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ANALYSIS OF PERSONNEL EXPOSURES IN NEUTRON THERAPY FACILITIES.

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ABSTRACT

In conventional radiation therapy facilities, radiation doses to medical personnel originate from the leakage radiation of ^{60}Co teletherapy systems or from photoneutrons produced during the operation of X-ray generators at energies over 10 MeV in unsuitably shielded therapy rooms. In neutron therapy facilities, during patient set-ups and position verifications, medical personnel are exposed to photons from remanent radioactivity induced in the shielding around the neutron producing targets and in the beam collimators. At Fermilab, the use of an elevating platform limits personnel exposure periods to those times when collimators are being exchanged. Comparisons with other facilities are shown.

Introduction

In conventional radiation therapy facilities radiation doses to medical personnel originate from the leakage radiation of ^{60}Co teletherapy systems (Jo74) or from photoneutrons from the operation of X-ray generators at energies over 10 MeV in unsuitably shielded therapy rooms (He79). In neutron therapy facilities, on the other hand, medical personnel, in particular radiation therapy technologists, are exposed to photons from the remanent radioactivity induced in the shielding around the neutron producing targets and in the beam collimators themselves (Sm78,Ra81). Additionally, professional personnel, such as medical physicists and technicians, are occasionally exposed to high levels of radioactivity when performing maintenance in the vicinity of the neutron producing target (Sm78).

The Neutron Therapy Facility (NTF) at Fermilab

The facility at Fermilab has been treating patients with neutrons since September, 1976 (Co76,Aw79). The characteristics of its beam, produced by 66 MeV protons striking a semi-thick (49 MeV) Be target, have been described elsewhere (Ro81,Aw81a,Aw81b). The treatment room has an 2.4 x 2.7 m^2 surface area (Fig. 1), and the beam port is situated 1.2 m beneath the ground floor level (Fig. 2). The floor of the room is an

adapted freight elevator that can travel between the set-up and treatment levels in less than 1 minute. The room is enclosed by thick concrete walls, which provide adequate "beam-on" protection to personnel outside the room. Steel is used for additional shielding in the target area and in the primary shielding wall opposite the fixed horizontal beam opening. The latter steel barrier is lead-lined for "beam-off" protection of personnel inside the room from activity induced in the steel.

The neutron beam is defined by one of several interchangeable polyethylene-concrete collimators (Aw78) placed in a steel and Benelex collimator assembly (Ro81). The collimators have to be removed and inserted by hand. They are 80 cm long and consist of a mixture by weight of 50% Portland Cement, 20% polyethylene pellets and 30% water. The mixture's density is 1.6 g cm^{-3}, yielding a range of weights from 20 to 30 kg, easily handled by the radiation therapy technologists (Aw79).

Sources of Radiation Exposure

1.) Remanent Radioactivity in the Treatment Room.

At the end of an irradiation, high levels of exposure rate persist in the area immediately in front of the beam opening due to the activity induced in the target assembly and in the collimator. This remanent activity, though, is mostly short lived and does not accumulate significantly over a treatment day. Typical exposure rates before and after irradiations are shown in

Table 1. Those values represent the averages of several readings taken with a suitably calibrated survey meter. Location A (Fig. 1) is at the exit of a 10x10 cm^2 collimator (110 cm from the target); location B is 30 cm from the beam axis, at the shielding wall; location C is at the treatment isocenter, 190 cm from the target; location D is close to the elevator control console (250 cm from the target and 150 cm away from the beam axis); and location E is directly above the neutron producing target on the upper landing, about 280 cm from the target, 120 cm of which are part of the shielding. The pre-irradiation levels were taken at the start of a treatment day, approximately 48 hours after the last irradiation, and very likely represent the level of long-term activation of the target area.

2.) Collimator Handling.

The upstream ends of the collimator inserts become quite radioactive after irradiations. Although the activity depends on the total dose delivered and on the irradiation time, typical exposure rates are on the order of 250 mR/hour at contact (30 mR/hour at 30 cm) 5 minutes after 1 Gy (100 rad) are delivered to a patient at the isocenter at a rate of 0.2 Gy/min (20 rad/min). These levels, though, decay to about 10 mR/hour at contact 24 hours after the last irradiation.

Treatment Procedures

Patient treatments at the NTF are delivered two or three days a week, with each patient being irradiated either once, twice or three times weekly for a total of between five and twenty-two fractions, depending on site and management requirements. Each fraction consists of from one to four fields, with an average of 2.2 fields per fraction, delivered to different locations or orientations of the patient.

At each treatment, a patient is first immobilized on a treatment "chair" and then placed in his/her treatment position on the upper level. Proper positioning is achieved by aligning marks on the patient's skin with the lights from a set of four localization laser beams, which are directed toward the patient from front, back and both sides. The laser beams are co-planar and, if unobstructed, would intersect at a point in space which is also on the axis of rotation of the "chair". This "isocenter" is also on the central axis of a diagnostic x-ray beam which is used for treatment verification. The alignment procedure accounts for the longest period of time in which the radiation therapy technologists (RTTs) are present in the treatment room with the patient, and it conveniently takes place at the upper level away from the beam opening. When alignment is completed, the elevator platform is lowered until the patient's marks coincide with a

second set of four laser beams located on the lower level. These beams are also co-planar and intersect at a second point which is on the central axis of the neutron beam and also on the axis of rotation of the "chair". This treatment isocenter is directly below the upper level isocenter. The time needed to verify the final alignment at the lower level is thus kept to a minimum. The RTTs then exit by means of a ladder. For each subsequent field, usually only rotation of the "chair" platform around the vertical axis through the isocenter is required. Thus, the total time that the RTTs spend at the beam level is short, on the order of 1-2 minutes. A minimum of one collimator interchange is usually necessary per fraction. This is done after patient alignment, on the way down, and thus at least 10-15 minutes would have elapsed since the last irradiation. When an extra change of collimator is required for the same patient, in about 26% of all fractions, or further motions of the patient are required between fields of the same fraction, additional exposure may be incurred by the RTTs. It is, however, physically difficult for the RTTs to descend to the lower level in less than one minute, and thus the exposure levels shown in Table 1 apply to these situations. After the last field is delivered, the platform can be raised to the upper level without an RTT having to climb down to the neutron treatment level to operate the controls.

Radiation Exposure to NTF Personnel.

As a result of these procedures and further precautions, such as standing to the side of the collimator opening and not hugging the collimator while changing it, radiation exposures to the RTTs have been kept well below maximum permissible limits (NCRP71) and it has not been necessary to periodically change the RTTs on duty to keep their cumulative doses down. In fact, the same team of two RTTs has worked continuously at the NTF for the last three years. They have had monthly film badge monitoring of their body dose, as well as finger badges. No monthly whole body dose above 1.5 mSv (150 mrem) was ever recorded, while their quarterly doses averaged 2.6 mSv (260 mrem) in 1980, our busiest year so far with over 260 patients. The corresponding doses to their hands, mostly from handling collimators, were 3.5 mSv (350 mrem) average quarterly dose, and 2.2 mSv (220 mrem) maximum monthly recorded dose, also in 1980. To put it in a different perspective, each RTT received 5 ($\pm$1) μSv [0.5 ($\pm$0.1) mrem] whole body dose, on average, for each fraction delivered, and their hands received 7 ($\pm$2) μSv [0.7 ($\pm$0.2) mrem] for each collimator exchanged. These figures are averages and standard deviations of the monthly readings taken over 18 months in 1980 and 1981, which included over 2600 fractions, and thus should represent a good guide for predicting future exposures. In fact, the quarterly averaged doses per fraction exhibited a monotonic 20% reduction from the

first quarter of 1980 to the second quarter of 1981, indicating that set-up procedures and precautions are steadily improving with practice.

Comparisons with Other Neutron Therapy Centers.

It would be interesting to compare the NTF experience of personnel exposure with that in other neutron therapy centers in the USA. Unfortunately, owing to facility closures, personnel rotation and inaccessibility of records, direct comparisons are not possible in all cases.

Two quantities are of interest when looking at exposures to radiation therapy technologists: the average RTT dose per delivered fraction, which depends on the amount of remanent radioactivity and on operational procedures; and the average quarterly or yearly dose to individual personnel, which is strongly influenced by patient load and personnel rotation. To facilitate comparison of the latter quantity with the NTF experience, an "equivalent" quarterly dose should be calculated on the basis of only two full-time RTTs being available.

At the University of Washington, Seattle, a d(22.5)Be(16) neutron therapy beam has been in use for several years (Sm75). A recent analysis of personnel exposures (Ee82) concluded that, with

two RTTs on duty at any given time, an average dose of 15 Sv (1.5 mrem) per fraction was incurred by each. This was achieved, in part, by waiting for 3-4 minutes after the end of irradiation before entering the room, to allow the short term radioactivity to decay. The average quarterly whole body dose to RTTs was 1.5 mSv (150 mrem) in the period 1975-1976, with four RTTs on duty on a rotational basis: the "equivalent" quarterly dose to two RTTs only would thus have been closer to 3.0 mSv (300 mrem).

At the University of Chicago Medical School, patients have been treated with a d(8.3)D neutron therapy beam (Wa78) since early 1981. During this period, an average of 25 portals per month (about 15 fractions per month) were delivered. Fortnightly readings of body film badges have consistently been below detectability for the one RTT permanently assigned to the neutron therapy room, but regular use of personnel and thermoluminescent dosimeters allowed an estimate for the dose per fraction of 4 Sv (0.4 mrem) to be obtained (Re83). These low exposures are due in part to the low energy of the neutrons (less than 11 MeV) and in part to the two minute wait regularly observed at the end of each irradiation (Re83).

At the Naval Research Laboratory in Washington, D.C., neutron therapy trials were done using a d(35)Be beam (Th74). Prior to March 1979, two RTTs received average quarterly whole body doses of 4.7 mSv (470 mrem) each (Ra81). Following improvements in

shielding around the treatment cone and the addition of a third RTT, the average quarterly dose dropped to 1.8 mSv (180 mrem) each (Ra81). The "equivalent" quarterly dose for two RTTs only would thus have been 2.7 mSv (270 mrem). No dose per fraction estimates are available.

Finally, a joint neutron therapy program by M. D. Anderson Hospital and Texas A & M University has recently been completed which utilized a d(49)Be neutron beam (Sm77). Exposures to medical personnel working on that project, as well as remanent radioactivity levels in the treatment room, have been reported (Sm78). No information can be extracted about dose per fraction or number of nurses (used as RTTs) on duty or on rotation at a given time, but average quarterly doses of less than 1 mSv (100 mrem) were achieved through appropriate precautions.

A summary of the above personnel exposures is given in Table 2.

Discussion.

At the Fermilab Neutron Therapy Facility, the use of a mobile floor limits the personnel exposure periods to those times when collimators are exchanged. This arrangement, along with further precautions, helps achieve a low average exposure rate of 5 ($\pm$1)

Sv whole body dose per fraction to each of two radiotherapy technologists. Cumulative whole body doses are well within recommended limits, requiring no rotation of personnel in spite of a heavy patient load. The exposure levels encountered compare favorably with those experienced in other neutron therapy centers.

The exposure levels to the hands recorded at the NTF are comparable to those that physicians and physicists may receive in centers where pre-loaded interstitial therapy is regularly practiced. One such center recorded an average quarterly hand dose of 2.8 mSv (280 mrem) to personnel involved in brachytherapy in 1982, while the corresponding average whole body dose was 0.66 mSv (60 mrem) a quarter (Mu83). The whole body doses recorded at NTF are, however, significantly larger than those generally encountered in conventional radiotherapy centers, where the monthly film badge readings for RTTs and physicists are typically at background levels, that is, less than 0.1 mSv (10 mrem) (LaXX).

The situation should improve considerably for the newer clinical neutron therapy facilities now under construction. Many of these dedicated machines, such as those planned at the University of Washington in Seattle and at UCLA Medical School, will have gantry-mounted neutron-producing targets and remotely adjustable collimators. As collimator exchange is the largest source of RTT exposure, the elimination of this operation should dramatically reduce the exposure to personnel. Furthermore, the

other major source of exposure, radioactivity from the target assembly, could easily be minimized by ensuring that the adjustable collimators are completely closed for most of the set-up period.

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Table Captions

Table 1. Radiation levels (in mR/hour) in selected treatment room locations (Fig. 1).

Notes: Before irradiation: approx. 48 hours after last irradiation.

<<1: no appreciable movement of the meter.

Table 2. Summary of Personnel Exposures in Neutron Therapy Centers.

Notes:

(a) Average dose per fraction to each radiation therapy technologist (RTT) on duty.

(b) Average quarterly dose to one RTT.

(c) "Equivalent" average quarterly dose to one RTT if only two full-time RTTs were available.

Table 1

Radiation levels (in mR/hour) in selected treatment room locations (Fig. 1).

Time After Irradiation	Location				
	A	B	C	D	E
Before irr.	20	<1	8	<<1	<<1
1 min. after 1.0 Gy to C	200	11	25	3	1
5 min. after	100	4	15	1	<<1
10 min. after	50	3	10	<<1	<<1

Notes: Before irradiation: approx. 48 hours after last irradiation.

<<1: no appreciable movement of the dose meter.

Table 2

Summary of Personnel Exposures in Neutron Therapy Centers

Institution	Neutron Beam	Dose/fx[a] (mrem)	Quarterly Average Dose[b] (mrem)	Equivalent Average Dose[c] (mrem)
Fermilab NTF	p(66)Be(49)	0.5 (±0.1)	260	260
U. of Chicago	d(8.3)D	0.4	-	-
U. of Wash.	d(22.5)Be(16)	1.5	150	300
MANTA	d(35)Be	-	180	270
TAMVEC	d(49)Be	-	100	-

Notes: (a) Average dose per fraction to each radiation therapy technologist (RTT) on duty.

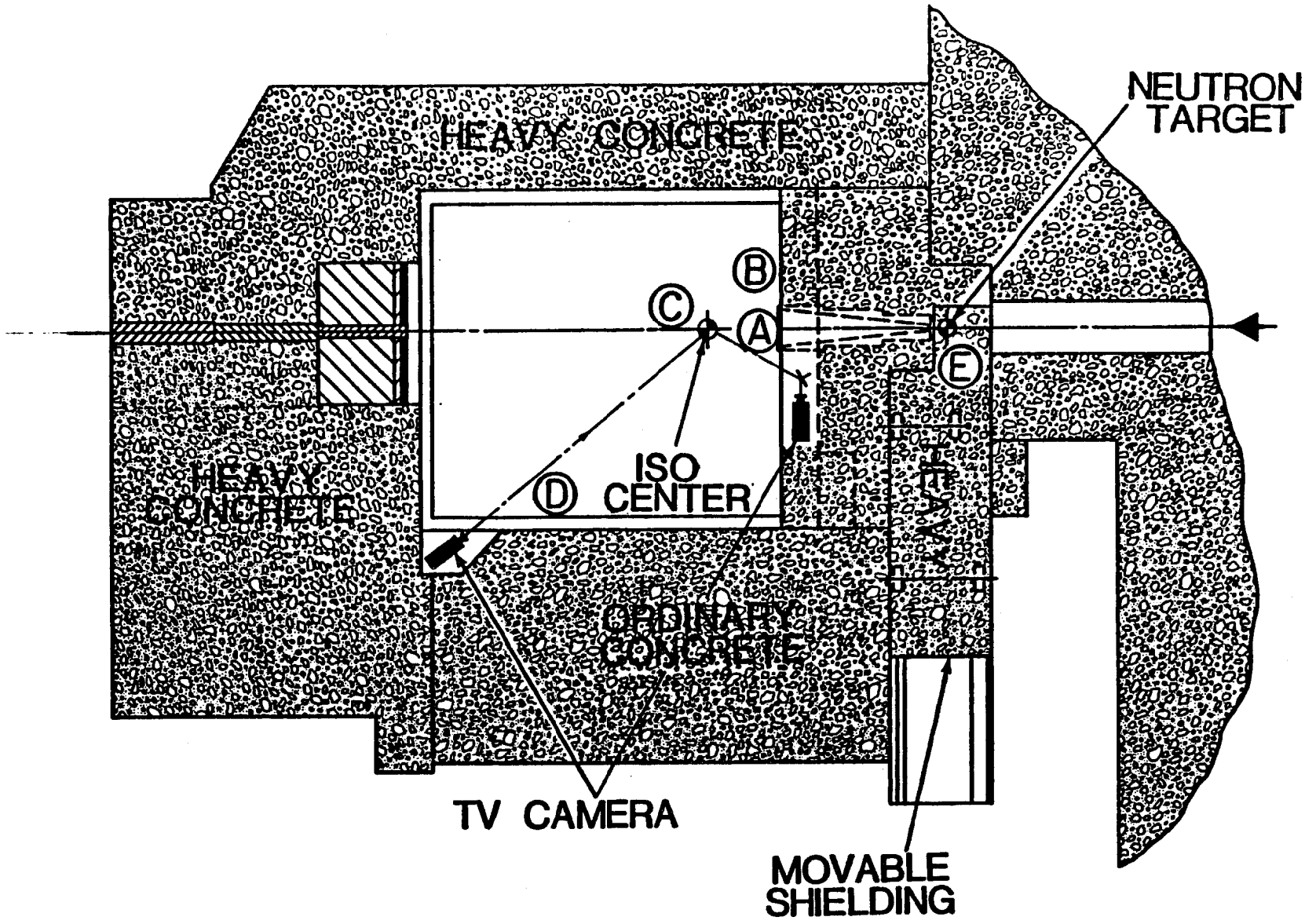
(b) Average quarterly dose to one RTT.

(c) "Equivalent" average quarterly dose to one RTT if only two full-time RTTs were available.

Figure Captions

Fig. 1 Plan view of NTF treatment room at Fermilab. Circled labels correspond to locations surveyed and listed in Table 1.

Fig. 2 Elevation view of NTF treatment room at Fermilab.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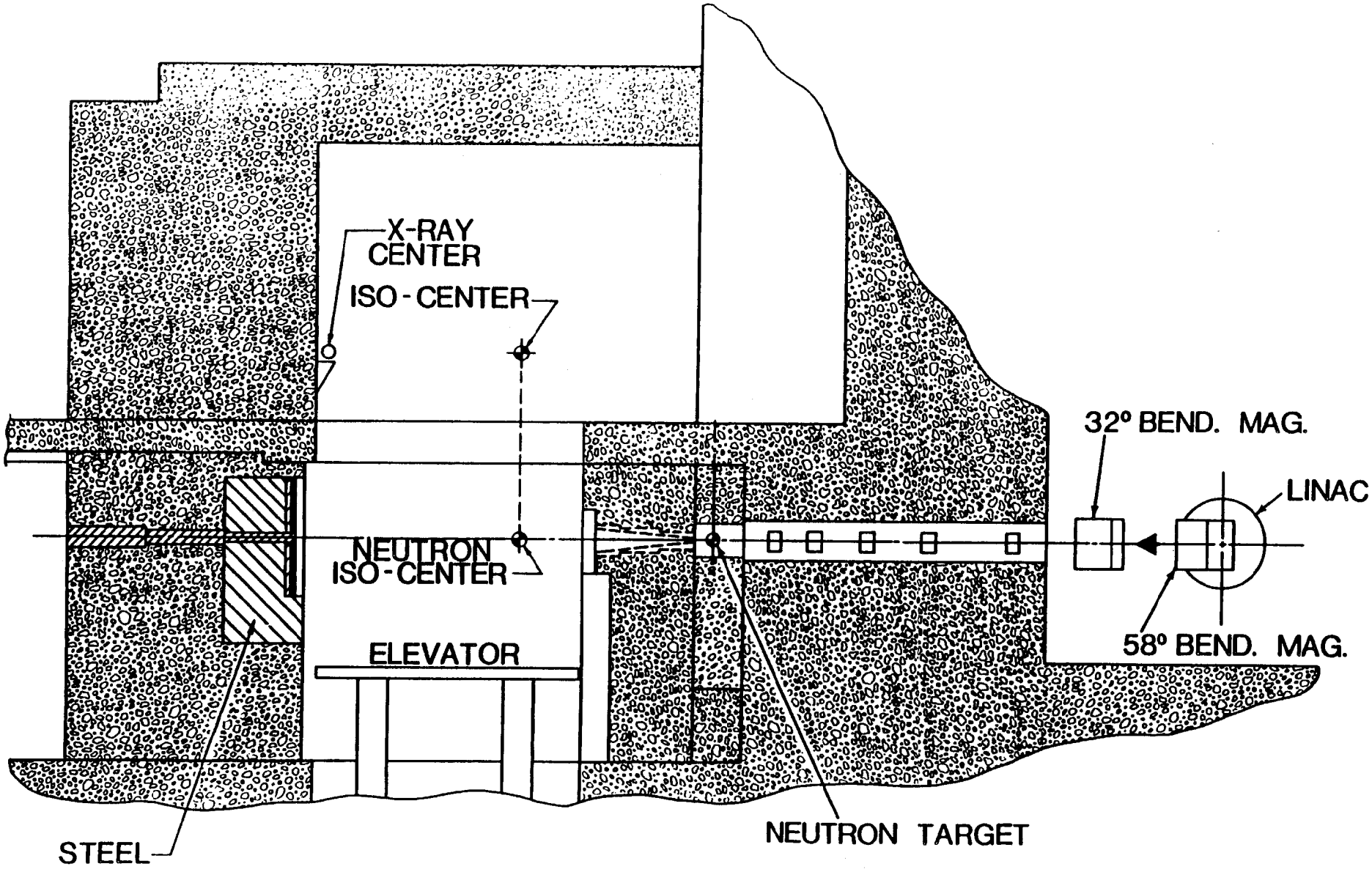
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