BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, L.I., N.Y.

ACCELERATOR DEPARTMENT

A Report Prepared for the AEC Advisory Panel on Accelerator Safety

SHIELDING OF THE AGS FOR THE CONVERSION PROGRAM

Staff

July 15, 1966

I. Introduction

G.W. Wheeler

The proposed increase in the beam intensity of the AGS resulting from the AGS Conversion Program will require additional shielding for the synchrotron enclosure. The existing shielding is barely adequate for the present operational level of about 10^{12} protons accelerated per pulse. This report describes the proposed increases in the synchrotron shielding and discusses the calculations and measurements which were made to determine the shielding requirements. Also included are a description of the proposed structural work required to support the shielding and brief discussions of activation, radiation damage and personnel safety procedures. This report is intended to supplement the material presented in BNL-7956, "A Proposal for Increasing the Intensity of the Alternating-Gradient Synchrotron at the Brookhaven National Laboratory," May 1964, and BNL-9500, "Alternating-Gradient Synchrotron Conversion Program, Scope of Phase I," September 1965. In addition, modifications to the proposed increase in shielding are discussed on the basis of further studies which have been conducted since the last report was issued.

The AGS Conversion Program proposes an increase in the beam intensity of the AGS but not an increase in the beam energy. It is appropriate first to consider the intensity level of the primary beam which will cause radiation. The design goal of Phase I of the Conversion Program calls for 10^{13} protons accelerated per second. Phase II calls for 2×10^{13} protons accelerated per second. These numbers are also the number of protons accelerated per pulse because the maximum design repetition rate is one pulse per second, with no flat-top. It is expected that a flat-top will generally be used (provision is made for a one second flat-top), in which case the average accelerated intensity will be lower by a factor of 2. However, it is important to design the shielding with due concern for the highest intensity to be encountered. Furthermore, while only Phase I is presently proposed, it is desirable to consider the future requirements of Phase II since it is difficult and costly to modify the shielding once it is in place.

Extensive use will be made of external beams. In fact, the operational plans are based on allowing only a fraction of the accelerated beam to impinge on an internal target or other part of the synchrotron proper. The shielding and radiation problems could be reduced substantially by completely eliminating the use of internal targets, but this would reduce the flexibility of the experimental program for the machine seriously. A reasonable compromise between internal and external target operations and general machine efficiency has set the following limits for the number of protons per second impinging on internal targets or other parts of the synchrotron (primarily septum magnets):

1. Internal targets, restricted to the F-20 and G-10 locations (but with the possibility of a target at I-10):

   For Phase I: 2×10^{12} p/sec   For Phase II: 4×10^{12} p/sec

   This is the total time average figure for all internal targets. However, under certain circumstances, this entire amount could be deposited on one target.

2. In the extraction process:

   For Phase I: 10^{12} p/sec   For Phase II: 2×10^{12} p/sec

   This assumes a 90% extraction efficiency for a fast beam pulsed once per second and 80% efficiency for a slow beam pulsed once every 2 seconds. External beams are proposed to be extracted at B-10, F-10, H-10 and I-10.

Thus, the maximum loss will be 4×10^{12} protons/sec at any point around the synchrotron. Because of the wide distribution of targeting and extraction locations and the uncertainty about future needs, it has been decided to shield the entire enclosure for the maximum loss, thereby allowing the maximum flexibility. There is little difference in cost between shielding now for 2 or 4 X 10^{12} protons/sec, whereas to add shielding later could be far more expensive. Consequently, the shielding is designed for 4 X 10^{12} protons/sec stopping at any point as the source of radiation.

The recommended permissible levels of radiation for both radiation workers and the general population have remained essentially unchanged since 1956. Present AEC regulations[1] require levels of radiation to the general population off-site to be less than 0.5 rem/year corresponding to 0.06 mrem/hour for permanent occupancy. Radiation workers of age N years are permitted an accumulated whole body dose of 5(N - 18) rem, with a maximum exposure of 3 rem in any quarter. In accordance with present practice this can be interpreted to imply 5 rem/year or 2.5 mrem/hour for a 40-hour work week.

Service areas around the accelerator such as offices, shops, and laboratories will be kept to less than 0.25 mrem/hour. Operating areas near the synchrotron including experimental areas will, in general, be kept to less than 2.5 mrem/hour; certain beam paths, etc. which may have higher levels will have controlled access. Remote areas around the accelerator ring may on occasion have higher levels than 2.5 mrem/hour; these areas are seldom populated by radiation workers and will in all cases be fenced and access permitted only under controlled conditions. During maintenance of the ring, whole body dose will be limited to 5 rem/year; however, AEC regulations permit radiation workers to receive 75 rem/year to the extremities with a maximum of 25 rem in any quarter.

The shielding for the Conversion Program must provide for safe conditions with 4 X 10^{12} protons/sec targeted. In addition to personnel safety, it must be remembered that radiation escaping from the shield also contributes background to experimental detection equipment located at or near the AGS and the background requirements for these experiments may place more stringent

---

1. Rules and Regulations, Title 10, Code of Federal Regulations (AEC, Washington, D.C., June 1962), Chap. 1, Part 20; Standards of Radiation Protection, in Atomic Energy Commission Manual (AEC, Washington, D.C., May 1964), Chap. 0524.

requirements on the shielding than does personnel safety. The foregoing factors have been considered together with structural and economic factors to arive at the final design proposal for the shielding thickness over the AGS tunnel. The existing sand cover over the AGS tunnel is nominally 10 ft thick. However, there are several areas where the sand is considerably thinner. It has been decided to increase the sand cover over the tunnel to a full 20 feet,* with provision to add 5 feet more if needed at a later date. In the special sections of the accelerator where sand cover cannot be used, an equivalent amount of other materials (concrete, steel) will be used. This amount of shielding (with fencing in certain remote areas) will lead to a completely safe situation for all personnel. Furthermore, the general radiation background around the accelerator is expected to be lower than it is at present. Leakage of radiation through the ducts which penetrate the shield will lead to somewhat higher levels in localized areas and these will be fenced off as necessary.

In Section II of this report, the use of 20 feet of sand cover is demonstrated to be adequate on the basis of the standard and proven techniques of shielding design. In Section III, the preliminary data from a series of radiation measurements around the AGS are reported. While it is perhaps still premature to draw final conclusions from these data, the tentative results are interesting. Of significance is the fact that these results suggest that the proposed shielding for the Conversion Program may be somewhat more conservative than shown in Section II.

---

*It will be noted that this figure is as originally proposed (BNL-7956) and the discussion justifying this amount will be found on pp. 224-232 of BNL-7956.

II. Calculation of the Shielding Requirements

S.J. Lindenbaum

Because the Conversion Program for the AGS entails only an increase in the circulating beam intensity and not an extension to an unknown energy, forecasting the shielding thicknesses (as far as dose rate is concerned) is straightforward. The dose rate is proportional to the circulating beam intensity, hence measurements made at the existing intensity can be relied upon to predict the dose rate at the same point of measurement to within the accuracy of the measurements, if the shielding arrangement remains constant.

As a consequence, we have much confidence in a result which is based upon a measurement program and which is consistent with reasonable calculations.

An extensive series of measurements was performed to assess the levels and character of the radiation emanating from the present Target Building shielding and the earth cover over the ring under certain standard target conditions. In addition, the normal radiation monitoring provided radiation data under a considerable variety of operating conditions. For a given shield geometry, beam energy, and mode of operation, the radiation character does not change with intensity, and the dose is strictly proportional to source intensity. Thus, it has been possible to predict quite accurately the levels at the outside of the present shielding as a function of intensity. Therefore, the problem essentially reduces to adding sufficient shielding to reduce the increased radiation levels to the desired levels.

In BNL-7956[1] the general conclusion was reached that the AGS shielding arrangement was reasonably well balanced for levels of beam intensity $\sim 1.3 \times 10^{11}$ protons/sec. It was concluded that for the Phase II intensity increase, supplemental shielding which gave a factor of about 30 further attenuation at all exterior parts of the shield would meet the specification that the shielding be sufficient for 4×10^{12} protons/sec lost at any point in the ring.

1. "A Proposal for Increasing the Intensity of the Alternating-Gradient Synchrotron at the Brookhaven National Laboratory," BNL-7956, May 1964.

Now let us consider the question of the effective removal mean free path, and the method of calculation to be used in estimating the required additional shielding. A discussion of the various terms and methods used is given in Reference 2. However, a brief resumé may be of interest here.

The mean free path for removal (λ_r) is that thickness which reduces the radiation parameter measured to 1/e of its value. The half value thickness for removal ($d_{\frac{1}{2}}$) is that thickness which reduces the radiation parameter measured to one half its value. The mean free path for removal is related to the half value thickness by $\lambda_r = d_{\frac{1}{2}}/0.69$.

In a shield for a high energy (33 BeV) proton synchrotron such as the AGS, the mixture of nucleon, pion, and muon components of the beam and the well-known extreme forward collimation of the high energy pions and nucleons produced originally* give the shield characteristics a very directional multi-component character which changes with distance. Furthermore, due to the high energy, the approach to truly equilibrium exponential attenuation may be slow under many circumstances, requiring many mean free paths, and may not be complete until most of the muons generated in the air drift spaces and first few mean free paths of shield are stopped by ionization loss. Also, the effective radiation pattern may be changed drastically by the targeting conditions and the exact geometry of material surrounding the target.

These phenomena have been well known for a long time and shields[2] much thicker in the forward direction than to the side have been used for many years at the Brookhaven AGS and at CERN in order to attenuate the muon component which is the controlling element in the forward direction.

Of course, if the shield is thick enough, one should expect eventually to reach a near equilibrium and approximately isotropic condition again with

---

2. S.J. Lindenbaum, "Shielding of High Energy Accelerators," Ann. Rev. Nucl. Sci. 11, 213 (1961).

*The production process is characterized by a "momentum transfer squared" invariance. This means, at least for not too large angles, that the angular width of the hard component's distribution decreases inversely with the mean momentum of the secondaries.

one controlling, well defined removal mean free path corresponding to the high energy, strongly interacting components. However, we know we are very far from this condition in the forward direction at AGS and special consideration must be given to the muon problem. But it is well known[1,2] that parallel side shields are most effective for this type of accelerator.

There are two different definitions of removal mean free path generally employed in accelerator shielding calculations; one is the good geometry mean free path (λ_g) which is strictly defined for an isotropic point source surrounded by a spherical shield starting at a distance r_o. The appropriate equation utilizing this mean free path is:

$$(R.F.P.)_r = (R.F.P.)_{r_o} \times \frac{r_o^2}{r^2} \; \beta(r) \; e^{-(r-r_o)/\lambda_g} \quad ,$$

where R.F.P. stands for radiation flux parameter,

$\beta(r)$ is the build-up factor. For $r - r_o \gg \lambda_g$, $\beta(r)$ tends toward a constant value.

This formula can be generalized for the anisotropic situation to:

$$(R.F.P.)_{r,\theta} = (R.F.P.)_{r_o,\theta} \times \frac{r_o^2}{r^2} \; \beta(r,\theta) \; e^{-(r-r_o)/\lambda_g} \quad .$$

If several components are involved, sums of terms similar to these will apply. In view of this one must be very careful in interpreting actual measurements which deduce and compare conclusions about the removal mean free path from different experiments. For example, the effective mean free path along an arbitrary direction in a certain path in the shield may be a function bearing no simple relationship to the effective mean free path along an arbitrary direction at another point.

However, many experiments at Brookhaven, Berkeley and CERN have demonstrated that $\lambda_g \simeq 150$ to $160\ g/cm^2$ when a high energy nucleonic component is the controlling element (longest mean free path) in a shield thick enough that approximate equilibrium build-up is reached.

A second mean free path that has been used extensively is the so-called bad geometry mean free path (λ_b). Assuming the source to be an infinite plane, this mean free path uses a simple exponential attenuation without a $1/r^2$ factor.

Many experiments with geometry far from good, but not quite strictly bad have been analyzed using this definition. In general, a good average value of λ_b is about 130 g/cm^2 for ilmenite-loaded concrete when high energy nucleonic components dominate in thick enough shields. Thus, measurements at BNL on attenuation in sand (Section III) should not be accepted uncritically as justification for a lower mean free path than the conventional $\lambda_b \approx 130$ g/cm^2.

In fact if one looks closely at these measurements their inherent complexity is emphasized by the fact that at a thickness of about 20 to 25 feet of sand, which corresponds to 8 to 10 feet of ilmenite, a transition in controlling component seems to be taking place. The weakly interacting tails found on the dosimeter attenuation curve appear to be muons coming from charged pions originating in the H-10 target. Therefore in adding more shielding it is even possible that a transverse mean free path greater than λ_b should be used in some spots. If this should be necessary, it can be locally provided for later. It appears that using the conventional λ_b is sufficiently conservative at present. A $\lambda_b \approx 130$ g/cm^2 corresponds to 13 in. of ilmenite and about 22.5 in. of ordinary concrete (150 lb/ft^3).

Target Building Shielding

At 10^{12} protons/pulse or 4×10^{11} protons/sec it has been possible to attain, on the average, tolerance conditions (≤ 2.5 mrem/hour) outside the shield for targets in the G-area. A special inner shield of 2 ft of concrete has been added around the G-target area since the earlier investigation. Therefore the conclusions are still consistent since the average effect of this inner target shield should be an attenuation of about 3. For general purpose shielding to allow 4×10^{12} protons/sec to be targeted anywhere inside the Target Building shield we should discount this factor of 3, thus leaving the earlier average tolerance estimate of 1.3×10^{11} protons/sec. Therefore we still need a factor ~ 30 increase in the side wall shielding attenuation.

Since it was also concluded[1] that skyshine (or particles emanating from the Target Building shield roof) is appreciable and may contribute ~ 50% of the dose, it is clear that the Target Building roof shielding should be increased also to provide an additional factor of 30.

It may be desirable[1] to use ordinary concrete for the Target Building side wall additions because ground shine is already a problem (contributing $\approx$ 30% of the dose near the floor) with the present shield. Therefore using ilmenite for the additional shielding would magnify the problem considerably.

Ordinary concrete requires an additional length factor of about 1.75 compared to ilmenite. Hence (λ_b) in ordinary concrete $\approx$ 22.5 in. Therefore to attain the attenuation factor of 30 we need 3.4 m.f.p., which corresponds to 76 in. A 6 ft block of ordinary concrete is therefore selected as consistent with the approximation involved in the calculations. Since ordinary concrete still differs in density from the sand ($\rho_{sand} \sim 115$ lb/ft^3) under the ordinary concrete floor pads, we have therefore introduced the equivalent of $\sim$ 2 ft less (or $\sim$ 1 m.f.p.) of ordinary concrete for the ground shine component. Hence there may be a factor of 2 to 3 increase in the relative effect of the ground shine which may now become comparable with or exceed the other general levels in the area near the exterior of the shield. A sketch of the proposed shielding is shown in Fig. 2-1. If it should be necessary to remove this ground shine effect, the addition of a 2 or 3 ft wide by 2 or 3 ft high ordinary concrete block placed at the outside bottom corner of the shield should attenuate the ground shine sufficiently and still serve as a pad for experimental magnets, collimators, etc.

Where sections for the forward beam direction are utilized in the shield arrangement, special attention to muon attenuation will be needed and considerable increases in wall thickness will be required locally. Some attention to additional muon shielding for the side wall may be necessary but this may effectively be handled by an internal local target shield as now used in the G-area and by the placement of collimator material near the pion source to attenuate pions before they decay to muons.

The roof shielding problem is complicated by the fact that only eight feet of shielding material can be stacked over the magnets in the Target Building without serious structural modifications to the building. Therefore the additional shielding required will be obtained by replacing with steel the inner layer of 4 ft thick ilmenite blocks. An estimate based on our experience and calculations is that steel is about 1.8 times as effective as ilmenite per unit length in high energy shielding applications provided it is followed by several feet of concrete in order to stop the leakage of low energy neutrons through steel. Four feet of steel equals 7.2 feet of ilmenite, hence we gain the additional effect of 3.2 ft of ilmenite which is about 3 m.f.p. and corresponds to an attenuation factor of $\approx$ 19 instead of the 30 originally desired. In view of the practical difficulty involved and the approximate nature of the calculation it has been decided to accept this slightly less effective roof shield, which is certainly adequate for Phase I. Experience after the Conversion will demonstrate whether or not additional shielding is necessary.

Let us now discuss the effect that the possible range of uncertainty of the transverse bad geometry mean free path has on these considerations. Since we are shielding for an additional factor of 30, let us assume a mean free path, $\lambda_b = 130 \pm 30$ g/cm^2. At the lower limit, this mean free path equals the raw transverse mean free path (corrected for geometry) observed in the sand measurements at BNL. At the higher limit the mean free path equals the generally assumed mean free path for good geometry. If the lower limit is assumed we would have 4.4 instead of 3.4 m.f.p. so that we would have an additional factor of 3 reduction in levels. Since no arbitrary safety factor was included, this is not unreasonable conservatism. If the upper limit were appropriate we would have 2.8 m.f.p. and would lose about a factor of 2 in shielding effectiveness. This could require some additional local shielding which could be installed if the need arose.

<u>The Earth Cover Over the Ring</u>

A series of radiation level measurements in the sand above and to the side of the H-area target was made (Section III). It was concluded that for 4×10^{11} protons/sec incident in a thin target in the H-area, the maximum level on top of the present sand shielding is about 1 rem/hr. The absolute value of this level depends strongly on the value of the RBE applied to the reading. This author strongly favors the conservative approach and uses an RBE of 10. Measurements show that this radiation leads to a skyshine level of $\sim \frac{1}{4}$ to 1 mrem/hour at $\sim$ 100 meters from the target. After the AGS Conversion this maximum skyshine radiation level would be raised to about 10 mrem/hour for the stated internal targeting condition limitation of only 4×10^{12} protons/sec.

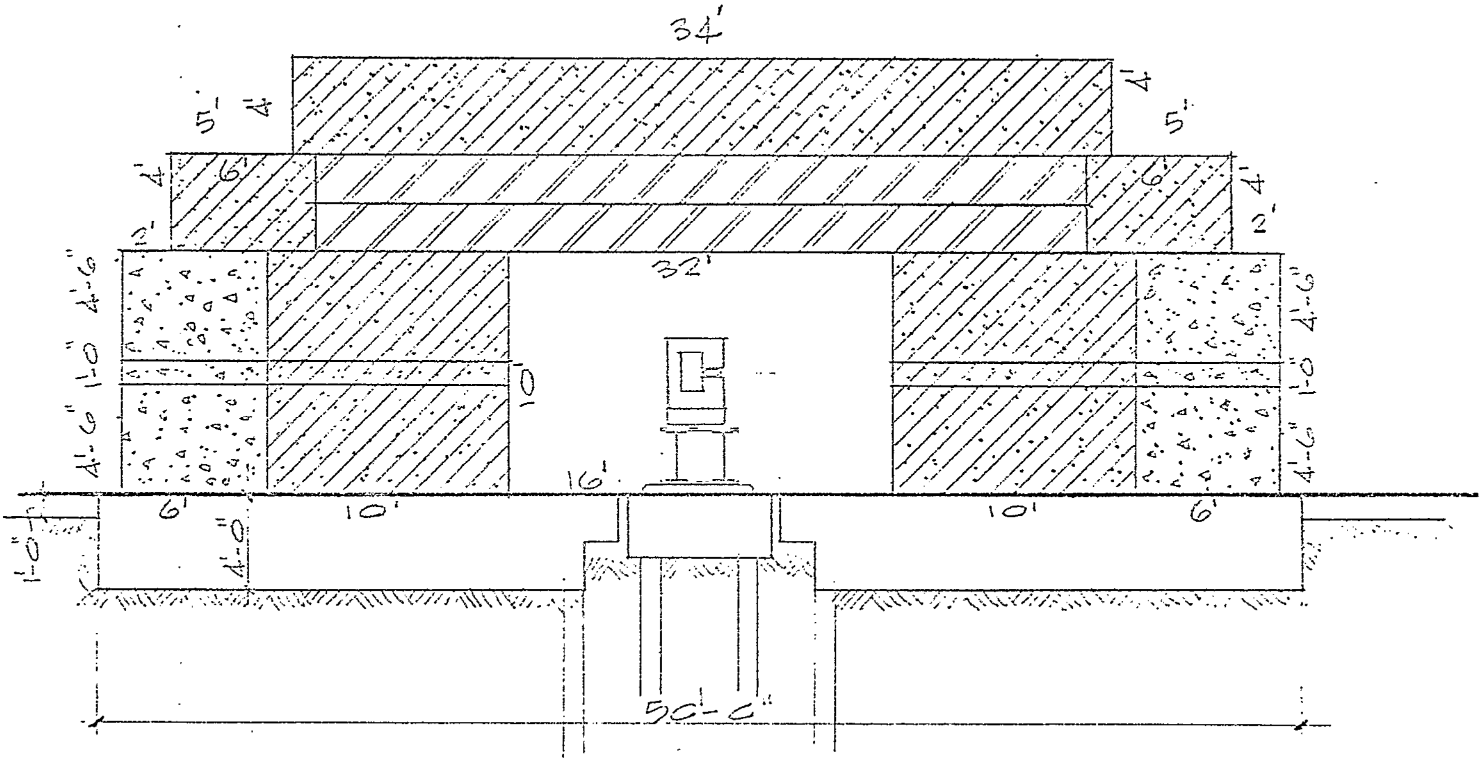
As a design goal for the sand cover, we have adopted the criteria: (1) that radiation levels at the sand surface should be kept below 1 rem/hr for 4×10^{12} protons/sec targeted internally, (2) that the skyshine at the 100 meter distance for 4×10^{12} protons/sec targeted should correspond to about the general population limit level for average continuous operation (40-hour week) (i.e., ~ 0.25 mrem/hr). This would correspond to ~ 2.5 mrem/hr if the full beam were targeted internally or the normal occupational tolerance per 40-hour week. The skyshine at the site boundary has been measured to be less than one one-hundredth the values at 100 meters and therefore negligible in all cases.

Both of these conditions are approximately met if the previously used factor of 30 improvement in shield attenuation is used again.

From the foregoing discussion it is not clear what bad geometry mean free path should be used. Since the skyshine, at near distances at least, is most sensitive to the nucleonic secondaries generated by the nucleonic component, it appears reasonable to use the conservative $\lambda_b \simeq 130$ grams. Since we are shielding for a small additional attenuation (~ 30) we are not very sensitive to the mean free path assumed.

Of course, as indicated in some of the measurements, minimum ionization hot spots due to muons and nucleonic and pionic hard components may require longer mean free paths than this at some spots. On the other hand, as shown by the measurements at least in some transverse regions of the shield, a shorter mean free path would be adequate. Therefore $\lambda_b \approx 130$ grams in general experience seems to be reasonably conservative for general design purposes. For a factor of 30 we need 3.4 m.f.p. ≈ 440 g/cm^2. Since earth has a density of $\simeq 100$ lb/cu.ft, each foot of earth thickness is equivalent to 48 g/cm^2. Hence we need 9 ft of additional earth. Therefore it is planned to add a new structure which will support an additional 10 feet of earth fill (see Section IV).

PROPOSED TARGET BLDG. SHIELDING



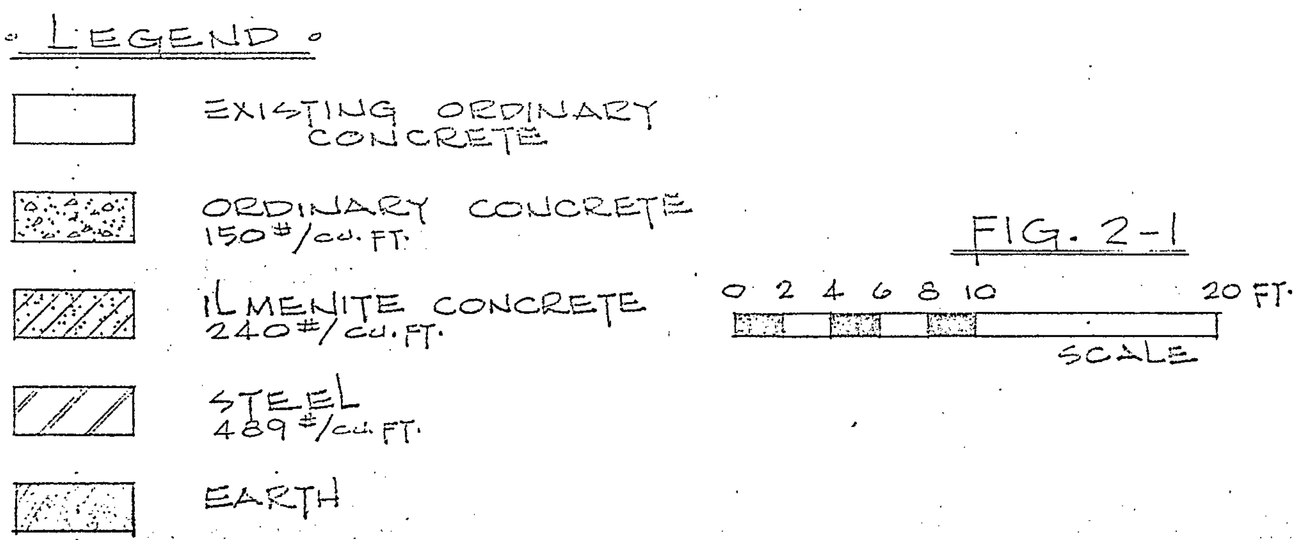


FIG. 2-1

III. Radiation Measurements Around the AGS

W.H. Moore, G.S. Levine, R. Casey,
L.W. Smith and C. Distenfeld

Since the AGS Conversion Program involves increasing the intensity of a presently operating accelerator, it is highly worthwhile to study the shielding of the existing machine in order to determine the shielding requirements for the converted AGS. This is particularly appropriate, since there is involved a known increase in the intensity of beam but not an extension of the energy into a region where the shielding properties of materials are less well known. Consequently, a program of radiation measurements has been in progress for over a year using the AGS beam internally targeted as the source of radiation. This program of shielding measurements is not yet complete and is being actively continued. However, there are some interesting and significant results which are reported here.

Fast Particle Flux in the Sand

In order to predict the fast flux intensity for strongly interacting particles (E > 20 MeV) emerging from the increased thickness of sand cover, C^{11} activation both in polyethylene foils and in plastic scintillators was studied in the existing sand over the tunnel. Measurements were made in the vertical plane above the beam and in the median plane outside the tunnel. Two inch pipe wells were driven from the sand surface to the tunnel roof directly over magnets H-11, H-13, and H-15 (Fig. 3-1). These wells nominally extended through 10 feet of sand. Similar wells were also placed in the side sand out to 40 or 50 feet, driven below the median plane at H-11, H-12, H-13, H-14, and H-15 (Fig. 3-2). At H-13 an array of wells enabled the sand to be probed 14 feet inside the ring from the inside tunnel wall.

To generate the particle fluxes in the sand, the AGS was operated at 30 BeV and a 0.040 inch beryllium target one half inch long was flipped into the circulating beam at H-10. It has been assumed that all of the circulating protons eventually interacted in this target because of multiple traversals around the AGS magnet ring.

For the results described in this report the only important shielding masses were the AGS magnet downstream from H-10, the tunnel concrete, and the sand cover.

In the vertical plane over the circulating beam polyethylene foils were placed at two foot intervals in the pipes at H-11, H-13, and H-15. The fast flux intensities for the three wells at various depths are shown on Fig. 3-3 and a contour plot of the isofluxes appears on Fig. 3-1. The details of the calculations are given in Appendix A.

Since the present sand cover is limited to a nominal 10 feet in the vertical plane over the beam, it was decided to measure the fast particle flux intensities in the median plane of the AGS outside the tunnel where sand penetrations up to 50 feet can be realized. Direct comparison between results in the vertical plane and in the median plane is complicated by two factors:

(a) A large access tunnel leading to the H-10 area creates a void in the side shielding (see Fig. 3-2).

(b) There is an asymmetry in the AGS magnet shielding. Vertically over the beam there is over a foot of magnet steel and in the median plane there is an open magnet gap facing the side where the measurements were made (see Fig. 3-4).

From the foil counting over the beam, it was learned that the foil counting rate near the top of the ring was near the background limit for fluxes on the order of a few hundred per centimeter^2 per second. To increase the counting rate, scintillators (Pilot B) in the form of cylinders one inch in diameter and two inches long were used instead of the polyethylene foils. The plastic scintillators were suspended in the side wells at a depth corresponding to the median plane. The plastic scintillators were calibrated against the polyethylene foils as described in Appendix B.

Semilog plots of the results are shown on Fig. 3-5 for radial distances outward on the median plane from various magnets, and a contour map for the same data is given on Fig. 3-2.

Comparison between the semilog plots, Figures 3-3 and 3-5, does not reveal any significant differences for the particle intensities at corresponding thicknesses of sand. From this it is concluded that the AGS magnet does not contribute to the side and roof shielding for fast particles emerging from the H-10 target. The data from the H-11 side wells have not been included because they are greatly influenced by the void created by the access tunnel (see Fig. 3-2).

14-MeV Neutrons

a. Scintillation counters

Fluxes were measured at many points in the earth cover utilizing scintillation counters. The counters consist of Pilot B diphenylstilbene scintillators mounted on the end windows of Type 6199 photomultipliers. Counter gain is controlled by varying the photomultiplier high voltage. Signals developed at the anode of the tube are passed through a limiter circuit and then to a discriminator circuit which registers only those pulses which exceed 100 millivolts of amplitude. The circuitry is capable of counting at rates as high as 100 Mc/sec. Table 3-1 summarizes the differences in the scintillators. Figure 3-6 is a typical response curve for a given counter, showing its sensitivity to a variety of radiations.

Scintillation counter data were always obtained by recording the flux detected at a particular point during targeting, and for an equivalent time when there was no accelerated beam. In the great majority of cases no background was detected. Two methods were utilized to normalize these measurements: the internal beam intensity was monitored for each run, and a second counter was fixed at some point in the earth cover and its output recorded.

TABLE 3-1

Scintillator Dimensions

Counter	Scintillator			
	Material	Diam (inch)	Length (inch)	Volume (cm^3)
1,2	Pilot B	1	1-7/8	25.7
3	"	1½	¼	7.3

The data plotted in Fig. 3-4 were obtained with Counter No. 3 operating at 725 volts. Figure 3-6 indicates that for this voltage the sensitivity of the counter is such that it does not detect 1.3-MeV gamma rays or neutrons from a Pu-Be source (end point energy about 10.5 MeV), but responds to 14-MeV neutrons with an efficiency of about one count for each 100 neutrons incident on the scintillator.

The data of Fig. 3-4 show an intensification of lower energy particles, which were not detected by C^{11} activation, arising from the absence of one foot of steel in the magnet gap. There is also some indication of a lesser bulge on the side in the direction of the center of the magnet ring. Eliminating these bulges, the isoflux contours are approximately parallel to the tunnel walls.

The data on the median plane both outward from the magnet ring and inward are plotted on Fig. 3-7. The inward results are higher than the outward; this is most likely due to the target being closer to the inward wall.

The results show a tailing off at about 14 feet of sand, but the counting rate was low and this should not be given much importance.

b. Na^{24} activation

Aluminum foils were included with the plastic scintillators to measure the neutrons with energy in the neighborhood of 14 MeV, which is the peak for the giant resonance in the cross section for neutrons bombarding aluminum making Na^{24}. The foils were counted three hours after bombardment when only

Na^{24} and F^{18} were present in significant amounts. The foils were counted again 20 hours after bombardment when the F^{18} ($T_{\frac{1}{2}}$ = 110 min) had decayed, leaving the Na^{24} ($T_{\frac{1}{2}}$ = 14.8 hours).

Unfortunately, only those foils within seven or eight feet of sand were active enough to give a counting rate above background. The results are shown on Fig. 3-8, and a plot transverse to H-13 is shown on Fig. 3-9.

Dose Measurements in the Sand

Dose measurements in the sand were made by Kodak NTA film, Dupont 555 and 1290 β-γ film, and with Bendix pocket dosimeters. The films were packaged in a standard BNL film badge container and lowered to the median plane in the side wells as previously explained. The container has 43 mil cadmium and 64 mil aluminum filters over different areas of the film. An open window is also present. The films were processed and calibrated by the Personnel Monitoring Section of the Health Physics Division of Brookhaven.

a. NTA film

NTA film will respond to any ionizing particle having a specific ionization greater than 60 MeV/cm in the film. This limits the muon detection to those with energies less than 3 MeV and protons of less than 20 MeV.[1] For protons of less than 0.5 MeV there is not sufficient energy to produce a recoil track. Therefore, the proton response of NTA film ranges from 0.5 to 20 MeV.

Track densities in NTA film up to 14-MeV neutrons have been determined by Cheka.[2] Using his calibration curve, a dose equivalence can be determined for neutrons of known energy (see Appendix C). Since the neutron spectrum in the sand is not known, an average energy of 2 MeV was assumed. This leads to a dose five times greater than seen by the dosimeters under comparable conditions. This amounts to an uncertainty of about 2.5 feet of sand.*

---

1. R.L. Lehman, UCRL Report 9513 (1961).
2. J.S. Cheka, Nucleonics 12, No. 6, 40 (1954).

*Data of C. Distenfeld and R. Colvett (private communication) indicate that NTA film sensitivity in the H-10 region is 3 mrem/track.

Figure 3-10 shows the dose rate as found from the NTA film in the side wells beyond 13 feet of sand. The film located closer to the tunnel wall had too many tracks to be counted. A contour map showing the isodose lines is shown on Fig. 3-11.

It is to be noted (Fig. 3-10) that beyond 25 feet of sand (or about 40 ft from the beam line) the dose rate suddenly becomes essentially constant suggesting a background of weakly interacting particles.

b. Pocket dosimeters

For the measurement of the total dose at each well location (both in the vertical plane and in the median plane) Bendix condenser ionization chambers (manufactured by the Bendix Aviation Corporation, Cincinnati, Ohio) were used. These dosimeters are in use at the AGS as a quick method for personnel monitoring. The wall of the instrument is thin aluminum and the ionization chamber is encapsulated in tissue-equivalent plastic. These were charged in accordance with the manufacturer's specifications - 160 volts.

Calibration runs were made on each of the dosimeters used with gamma rays from Co^{60}, neutrons from a Pu-Be source, and minimum ionizing protons in the external beam from the Cosmotron. Previous calibrations made by the Health Physics Division showed that these instruments are tissue equivalent for neutrons up to $\sim$ 20 MeV. Calibrating the dosimeters using 14-MeV neutrons and comparing the results with a known response from NTA film showed agreement within 20% for the average dosimeter. A quality factor of 6.5 was taken for determining the rem dose for the dosimeters. Another calibration was made utilizing a 1-BeV proton beam from the Cosmotron. The results showed the pocket dosimeters to be underreading by a factor less than three, however the uncertainty about the distribution of the proton intensity across the beam could account for the disagreement.

For the collection of data, one dosimeter was inserted in each well. Because of the rapidity of dose rate fall-off with increasing sand thickness from the circulating beam, three different sensitivities ranging from 600 R to 200 mR full-scale were used. All instruments were identical in construction, differing only in the size of the capacitor.

The selection of the sensitivity of the dosimeter to be placed in a particular well was precalculated from the results obtained previously in the vertical plane such that the instrument would not go off-scale during a 16 hour run. Several dosimeters were buried in the sand in a remote, quiet area to determine any background radiation which may be present in the earth. No discharge was observed on any of these after 48 hours.

The dosimeters were read immediately after the run, which gave a result in roentgens for a 16 hour exposure. The readings were converted to rads by a 0.93 factor and a quality factor of 10 gave the rems/hr which was corrected for the normalization.

The results are plotted on Fig. 3-12 which, as in the case of the NTA film, show an abrupt change in slope at about 25 feet of sand.

Attenuation Length in the Sand

Examination of Figures 3-3, 3-5, 3-7, 3-9, 3-10 and 3-12 shows an apparent half value thickness of 1.1 feet of sand or a mean removal mean free path of 1.57 feet of sand.

TABLE 3-2

λ_e vs. Detector

Detector	λ_e (ft)
C^{11} (Fig. 3-3)	1.6
C^{11} (Fig. 3-5)	1.53
Scint. (Fig. 3-7)	1.48
Al (Fig. 3-9)	1.50
NTA (Fig. 3-10)	1.80
Dosimeter (Fig. 3-12)	1.50
	1.57 ± 0.07

$$\lambda_e = 1.57 \times 30.48 \times 1.82 = 87 \pm 4 \text{ g/cm}^2$$

An average moist density of the AGS sand cover is 1.82 or 114 lb/ft^3 or 87 ± 4 g/cm^2. Fifteen samples were obtained from a variety of locations and depths in the ring top. Their densities and moisture contents were measured by Dames & Moore.[3]

The moisture content varied from approximately 4% to 17% by weight of the wet weight. It is therefore assumed in this report that the attenuation lengths measured are those of sand whose average density is 1.82 and whose average moisture content is 10%.

The measured value of 87 ± 4 g/cm^2 for the mean absorption length is considerably less than the 150 g/cm^2 normally used to design shield thickness. The basic reason for the difference is believed to be because the sand cover is a side shield and the attenuation lengths in the neighborhood of 150 g/cm^2 have been obtained from head-on beam stoppers.

The results[4] from the C^{11} activation in the vertical plane were examined in detail. It was found that if the fast flux attenuation was considered, not transverse to the beam but along a line in the sand which extended through the target, the interaction lengths were a function of the polar angle from the circulating beam direction. This was also done for the side well measurements in the median plane and the results are shown on Fig. 3-13.

The C^{11} activation data from both the vertical and median planes have been converted to dose rates[5] from

$$4 \times 10^3 \text{ neutrons/cm}^2\text{/sec} = 1 \text{ rem/hr} .$$

The dosimeters which read in roentgens were multiplied by 0.93 to convert to rads. A quality factor of 10 was used to determine the rem dose for the 16 hour run. Hence the dose rate is

$$\text{Rem/hr} = \frac{10 \times 0.93 \times \text{roentgens}}{16}$$

3. Dames & Moore, Soils Investigation, AGS Magnet Enclosure Structure, May 20, 1966.
4. W.H. Moore, BNL Accelerator Dept. Internal Report AGSCD-6, January 24, 1966.
5. 200-BeV Accelerator, Preliminary Project Report, January 1966, LRL; also, CERN uses 10^4 neutrons/cm^2/sec = 1 rem/hr.

for the sand region where the strongly interacting flux is dominant. For the region where the weakly interacting flux prevails a quality factor of unity was used. The C^{11} and dosimeter dose rates have been plotted on Fig. 3-14 normalized to 4 X 10^{12} protons/sec stopping.

Attenuation Through a Duct

An eight inch aluminum tube, 10 feet long, has been installed vertically in the earth cover above the BC survey monument. It is coupled to and colinear with a 12 inch penetration through the concrete roof of the tunnel. It projects six inches above the surface of the earth cover. The survey monument is nine feet radially outside the vacuum chamber, at the 10 foot BC straight section.

Measurements of the radiation intensity at various levels in this vertical duct were made with the scintillation counter described earlier and at three levels with a standard BNL Health Physics integrating ionization chamber.

During the measurements AGS beam studies were in progress. The beam was accelerated to about 19 BeV and then allowed to die in the vacuum chamber.

Figure 3-15 summarizes the data. Uncertainties in position are ± 1 inch for the counter. Points were repeated to establish reproducibility and the statistical uncertainty is less than 1%. However, since the accelerator parameters were being varied to some extent during the measurement, an error of ± 10% seems reasonable.

The ionization chamber measurements are rather crude. In the last minutes of beam time an average dose per pulse was measured at the top, middle, and bottom of the pipe. The position error may be as much as ± 1 foot. The doses represent the variation about the peak intensity at each point and assume a constant pulse-to-pulse circulating beam intensity of 1.5 ± 0.5 X 10^{12} protons per pulse at a 2.4 second repetition rate.

The data show that the distance along the duct necessary to reduce the dose to 1/e of its initial value is 2.5 feet. Consequently, with 20 feet of earth cover over the ring it seems reasonable to expect that the radiation transmitted along a duct of this sort will be reduced by a factor of

$$\frac{N_{20'}}{N_o} = e^{-20/2.5} = 3.3 \times 10^{-4} .$$

APPENDIX A

Foil Counting Calculations

At any time, t, during bombardment of the foils, the number of C^{11} atoms present in the foil can be found from

$$\frac{dC^{11}}{dt} + \frac{C^{11}}{\lambda} = k\,\frac{dN}{dt} = k\,\eta\,\frac{dP}{dt} \tag{1}$$

whose solution is

$$C^{11}(t) = e^{-t/\lambda}\left(K + k\int \frac{dN}{dt}\,e^{t/\lambda}\,dt\right) \quad \text{or}$$

$$= e^{-t/\lambda}\left(K + k\,\eta\int \frac{dP}{dt}\,e^{t/\lambda}\,dt\right) \tag{2}$$

where

$\frac{dN}{dt}$ is the fast particle flux/cm^2/min

$\frac{dP}{dt}$ is the circulating protons in the AGS per minute

η is a factor depending only upon the position of the foil with respect to the target and has units cm^{-2}

λ is the mean life of C^{11}
= 20.3 min X 1.44 = 29.2 minutes

k = $A(1 - \alpha)\,\sigma(E)$ w/m.w.

A = Avogadro's number, 6.0228×10^{23} mole^{-1}

$\sigma(E)$ = the cross section for inducing C^{11} taken as $29.0 \pm 1.3 \times 10^{-27}$ cm^2

$(1 - \alpha)$ = (0.88 ± 0.018) is the correction for the cross section for a 0.004 in. polyethylene foil due to the escape of active hydrocarbon molecules from the foil during bombardment[6]

---

6. J.B. Cumming, A.M. Poskanser and J. Hudis, Phys. Rev. Letters 6, No. 9, 484 (1961).

w = foil weight 0.1028 ± 0.0008 grams

m.w. = molecular weight of polyethylene = 14.03 grams/mole

$k = (11.26 \pm 0.75) \times 10^{-5}\ cm^2$.

If the foils are bombarded for 60 minutes with a uniform circulating beam intensity and $(dC^{11}/dt)_o$ is the true count/minute after an hour's bombardment

$$\left(\frac{dC^{11}}{dt}\right)_o = \frac{C^{11}(t_1)}{\lambda} .$$

From (2)

$$\left(\frac{dC^{11}}{dt}\right)_o = k\,\frac{dN}{dt}\,(1 - e^{-t_1/\lambda}) = \frac{dC^{11}(t_1)}{E\ dt}$$

where E is the counter efficiency which for the well counters in the BNL Chemistry Department is[7]

0.737 ± 0.011 .

$$\frac{dN}{dt} = \frac{(dC^{11}/dt)t_1}{k\ E(1 - e^{-t_1/\lambda})}\ /cm^2/min$$

$$= \left[11.26 \times 10^{-5} \times 0.737 \times 60 \times (1 - e^{-60/29.2})\right]^{-1} \left(\frac{dC^{11}}{dt}\right)_{t_1}$$

$$= 230\ (dC^{11}/dt)_{t_1} \quad \text{strongly interacting particles/cm}^2\text{/sec}$$

where $(dC^{11}/dt)_{t_1}$ are the counts/minute corrected for decay to the end of the bombardment time.

---

7. J.B. Cumming, J. Hudis, A.M. Paskanser, and S. Kaufman, Phys. Rev. 128, No. 5, 2392 (1962).

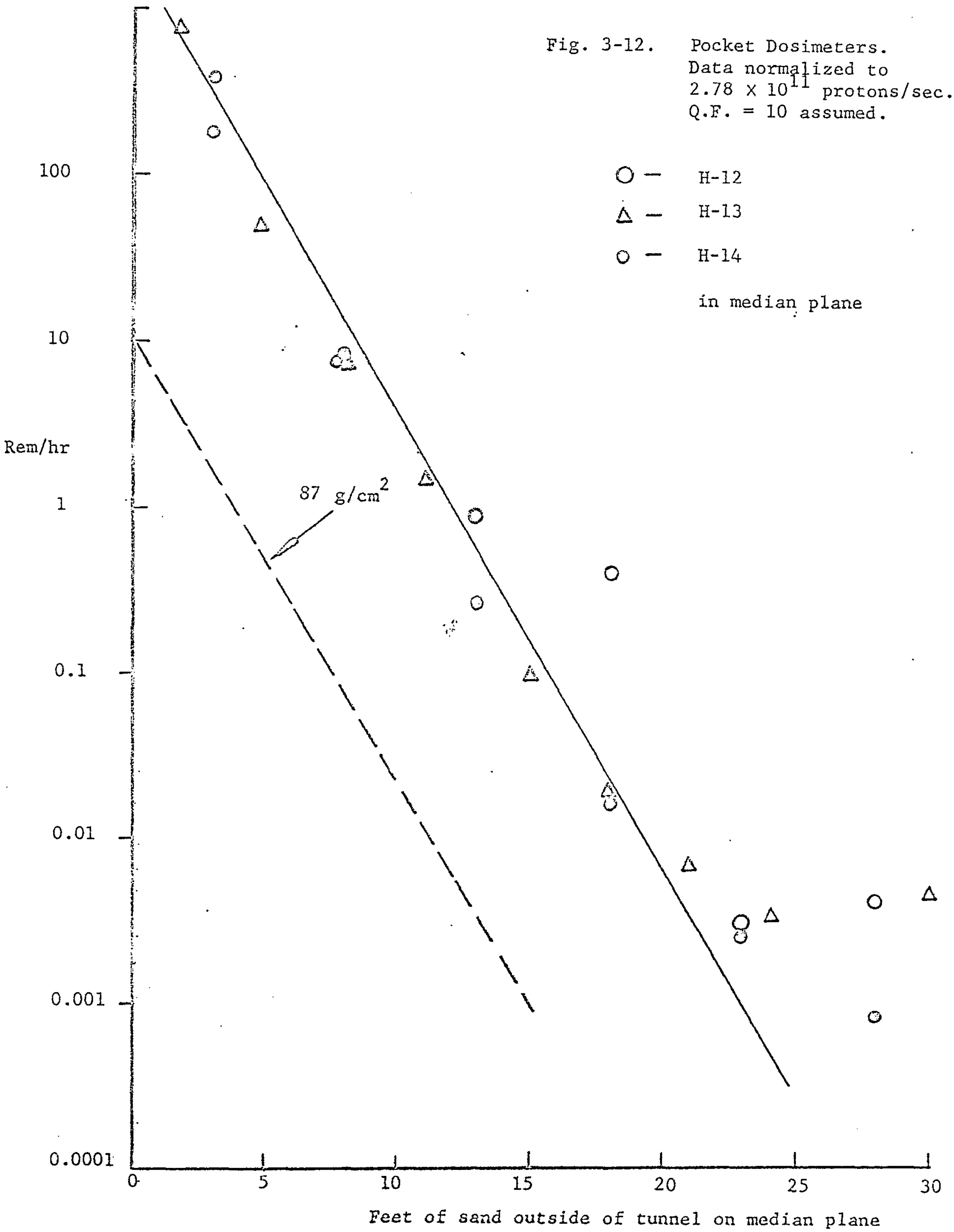


Fig. 3-12. Pocket Dosimeters.
Data normalized to
2.78 x 10^11 protons/sec.
Q.F. = 10 assumed.
H-12
H-13
H-14
in median plane
100
10
1
0.1
0.01
0.001
0.0001
Rem/hr
87 g/cm^2
0
5
10
15
20
25
30
Feet of sand outside of tunnel on median plane

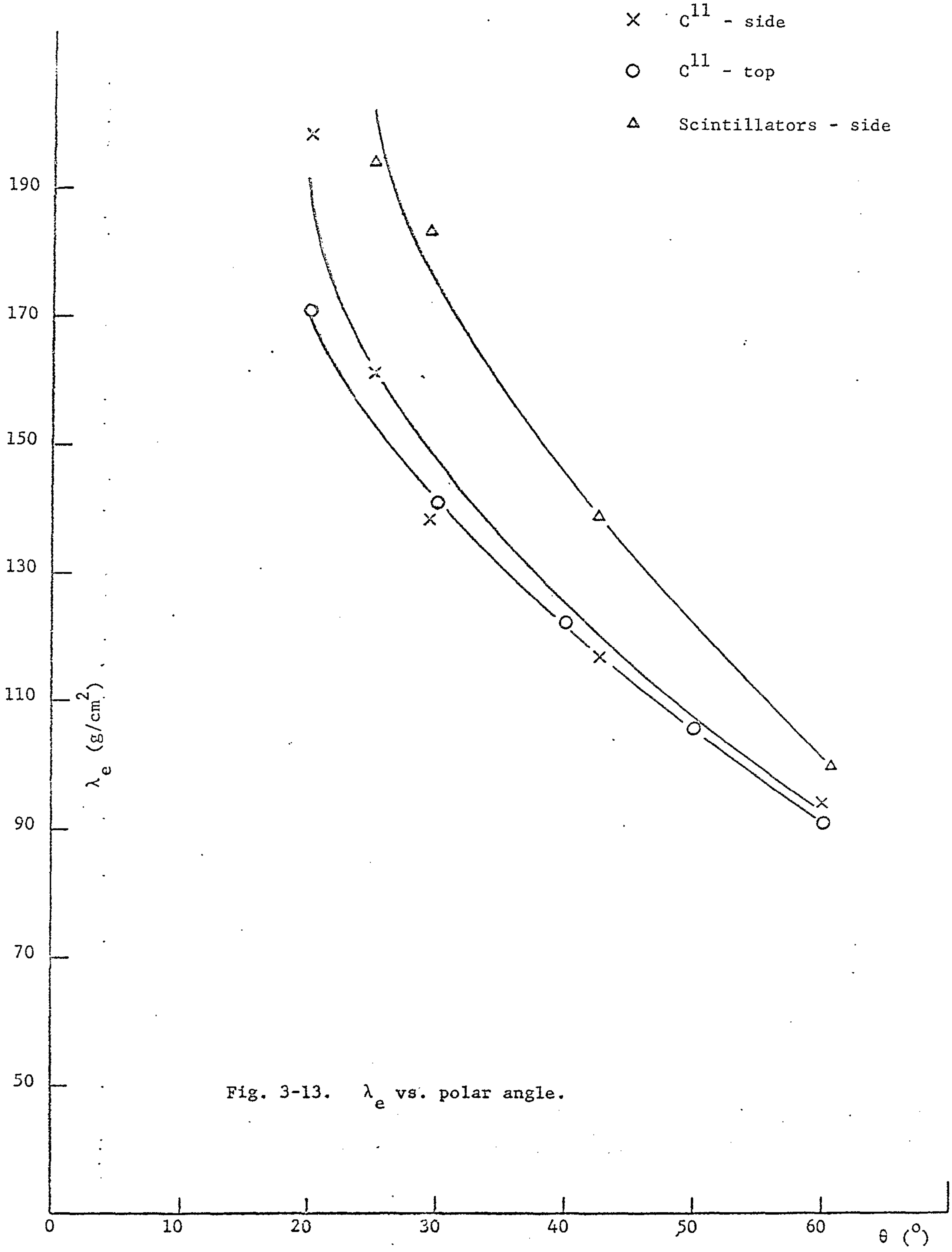
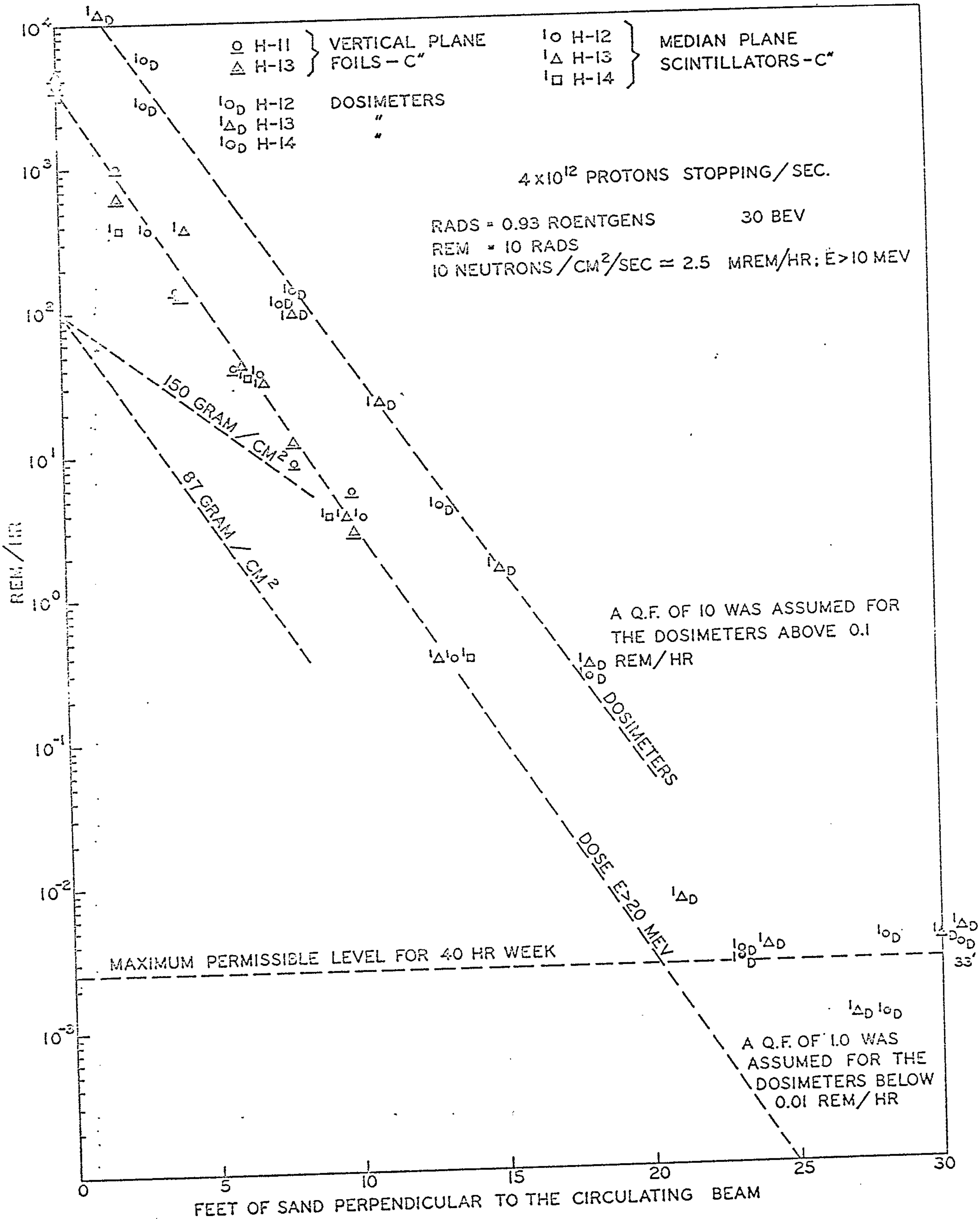


Fig. 3-13. λ_e vs. polar angle.



o H-11
△ H-13
VERTICAL PLANE FOILS – C"
Io H-12
I△ H-13
I□ H-14
MEDIAN PLANE SCINTILLATORS - C"
IoD H-12
I△D H-13
IoD H-14
DOSIMETERS
4 x 10^12 PROTONS STOPPING/SEC.
30 BEV
RADS = 0.93 ROENTGENS
REM = 10 RADS
10 NEUTRONS/CM²/SEC ≃ 2.5 MREM/HR; E>10 MEV
150 GRAM/CM²
87 GRAM/CM²
A Q.F. OF 10 WAS ASSUMED FOR THE DOSIMETERS ABOVE 0.1 REM/HR
DOSIMETERS
DOSE E>20 MEV
MAXIMUM PERMISSIBLE LEVEL FOR 40 HR WEEK
33'
A Q.F. OF 1.0 WAS ASSUMED FOR THE DOSIMETERS BELOW 0.01 REM/HR
REM/HR
FEET OF SAND PERPENDICULAR TO THE CIRCULATING BEAM

Fig. 3-14

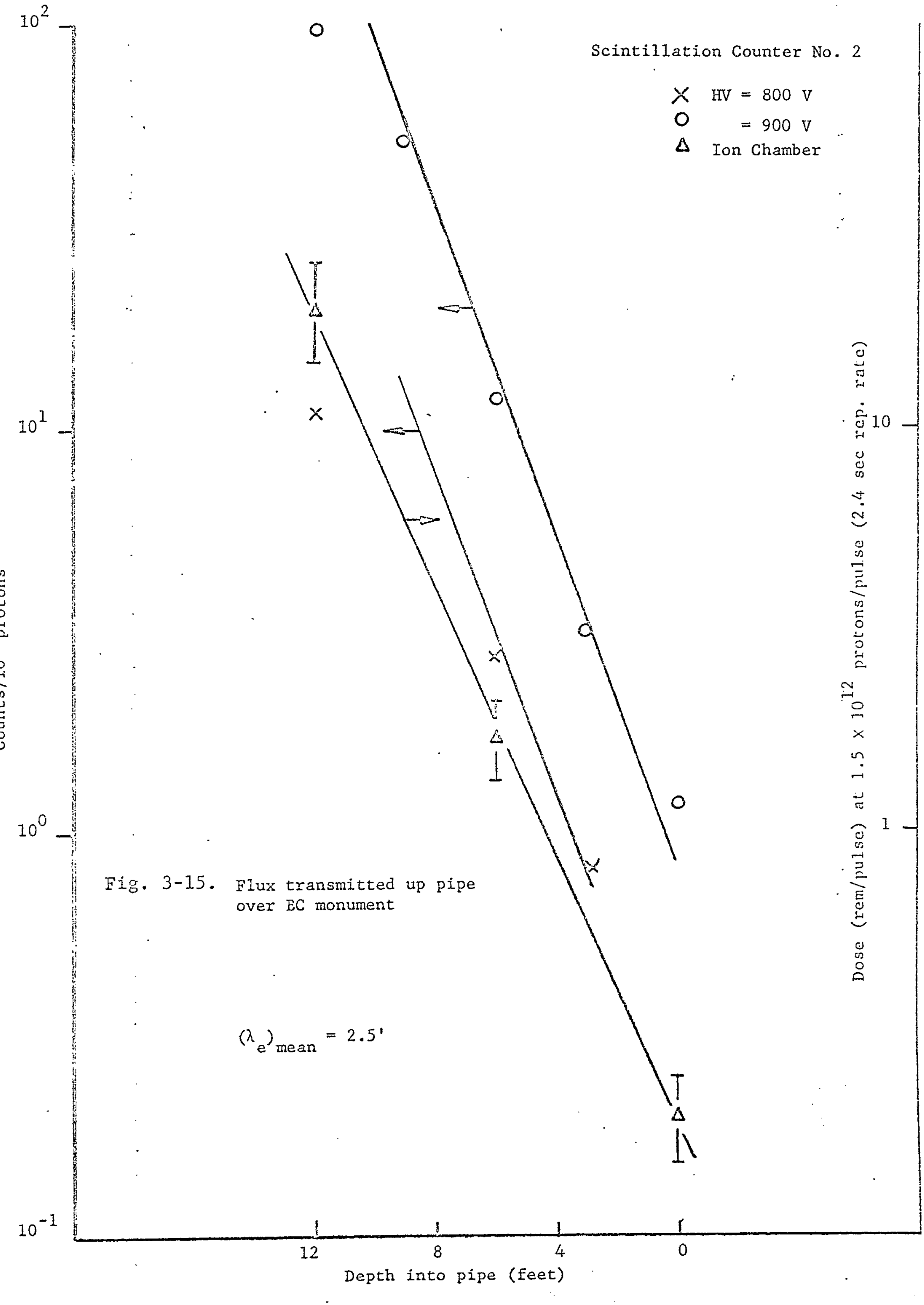


Fig. 3-15. Flux transmitted up pipe over EC monument

IV. Structural Work

J.H. Lancaster

Extensive calculations by the firms of Stone & Webster Engineering Corporation and Charles T. Main, Inc., and by Brookhaven's consultant, Professor Clarence Dunham, have shown that the existing reinforced concrete magnet enclosure, which was originally designed for five feet of earth fill and which is now carrying ten feet of earth fill, cannot carry additional weight without major structural modifications.

During preliminary investigations a considerable number of alternate designs were investigated. Among these were: chemical soil solidification around the existing tunnel; sonic driven piles supporting new roof girders; drilled-in caissons supporting similar girders; new roof girders supported on spread footings; steel culvert sections over the tunnel; steel arch construction; concrete arch construction; and a number of designs using the small residual strength of the tunnel for partial support.

The current design, shown in Fig. 4-1, is based on two reinforced concrete slabs, pitched to form a three-hinged arch type structure spanning the existing tunnel. The pitch angle, size, location and shape of the slabs and footings have been selected to minimize additional loading on the tunnel. The new structure will be designed to support ten additional feet of earth fill immediately upon construction plus an additional five feet of fill after the concrete has reached its ultimate strength and the footings have developed maximum resistance to settlement and sliding. This will provide an ultimate total of 25 feet of earth fill over the magnet enclosure. Radiation will also have to penetrate two reinforced concrete slabs having a total thickness of 33 inches.

There are a number of special sections of the tunnel which cannot employ the arch shown in Fig. 4-1. These are the junctions of the tunnel with the north and south ends of the Target Building, the extracted beam conjunction sections at H-10 and I-10, the existing conjunction at the 50-MeV linac and the new conjunction at the inflector for the 200-MeV linac. Special construction work is needed at each of these points to carry the additional sand cover. The shielding of the ring in the Target Building is discussed in Section III.

There will be a large number of penetrations into the tunnel each of which must be handled separately. There are four general types of penetrations.

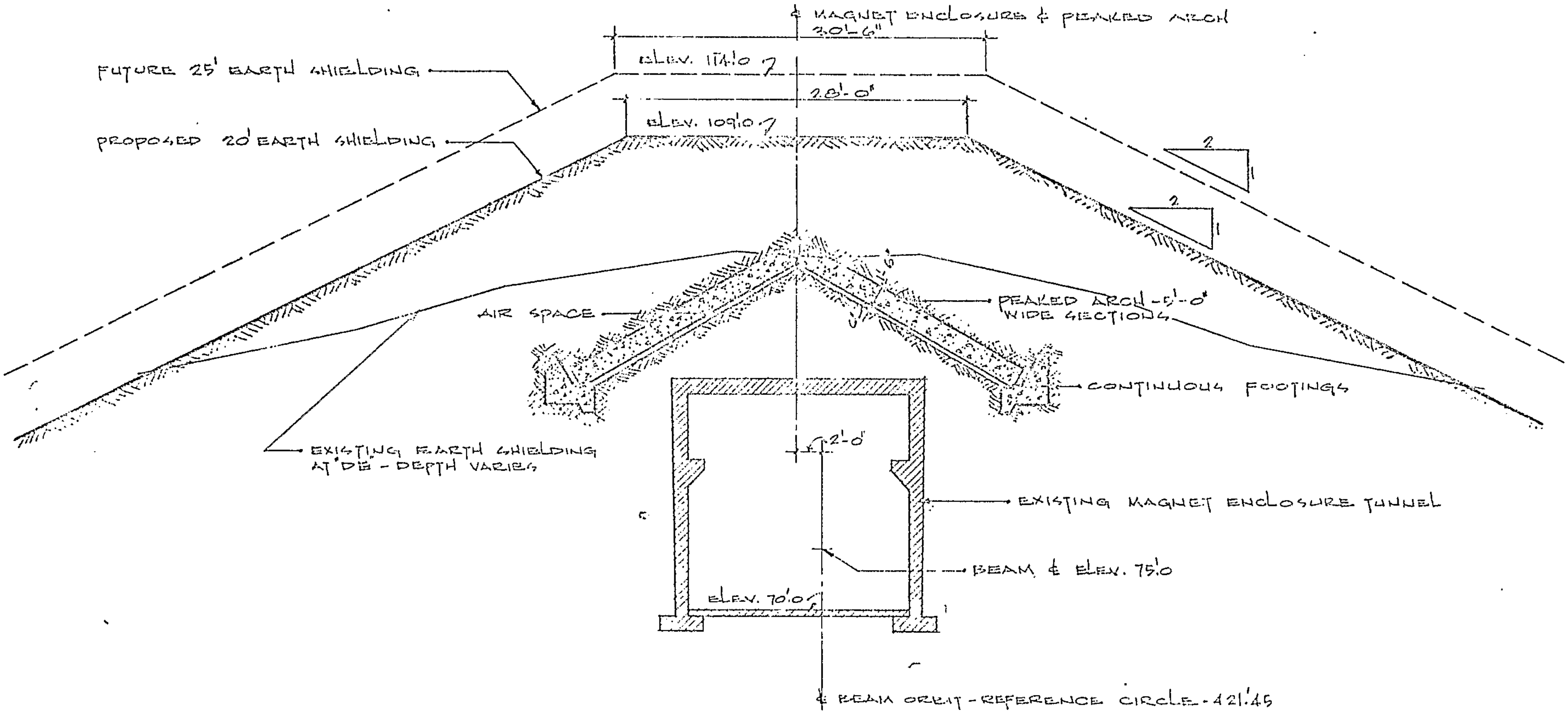
1. Remote surveying holes. There will be twenty-two 18 inch diameter holes spaced around the ring for use in remote surveying of the magnets. These will be vertically over the roof of the tunnel directly over the appropriate pile caps. Since surveying will only be done when the accelerator is not operating, shielding will be accomplished by solid plugs filling the upper portion of each hole when the machine is operating.

2. Personnel and equipment access ports. The existing access ports will be treated as is presently done, that is, a maze through the shielding with sufficient bends to attenuate the radiation and with access gates and restricted areas. Several new access ports will be added through the sand shielding of the tunnel. When the accelerator is operating, these ports will be closed with thick plug doors of heavy concrete.

3. Cable and service penetrations. In order to facilitate the location of as much as possible of the auxiliary equipment outside of the tunnel, it will be necessary to supply a duct bank at each ten foot straight section to permit entrance of the required services. Each duct bank is expected to consist of twelve 4 inch diameter pipes cast in a concrete bank. The banks will enter the tunnel below the median plane and will pitch up at an angle of about 30°. The pipes will be about 40 feet in length and will sweep in a gradual curve so as to destroy the line of sight through the duct. The attenuation factor through such a duct is expected to be of the order of 10^{-5}. A radiation shield and barrier will be used at the outside end of the bank, should this be necessary.

4. Fan houses. Five fan houses contain the tunnel air handling equipment and are connected to the tunnel by large straight ducts. It will be necessary to erect shielding walls around the fan houses and to fence the area inside the shielding so that there will be no access while the accelerator is operating. In addition, the straight ducts between the tunnel and the fan house will be replaced with a duct having a double bend in it, constructed of heavy concrete. Further measurements will be made around the fan houses.

The presently existing escape hatches located around the tunnel will be abandoned and permanently plugged with concrete.



EARTH SHIELDING SUPPORT STRUCTURE

CROSS SECTION - FIG. 4-1

0 2 4 6 8 10 20 FEET

V. Activation and Radiation Damage*

C. Lasky

Present average radiation exposure of the operations personnel runs between 30 to 40% of continuous working allowance. It arises primarily from exposure to residual activity inside the machine tunnel and in particular from those portions of the ring in the immediate vicinity of experimental targets and external beam equipment. Following the Conversion, these residual levels can be expected to increase by significant factors. The decay rate will depend on the particular concentration of materials in the neighborhood of the individual target. The decay of gamma activity of all of the materials normally found in the AGS tunnel has been studied by the Chemistry Department at BNL for two typical irradiations. These decay curves were published as Figures IV.6-2 through IV.6-7 in BNL-7956, pp. 241-246.

Since high levels will be unavoidable in these areas the following several-pronged approach is being taken to reduce drastically the time spent in these areas by operating personnel. It is anticipated that after conversion a magnet module can be removed completely from the ring structure in approximately 10 minutes. All of the disconnect devices will be of a quick operating nature. Vacuum chamber flanges will be connected with quick disconnect "Marmon" clamps, water manifolds will be of a self-sealing boltless type, and the electrical bus bar will be a single nut, clamp type, relocated in a readily accessible position. The vacuum chamber clamp and the bus bar connection are being designed for operation with long-handled wrenches and will be compatible with the remote-handling device being developed.

---

*This subject is covered in considerable detail in BNL-7956, "A Proposal for Increasing the Intensity of the Alternating-Gradient Synchrotron at the Brookhaven National Laboratory", May 1964, and BNL-9500, "Alternating-Gradient Synchrotron Conversion Program, Scope of Phase I", September 1965.

Where an operation is rigorously defined, such as target changing, special single purpose, completely unattended automatic machines will be built. The first such target changing machine is presently installed on the operating AGS at the G-10 target position.

Magnet coils in the immediate vicinity of targets will be replaced with coils having insulation good for at least a nine year life at the new operating levels of the AGS. Samples of these insulations have already been tested in the BNL high gamma flux facility to exposure levels of 2×10^{10} rads, the equivalent of nine years' exposure immediately downstream from a target absorbing 2×10^{12} protons per second continuously. This is based on a radiation survey which indicated that the hot spot on the coil immediately downstream from a target in a ten foot straight section absorbed 3.8×10^{8} rads for 10^{18} protons absorbed in a beryllium target. Exposure levels at the next downstream magnet are lower by a factor of six. With any reasonable diversity factor among the several experimental areas of the converted machine the minimum insulation life of the most exposed coil is estimated to be of the order of ten years even for Phase II operation.

The Conversion also has as a design goal the replacement of all organic gaskets in the vacuum chamber. Present designs show a double metal gasket with a pump-out between the gaskets. The pump-out space is also provided with a valved vent. The normal operation will not call for fore-vac pressure in the pump-out region. Instead, the vent valve will be left open and a long tube will be run from the pump-out port to a leak test manifold at some distance from the target area. It will then be possible to leak test the vacuum chamber gaskets quickly without involving personnel in the high residual activity areas. Almost all of the present vacuum group exposure comes from leak testing and replacement of radiation damaged organic (Viton A) gaskets in the vicinity of targets. The replacement of vacuum pumps and gauges presently on an approximate 50 foot spacing with pumps and gauges on an 8 foot azimuthal spacing and the subdivision of the ring into 24 rather than the present 12 sections will greatly aid in localizing vacuum problems and tracing them to their ultimate source.

To complete the general pattern of minimizing time spent in the ring on the part of operating personnel, the Conversion will also provide for remote observation of possible radial and vertical motion of magnets on the ring structure. Twenty-two new penetrations will be made of the tunnel roof to allow optical instruments above the tunnel shielding to observe, through a system of fixed mirrors, targets fixed to each of the ring magnets. These penetrations will be provided with removable radiation plugs. The magnet locating pins, the vertical and the radial adjustments, will also be redesigned for more easy manipulation by remote-handling devices or by motorized drives.

The AGS closed magnet cooling system contains 15,000 gallons (5.7×10^4 liters) of deionized water. The present flow rate is 1,400 gpm with provision for passing 25 gpm through a mixed bed deionizer. After conversion the flow rate will be approximately 2,000 gpm with the same provision for continuous deionization. The degree of deionization is presently controlled by the measured conductivity of the water in the closed system. At times it is desirable to drain the closed system and the possible hazard has been looked into. Decay curves for gamma-ray emission and some gamma-ray spectra have been obtained from AGS magnet water samples by the BNL Chemistry Department. A tritium analysis was also made. Decay curves measured shortly after drawing the samples showed that most of the gamma activity has a short half life consistent with 20.4 minute C^{11}, a major spallation product of oxygen. A component of half life $\simeq$ 1 day, possibly 15 hour Na^{24} or 12.8 hour Cu^{64}, is present and also a component of half life > 50 days. Gamma spectra of the long-lived tail show peaks at 0.48 MeV (53.6 day Be^7) and at 0.81 MeV (possibly 71 day Co^{58}). The results of a radioassay are listed below. The concentration in $\mu Ci/\ell$, the total content of the system in mCi, and the dose rate above an infinite sea of such water is given for the principal constituents of the water samples. With a factor of even 100 (this implies $3\text{-}4 \times 10^{13}$ protons/sec) the external hazard would still be trivial although some C^{11} radiation would be measurable near large masses of water (heat exchanger and storage tank).

Results of Radioassay of AGS Magnet Water*

Isotope	Half-life	Concentration (μCi/l)	Total Content (mCi)	Dose Rate (μR/hr)
C^{11}	20.4 m	1.9×10^{-1}	11	70
Na^{24}	15 h	3.5×10^{-4}	0.02	0.9
Be^{7}	53.6 d	3.6×10^{-3}	0.21	0.06
H^{3}	12.3 y	1.5×10^{-2}	0.85	--

The short half-life of the C^{11} inventory will present only a minor problem if the necessity arose to dump the contents of the closed system. Should this necessity arise, the Be^{7} inventory can be retained in the deionizer by discharging through it. Another and more satisfactory solution would be to control the bypass through the deionizer by means of the measured Be^{7} concentration and thereby maintain the total content below some safe level in the event of a catastrophic rupture of the closed system.

Air activity under AGS operating conditions** of 3 to 4 $\times 10^{11}$ protons per second was assayed by filling a previously evacuated vessel with the discharge of a vacuum pump drawing air from the target area in use. Results indicated gross levels of 4×10^{-7} μCi/cc decaying with an initial 16 minute half-life, strongly suggesting a mixture of C^{11} and N^{13}. Sample air drawn from upstream of the target yielded a level of 0.1×10^{-9} μCi/cc.

Several 400-channel analyses were conducted with fresh 50 ft^3 particulate air samples collected on Whatman-40 filter paper. The sampling rate was 5 ft^3/minute. The low levels measured did not permit constituent isotope identification. Longer samples were not taken because of the radioactive decay of the major components during the sampling. The decay curve of the dust sample was

---

* Taken from BNL-7956, p. 248.

** Abstracted from "Alternating-Gradient Conversion Summary", C. Distenfeld and R. Colvett, Health Physics Division, Brookhaven National Laboratory.

resolved into three constituents. During the first hour it decayed with an 11 minute half-life. Between 1 and 4 hours the curve fitted a 45 minute half-life, and between 4 and 10 hours it fitted a 13.5 hour half-life.

Considering the gamma scans, half-lives, and available materials, a mixture at time zero of 60% N^{13}, 38% Mn^{51}, and 2% Na^{24} would account for nearly all the dose. Based on the above, a long exposure dose of 0.075 mR is indicated due to dust. The observed gaseous activity will constitute an immersion dose. Assuming an infinite cloud of Ar^{41} the measurements indicate an entrance dose rate of 2.5 mR/hr or a long exposure dose of about 5.0 mR. This probably overestimates the exposure by a factor of 20 due to the actual presence of the short-lived N^{13} and C^{11}. In either event these dosages are insignificant when compared to the dose due to activated machine components.

The above results are somewhat at variance with previous measurements reported in BNL-7956. The differences lie primarily in the manner in which the air and dust samples were drawn. The results reported above more nearly approach the actual dynamic situation than does the static situation represented by measurements on air contained in balloons and exposed near a target. Normal operation of the air-conditioning fans (10% fresh air intake) results in a complete air change every 90 minutes. Under emergency conditions the entire tunnel air can be changed in a little over 9 minutes. The Conversion Program calls for the necessary modifications to the air handling systems to permit operation of the entire machine enclosure at a slightly negative pressure relative to the outside ambient.

Production of Na^{24} in the concrete tunnel walls and shielding blocks will contribute to the activation radiation levels in the tunnel. Boron loading in the concrete can reduce this effect substantially. In the existing tunnel walls addition of boron to the concrete is impossible. However, it seems possible to develop a boron loaded plaster which could be applied to the tunnel walls in high activation areas where the Na^{24} contribution is significant. In new construction, boron loading of the concrete will be used where appropriate.

VI. Personnel Radiation Security System*

R.R. Kassner

The basic philosophies, procedures and techniques presently used at the AGS for personnel control in areas of high radiation levels are considered to be fundamentally in accordance with the nature of the hazards existing and will be continued for the converted AGS operating at the higher intensities. Modification of certain details will be made to accommodate other basic changes in the converted AGS. For example, less operating equipment within the magnet enclosure will shift the emphasis away from the present, periodically used, "brief shutdown". In addition, as other techniques, equipment and systems are developed and evaluated, these will be added to a "secondary line of protection" to improve the safety factor and/or flexibility of the systems.

To describe the present AGS system briefly, the basic mode of protection is that all doors, gates, hatches, and other personnel barriers separating areas of high radiation levels from other (habitable) areas are fully secured and locked and are considered (and designed) to be quite impassable except by extraordinary means. Further, procedures as well as all gate functions (lock, unlock, reset, personnel check-in and check-out, etc.) are arranged to require action locally at the gate by trained and responsible personnel; fully remote actions generally are not utilized.

The philosophy here is that there is no substitute for human observation, judgment and responsibility to insure, by personal action, that all conditions for personnel security are maintained. In addition, a human can accommodate the greatest variety of abnormal situations as well as providing whatever flexibility may be required. Conversely, various mechanical and electrical protective arrangements will match only those situations for which they were designed. Further, such arrangements can and do fail. Redundancy can improve the reliability, but can be misleading. At a minimum, such redundancy can

---

*See also R.R. Kassner and W. Livant, IEEE Transactions on Nuclear Science, Vol. NS-12, p. 689 (June 1965).

involve considerable additional complexity required to monitor the various redundant paths, which itself can contribute to potential failure and certainly to the maintenance program. For these and other reasons, such arrangements of various mechanical and electrical protectives as are included in the AGS are considered as a part of the secondary line of protection.

The procedure for initial clearance of the AGS magnet enclosure and adjacent areas prior to beam injection and acceleration involves the personal inspection of all the areas by two teams of two men each. These teams start their inspection at one of the main gates, which is manned by a fifth person. The inspection teams proceed in opposite directions from the gate around the ring, pass each other in the vicinity of the injector, and continue around back to the starting point. Thus, all areas are inspected twice. The duties of these teams are as follows:

a) Account for each and every person in these areas, name by name, including film badge number, and pass this information to the man at the gate who maintains a detailed check list.

b) Secure, lock, and reset all doors and gates.

c) Make a general visual inspection of the machine itself, particularly the main magnets.

The first team to pass each door or gate locks it, and insures by visual and physical observation that it is indeed properly and fully locked. In addition, the door switch circuit at each gate must be reset, and this serves to indicate that every door and gate has, at least, been visited (equivalent to a watchman's key arrangement). The second team passing each door or gate inspects and verifies the gate status.

As the various personnel who were in these areas leave through the manned gate, their names and film badge numbers are checked off. When all personnel have thus been accounted for, the gate is locked, local circuits reset, and clearance is given to main control. Additional circuits can then be reset at the main console. Machine operation, in particular main magnet pulsing and accelerated beam, can proceed.

In the over-all operation of the AGS, situations arise requiring personnel to enter and be in these areas for relatively brief periods of the order of an hour. To avoid the moderately lengthy process of complete inspection, a brief shutdown is declared and machine operations are secured. Men are stationed at appropriate gates and detailed check lists are maintained of all personnel entering and leaving. Once all personnel have left and been accounted for, machine operations are resumed in the same manner as for the initial clearance.

In the over-all system, fundamental redundancy exists in that there are two lines of protection, the first being the fully locked and bolted gates with all gate operations performed by trained personnel locally at the respective gate. The secondary line of protection acting as back-up consists of the more conventional door switches, interlocks, warning devices, etc., each with their own redundant features, as will be mentioned briefly in the following.

Each personnel barrier has two limit switches, one which is actuated when the barrier is closed, and a second which is actuated by the locking bolt when it has fully entered the strike plate. These are wired in a trip-free circuit requiring reset at the gate. The bolt is electrically actuated, but can be retracted mechanically through a break-glass/turn-knob arrangement for emergency exit. In this case, however, a mechanical interlock is released and requires physical resetting to permit the associated switch (which is also wired in the door switch circuit) to be put in the permissive condition. This emergency release is indicated in the main control room by a flashing light to differentiate between a normal "not reset" gate condition light. All wiring, switches and relays are of the industrial class to insure maximum reliability and minimum failure through physical abuse and misuse in a system which is distributed over a wide area.

To help insure full understanding and agreement on machine status prior to entry into the areas, the actuating circuit for the release solenoid on the gate bolt uses two switches, one locally at the gate and a second one at the main console. The circuit is actuated only when both of these switches are pressed simultaneously.

Information lights and lighted signs are liberally located in all these areas, particularly at the gates, to indicate the various states of accelerator operation and security system. In addition, prior to any change in accelerator status or operating condition, appropriate public address system

APPENDIX B

Plastic Scintillator Calibration

The plastic scintillators were calibrated against the polyethylene foils by means of a simultaneous exposure in the median plane at H-13. The comparison was made with 1.2 feet of sand intervening between the outside of the tunnel wall and the place of detection which was C^{11} activation. The foil gave 743 counts/min and the scintillator 3.25×10^5 counts/min corrected for background, decay and counter efficiency.

From Appendix A, the fast particle flux intensity from the foil

$$\phi_F = 230 \times 743 = 1.76 \times 10^5/\text{cm}^2/\text{sec}$$

$$\phi_{Scin} = \frac{1.76 \times 10^5}{3.25 \times 10^5} \left(\frac{dC^{11}}{dt} \right)_{Scin} = 0.54 \left(\frac{dC^{11}}{dt} \right)_{Scin}$$

where $(dC^{11}/dt)_{Scin}$ are the counts/minute corrected for background, decay, and counter efficiency.

APPENDIX C

Neutron Flux from NTA Film

From NTA efficiency curve, assuming mean energy of ~ 2 MeV or 3 tracks/25 fields for 10^6 neutrons/cm^2. For 2 MeV neutrons

18 neutrons/cm^2/sec = 100 mrem/40 hours or,

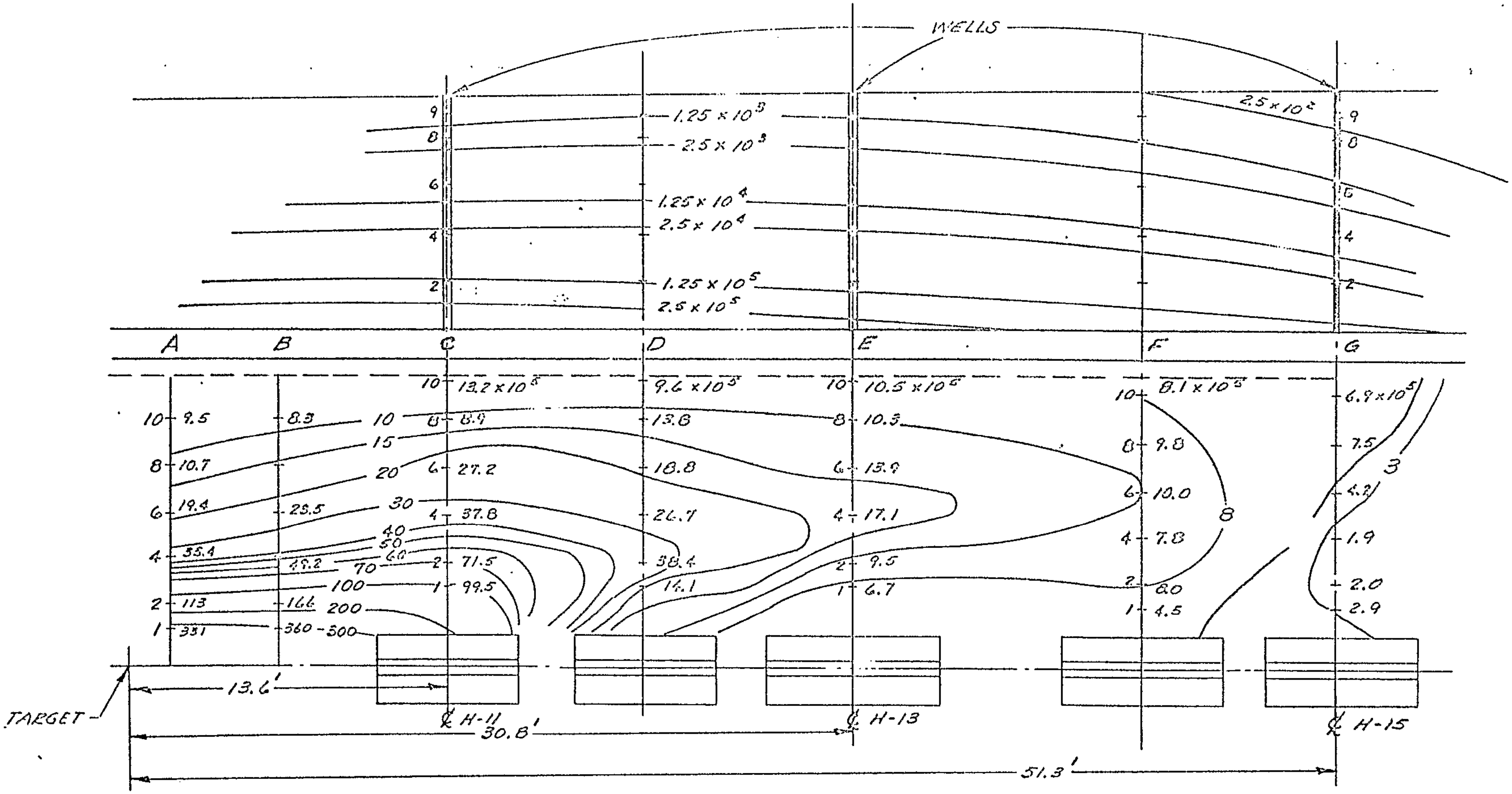
6.5×10^4 neutrons/cm^2/hr = 2.5 mrem/hr and

2.6×10^4 neutrons/cm^2 = 1 mrem .

Since

$$\frac{1 \text{ track}}{25 \text{ fields}} = \frac{3.2 \times 10^5 \text{ neutrons/cm}^2}{2.6 \times 10^4 \text{ neutrons/cm}^2/\text{mrem}} \approx 12.5 \text{ mrem}$$

$$\frac{1 \text{ track}}{25 \text{ fields}} = \frac{12.5}{16 \text{ hours}} = 0.77 \text{ mrem/hr} .$$



FAST FLUX (CH_2 FOILS)

FIG. 3-1

NOTE –

1- NORMALIZED TO 2.78×10^{11} PROTONS/SEC –
2- 8" VACUUM PIPE AT TARGET
3- READINGS ARE FAST PARTICLES/CM^2/SEC

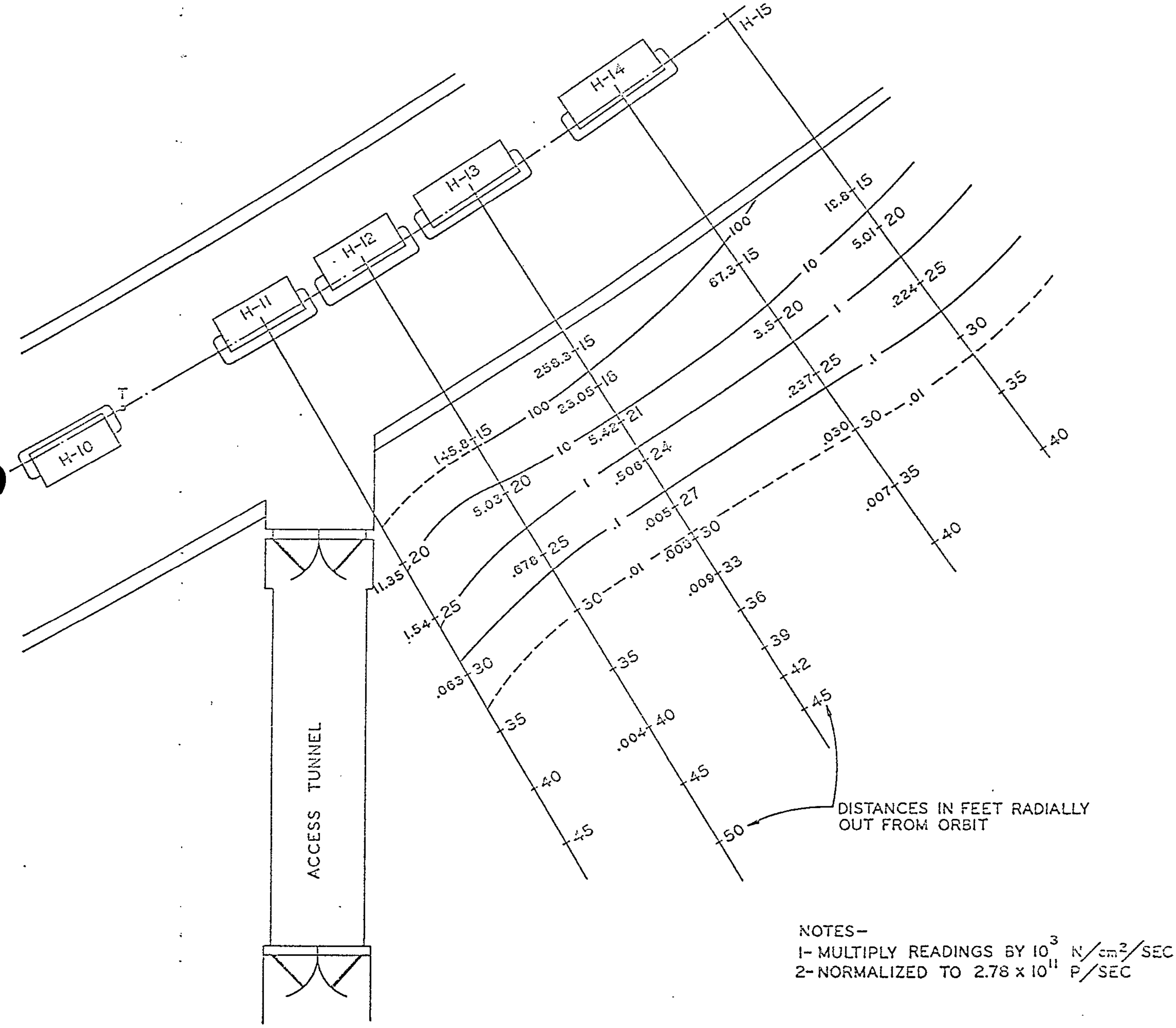
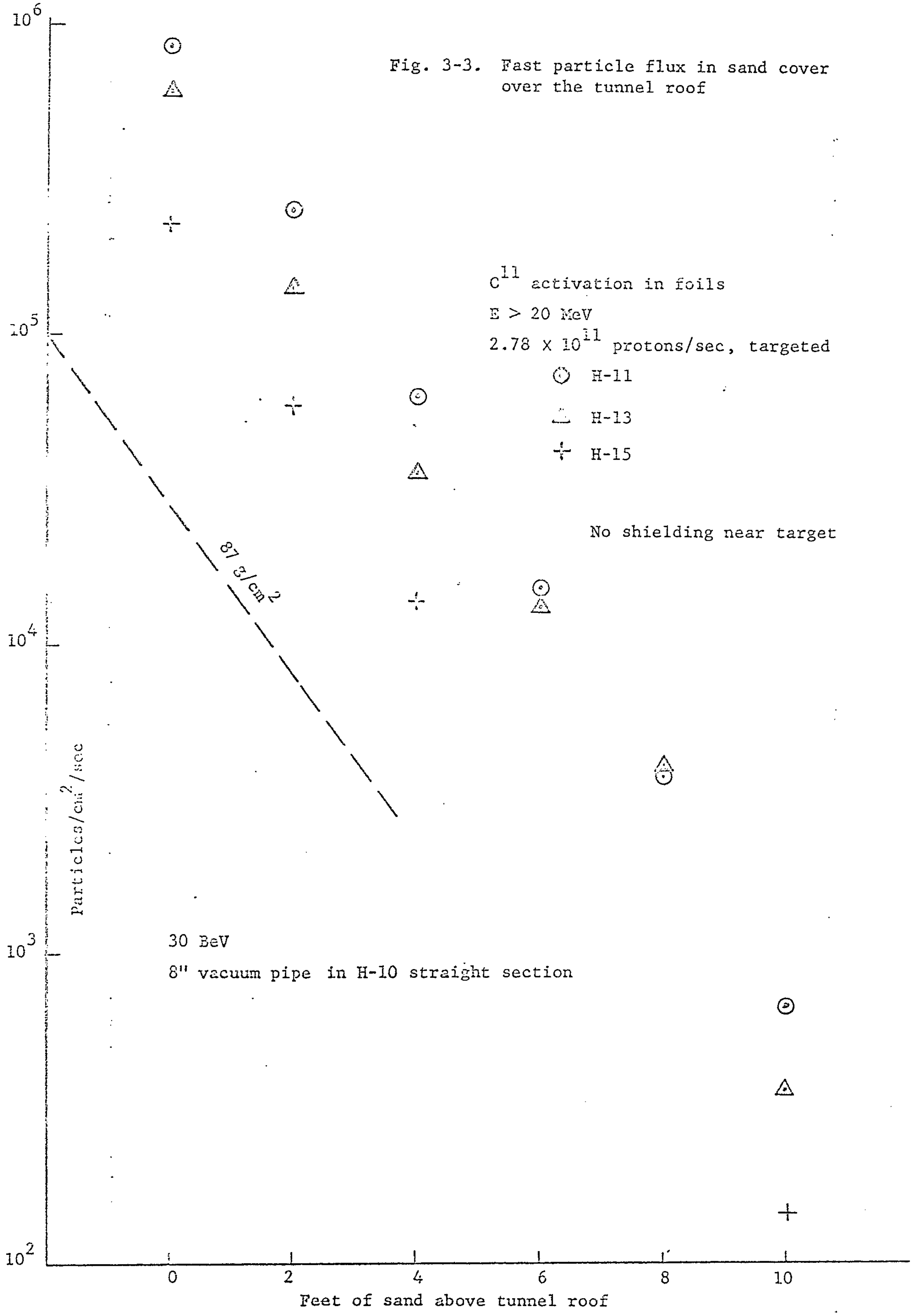


FIG. 3-2

PLASTIC SCINT; MED. PLANE
5/25/66

Fig. 3-3. Fast particle flux in sand cover over the tunnel roof



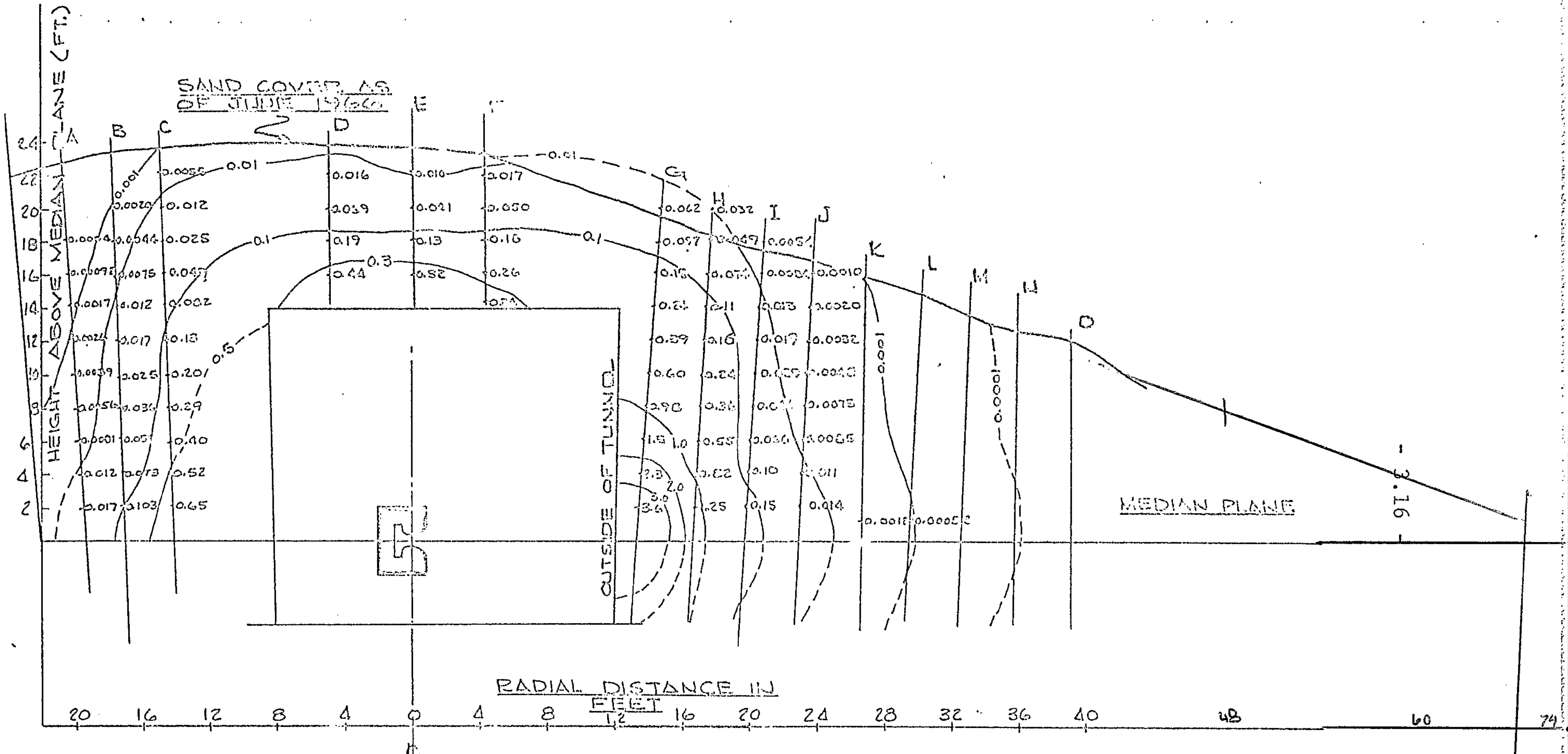


FIG 3-4

RELATIVE ACTIVITIES FROM SCINTILLATION COUNTER · H-13

70 - 12 = 58

48 - 12 = 36

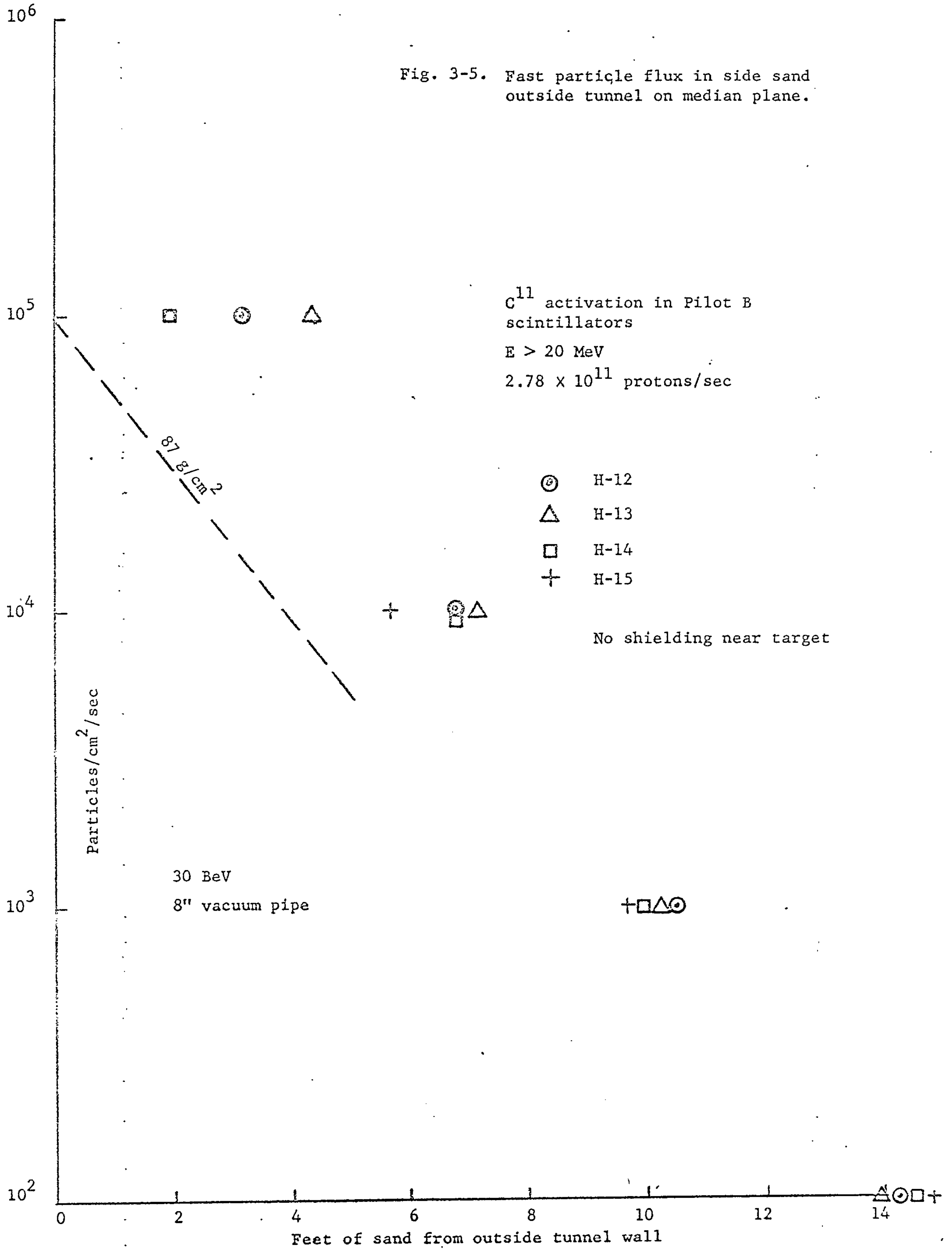


Fig. 3-5. Fast particle flux in side sand outside tunnel on median plane.
C11 activation in Pilot B scintillators
E > 20 MeV
2.78 x 10^11 protons/sec
H-12
H-13
H-14
H-15
No shielding near target
87 g/cm2
30 BeV
8" vacuum pipe
Particles/cm2/sec
10^6
10^5
10^4
10^3
10^2
0
2
4
6
8
10
12
14
Feet of sand from outside tunnel wall

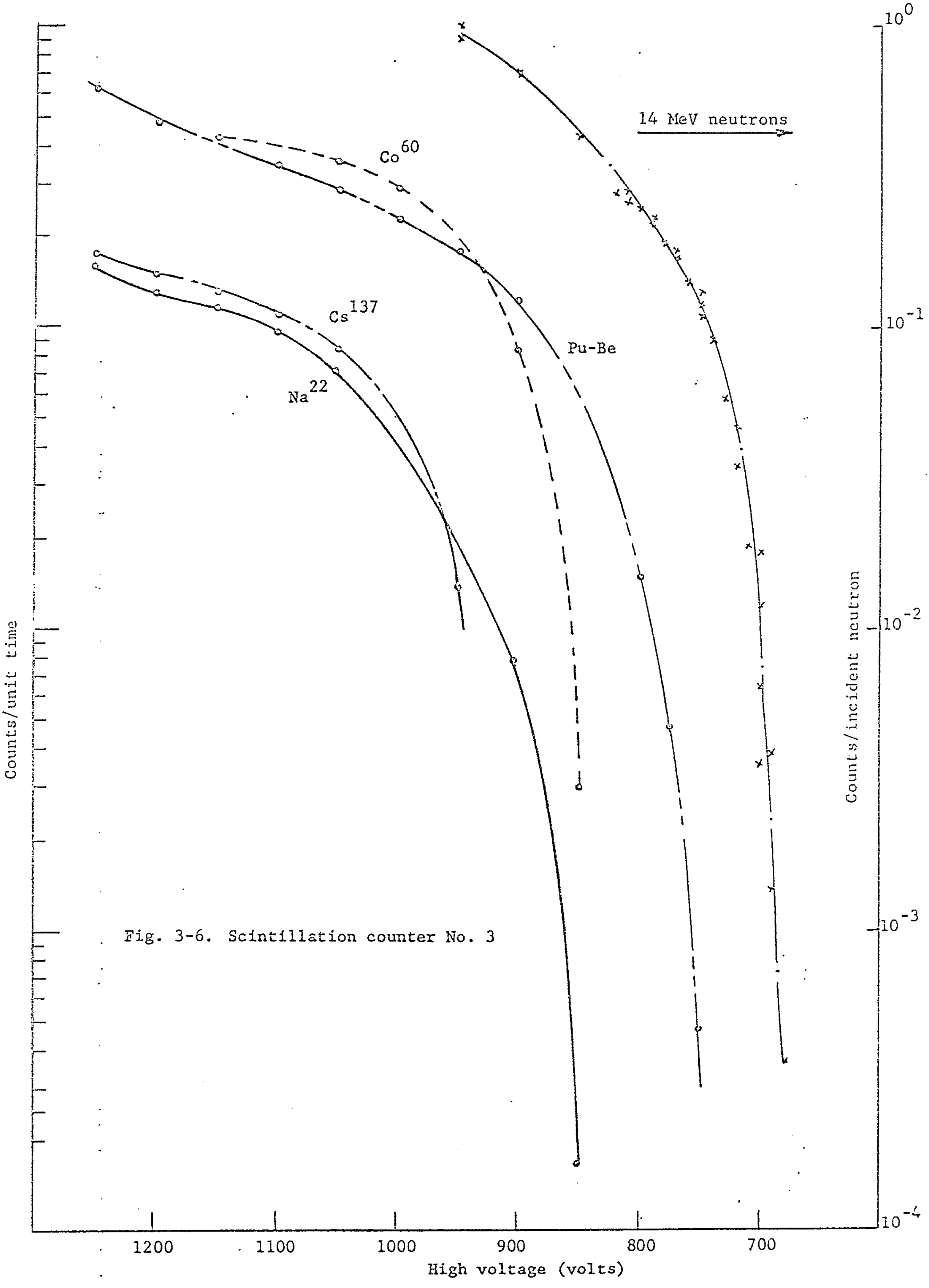


Fig. 3-6. Scintillation counter No. 3

Fig. 3-7. Scintillation counter data.

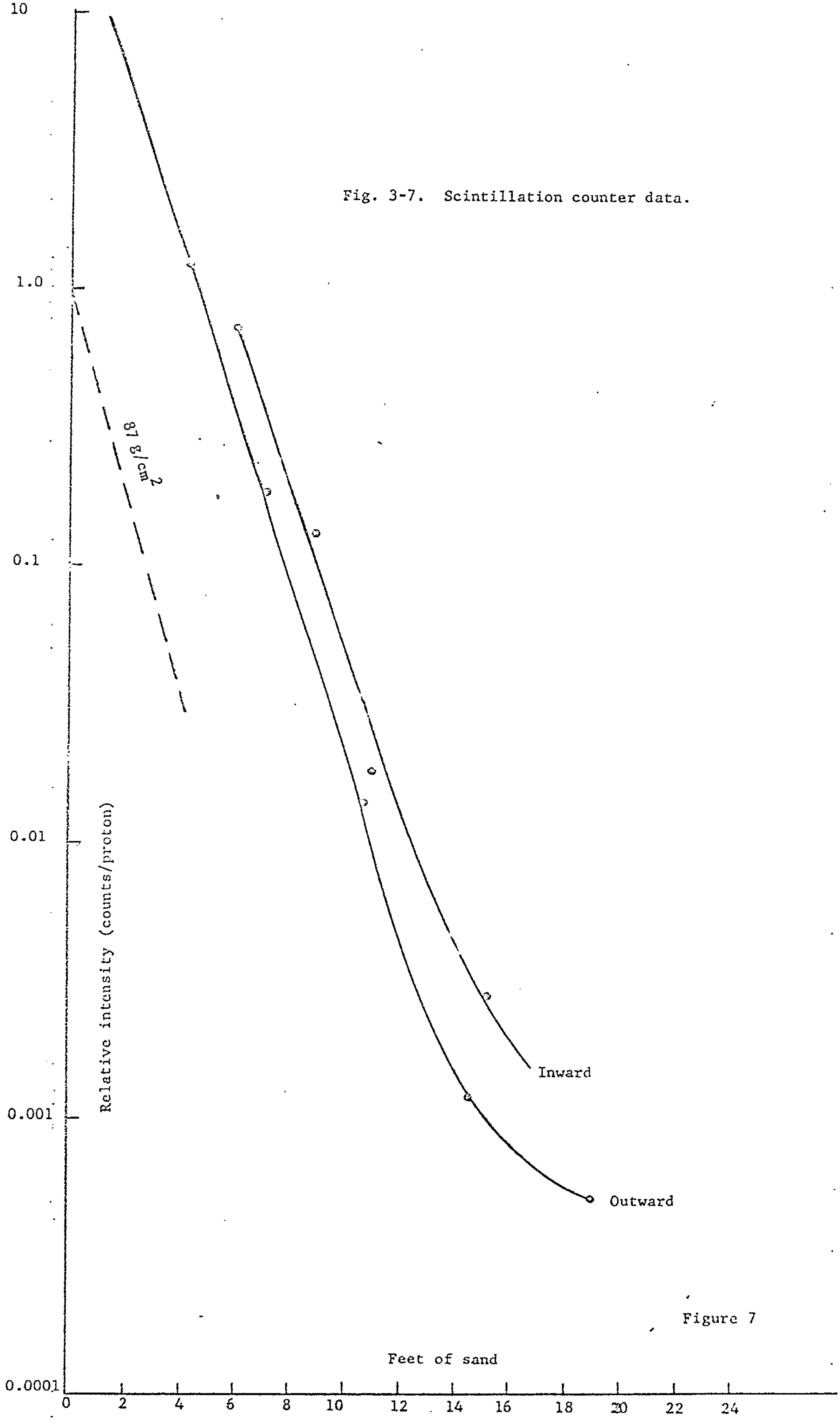
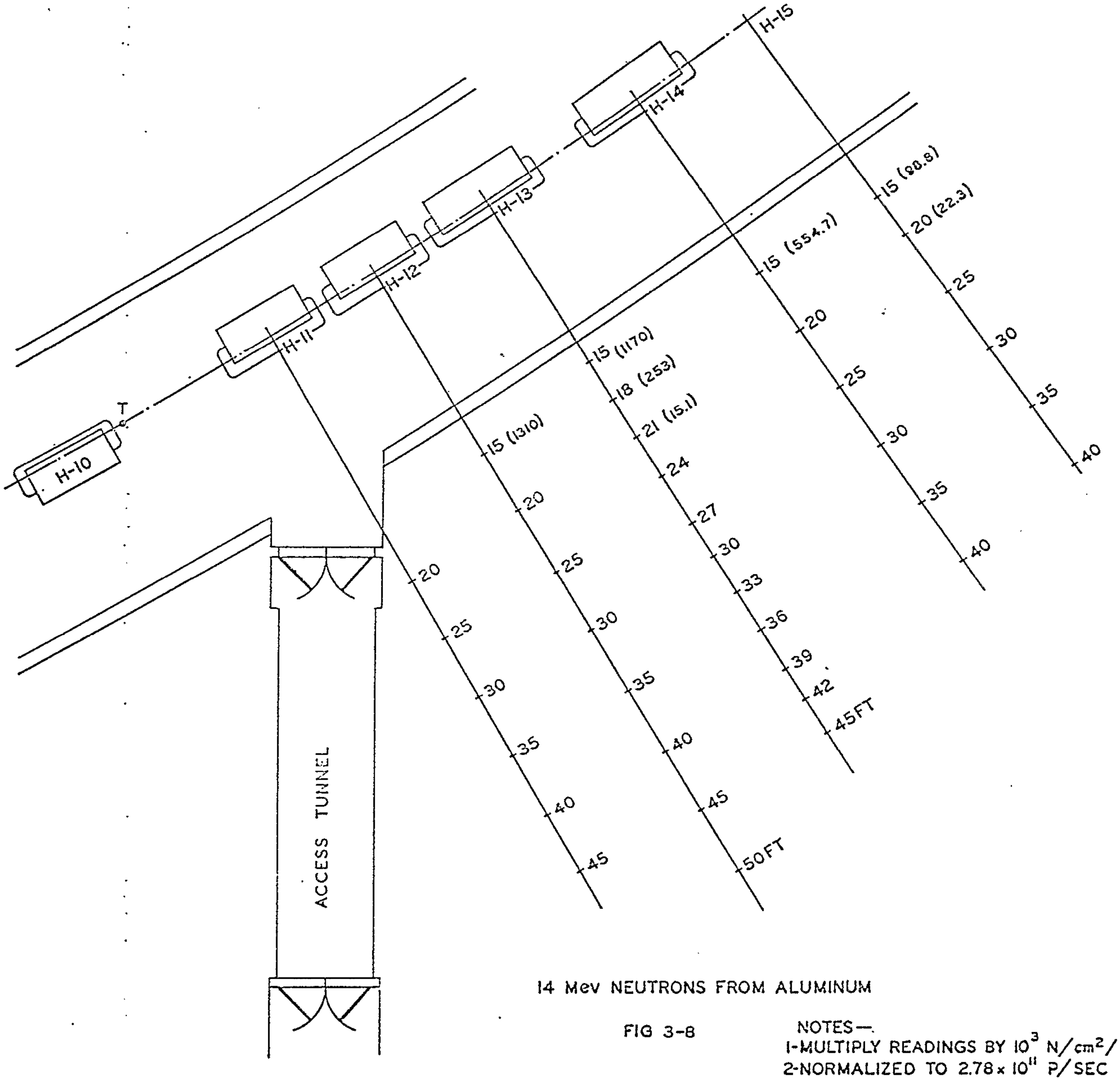


Figure 7



14 Mev NEUTRONS FROM ALUMINUM

FIG 3-8

NOTES—
1-MULTIPLY READINGS BY 10^3 N/cm^2/SEC
2-NORMALIZED TO 2.78×10^{11} P/SEC

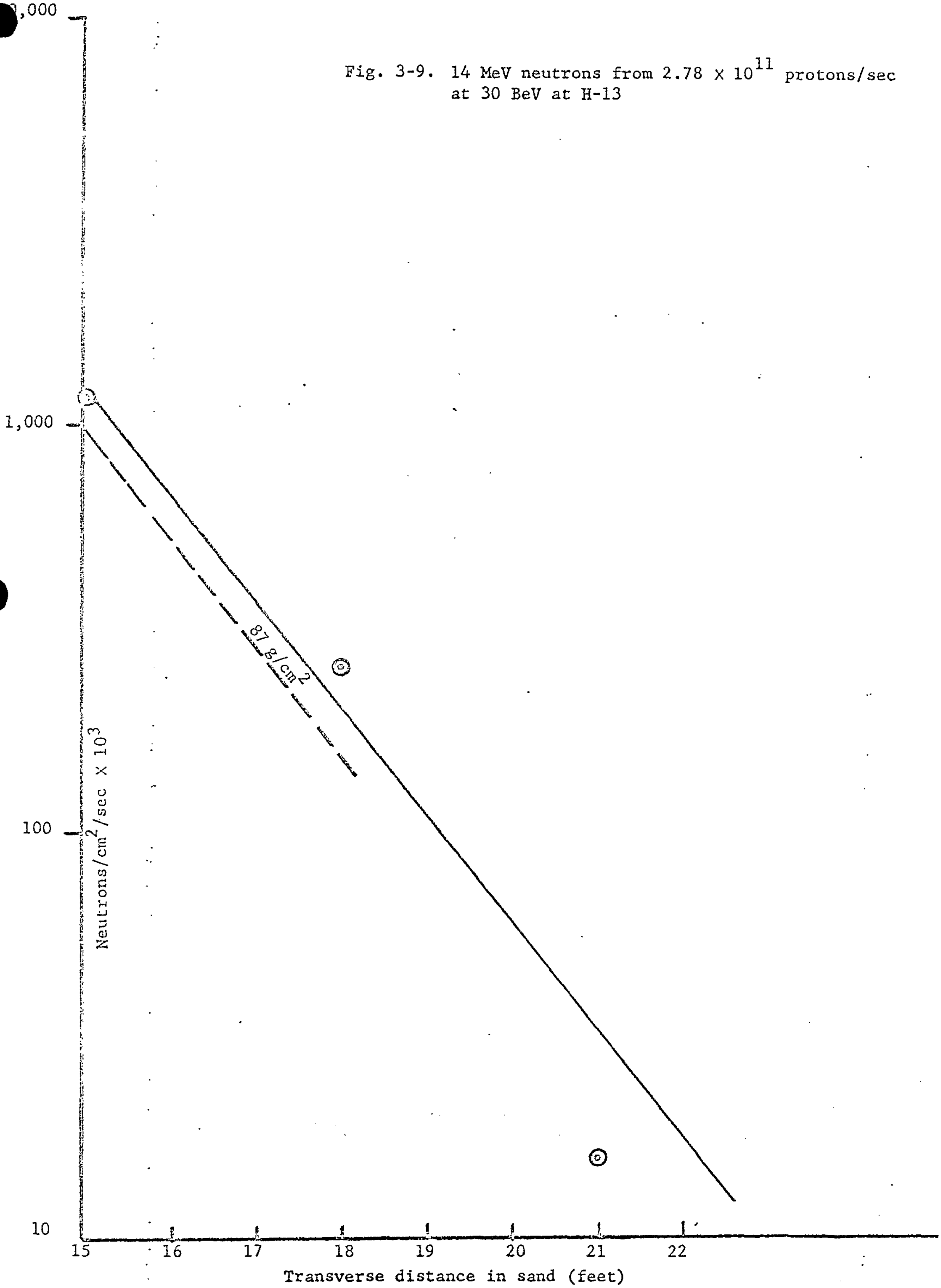


Fig. 3-9. 14 MeV neutrons from 2.78 X 10^{11} protons/sec at 30 BeV at H-13

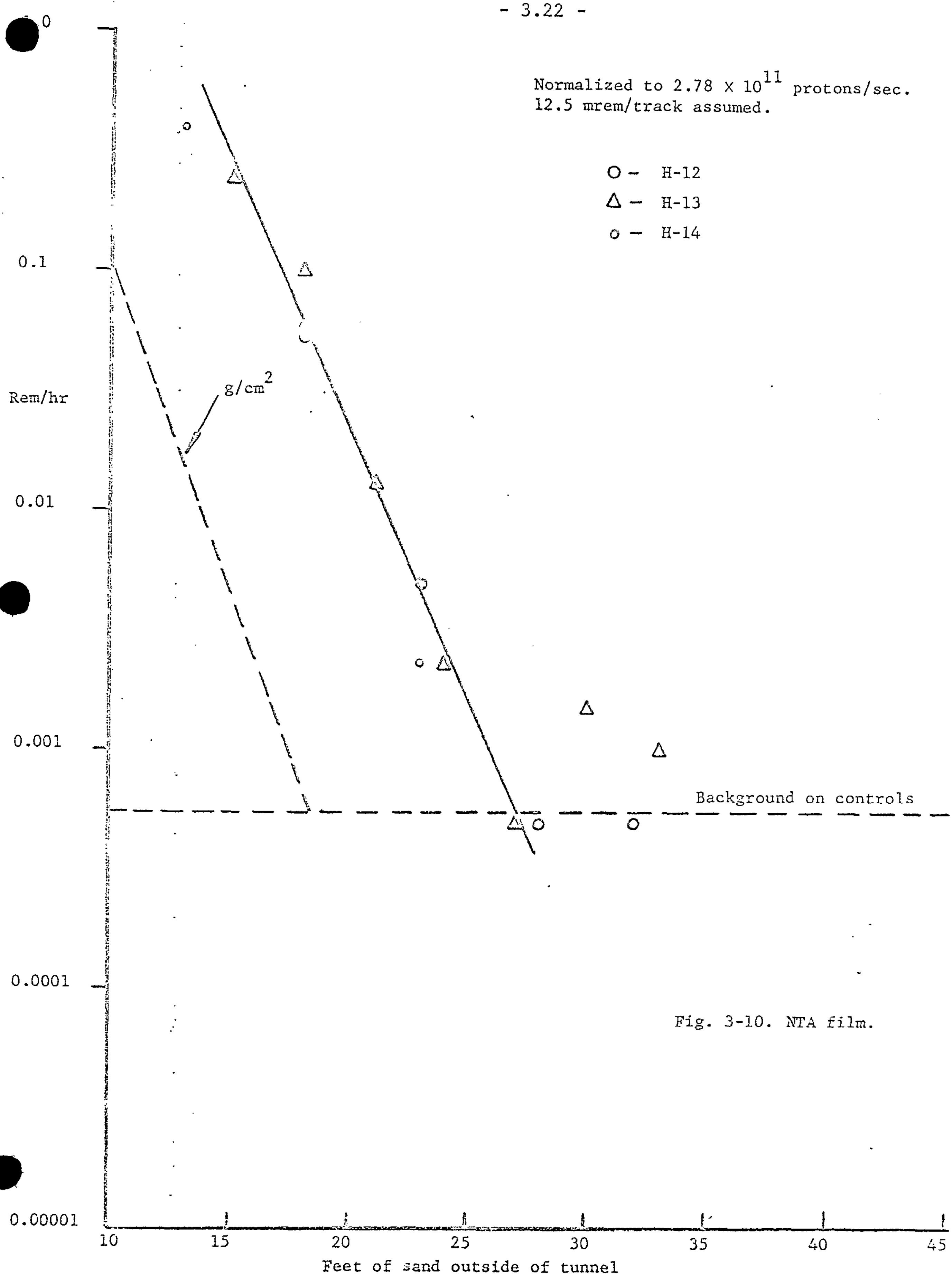


Fig. 3-10. NTA film.

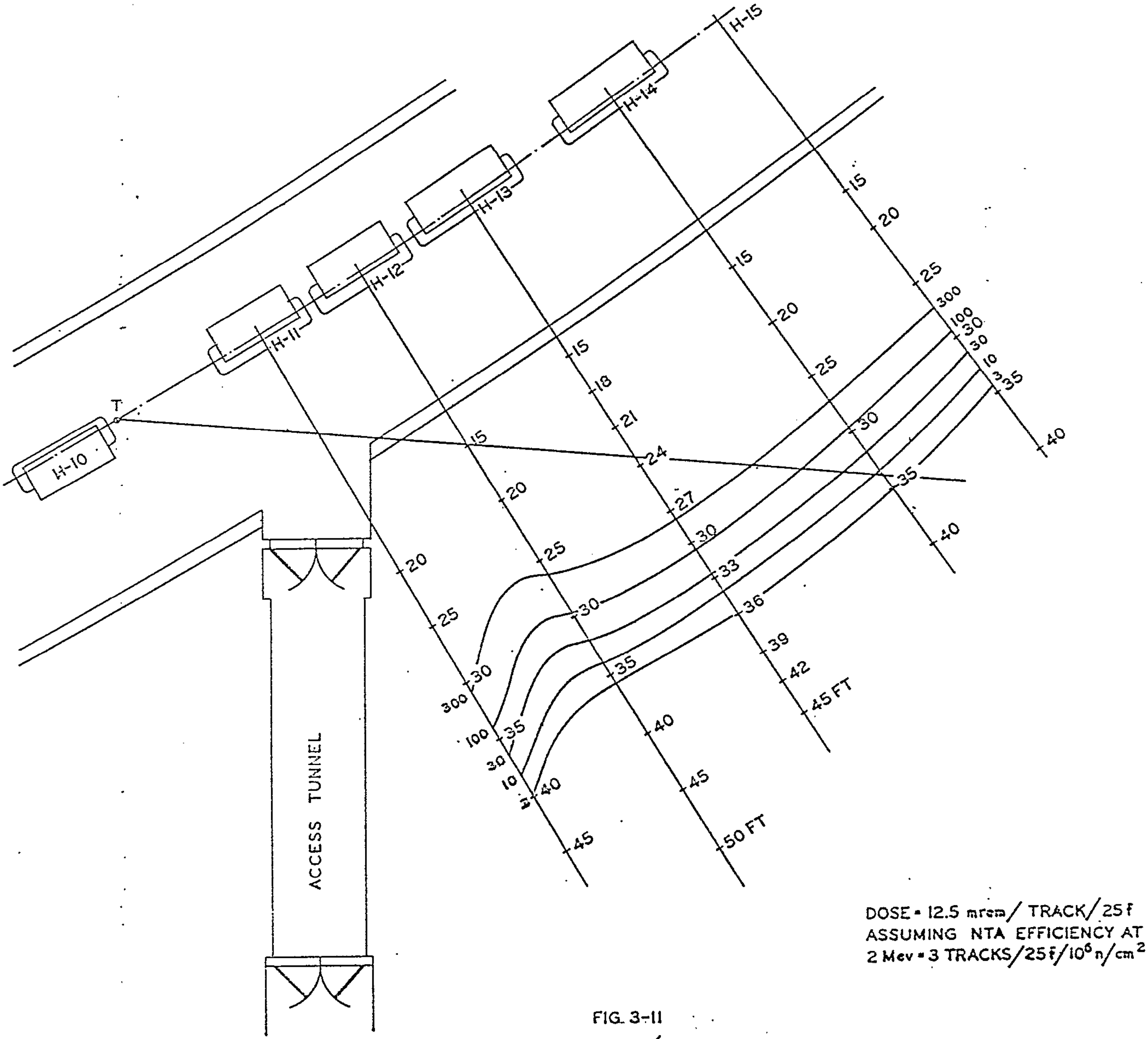


FIG. 3-11

NTA FILM TRACKS/25 FIELDS
FOR 2.09×10^{16} PROTONS TARGETED