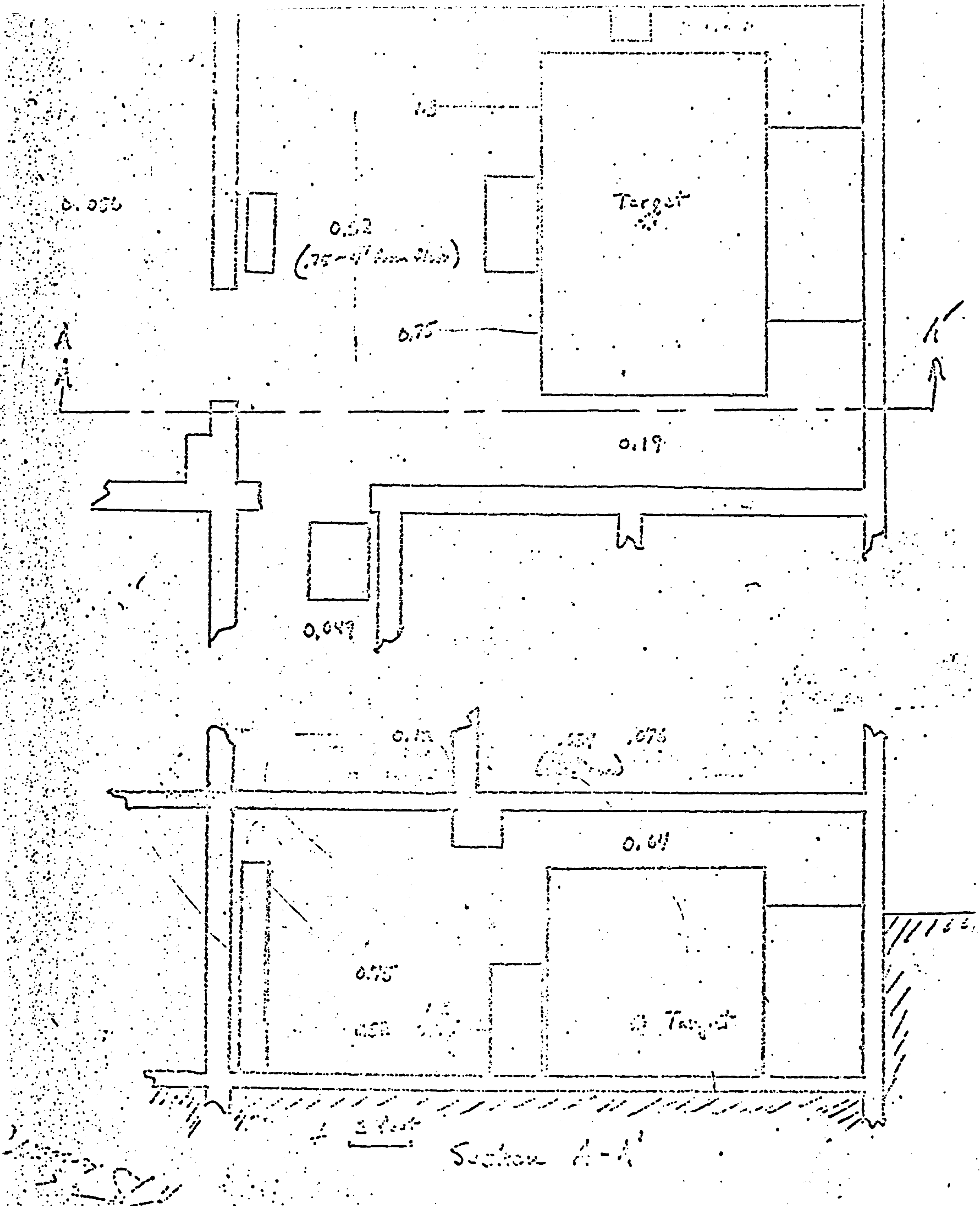

Fig 7

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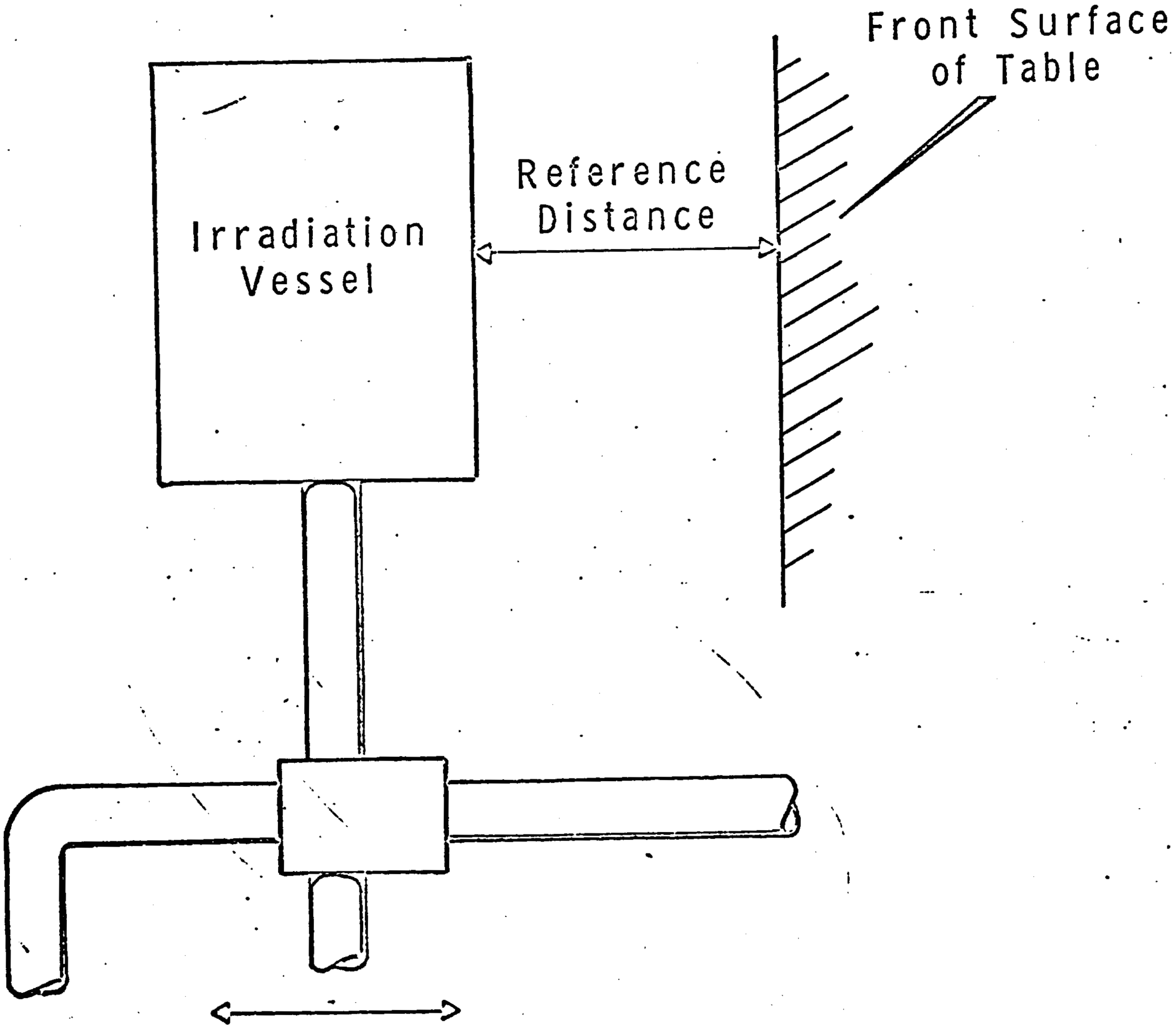

Figure 8

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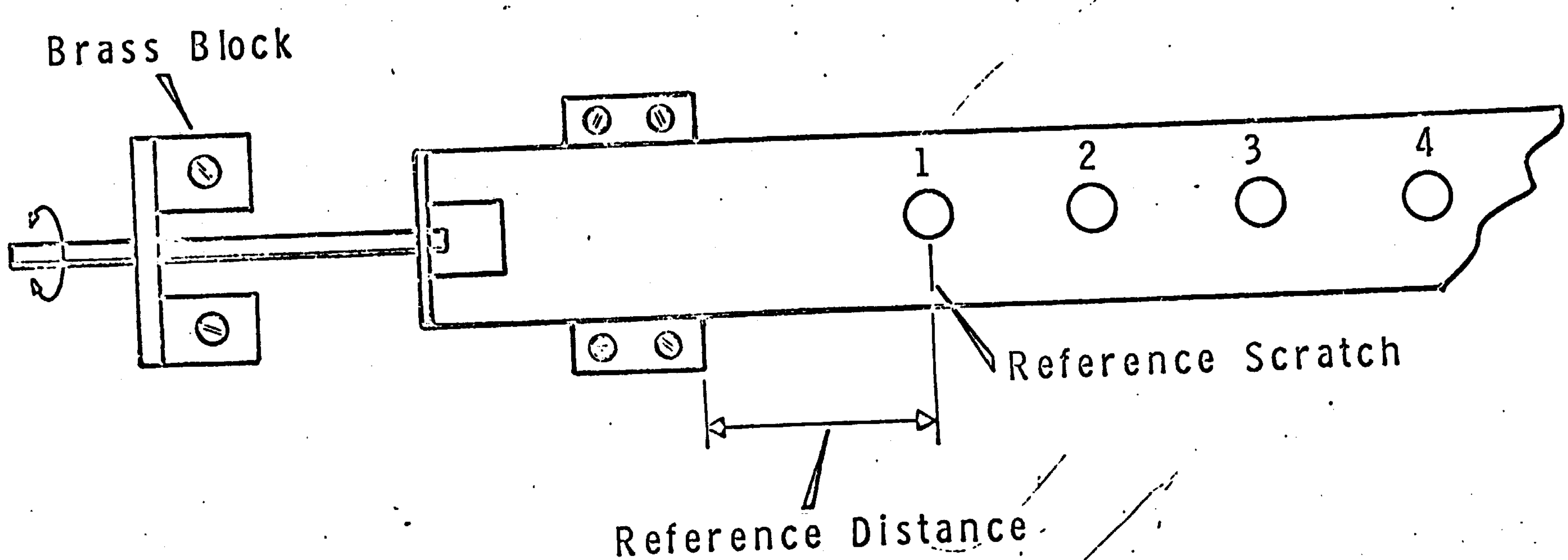

Figure 9

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