NAL OFF-SITE DOSE-EQUIVALENT RATES DUE TO ACCELERATOR-CAUSED RADIATION

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Three examples of dose-equivalent rates off the NAL site are presented. The first estimate is for neutrons from the main accelerator to Butterfield Road, which forms the southern boundary of the site. The other two are for muons from the Meson Laboratory and the Neutrino Laboratory at the site boundary.

A. Main Accelerator

1. Dose Rate at Butterfield Road. The dose equivalent (DE) rate at Butterfield Road will be calculated using the neutron flux emanating from the shielding berm over the main accelerator. Typical cross sections of the berm over the main-accelerator enclosure are shown in Fig. 1. The dose rate at the surface of the berm has been estimated in a previous note[1] to be 4×10^{-4} rem/hr. This estimate already includes a safety factor of ten in beam loss. One may estimate the dose rate at points on the berm to be between 0.4 and 0.6 m rem/hr, using a relaxation length[2] of 120 G/cm^2 and a geometric factor of $1/R$. We shall therefore use a mean value of 0.5 mrem/hr.

Using a flux-to-dose conversion factor[2] of 4.9×10^{-8} rem/(n/cm^2), the neutron flux at the surface of the berm is them 10^4 $n/(cm^2\ hr)$.

There are two types of contributions to the neutron flux at the site boundary: direct radiation from the side of the berm and "sky-shine," i.e. neutrons reaching the detector via scattering or production processes in the atmosphere.

2. Direct Radiation. Of the flux emanating from the berm side, only the low-energy component ($E \lesssim 200$ MeV) is expected to exit at an angle proper to contribute to the dose at the site boundary. Hence only about[3] 0.5 of the exiting flux should be used to calculate the direct radiation contribution to that off-site area.

To simplify the calculation, we will replace the accelerator by an infinite line source at the distance of closest approach. Then the flux at the site boundary is (for a small spherical detector)

$$\phi_d = \frac{S}{2\pi}\int_{-\infty}^{+\infty} dz\ \exp\left(-\sqrt{R^2+z^2}/\ell\right)\Big/(R^2+z^2), \qquad (1)$$

where $S \equiv$ linear source strength density (neutrons emitted per unit time and per unit length of the line source)

$= 3.8\times10^6$ n/(hr · cm) (based on a berm slope length of 25 feet)

$R \equiv$ distance of closest approach between the main accelerator and Butterfield Road

$= 6.25\times10^4$ cm

$\ell \equiv$ neutron interaction length in air

$= 5.4\times10^4$ cm.

In Eq. (1) a factor of 2 appears instead of 4 since the estimated flux is the outgoing one. Evaluation of Eq. (1) yields a flux of 5.5 $n/(cm^2\ hr)$ and hence a direct dose rate of 0.22 microrem/hr. A conversion factor of 4×10^{-8} rem/(n/cm^2) is used here since the expected average energy of the neutrons is 2 MeV.

3. Skyshine. Here, the source includes both sides and the top of the berm (25 ft for each side, 13 ft of top). This outgoing flux is assumed to interact with air nuclei and produce evaporation neutrons. The interaction length was assumed to be 5.4×10^4 cm. Using a crude model, the average number of evaporation neutrons per interaction is estimated to be 1.3 with an average energy of 2 MeV. These evaporation neutrons are assumed to be emitted isotropically. Elastic scattering, cascade particles, charged evaporation particles, and cascade development in air are neglected.

Based on these considerations (and again replacing the accelerator by an infinite line source) the skyshine flux becomes

$$\phi_{SS} = \frac{Sm_n}{2\pi^2 \ell} \int_{r_1=0}^{\infty} \int_{\theta=0}^{\pi} F(r_1)\, F(r_2)\, r_1 dr_1 d\theta. \qquad (2)$$

Here $S = 2\times10^7$ n/(hr cm)

$m_n \equiv$ average neutron multiplicity

$= 1.3$

$\ell \equiv$ interaction length in air

$= 5.40\times10^4$ cm.

$$F(r) = \int_0^{\infty} dz \, \exp\left(-\sqrt{r^2 + z^2}/\ell\right) \Big/ (r^2 + z^2).$$

$r_1, \theta \equiv$ polar coordinates measured from the detector in a plane perpendicular to the line source.

$r^2 = \sqrt{r_1^2 + R^2 - 2rR\cos\theta}$, where $R \equiv$ distance of closest approach.

Numerical evaluation of Eq. (2) yields a flux of 21 n/(cm^2 hr) or a corresponding skyshine dose rate of 0.84 microrem/hr.

4. Total Dose Rate. Hence, at Butterfield Road, the total neutron dose rate due to operation of the main accelerator is expected to be less than (0.22 + 0.84 =) 1.1 μrem/hr or 9.6 mrem/yr. This may be compared with the 110 mrem/yr of the natural environmental background and the 170 mrem/yr permitted by the AEC Manual, Chapter 0524. Thus we estimate that the accelerator will produce approximately 8% above the natural background and approximately 6% of the AEC Manual maximum permissible dose rate for the population at large.

It is very important to note that the estimate is extremely conservative. We have assumed full operation at full intensity throughout the year, and we have assumed beam losses ten times higher than we expect.

For off-site neutron doses, the main accelerator is the worst offender; however, the above estimates show that the worst offender is a very tame one.

B. Experimental Areas

1. Muon Dose Rate. Here we shall discuss the cases of the two laboratories that have been designed up to this time for high-energy physics research, the Meson Laboratory and the Neutrino Laboratory. These two laboratories are very different from the point of view of muon-shielding design, because the former tries to minimize muon production while the latter enhances it in order to maximize neutrino fluxes.

The techniques used for the muon dose-rate estimates have been previously described.[5-13] Therefore, only the results will be given summarily.

2. Meson Laboratory. The discussion refers to full beam intensity into the target box: 10^{13} protons/sec at 200 GeV, on a one nonelastic mean-free-path long Be target, at 100% duty cycle. The shield is 1300 ft long. At the far end, a muon flux of 10^{-13} μ/cm^2 incident proton is expected.[5] At the site boundary, 7000 ft further away, we estimate

$$\phi(\mu) \sim 10^{13}\ \frac{p}{\text{sec}} * 10^{-13}\ \frac{\mu/\text{cm}^2}{p} * \left(\frac{1.3}{8.3}\right)^2 = 2.4\times 10^{-2}\ \frac{\mu}{\text{cm}^2\,\text{sec}}$$

$$\text{DE} = 2.4\times 10^{-2} \times \frac{1}{7.8}\ \frac{\text{mrem/hr}}{\mu/\text{cm}^2\,\text{sec}} = 3\ \mu\text{rem/hr} = 26\,\text{mrem/yr}.$$

The conversion factor of 7.8 $(\mu/\text{cm}^2)/\text{sec}$ = 1 mrem/hr has been used because not all muons are minimum ionizing muons.[14]

3. Neutrino Laboratory. The discussion is for 10^{13} protons/second at 400-500 GeV, on a Be target one nonelastic mean free path long, 100%

duty cycle and broadband neutrino beam operation. The shield is 5000 ft long. The site boundary is a further 5000 ft distant. We take the muon fluxes from Ref. 5 and calculate as above.

$$\text{Off-site DE} \simeq 4 \text{ mrem/yr @ 400 GeV}$$
$$\simeq 40 \text{ mrem/yr @ 450 GeV}$$
$$\simeq 260 \text{ mrem/yr @ 500 GeV.}$$

In fact, the original shield as described here is not adequate for bubble-chamber operation with 500-GeV protons. The bubble chamber would be swamped with muon tracks. It has therefore been decided to add a steel plug and a steel magnetic lens to deflect muons away from the chamber, as described in Ref. 12. The effect of this system on direct radiation at the site boundary has not yet been completely calculated, but it will certainly be in the direction of diffusing the muons over a larger area and therefore will reduce the muon intensity at a given point and resulting off-site DE rate.

C. Conclusions

The dose-equivalent rates just outside the NAL boundaries as estimated in this note are small even with the worst-case assumptions used. We expect that the accelerator will never be operated at full energy, intensity, and duty cycle into the Neutrino Laboratory for any considerable period because there will always be other competing demands of the research program.

During the first year of operation, the accelerator will operate at considerably less than 10% of its full product of energy and intensity and the muon flux will be correspondingly reduced. During this time, measurements will be made from which to predict the dose rates with greater certainty. If extrapolation of these data to full energy and intensity would give rise to any significant increase in radiation over the estimates here, additional shielding will be added. The 5000 ft from the present termination of the shield at the bubble chamber has been purposely left undeveloped to provide space for this shield.

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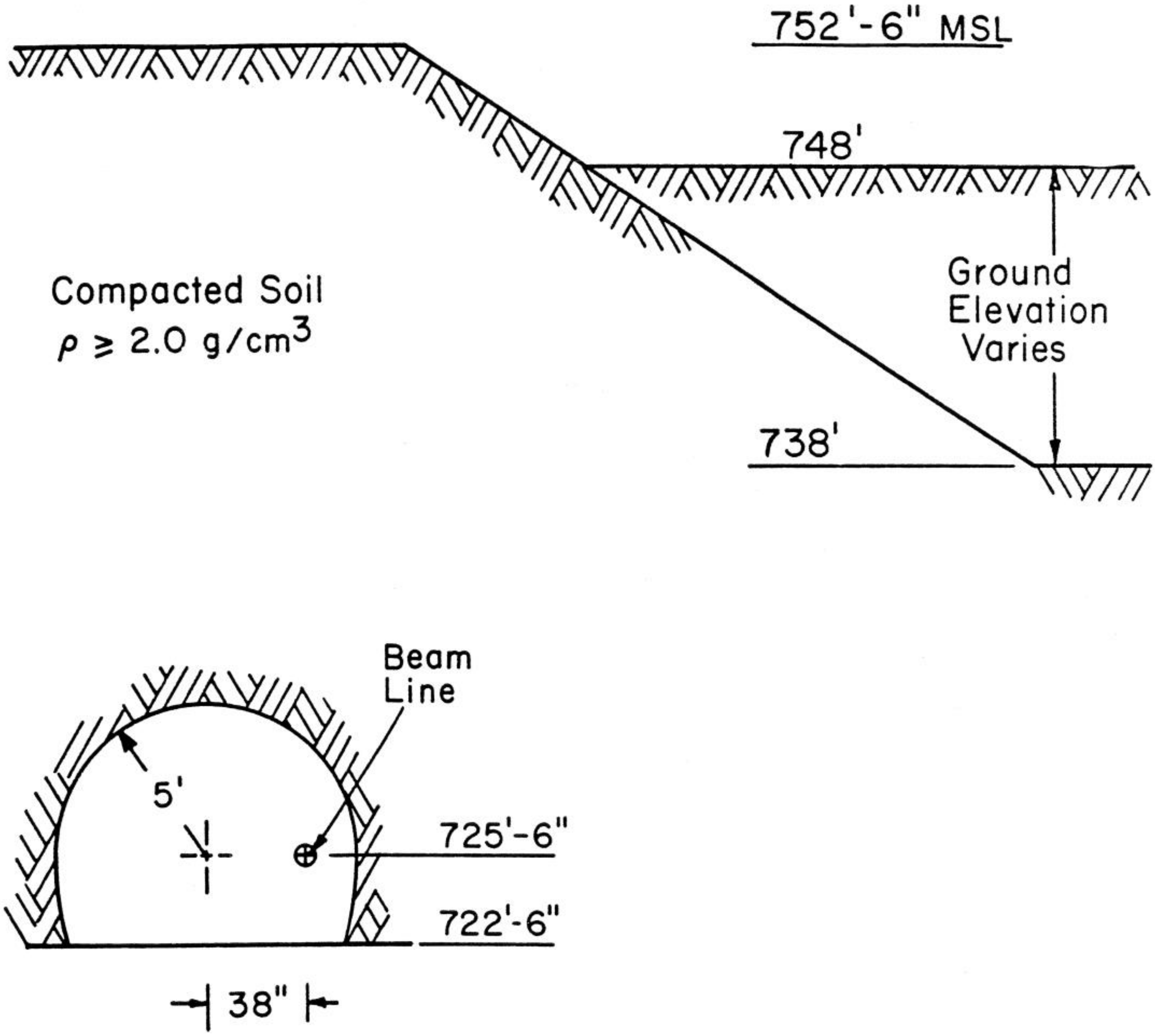

Fig. 1. Cross section of the Main-Accelerator shielding.

national accelerator laboratory

APPENDIX C

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CALCULATION OF THE RADIONUCLIDE PRODUCTION IN THE SURROUNDINGS OF THE NAL NEUTRINO LABORATORY

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ABSTRACT

For the design of beam dumps, target stations, and the Neutrino-Laboratory decay tunnel, it was necessary to gather previously unavailable data, to calculate the maximum amount of leachable radioactivity that may be produced annually in the surrounding soil, and to estimate that fraction of the radioactivity which may leave the site via the underground waters. This paper describes the calculations.

The Neutrino-Laboratory decay tunnel is discussed as an example. Making very conservative assumptions about underground water velocities, large average proton-beam currents (10^{13} p/sec, at 400 GeV, 100% of the time) and broad band neutrino beam operation (maximum beam power into the soil), it is shown that rather small amounts of H^3 (55 mCi/yr) and Na^{22} (31 μCi/yr) may leave the site.

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The NAL accelerator will have more than one order of magnitude greater beam power than any other proton accelerator now in operation. Hence, it was necessary to study with some care the problem of soil radioactivation when high-energy protons interact with accelerator components and the secondary hadrons continue the development of the extranuclear cascade in the accelerator itself, enclosure, and surrounding soil. The concern with the radioactivation of the soil arises from the fact that some of the radioactivity so created may be leached away by the underground waters and be carried to off-site domestic water systems.

The problem may be divided into several parts:

1. The extranuclear cascade, activation, and spatial distribution of radionuclides;

2. Leachability of radionuclides from NAL soils;

3. Calculation of the leachable and non-leachable radioactivity created annually in the NAL soils; and

4. Transport of the radionuclides by the underground waters to the site boundaries.

Once the radioactivity leaving the site is estimated, it can be compared with the pertinent rules and regulations.[1]

In the treatment that follows, different approaches for solving a problem are discussed when possible. This makes the presentation longer, but it may give a better feeling for the uncertainties involved in these calculations.

1. The Extranuclear Cascade

There is some uncertainty in the extranuclear cascade calculations because the most important input data, the source term, will only be known after the accelerator has become operational.

When a high-energy hadron undergoes a nonelastic event with a nucleus of the medium under consideration, it is said that a "star" has been created even if there is only one outgoing hadron. In the case of incident hadrons with energies of tens of GeV or greater, about 1 to 4 stars are produced per incident GeV of hadron kinetic energy.[2-4]

For any calculations involving stars and activations, nonelastic cross sections as well as activation cross sections are needed. The nonelastic cross sections of Belletini[5] are used, and they are assumed to be energy independent from about 30 MeV to the highest energy considered. For the sodium-22 activation, the cross-section calculations of Van Ginneken[6] are used. They are in excellent agreement with experimental results.[7-8] For the H-3 activation, experimental results are used exclusively.[7]

While studying the extranuclear cascade, we shall be interested in two of its characteristics:

1. The total number of radionuclides of a given type that are created per incident proton;

2. The spatial distribution of these radionuclides.

To calculate the quantity of nuclides and their distribution, two different but consistent approaches will be discussed below. They are:

(a) Some experimental results and Monte Carlo calculations

(b) Some other experimental results plus physical arguments.

a. The Monte Carlo Calculation

The calculation consists in picking random numbers to select polar and azimuthal angles as well as track lengths for the various hadrons produced in a collision, using energy-dependent mean free paths. Hadron momenta are chosen using random numbers and either Trilling's formula [9] for pions and or a modification of it for protons and neutrons. Energy is conserved at each interaction. Inelasticities are taken from cosmic-ray data when available and from R. G. Alsmiller's calculations [10] otherwise.

As the extranuclear cascade develops in configuration space, the star density and the energy spectra of the various components (p, n, and $\pi^{\pm}$) vary as functions of r and z, where r and z are cylindrical co-ordinates, with the incident primary hadron moving along the z-axis and the target-dump starting at z = 0.

There are three large Monte-Carlo programs to calculate extra nuclear cascades. The first one, TRANSK, written by J. Ranft, [11] was later modified and improved at NAL by Ranft and Borak. [9]

J. Ranft used this more modern version to write a new program called FLUTRA.[12]

There is presently at NAL a greatly improved version of FLUTRA that has great versatility and that can reproduce all published shielding experiments carried out at 28 GeV within factors of two to three[13] over a range of fluxes of $10^5:1$.

Figures 1 and 2 show the geometries of the Brookhaven experiment.[14,15] FLUTRA has been very successful in reproducing these results, as may be seen in Figs. 3-5. Figure 3 shows the prediction of the results for the side-shielding experiment of Bennett et al.[15] and actual results. Figure 4 is a prediction of the $C^{12} \rightarrow C^{11}$ activation in the beam-dump experiment[14] and actual results. Figure 5 is a prediction of the $Al^{27} \rightarrow F^{18}$ activation in the same dump[13] and the actual results. We can see that at 28 GeV the calculations are quite good for their intended use.

A virtue of FLUTRA is its simplicity. A much more elegant and accurate but slower program for similar calculations has been developed by R. G. Alsmiller and his group[10] at ORNL. In Alsmiller's model, the source function, i.e., the yield term, is the "extrapolation model,"[16] which is based on Bertini's nuclear model[17] for intranuclear cascades up to 3-GeV incident proton energy.[18] Figure 5 also shows Alsmiller's[19] prediction for the $Al^{27} \rightarrow F^{18}$ activation in the beam stop of the BNL experiment. This model makes more accurate predictions than

FLUTRA at 28 GeV. Other examples of this type of calculations may be found in Refs. 20 and 21.

Hence, we see that for energies up to 28 GeV, there are at least two independent programs that make absolute predictions very close to actual measurements. One should therefore consider their predictions for incident energies in the 200 to 500 GeV range to be probably as good as our ability to conceive source terms and so to predict particle production at higher energies. In particular, one should have additional confidence in Alsmiller's extrapolation model,[16] since it gives very good predictions of the π^- production at 75 GeV.

In practice, it is very difficult to separate the different components of the cascade in the midst of a thick shield. This is a consequence of the use of activation detectors for flux integration. Hence, it is customary to add all the components of the cascade into an undifferentiated hadronic flux. It is also customary to use the proton activation cross sections to estimate the magnitude of the undifferentiated hadron flux. Finally, it has also been customary to adopt an energy-independent value for the activation cross sections from threshold to maximum energy. Figure 6 shows, as an example, the C^{12} (n, 2n) C^{11} cross section as commonly used and the C^{12} (p, pn) C^{11} and C^{12} (p, pn)C^{11} as measured.[22] Figure 7 shows the measured Al^{27} (p, x) Na^{22} cross section as well as the macroscopic cross section for Na^{22}

activation in NAL soil. The present calculation, like many others,[6,23-25] recognizes that Na^{22} is produced by the spallation of Si, Fe, Ca, Mg, Na^{23}, K, etc.

In Table I, the macroscopic cross sections at 500 MeV for two types of NAL soils are presented. They show very similar nuclear characteristics in spite of their different natures. One is a composite of various NAL soils[26] and labeled "average NAL soil." The other one is from the glacial till at a location near the main accelerator.[7]

The results of the Monte-Carlo calculations may be used in various manners to calculate the production of a given nuclide. For example, Armstrong[19,20,21,27] and Gabriel[20,27] use a complete intranuclear cascade at the site of a non-elastic event in order to determine the residual nucleus. In the NAL version of FLUTRA, the macroscopic activation cross section is entered as a dimensional array. In the program TRANSK the energy-dependent cross section is calculated using Rudstam's formula.[28]

In all cases, the quantity sought is

$$A_i = \int_V dV\, A_i(r,z) = \int_V dV \int_0^E \Sigma_i(E')\phi(E',r,z)\,dE', \qquad (1)$$

where $A_i(r,z)$ is the production of the i-th nuclide per incident hadron at a point (r,z) of the medium. Sometimes A_i is expressed in curies for a given incident current and energy and after a certain irradiation

Table I. ^{22}Na Macroscopic Cross Sections at E_h = 500 MeV For NAL's Average Soils and Glacial Till.

		Average Soil						Glacial Till				
A	Element	% by Weight	N (a)	σ_{Na} (b)	$N\sigma_{Na}$ (c)	σ_{ne} (b)	$N\sigma_{ne}$ (c)	% by Weight dry	% by Weight moist	N (a)	$N\sigma_{Na}$ (b)	$N\sigma_{ne}$ (c)
16	O	55.0	2.07E22	0	0	0.31	0.642E22	50.8	56.5	2.13E22	0	0.660E22
28	Si	22.8	0.49	0.017	0.00833E22	0.47	0.230	25.7	21.8	0.47	0.0080E22	0.221
27	Al	5.51	0.123	0.013	0.00160	0.46	0.057	6.2	5.3	0.12	0.0016	0.0552
12	C	3.32	0.166	0	0	0.195	0.032	3.7	3.2	0.15	0	0.0292
1	H	1.23	0.737	0	0	0.025	0.018	-	1.67	1.01	0	0.0252
56	Fe	2.91	0.0314	0.0002	-	0.800	0.025	3.3	2.8	0.031	-	0.0248
40	Ca	6.08	0.0914	0.004	0.0037	0.62	0.057	6.8	5.8	0.087	0.00035	0.0539
25	Mg	2.09	0.0518	0.028	0.00145	0.43	0.022	2.4	2.0	0.050	0.0014	0.0215
23	Na	0.40	0.0104	0.036	0.00037	0.40	0.004	0.45	0.38	0.010	0.00036	0.0040
39	K	0.52	0.0080	0.004	0.00003	0.62	0.005	0.58	0.49	0.0077	0.00003	0.00471

Average Soil: $\Sigma N_i \sigma_{i,Na}$ = 0.012E22; $\Sigma N_i \sigma_{i,ne}$ = 1.09E22

Glacial Till: $\Sigma N_i \sigma_{i,Na}$ = 0.012E22; $\Sigma N_i \sigma_{i,ne}$ = 1.10E22

[a] atom/gram, moist soil
[b] barns
[c] barns/gram

time; E is the energy of the primary incident hadron, usually a proton; $\Sigma_i(E')$ is the macroscopic cross section for the formation of the i-th nuclide in the given medium by an undifferentiated hadron of energy E'; and $\phi(E',r,z)$ is the number of undifferentiated hadrons of energy E' per cm^2, per MeV per incident primary hadron, at a point (r,z) in the shield.

b. Experimental Results and Physical Arguments

The spatial distribution of the activity may be inferred from the measurements at CERN[29] and at BNL,[15] remembering that $p_\perp$ remains essentially unchanged as the energy of the incident hadron increases, while $p_\parallel$ increases monotonically with $p_{incident}$.

T. Toohig[30] has estimated that about one-third of all the activity is created in the soil surrounding the decay pipe of the neutrino-beam facility and two-thirds is created in the beam stop at the end of the pipe. This fractionation is in good agreement with the Monte Carlo calculations of Gabriel.[27]

In order to calculate the number of atoms of some nuclide, some manipulation of the cross sections and assumptions regarding the energy spectrum of the hadrons must be made.

If the total number S of "stars" has been obtained by calculation or estimation from experimental results, the ratio A_i/S (nuclides of the i-th type to all stars) can be calculated from

$$\frac{A_i}{S} = \int_v dV \int_0^E \Sigma_i(x)\phi(x,r,z)\,dx \Big/ \int_v dV \int_0^E \Sigma(x)\phi(x,r,z)\,dx, \quad (2)$$

where $\Sigma(E)$ is the energy-dependent macroscopic nonelastic cross section for the given medium.

The distribution of the radionuclides is commonly assumed to be the same as that for all the stars, unless the activation cross section for the particular radionuclide is used as part of the calculation.

Certain simplifying assumptions are commonly made such as

1. A single energy spectrum is used throughout; then the flux term can be split into a product of an energy-dependent term and a spatially dependent term. That is,

$$\phi(E,r,z) \rightarrow N(E)\phi'(r,z). \quad (3)$$

This may underestimate the Na^{22} production by not more than 10-15% in some regions.

2. In such geometries as the Neutrino-Laboratory decay tunnel ϕ' is assumed to be independent of z, which is a good first approximation.[4,27] Using the activities at the maximum of the distribution, the total Na^{22} is overestimated by less than a factor of three.

The change of the constant-flux cardioids of revolution[4,14,31] into spheres makes no difference in practical applications such as target boxes, because the forward shielding is dictated by considerations other than soil activities and usually is greater than that needed for soil protection.

Accepting the assumptions (a) and (b) above and that of energy-independent cross sections, then formula (1) becomes

$$A_i = \Sigma_i \int_V \phi\,(r,z)\,dV \int_{E_{th}}^{E} N(x)\,dx, \tag{4}$$

where E_{th} is the threshold energy for the macroscopic cross section Σ_i.

If a flux has been evaluated with a detector having a macroscopic cross section Σ_d and threshold energy $E_{th}(d)$, the two activities may be related by

$$A_i = A_d * (\Sigma_i/\Sigma_d) * \left[\int_{E_{th}(i)}^{E} N(x)\,dx \Big/ \int_{E_{th}(d)}^{E} N\,(x)\,dx \right] \tag{5}$$

where the subscripts i and d refer respectively to the nuclide under consideration and the monitoring detector used for flux evaluation in either a calculation or an experiment. Effectively, Eq. (5) is a re-written Eq. (1).

Figures 8 and 9 show graphs of the integral $\int_{E'}^{E} N\,(x)\,dx$ as a function of E' (the threshold energy) for incident protons of 200 and 500 GeV and soil as a moderating medium. They are taken from Ref. 8.

It is obvious that if a number S (total stars per incident hadron produced by hadrons with energy greater than a given threshold) is known from some source, then the number of nuclides may be found by substituting A_d by S.

The number S may be calculated using the expression

$$S = kE_0, \tag{6}$$

where S is the total number of stars created in a given semi-infinite medium, by incident protons of kinetic energy E_0, by all secondaries with energy greater than or equal to E', and k is the proportionality constant that depends on the medium and E'.

The value of k may be obtained from experimental results by studying the activation of foils through beam stops or other geometries. The value of k given in Ref. 2 is of experimental origin. It is very comforting that the values of k agree so well.

For our calculations, we have adopted the value k = 4, because FLUTRA tends to underestimate the flux at large radii by a factor of approximately 3. Hence, k = 4 should be conservative.

Table II. Values of the Proportionality Constant k.

Medium	E'(MeV)	k	Source
steel	100	1.68	3
steel	15	4.36[a]	3
steel	47	0.8	4
soil	15	1.4	4
steel-soil	"?"	~1-2	2

[a]A proper fit in the 40 to 1000 GeV range requires $S = kE_0 + 75$

2. Measurements of the Macroscopic Cross Sections and Leachability of Various Radionuclides for NAL Soils

In order to calculate the production of radionuclides in the soil, one needs: (a) the distribution of the components of the hadronic cascade in the phase-space of the generalized target (dump, shield, etc.) and (b) the energy-dependent macroscopic cross sections for the production of the radionuclides of interest in the medium under consideration.

In Section 1 a discussion of methods for flux estimation were given. To obtain the activation macroscopic cross section for NAL soil, one may refer to published activation cross sections and calculate them. This is possible to do for Na^{22} and an example of such a calculation at one energy was given in Table I. In Ref. 6 the energy-dependent macroscopic cross section is calculated and plotted. Figure 9 is a reproduction of Fig. 7 of Ref. 6 of the macroscopic cross section versus energy.

From Table I, we get the ratio of the macroscopic cross section, $\Sigma(Na^{22})$ to Σ (nonelastic) to be approximately equal to 0.011.

A second method consists of taking samples of NAL soils and exposing them at the Argonne ZGS and Brookhaven AGS, near internal targets and behind one foot of concrete. The results of such measurements are given in Ref. 7.

The agreement between the measured macroscopic cross sections for Na^{22} and the calculated ones is excellent. From Ref. 7 we have

$$\Sigma_{meas}(Na^{22}) = 1.5 - 2.2\times10^{-4}\ cm^2g^{-1}$$

$$\Sigma_{calc}(Na^{22}, 500\ MeV) = 1.2\times10^{-4} cm^2g^{-1}.$$

Note that the calculated Σ has a broad maximum at $1.7\times10^{-4}\ cm^2g^{-1}$.

A quantity that would be difficult to calculate is the fraction of the created activity of each radionuclide which would leach out in a first water pass and in subsequent water passes. Experimental results are given in Table III.

The importance of the fraction leached during subsequent washings of the soil is that it provides a means to calculate the relative ion velocity of the radionuclide in question with respect to the water velocity.

From the leachings following the first one, one can calculate the ion drift velocity using the expression[32]

$$Kd = \frac{q_A}{C_A} = \frac{(\mu Ci/g)\ \text{in dry soil}}{(\mu Ci/ml)\ \text{in solution}} = \left(\frac{ml}{g}\right), \qquad (7)$$

where Kd is the distribution coefficient, q_A is the radionuclide activity per gram of dry soil, and C_A is the radionuclide activity per ml of solution.

In actual practice, one can use the approximate relation

$$Kd = \frac{Co - C_E}{C_E} \times \frac{\text{volume of solution (ml)}}{\text{mass of dry soil (g)}}, \qquad (8)$$

where Co is the initial concentration of radioactivity (μCi/ml) in the solution, and C_E is the activity of the solution (μCi/g) after contact with the solution.

The diffusion coefficient Kd may then be used to calculate the relative velocity of the radionuclide with respect to the water carrying it.

$$\text{Relative velocity} = \frac{v(\text{radionuclide})}{v(H_2O)} = \frac{1}{1 + D}, \qquad (9)$$

where $D = Kd * (\rho_b/\epsilon)$ is a dimensionless quantity, p_b is the density of the dry soil (g/cm^3) and ϵ is the porosity (the fraction of the volume of dry soil occupied by the voids).

Formulas 7 and 9 were used in evaluating Kd for H^3 and Na^{22} in NAL's glacial fill. The results are given below:

Table III. Leachability of Sodium and Tritium.

Radionuclide	Na^{22}	H^3
Leachable Fraction, first wash	0.20	1.0
Leachable Fraction, other washes		
Kd	0.204	~O
Relative Velocity	0.44	1

The results of the batch work done at NAL are reported elsewhere.[7,33]

3. Calculation of Radionuclide Production

The beam parameters used in the calculations are

Table IV. Beam Parameters

Incident Proton Energy	= 400 GeV
Average Incident Proton Current	= 10^{13} protons/sec
Irradiation Time	>>half life of any one radionuclide under consideration.

All secondaries interact in the soil surrounding the point of interaction.

Note that the use of an average beam current implies some combination of actual beam current and duty cycle. In addition irradiation times much longer than the half-life of the radionuclide under consideration imply a condition of dynamic equilibrium between the number of radionuclides produced per second and the number of radionuclides decaying per second.

The calculations are summarized in Table V. Comparisons with calculations of other authors are also shown. The k's used are those of Table II, and for this work K = 4. The ratio of all Na^{22} stars to all stars is taken as 0.011, from Table I.

The activities derived from Ref. 27 were calculated averaging over all radii for the Z-interval 50 m to 100 m, and multiplying the activities is given by the ratio (400/500) to convert them to 400 GeV.

The calculations given below in Table V assume that all the beam power is dissipated in the soil. In Table VI, the geometry is taken into account.

The quantities given are total and leachable activity created per year. This rate of production is convenient for the calculation of the yearly activity leaving the site.

Table V. Comparison of Various Calculations for Yearly Radioactivity Production and Leaching from NAL Soils by a Proton Current of 10^{13} p/sec at 400 GeV.

Radio-nuclide	Radioactivity Production Rate (1) kCi/yr	Leachable Fraction	Leachable Radio-activity Produc-tion (1) kCi/yr	Reference
Na^{22}	3.04	0.20	0.608	2
Na^{22}	0.029	0.10	0.0029	30
Na^{22}	1.9	0.20	0.38	See a
Na^{22}	1.1	0.20	0.22	This work
Na^{22}	0.74	-	-	27
Na^{22}	0.41	-	-	34
H^3	0.34	-	-	27
H^3	1.1	1.0	1.1	This work
Ca^{45}	0.76	-	-	27
Ca^{45}	0.25	0.05-0.10	0.013	This work
Mn^{54}	0.40	-	-	27
Mn^{54}	0.054	0.003	-	This work

[a] The activity estimated in Ref. 30 was changed by the author of this note as follows:

1. Correction for Na^{22} macroscopic cross section. The macroscopic cross section given by Van Ginneken[6] at 100 MeV is used instead of only the aluminum spallation cross section. This gives an increase of 20 in the expected activity.
2. The energy scaling factor is taken as E^{+1}, instead of $E^{\frac{1}{2}}$, this gives an additional factor of $(400/30)^{\frac{1}{2}} = 3.65$.

3. The correction for threshold energy using the curves in Ref. 8, gives a factor of 0.90. Then, the activity created per year becomes

$$\text{activity/year (corrected)} = 0.029\ \text{Ci/yr} * 20 * 3.65 * 0.90 = 1.9\ \text{k Ci/yr}.$$

The Na^{22} activity created per year that has been estimated in this paper is just below the geometric mean of the maximum and minimum activities, $\sqrt{5 \times 7 * 0.41} = 1.5$ k Ci/yr.

To estimate the activity that may be leached annually to the aquifer, it is imperative to examine a drawing of the cross section of the neutrino laboratory meson decay pipe. This is shown in Fig. 10.

The cross-sectional area has been divided in sections for ease of calculations and for reasons of expected water flow. Sections 1 and 4 are backfilled with sand and gravel. Sections 3 and 3 are backfilled with compacted clay-like materials. Sections 5 and 6 are essentially undisturbed soils.

The significance of these sections is as follows. All radionuclides produced in Sections 1, 2, and 4 are assumed to be caught with 95% efficiency or greater by the imperious blanket.

Whatever escapes this "bathtub" is caught by the underdrains A and B. In addition, underdrains dry up a region determined, very approximately, by slopes of 5 in 1, near the tiles. These "draw-downs" form the lower boundaries of Section 5. It is also assumed that the activity created in Sections 3 and 5 is collected. Then, only the activity created in Section 6 escapes to the aquifer.

To calculate the fraction of the stars created in each section, a radial dependence of the star density of the form

$$\phi(r) = \phi(r_0)r_0\exp[-(r - r_0)\rho/\ell]/r, \qquad (7)$$

is assumed. Here, $r_0 = 45$ cm, $\rho = 2.0\ g/cm^3$, and $\ell = 100\ g/cm^2$.

A cylindrical geometry is assumed and all matter is clay. Then, the relative fractions are given in Table VI.

Table VI. Distribution of Stars by Soil Section Perpendicular to Decay Pipe of Neutrino Laboratory.

Section	Fraction of All Stars
1	0.495
2	0.00402
3	0.000577
4	0.495
5	0.00500
6	1.14×10^{-4}

Now, we can calculate the maximum and minimum leachable radioactivity created in the vicinity of the decay pipe. Three sets of numbers will be calculated: maximum (Ref. 2), and minimum (Ref. 34).

Table VII. Annual Na^{22} Radioactivity Produced in the Soil.

	Minimum	This TM	Maximum	
Total	0.41	1.1	3.0	k Ci/yr
In Dump (2/3)	0.28	0.74	2.0	k Ci/yr
In Soil (1/3)	0.13	0.37	1.0	k Ci/yr
In zones 1, 2, and 4 (0.994)	0.13	0.37	1.0	k Ci/yr
In zones 3 and 5 (0.0056)	0.73	2.1	5.6	Ci/yr
In zone 6	0.015	0.042	0.11	Ci/yr
Leachable in zone 6	3.0	8.4	22.	m Ci/yr

Similar calculations may be carried out for H^3.

Table VIII. Annual H^3 Radioactivity Produced in the Soil.

	Minimum	This TM	Maximum	
Total	0.41	1.1	3.0	k Ci/yr
In Dump (2/3)	0.28	0.74	2.0	k Ci/yr
In Soil (1/3)	0.13	0.37	1.0	k Ci/yr
In zone 6	15	42	110	m Ci/yr
Leachable in zone 6	15	42	110	m Ci/yr

The concept of the gravel and the "bathtub" as well as that of the underdrains and creation of "draw-down" surfaces were discussed with representatives of the Illinois State Water Survey.[35] It was considered adequate by them.

4. Transport of Radionuclides.

We now have to estimate the travel time for the Na^{22} and H^3 from the vicinity of the decay pipe to the aquifer and along the aquifer to the site boundary.

The vertical velocity of the water in the glacial till is estimated to be 8 ft/yr,[36] and 3.6 to 7.2 ft/yr.[37] Here, a conservative value of

7.2 ft/yr will be used. Now the Na ion velocity[33] is about 0.44 that of water, because of ion-exchange processes taking place. Hence, the Na^{22} ion velocity is taken to be 3.2 ft/yr. For H^3, the ion velocity and the water velocity are the same.

It is now possible to estimate the transit times to the aquifer for Na^{22} and H^3:

Vertical distance ≃ 70 ft
Na^{22} transit time ≃ 70/3.2 = 21.9 years
H^3 transit time ≃ 70/7.2 = 9.72 years.

Since the respective half-lives are 2.6 and 12.3 years, the surviving fractions are

$$Na^{22} \text{ surviving fraction} = \exp(-21.9 \ln 2/2.6) = 2.91 \times 10^{-3}$$

$$H^3 \text{ surviving fraction} = \exp(-9.72 \ln 2/12.3) = 0.58.$$

The horizontal velocity of water in the aquifer is relatively large. Hence it is now assumed that all ions travel with the velocity of water.

The horizontal velocity is estimated at 3-6 ft/day, with a maximum of 13 ft/day.[36] The distance from the decay pipe to the site boundary in a southeasterly direction, as it is expected to flow from measured gradients,[37] is about 4 km. Then the horizontal transit time becomes,

$$T_h = 4 \times 10^3 \text{ m}/(13 \text{ ft/day} \times 365 \text{ day/year} \times 0.304 \text{ m/ft}) = 2.7 \text{ years}.$$

Surviving fractions,

$$Na^{22} \text{ fraction} = \exp(-2.7 \ln 2/2.6) = 0.49$$
$$H^{3} \text{ fraction} = \exp(-2.7 \ln 2/12.3) = 0.86.$$

Finally, it is possible to estimate the radioactivity reaching the aquifer and the site boundaries.

Table IX. Production of Annual Radioactivity Reaching the Aquifer.

	Na^{22}	H^{3}	
Leachable, zone 6	3.0-8.4-22.	15. -42. -110.	m Ci/yr
Reaching aquifer	0.0087-0.024-0.064	8.7-24. -64	m Ci/yr
Reaching site boundary	0.004-0.012-0.031	7.5-21. -55	m Ci/yr

5. Conclusions

The present estimates of the annual amounts of radioactivity leaving the site are quite conservative since they include the maximum reasonable ion velocity both vertically and horizontally.

In addition, the leachable fraction of the total activity was mesured by the batch process. This certainly gives an upper limit to the leachability.

Finally, both a high beam power and 100% duty cycle of the broad band neutrino facility have been assumed. This is certainly a gross overestimate. It is, therefore, felt that the estimates of the annual radioactivities leaving the site as given in Table IX are very cautious and conservative.

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FIGURE CAPTIONS

Fig. 1. Geometry of the beam-stop equipment. The steel and air gap width, used in the calculations, are given.

Fig. 2. Geometry of the side shield experiment.

Fig. 3. Comparison of predictions[34] and measurements[15] in the BNL side shield experiment.

Fig. 4. Comparison of carbon activation results[14] and predictions[34] in the BNL beam-stop experiment.

Fig. 5. Comparison of the Al^{27} (hadron ?) F^{18} results[13] and predictions by the NAL group[34] as well as those of Alsmiller's.[10]

Fig. 6. The C^{12} (p, pn) C^{11} and C^{12} (n, Zn) C^{11} measured cross sections[22] (solid lines) and its energy-independent approximation[29] (dashed lines).

Fig. 7. The Al^{27} (p, x) Na^{22} measured cross section[22] as well as the macroscopic activation cross section for Na^{22} in NAL soil.[6]

Fig. 8. Graph of the function $\phi(E') = \int_{E'}^{E} N(x)\,dx$ where E' = threshold energy and N(x) is the undifferentiated hadron flux. Case: lateral shielding of 200-GeV protons lost on steel (200 g/cm^2) and soil to a total thickness of 1500 g/cm^2.[29]

Fig. 9. Same as Fig. 8, but for 500 GeV protons and secondaries. Data from spectrum given in Ref. 27.

Fig. 10. Cross section through the decay pipe of the neutrino laboratory showing the different types of fill and the undisturb soils.

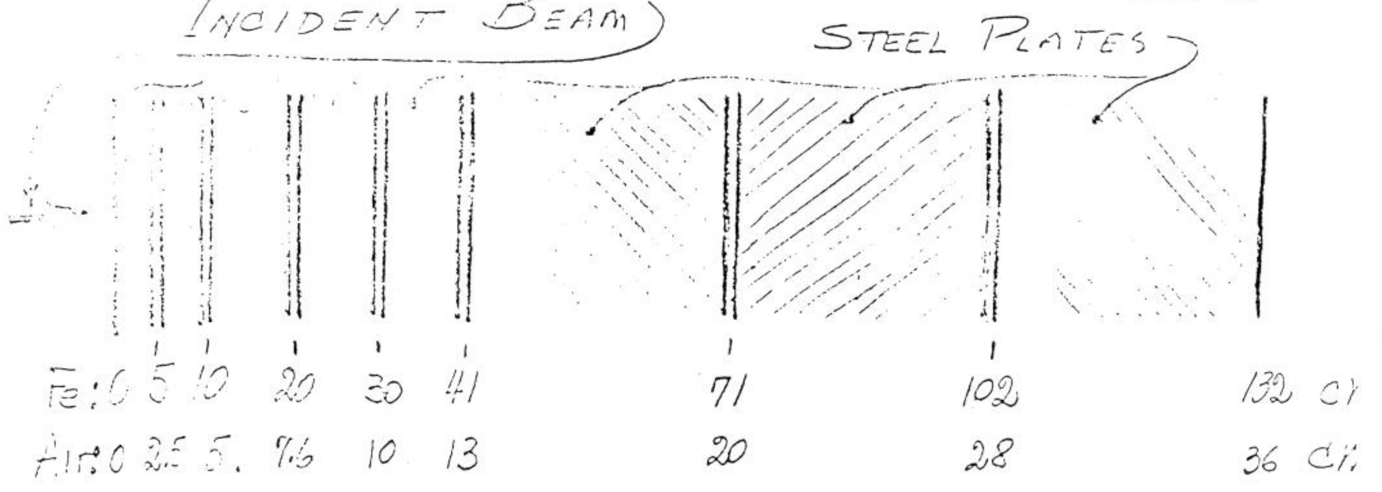

INCIDENT BEAM
STEEL PLATES
Fe: 0 5 10 20 30 41 71 102 132 CM
Air: 0 2.5 5. 7.6 10 13 20 28 36 CM

Fig. 1

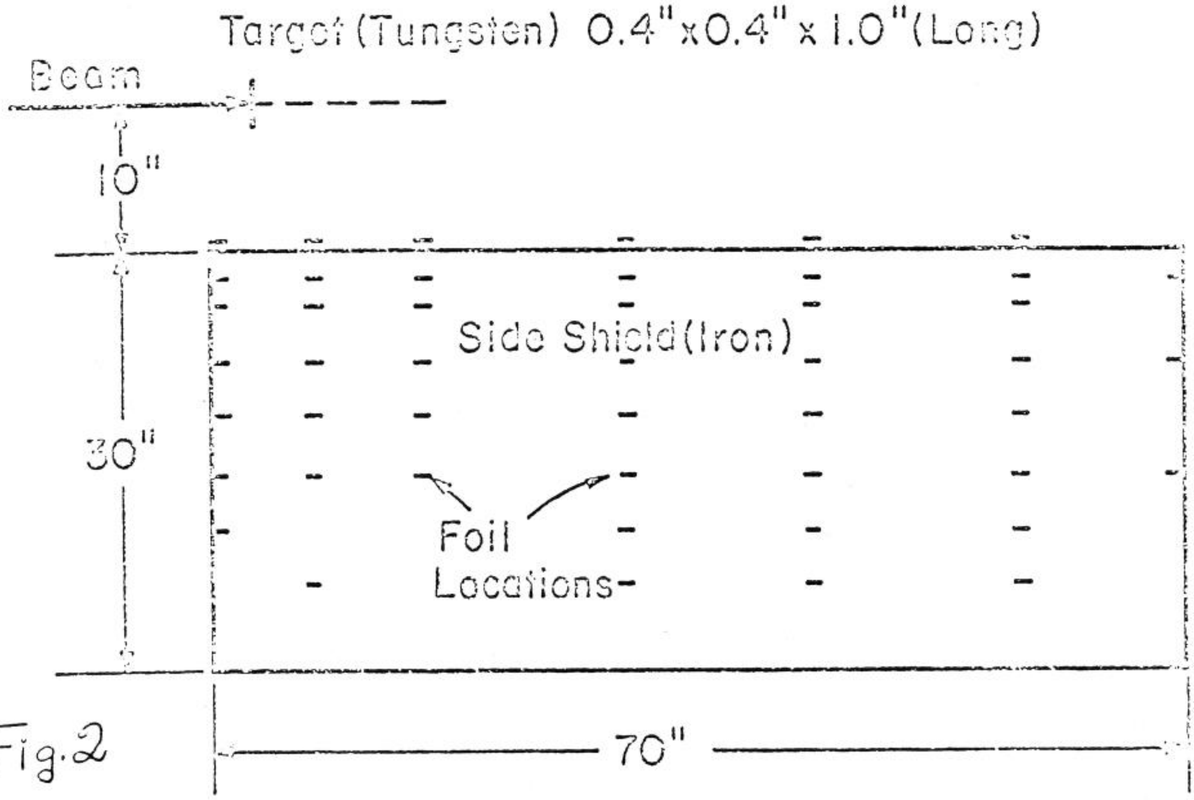

Target (Tungsten) 0.4"x0.4" x 1.0"(Long)
Beam
10"
30"
Side Shield (Iron)
Foil Locations
70"

Fig. 2

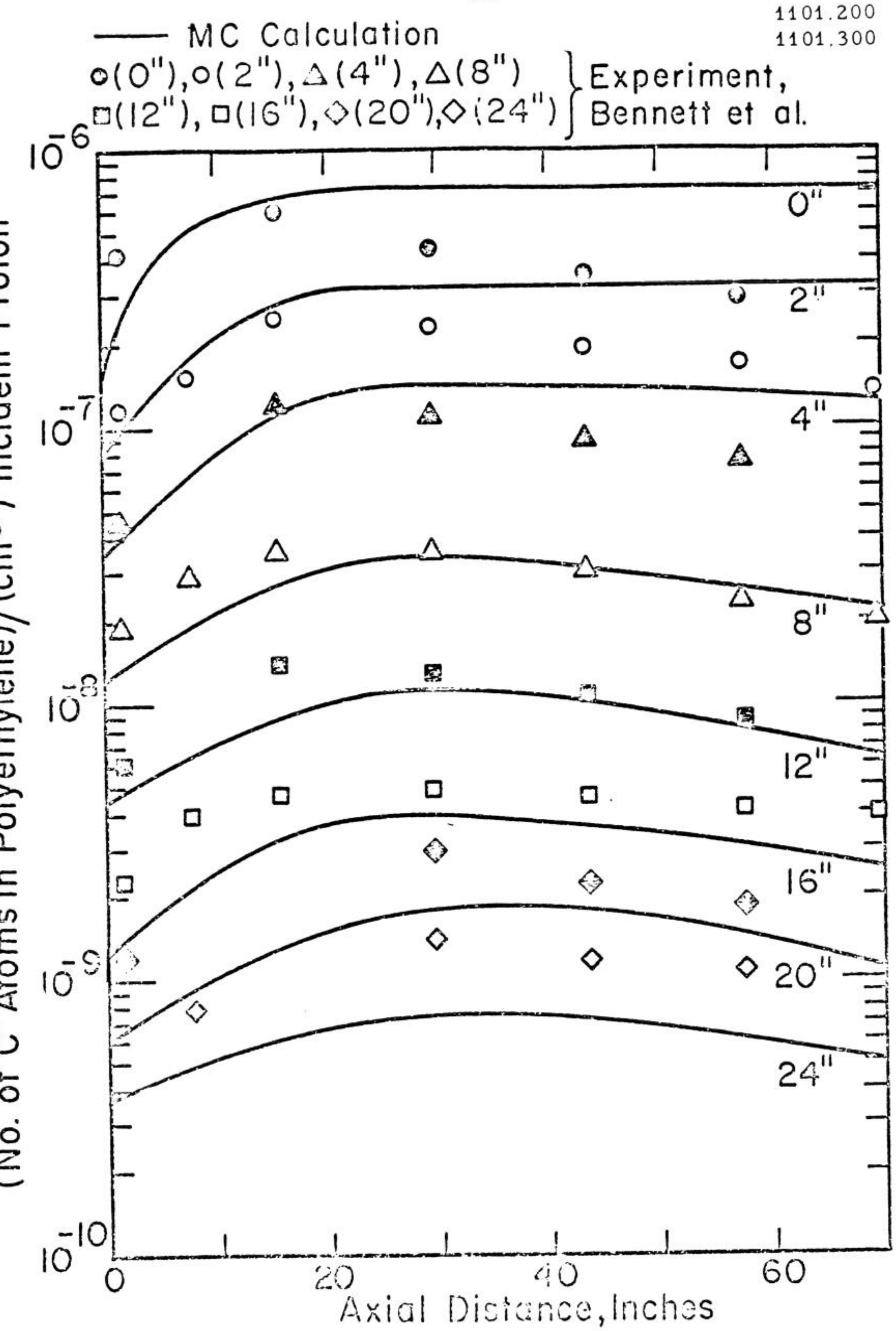

MC Calculation
o(0"), o(2"), △(4"), △(8")
□(12"), □(16"), ◇(20"), ◇(24")
Experiment, Bennett et al.
(No. of C" Atoms in Polyethylene)/(cm³) Incident Proton
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
0"
2"
4"
8"
12"
16"
20"
24"
0
20
40
60
Axial Distance, Inches

Fig. 3

FIG. 4

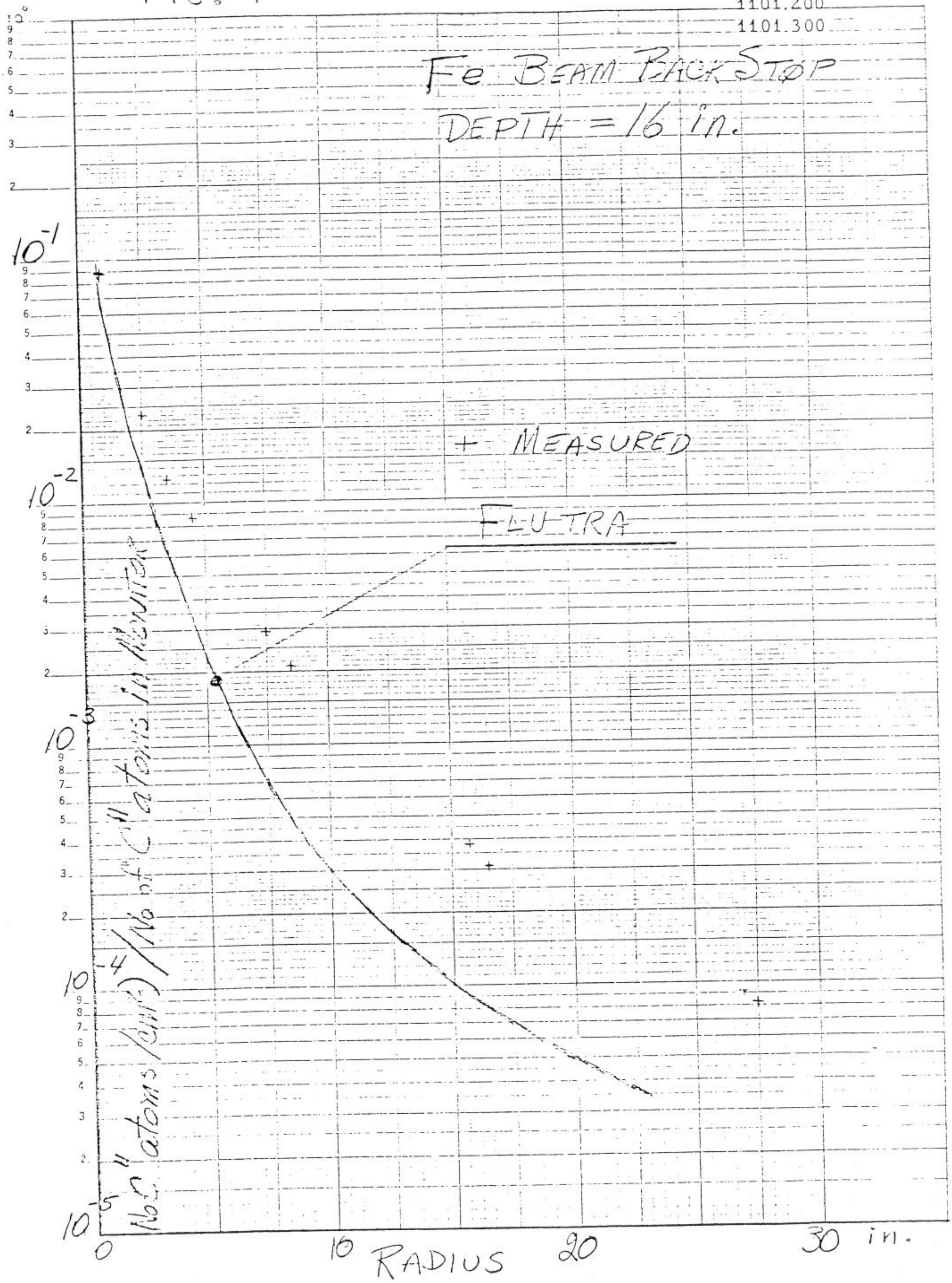
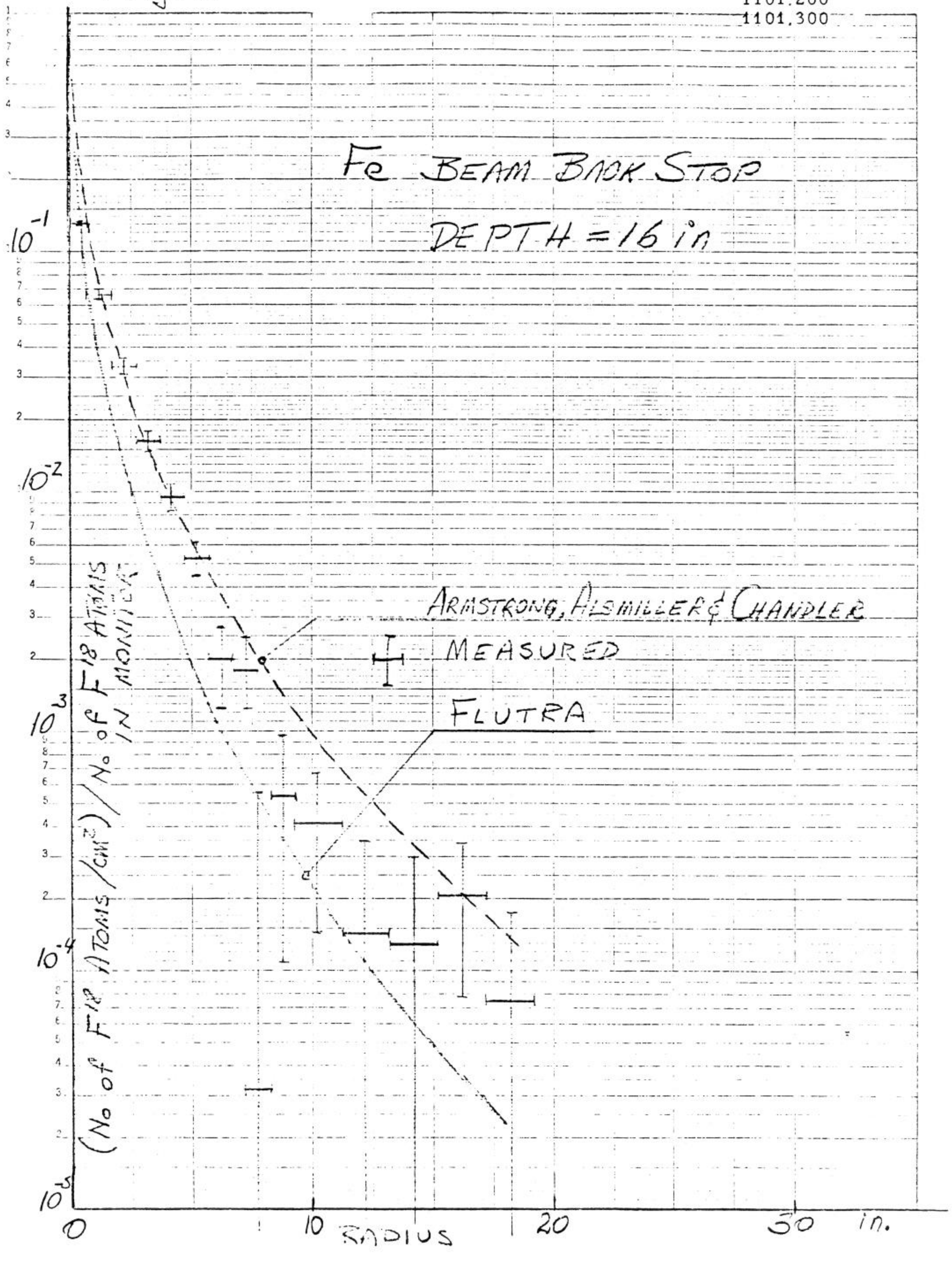

Fe BEAM BACKSTOP
DEPTH = 16 in.
+ MEASURED
FLUTRA
No. C[11] atoms/cm[3] / No of C[11] atoms in Monitor
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30 in.
RADIUS

Fig. 5


Fe BEAM BACK STOP
DEPTH = 16 in
ARMSTRONG, ALSMILLER & CHANDLER
MEASURED
FLUTRA
(No of F18 ATOMS/cm2)/No of F18 ATOMS IN MONITOR
10-1
10-2
10-3
10-4
10-5
0
10
20
30
in.
RADIUS

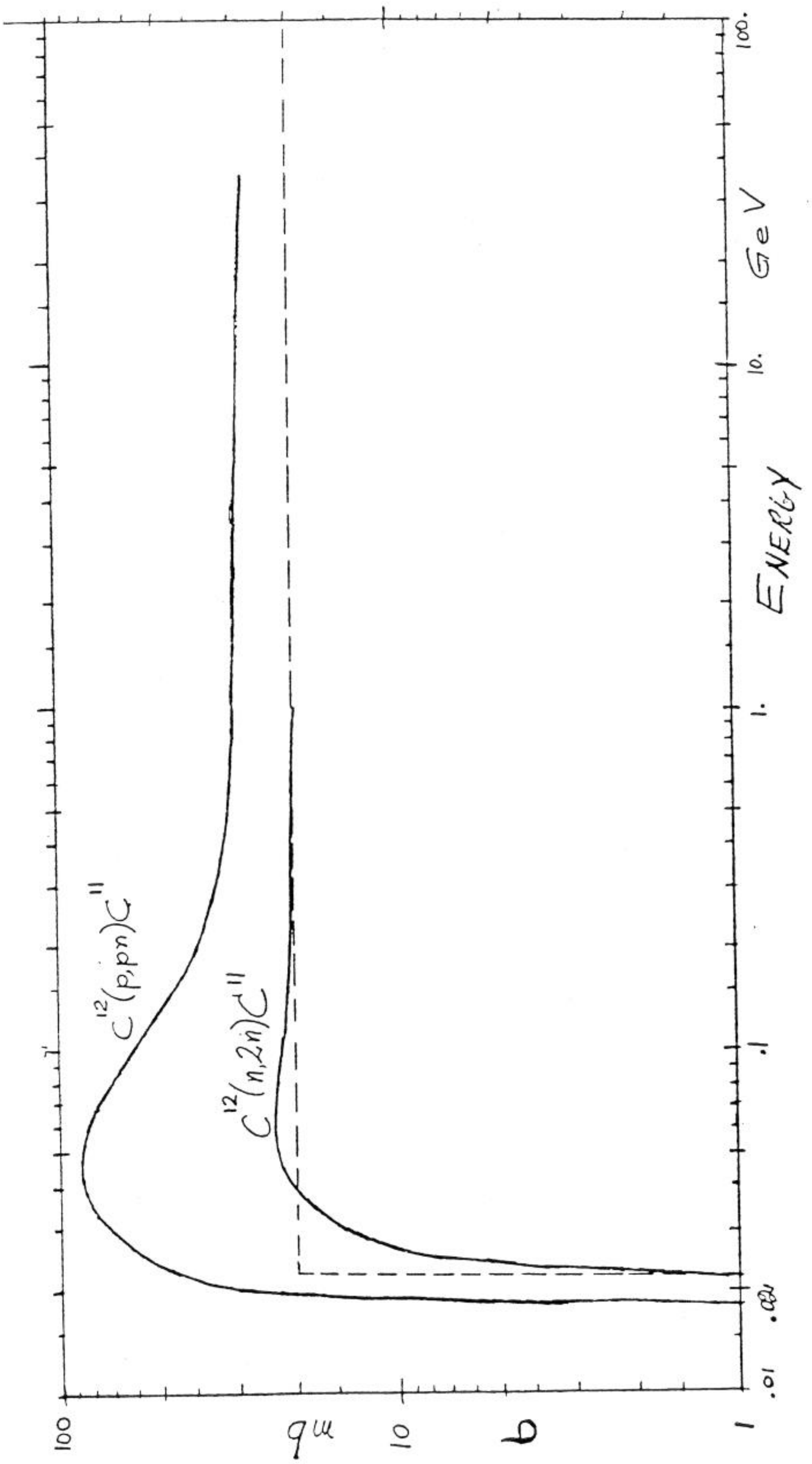


Fig 6

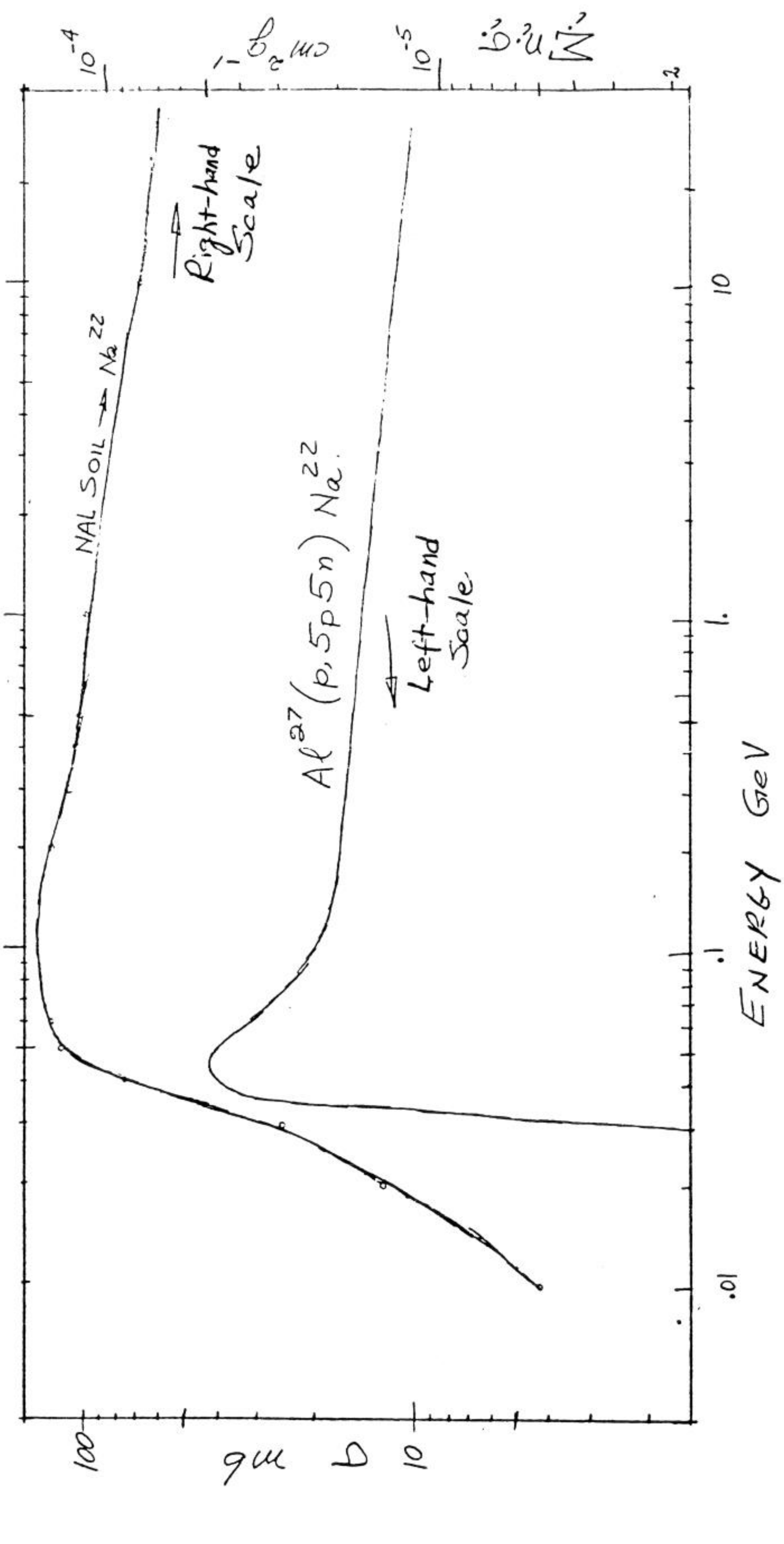

NAL SOIL → Na 22
Right-hand Scale
Al 27 (p, 5p 5n) Na 22
Left-hand Scale
ENERGY GeV
10 -4
10 -5
100
10
.01
.1
1.
10

Fig 7

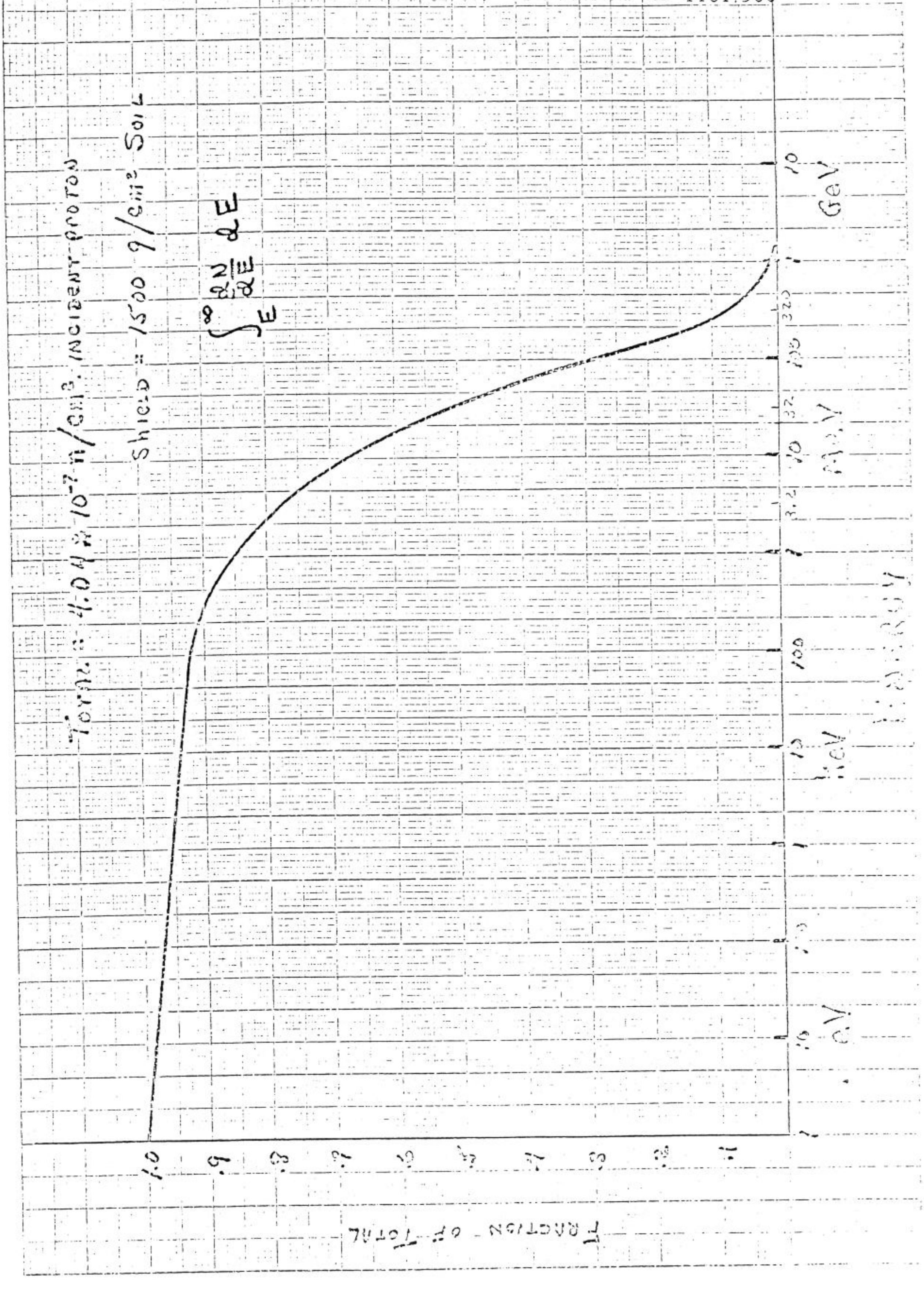

Total = 4.04 x 10^-7 n/cm^3, incident proton
Shield = 1500 g/cm^2 Soil
∫_E^∞ dN/dE dE
GeV
MeV
keV
eV
Fraction of Total

Fig. 8

Gabriel et al.
500 GeV p on Be
600 ν-tunnel

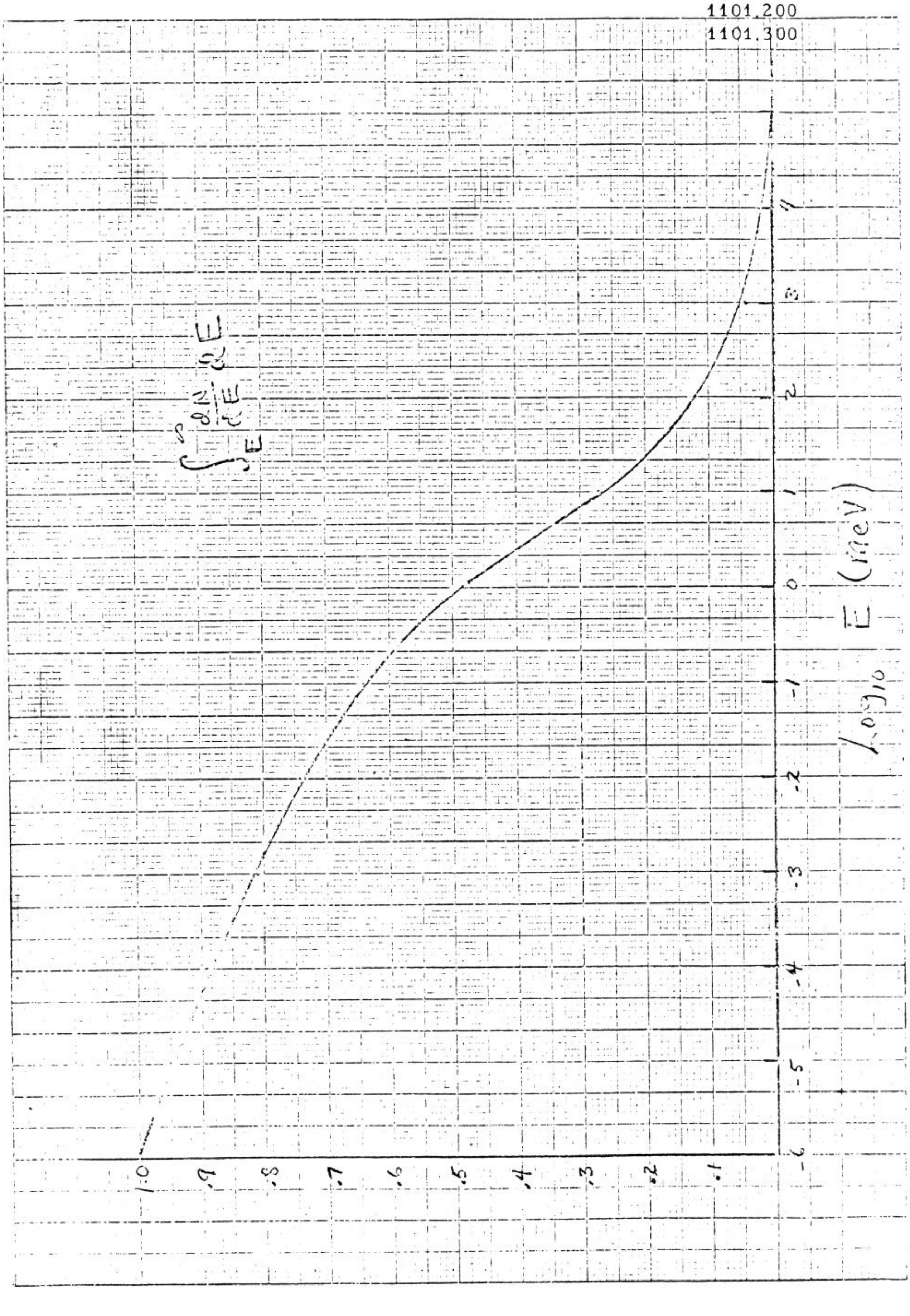


Fig. 9

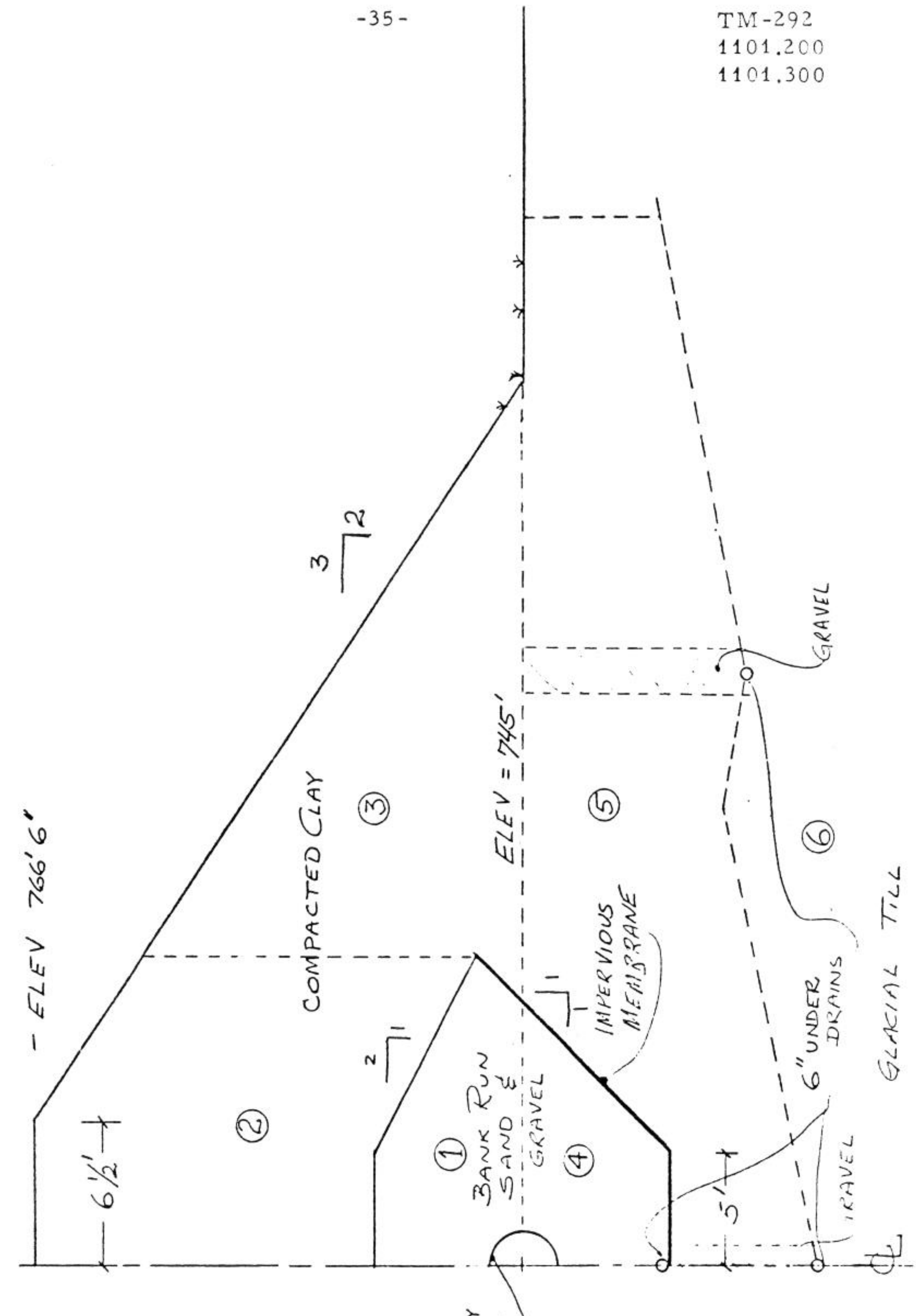

ELEV 766'6"
COMPACTED CLAY
3
2
ELEV = 745'
1
2
3
4
5
6
BANK RUN SAND & GRAVEL
IMPERVIOUS MEMBRANE
6½'
5'
6" UNDER DRAINS
GLACIAL TILL
GRAVEL
DECAY PIPE

Fig 10

APPENDIX D

COMMENTS RECEIVED ON DRAFT ENVIRONMENTAL STATEMENT AND AEC RESPONSES

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

DEC 3 0 1971

Dr. Roger O. Egeberg
Assistant Secretary for Health
and Scientific Affairs
Department of Health, Education,
and Welfare
Washington, D. C. 20201

Dear Dr. Egeberg:

This is in response to your letter of March 22, 1971, concerning the "Draft Environmental Statement for the National Accelerator Laboratory (NAL), Batavia, Illinois." At the time you indicated concern about the adequacy of the information in support of the conclusions reflected in the Environmental Statement on expected radiation levels at NAL. In the past couple of months, the Statement has been revised and strengthened, primarily in the Physical Impact - Part IVA. The final environmental statement is enclosed. In addition, the assumptions and calculations supporting the conclusions in the Statement have been formalized in TM-306, entitled, "NAL Off-Site Dose-Equivalent Rates Due to Accelerator-Caused Radiation," dated May 25, 1971; and TM-292-A, entitled, "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory," dated March 11, 1971. These documents are also enclosed.

Thank you for your review and comments.

Sincerely,

John A. Erlewine

John A. Erlewine
Assistant General Manager
for Operations

Enclosures:
1. Final Environmental Statement - NAL (4 cys)
2. Report TM-306
3. Report TM-292-A

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
WASHINGTON, D.C. 20201

OFFICE OF THE SECRETARY

John A. Erlewine
Assistant General Manager
for Operations
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dear Mr. Erlewine:

Thank you for your letter of February 1, 1971, to Mr. Roger Strelow transmitting the "Draft Environmental Statement for the National Accelerator Laboratory, Batavia, Illinois," dated January 1971. The staffs of our Bureaus of Radiological Health and Community Environmental Management have reviewed this statement as required by the provisions of the National Environmental Policy Act of 1969. Their report is enclosed.

The "Environmental Statement" indicates that the National Accelerator Laboratory can be built and operated at the Batavia, Illinois, site without adverse environmental effects or unacceptable radiation exposure of the surrounding population. While this may in fact be possible, it was the opinion of the reviewing staff that the general nature of the statement made it impossible to adequately evaluate the acceptability of the site or facility nor to assess the adequacy of the studies made by the AEC and the conclusions summarized in the "Environmental Statement." For instance, the maximum dose rate of 30 mrem/yr at the site boundary is well within the standards for exposure of the public; however, the acceptability of this calculated exposure is dependent on the data and assumptions made. Such information is not presented. Further, this level would be considered unacceptable for a reactor installation.

Based upon the information presented, the proposed facility should not represent an unacceptable hazard to the public or the environment. However, it has not been possible to evaluate the adequacy and completeness of the data and assumptions used in formulating the statement's conclusions on the basis of data provided.

Sincerely yours,

Roger O. Egeberg, M.D.
Assistant Secretary
for Health and Scientific Affairs

Enclosure

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

PUBLIC HEALTH SERVICE

Bureau of Radiological Health

Date: March 11, 1971

Reply to Attn of:

Subject: Comments on the Environmental Statement for the National Accelerator Laboratory

To: Deputy Director
Bureau of Radiological Health

1. The subject document has been reviewed by staff members of the Radioactive Materials Branch, DMRE and the Product Testing and Evaluation Branch, DEP. The following statement summarizes the information presented which indicates that there is no unacceptable radiation hazard to the general public or the environment from the operation of the facility.

a. External Radiation The main accelerator is contained in an underground tunnel which is covered with the equivalent of 20 or more feet of earth shielding. Peak radiation levels at the site boundary are calculated to be no greater than 0.009 mrem/hr above background at the northeast corner and no more than 0.003 mrem/hr at other points due primarily to neutron and muon radiation.

Allowing for operational variations in beam intensity, beam energy, and operating times, cumulative levels are expected to be less than 10 mrem/yr at the major fraction of the site perimeter and less than 30 mrem/yr at the northeast corner.

b. Residual Radioactivity will be produced in the tunnel walls, components, cooling water, tunnel air and ground water. The beam tunnel enclosures will be sealed during operation and for a period of time after shutdown to allow decay of the radioactive air. The primary cooling is a completely closed system and the radioactive water will be contained.

c. Ground Water The irradiation of soil adjacent to the external target areas can be expected to produce ^{55}Fe, ^{39}Ar, ^{14}C, and ^{22}Na. To prevent the majority of these activation products from reaching the ground water a collection system will drain the target areas into a holding pond for monitoring prior to any release. Using hypothetical assumptions it was calculated that the concentration of ^{22}Na (the most significant radionuclide) in well water on the facility site would be less than 5% of the general public permissible concentration.

2. The document however is so limited in scope that it is impossible to make an evaluation of the radiation hazards of the facility or to assess the adequacy of studies made by the operator-contractor which are presented in the "Environmental Statement." It is highly questionable that a document of this nature serves any useful purpose in determining deleterious efforts on the environment from the construction and/or operation of this facility.

3. I discussed this "Environmental Statement" with Dave Harward, EPA, and he indicated that they felt it to be inadequate even though better than some they have received. He further noted that the estimate of 30 mrem/yr at the site boundary would be considered unacceptable for a reactor site. Without any data relating to the basis for this dose rate from neutron and muons and its fall off with distance or the area involved there may be a valid reason to hold this opinion. At the same time one should realize that by-product and x-ray facilities are generally accepted when it is shown that the dose at the site boundary does not exceed 500 mrem/yr.

4. This "Environmental Statement" was also referred to BCEM and has been discussed with Francis Jacocks. Mr. Jacocks stated that based on the statements made, the site and facility were acceptable from a community planning and management viewpoint. Again it was noted that insufficient data was presented to evaluate and assess the facility. Mr. Jacocks suggested that we respond directly (without a sign-off by BCEM) noting that they found the facility acceptable based on the statements made by the AEC.

Gail D. Schmidt
Chief, Radioactive Materials Branch
Division of Medical Radiation Exposure

cc: Mr. Gundaker
Mr. Jacocks

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

DEC 30 1971

Mr. Thomas E. Carroll
Assistant Administrator for
Planning and Management
Environmental Protection Agency
Washington, D. C. 20460

Dear Mr. Carroll:

This is in response to your letter of April 7, 1971, regarding the Draft Environmental Statement for the National Accelerator Laboratory (NAL), Batavia, Illinois. Your comments pertained primarily to expected radiation levels and control, and the handling of sewage wastes. In the past couple of months, the Environmental Statement has been revised and strengthened primarily in the Physical Impact - Part IVA. Copies of the final environmental statement are enclosed. In addition, the assumptions and calculations supporting the conclusions in the Statement have been formalized in TM-306, entitled, "NAL Off-Site Dose-Equivalent Rates Due to Accelerator-Caused Radiation," dated May 25, 1971; and TM-292-A, entitled, "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory," dated March 11, 1971. These documents are also enclosed.

It is noted that discussions are still underway with the City of Batavia for possible use of the City's sewage treatment plant, however, at this time an agreement has not been reached and we therefore must indicate alternate methods for handling of this waste.

Thank you for your review and comments.

Sincerely,

John A. Erlewine

John A. Erlewine
Assistant General Manager
for Operations

Enclosures:
1. Final Environmental Statement - NAL (7 cys)
2. Report TM-306
3. Report TM-292-A

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 7 1971

OFFICE OF THE ADMINISTRATOR

Mr. John A. Erlewine
Assistant General Manager
for Operations
U.S. Atomic Energy Commission
Washington, D. C. 20545

Dear Mr. Erlewine:

Thank you for your letter of February 2, 1971, requesting comments on the Draft Environmental Statement for the National Accelerator Laboratory to be located at Batavia, Illinois. The enclosed report constitutes a summary of the technical comments developed by the various operating offices of the Environmental Protection Agency.

We are of the opinion that the facility, as proposed, can be operated safely from an environmental point of view. It is quite important, however, to take all steps possible to minimize the radiation dose to the population from the secondary radiation produced when the accelerator is being operated. In this regard, it is essential to control movement of personnel onto the site exclusion area when the accelerator is being operated. It is also extremely important to have an off-site monitoring program to confirm that the facility is operating as anticipated and to insure that the general public is not being unduly exposed to radiation originating at the site. The control over the site boundary and the area within along with the details of the off-site environmental surveillance program should be included in the final environmental statement. The Atomic Energy Commission should make available at frequent intervals the results of this surveillance program so that a continuing evaluation can be made that population doses are at the lowest practicable levels from operating the facility.

We would be pleased to discuss any of our comments on the National Accelerator Laboratory. If we can assist you further in this matter, we will be happy to do so.

Sincerely yours,

Thomas E. Carroll

Assistant Administrator
for Planning and Management

Enclosure

ENVIRONMENTAL IMPACT REVIEW

NATIONAL ACCELERATOR LABORATORY

BATAVIA, ILLINOIS

Coordinated By
Radiation Office
ENVIRONMENTAL PROTECTION AGENCY
5600 Fisher's Lane
Rockville, Maryland 20852

March 1971

PREFACE

This report is one of a series designed to summarize the results of evaluations by the Environmental Protection Agency of the radiological effects of nuclear facilities on the environment. The evaluation is based on a detailed technical review of the "Draft Detailed Statement on Environmental Considerations" submitted by the Atomic Energy Commission pursuant to the requirements of the National Environmental Policy Act of 1969. The reviews are coordinated with the operating offices of the Environmental Protection Agency by the Division of Technology Assessment, Radiation Office. The Water Quality Office has the major role in developing comments on water quality; comments by other offices are included as appropriate for specific problem areas. As part of this review process, several technical documents have been developed and referenced to support the discussions presented.

The evaluation presented in this report is directly responsive to the requirements placed on Federal agencies by the National Environmental Policy Act and as such is intended to state the position of the Environmental Protection Agency on the environmental effects of carrying out the various nuclear activities. The report is also intended to provide information to the State involved for its use in developing and conducting environmental programs for the particular nuclear activity.

INTRODUCTION AND CONCLUSIONS

The purpose of this report is to summarize the results of an evaluation by the Environmental Protection Agency of the potential environmental effects of the National Acceleratory Laboratory (NAL) to be located at Batavia, Illinois. The laboratory is to be located on a tract of 6,800 acres approximately 30 miles west of the center of the city of Chicago and 15 miles northwest of the Argonne National Laboratory. The main research facility at the laboratory will be a 200 GeV proton synchrotron, with possible extensions to 500 GeV, which will be fed by a linear accelerator and booster synchrotron. The accelerator will be constructed underground in a circular ring about 4 miles in circumference.

The Atomic Energy Commission will operate the proposed facility and has submitted a draft environmental statement[1] which discusses the potential environmental impact. This review is based on this statement and has considered primarily radiological effects on the nearby environment and population. The principal conclusions are:

1) The draft environmental statement should include a presentation of the following: a) the control over the site boundary and exclusion areas within, b) the radionuclide inventory and discussion of operating procedures of the cooling water system, c) the method and assumptions used to determine the site boundary dose, and d) potential off-site radiation emergencies associated with the operation of the facility.

2) It appears that the facility can be operated such that public radiation exposures will be within the guidance of the Federal Radiation Council; however, consideration should be given to practicable means of reducing the dose in the public environs of the NAL either by additional shielding or extension of the restricted area.

3) Possible contamination of ground water could occur from percolation to the aquifers of sodium-22 produced by activation of soil by secondary radiation. The assumptions concerning the rates of production and percolation of radionuclides to the aquifer should be discussed relative to estimated radionuclide concentrations in domestic water supplies.

4) Environmental surveillance for the site should be established to monitor radiation levels in the environment especially for underground water supplies and external radiation doses outside the restricted area.

5) The probable volume and composition of sewage wastes as well as the ultimate disposal methods and sites to be used by the contractor should be indicated. Since the nearby Batavia treatment plant meets water quality standards and has additional capacity available, the Atomic Energy Commission is encouraged to utilize this facility.

6) If the considerations discussed here are carried out, we are of the opinion that the National Accelerator Laboratory can be built

and operated such that the environmental impact would be acceptable. The recommendations are, in our judgment, both prudent and reasonable in minimizing risk to the public.

SITE CONSIDERATIONS

It appears that the main public risk will be associated with secondary radiation produced when the accelerator is being operated. Secondary radiation refers to all radiation resulting from the interaction of the primary beam with matter other than the radiation from induced radioactivity. In this regard it was indicated that a private guard service will be employed at the site to control movement of personnel onto the site when tests are being conducted. It is extremely important for these control measures to be sufficient to enforce the site boundary and exclusion areas in order to protect the public from radiation. Detailed information should be provided describing access controls to the area and the distance of exclusion area fences from all critical portions of the facility from the standpoint of radiological protection of off-site areas.

The accelerator will use a cooling water system which is made up of three or four shallow basins on site to retain and cool the water. Radionuclide composition and activity levels of the cooling water in the basins should be presented along with the possible environmental effects since it was stated that the basins will be used as a natural preserve for fish and wildlife. Operational procedures for the cooling water system should also be discussed to verify that the cooling water is in a completely closed system and that the water in the basins will not mix with water outside the exclusion area before appropriate treatment to remove radioactive materials.

Expected radioactive waste discharges from the NAL ventilation systems should also be discussed in the final environmental statement. Radioactive materials which are powdered and those that tend to flake should be handled in hoods in which adequate ventilation is provided. The hood ventilation system should exhaust outside the building and include a high efficiency particulate air filter to limit radioactive airborne particulate emissions. There is also the possibility in the operation of an accelerator that gaseous and airborne particulate activity will be produced as the result of activation of air in rooms or cavities surrounding the target area. If this is to be potential source of radioactive waste, high efficiency particulate air filters should be provided to reduce discharges to the environment.

The draft environmental statement(1) indicates that waste from the industrial water treatment facility, solid wastes from the sewage treatment facility, and other sources will be disposed of by a contracted service in accordance with applicable Federal, State and local standards. The probable volume and composition of these wastes, as well as the ultimate disposal methods and sites to be used by the contractor should be indicated.

It is also indicated that sewage treatment will be accomplished by either a "full sewage-treatment plant" constructed on the site or by the City of Batavia treatment plant with either of these alternatives fully meeting Federal and State standards.[1] Additional information should be included regarding sewage treatment processes to be provided and a discussion of plans to be followed until waste treatment arrangements are completed. Since the nearby Batavia sewage treatment plant meets water quality standards and has additional capacity available, the Atomic Energy Commission is encouraged to utilize this facility.

ENVIRONMENTAL IMPACT

In our opinion, the most significant off-site radiological effect of the operation of the accelerator will be the population dose that results. It is stated that the external dose due to the operation of the accelerator will be kept below 170 mrem/yr, which is the standard for population groups in uncontrolled areas as expressed in chapter 0524 of the Atomic Energy Commission Manual.[2] The analysis of beam energies, and operating conditions led to the conclusion that "cumulative dose levels are expected to be less than 10 mrem/yr at the major fraction of the site perimeter and correspondingly less than 30 mrem/yr at the northeast corner."[1] Information is needed on the method of making these dose estimations; especially on the energy distribution and intensity of the neutron beam, the quality factors used, the accelerator "down time," and the dose as a function of distance from the multiple target stations. The dose estimates should also include contributions from bremsstrahlung. Even though the bremsstrahlung associated with a 100 GeV proton is approximately equivalent to that of a 30 KeV electron, it is conceivable that other bremsstrahlung which is more intense and energetic could originate from the interaction of the "shower" produced by the impact of the proton beam in the target area.

Even though these population dose estimates are less than the Federal Radiation Council's Radiation Guide of 170 mrems/yr for a suitable sample of the exposed population, their potential magnitude is sufficently high that every reasonable consideration of additional actions should be taken to keep them as low as practicable. Additional shielding and/or extension of the exclusion radius could be employed in order to reduce the maximum off-site doses well below the expected dose of 30 mrem/yr.

It is indicated that ^{22}Na will be produced as a result of soil activation by secondary radiation, and that through percolation, significant ground water concentrations could result. Estimates have been made of the maximum amount of radioactivity that could be produced, that could escape the drainage system, and that could migrate downward to the aquifer. The assumptions made in calculating the radioactivity produced and its migration rate were not presented in the draft environmental statement.[1] Levels of radionuclide production in the soil and assumptions concerning the percolation of radionuclides to the aquifer should be presented in the final environmental statement so that an independent estimate of radionuclide concentrations in domestic water supplies can be made.

ENVIRONMENTAL SURVEILLANCE

An environmental surveillance program is essential to confirm that the facility is operating as anticipated and to insure that the general public is not being unduly exposed to radiation originating at the site. Adequate surveillance should be done by the Atomic Energy Commission and the Illinois Department of Public Health to insure that there is no encroachment of radioactivity into drinking water supplies or other critical environmental pathways to man. Local wells should be sampled periodically, especially for sodium-22, to ensure that this potential pathway is not being contaminated as a result of operating the facility.

The Radiation Physics Section of the Laboratory will monitor the site boundaries continuously to ensure that the minimum radiation levels are maintained. In this regard, we recommend that integrating dosimeters changed at appropriate intervals be utilized. Besides the expected neutron and muon radiation at the site boundary there may be significant levels of gaseous radioactivity discharged into the atmosphere through the ventilation system and the vacuum pumps. The exhaust from the ventilation systems and vacuum pumps should be monitored at the points of discharge and off-site air samples taken and analyzed until it is shown that the potential environmental effect from these sources will not be significant. Shielding surveys should be performed periodically to determine if the escaping neutron flux is within acceptable limits and to determine the structural integrity of the shielding material. The final environmental statement should indicate that such procedures will be followed to provide maximum protection of the public.

REFERENCES

1. United States Atomic Energy Commission "Draft Environmental Statement for the National Accellerator Laboratory - Bativa, Illinois"- January 1971.

2. United States Atomic Energy Commission, "Standards for Radiation Protection," Atomic Energy Commission Manual, Atomic Energy Law Reports, Chapter 0524, pp. 12,024a - 12,026, Washington, D.C.

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