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ENVIRONMENTAL PROTECTION INFORMATION MEETING

November 6-8, 1984
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Albuquerque, NM

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8L: FERMILAB SOIL ACTIVATION EXPERIENCE

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ABSTRACT

Soil borings were made at Fermilab locations of highest soil activation and samples analyzed to determine whether or not any leached radionuclides were moving toward the aquifer under the site. One boring extended underneath the primary target in the Neutrino Area, a target which has received most of the protons produced by the accelerator. The other recent boring was adjacent to the thinly shielded abort system which received protons which were improperly transported through the accelerator magnets or left in the accelerator after proton beam extraction. No evidence was found for movement of radionuclides toward the aquifer in concentrations approaching the community drinking water supply standards.

INTRODUCTION

Fermi National Accelerator Laboratory (Fermilab) is an accelerator facility performing basic high energy physics research. The synchrotron delivered protons with 200 billion electron volts (GeV) of energy to external targets in 1972 and operated routinely at 400 GeV from 1976 to 1982 with more than 10^{13} protons per acceleration cycle using conventional magnets. At that time a new ring of superconducting magnets was added and the energy doubled while saving electrical power. This paper will cover the period of operation using conventional magnets.

Radiation shielding in the vicinity of targets and dumps at Fermilab consists of massive amounts of steel inside concrete enclosures in most places. There are two exceptions which resulted in significant radioactivation of the soil. One such location was the main accelerator abort target and beam dump. This thinly shielded abort system was recently replaced by a well-shielded dump external to the main accelerator tunnel (Main Ring). The other was the primary target in the Neutrino Area. This target was inside a steel tube surrounded by sand and gravel. The primary target has been relocated to a better-shielded location 100 m away.

The two targets received protons for over ten years. Thus, a considerable inventory of radionuclides was built up in the soil. There were drainage systems to collect any leached radioactivity down to a certain depth below the targets. However, below these underdrains there was no information on movement of radionuclides. To obtain that information soil borings were made into the region below the underdrains and the samples analyzed for the radionuclides leachable from the soil.

The techniques for obtaining and assaying the samples will be described and the results of the analyses will be given below. In addition, a comparison will be made between the amount of soil activation observed and the amount calculated based on the number of protons incident on the abort target.

ABORT TARGET SOIL ACTIVATION

The Main Ring Abort Target was located inside the Main Ring tunnel in the D0 straight section and used from the initial operation of the Main Ring through June 1982. It was replaced by a better-shielded abort system at C0 with deflection of protons into a dump external to the tunnel. The target at D0 consisted of an aluminum bar approximately 15 cm square x 274 cm long. On May 20, 1974 (two years after the first protons were extracted from the accelerator) steel, 10 to 15 cm thick, was placed around the target, mainly to reduce radiation exposure to Accelerator Division personnel working in the tunnel. Two magnet cores each approximately 6 m long were located between 25 m and 40 m downstream from the target to stop the particles coming off at small angles with respect to the incident beam direction. Most of the soil activation occurred just downstream from the abort target.

The purpose of the Main Ring Abort System was to provide one location inside the Main Ring where a misguided proton beam could be directed without harming accelerator components. Also, it served as a place where any protons left in the ring after extraction could be sent. The total number of protons aborted was 3.1 x 1018 during the lifetime of the Main Ring Abort System. The soil activation caused by these aborts was monitored by a system of aluminum and copper tags placed inside the Main Ring tunnel. These were changed periodically (usually once a year) and the radioactivity in the tags assayed. The copper tags were useful in the early running periods when the activation was low and the tags were changed frequently. In later running periods, the aluminum tags were used almost exclusively because the ^{22}Na production in soil could be directly related to ^{22}Na production in aluminum and the 2.6 year half-life of ^{22}Na made the error resulting from an annual tag change acceptably small.

In addition to the monitoring tags some direct measurements were made by coring into the soil 30 cm from the tunnel wall adjacent to the abort target in 1973. The coring stopped at the abort target elevation which was 8 m below the top of the earth shielding berm (Figure 1) to avoid damaging the underdrain which collects water from around the tunnel footings.

The samples of soil collected were assayed for radioactivity. The assay included direct gamma-ray counting of ^{22}Na and leaching studies to determine the amounts of ^{3}H and ^{22}Na which could be removed by percolation of water through the soil. Direct counting of ^{3}H was not possible because of the low beta endpoint energy (0.02 MeV). The samples were sealed and returned to the hole for future comparison with samples which could be leached by percolation of rainwater.

Ten years later in July 1983 a new soil boring was made near the old one at the abort target. This time the hole was drilled 120 cm from the tunnel wall to allow samples to be collected below the underdrain without damaging it. Samples were retrieved to 4 m below the target (Figure 1). The sealed samples from the first hole were recovered and analyzed in addition to the new samples. The results are presented in Figures 2 and 3. The soil activation and the leaching of radionuclides from the new samples were expected to be ten times lower than those measurements for the sealed samples provided no percolation of rainwater <u>in situ</u> had removed the radioactivity from the soil. This was the observed result.

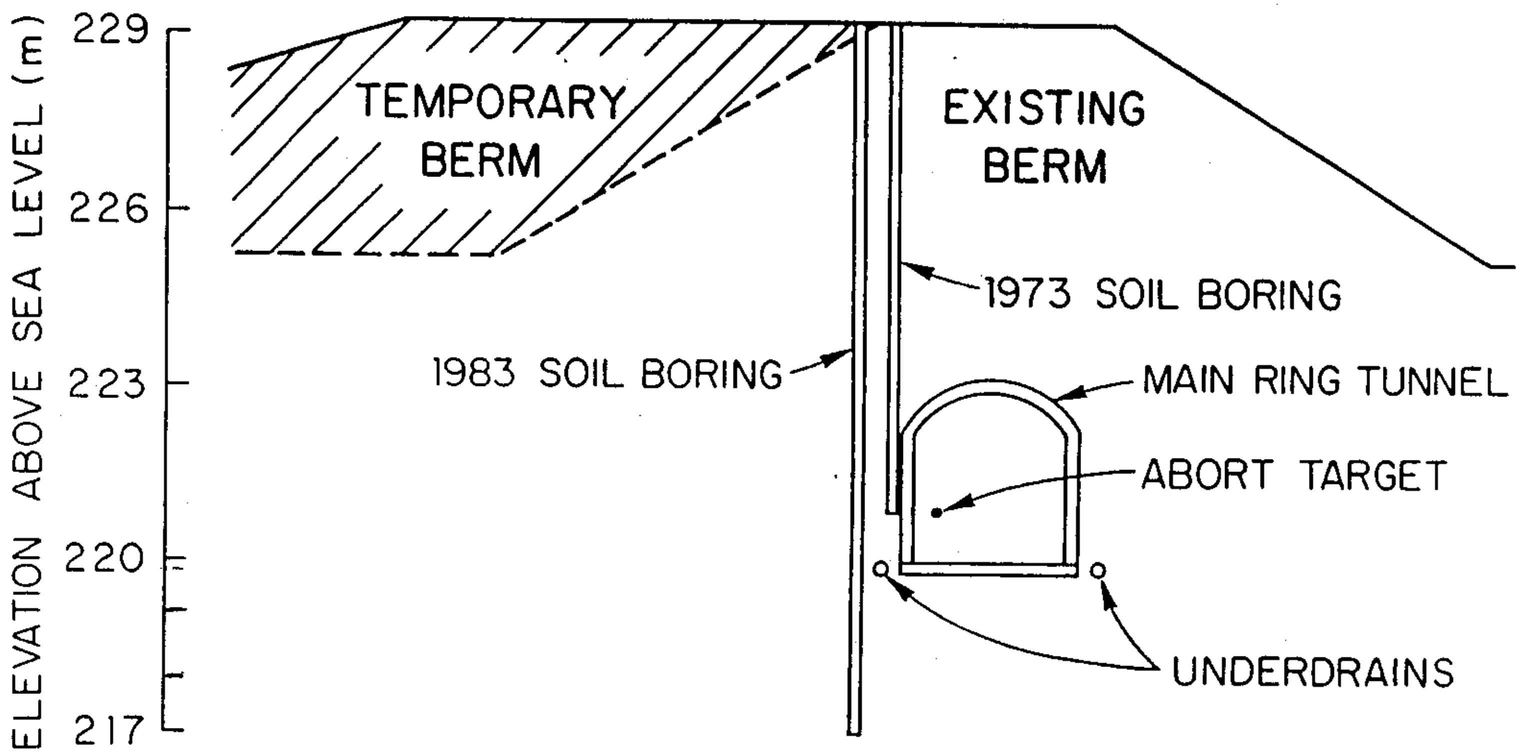

FIGURE 1. Cross Sectional View Near Main Ring D0 Abort Target

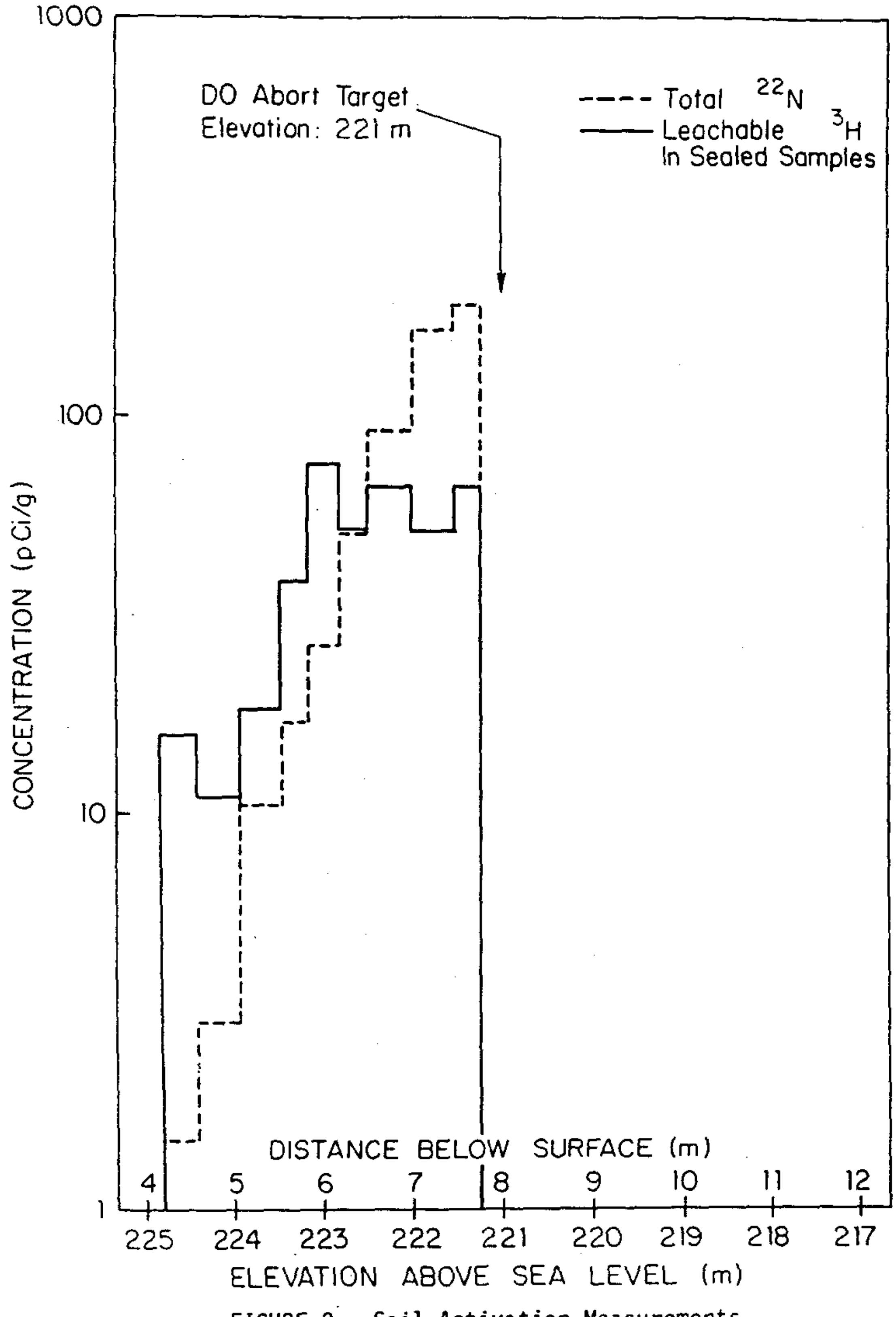

FIGURE 2. Soil Activation Measurements
30 cm from DO Tunnel Wall

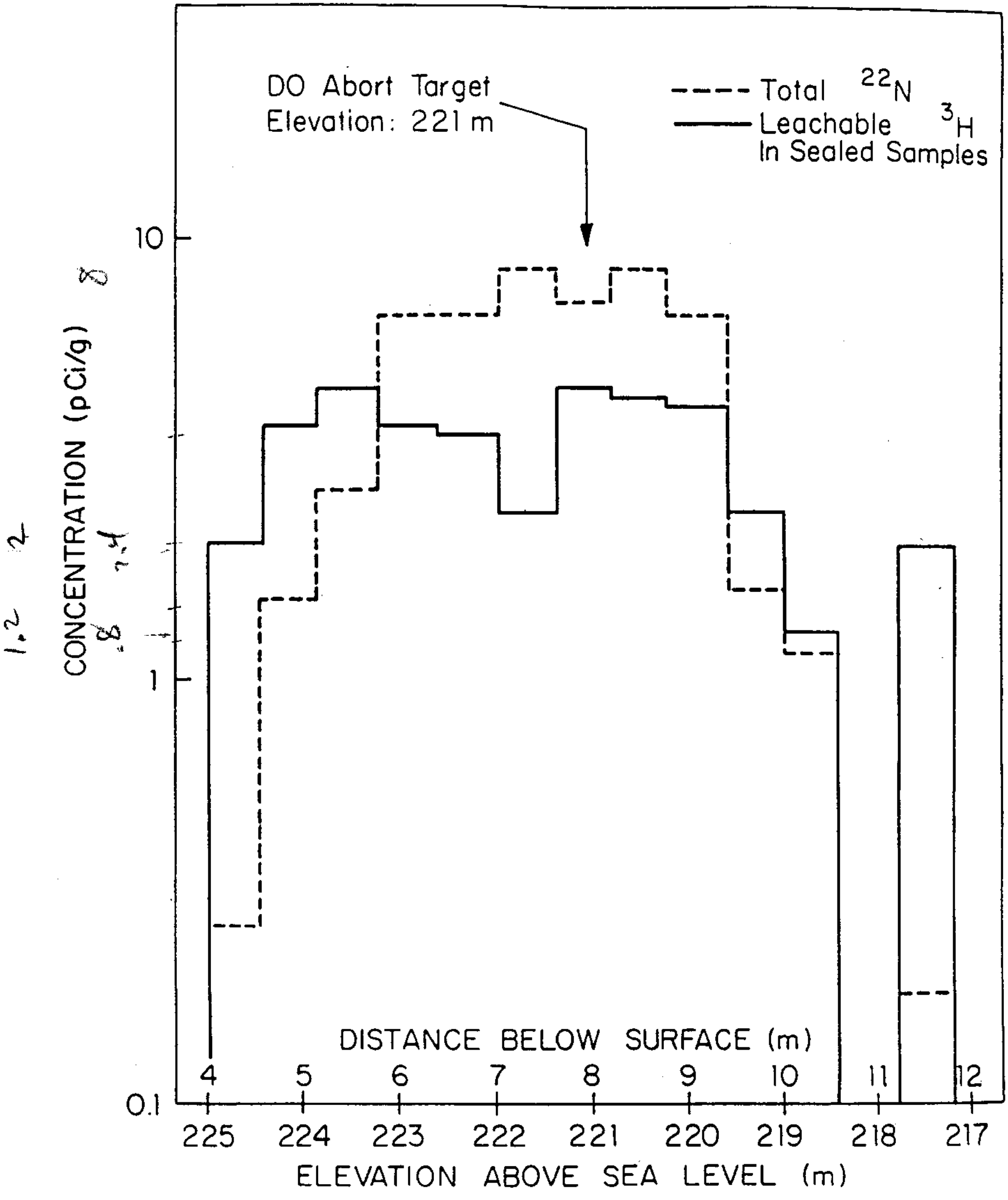

FIGURE 3. Soil Activation Measurements 120 cm from DO Tunnel Wall

COMPARISON WITH CALCULATIONS

The above results were compared with predictions using the computer program CASIM.[1] This program uses a modified Monte Carlo technique to model the hadron cascade resulting from the proton interactions. It calculates the density of nuclear interactions as a function of distance from the target. If one knows the number and energy of the incident protons, one can calculate the number of stars (nuclear interactions) and from the cross sections and half-lives determine the concentrations of the radionuclides in the soil.[2]

The prediction for the highest ^{22}Na concentration in the soil at 30 cm from the wall agreed with the measurement of approximately 200 pCi/g. For the new hole at 120 cm from the wall the prediction was 20 pCi/g while the measurement was 9 pCi/g. This discrepancy is within the uncertainty expected for CASIM at 120 cm where the attenuation factors are large.[3] Furthermore, leaching of ^{22}Na is at most about 20% and could not account for the discrepancy.[4]

The above discussion does not preclude some leaching of radionuclides. A water sample taken from a pocket of water discovered at 2 m below the bottom of the tunnel (217.5 m above sea level) contained a tritium concentration of 3×10^{-6} μCi/mℓ. Since the maximum ^{3}H concentration permitted in a community water supply is 2×10^{-5} μCi/mℓ, this is well below the allowable concentration without further dilution! Note that the leachable ^{3}H concentrations in the adjacent soil samples (Figure 3) were approximately the same as that in the water sample. The concentrations are expressed in pCi per gram of wet soil rather than pCi per milliliter of water in the soil for comparing ^{22}Na present in soil with ^{3}H leachable from soil and for comparing leachable ^{3}H with ^{3}H present in a water sample.

Thus, no evidence has been found for leaching of radioactivity and subsequent movement of a large inventory of radionuclides toward the aquifer approximately 15 meters below the abort target.

NEUTRINO AREA PRIMARY TARGET SOIL ACTIVATION

The Neutrino Area primary target received a total of 10^{20} protons, most of the protons produced by the accelerator. The target was in operation from May 1972 until June 1982 inside a steel tube approximately 2 m in diameter and 2.5 cm thick, surrounded by sand and gravel. See Figure 4. The production and leaching of radionuclides was monitored by making a soil boring in 1975 into the sand and gravel. The results were presented at an earlier Department of Energy conference.[5] The analyses indicated that the clay berm was protecting the sand and gravel well except

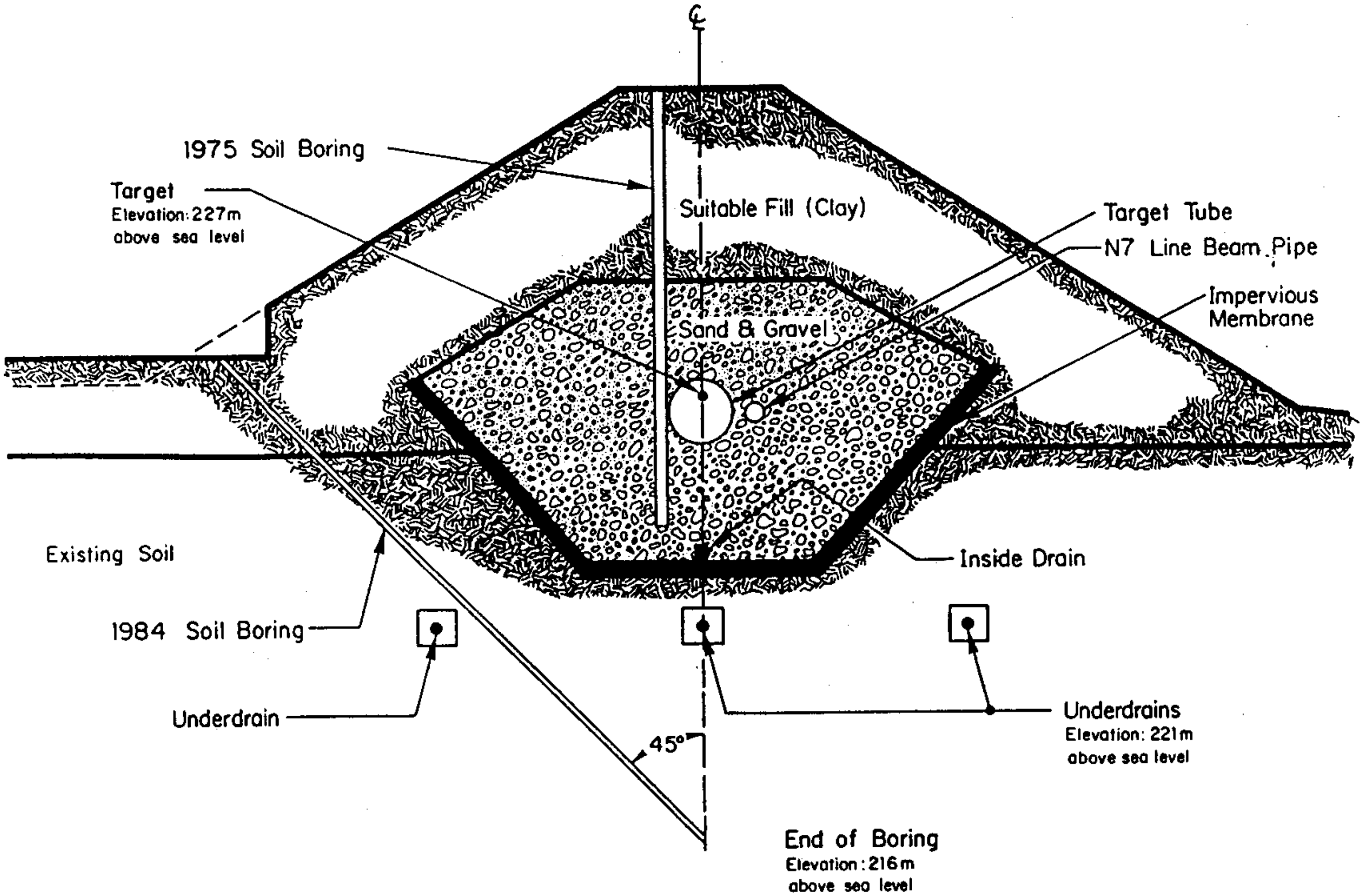

FIGURE 4. Cross Sectional View at Neutrino Area Primary Target

for some channeling which removed a small fraction of the inventory of radionuclides by leaching.

The sand and gravel region has a liner (impervious membrane) with one drain inside and three underdrains (Figure 4). The inner drain goes to a retention pit which is sampled periodically. When the ^{3}H concentration exceeds 10^{-3} μCi/mℓ, the water is evaporated, otherwise it is pumped out into a ditch. The peak concentration observed was 5×10^{-3} μCi/mℓ. Concentrations of other radionuclides such as ^{22}Na have remained below allowable concentrations for release to surface waters.[6]

The water from the three underdrains (Figure 4) is pumped directly to a ditch. It has always remained well below 10^{-3} μCi/mℓ. In 1980 the clay cap was removed temporarily for installation of the N7 Line beam pipe (Figure 4). Since that time the annual release from the underdrains has been elevated. See Figure 5. The concentration of ^{3}H has consistently remained below allowable concentrations for release to surface waters, however it has exceeded the community drinking water standard for ^{3}H.[7] Therefore, a soil boring was made to see if ^{3}H was moving down toward the aquifer. No accelerator-produced radioactivity has ever been detected in the aquifer.[8]

In order to sample the region below the underdrains without puncturing the liner, a boring hole was drilled at 45° adjacent to the liner (Figure 4). The hole was far enough away from the target so that it was just outside the region activated directly by interactions of secondary particles resulting from the proton beam. Thus, the only accelerator-produced radioactivity expected would be from movement of leached activity out from the soil activation region. The boring hole sampled the soil directly below the region with the highest concentration of radionuclides, and the bottom of the hole was 5 m below the center underdrain (Figure 4).

The soil samples were leached and the concentration of ^{3}H at the bottom of the hole was $(3.8 \pm 2.1) \times 10^{-6}$ μCi per gram of wet soil. The concentration at the underdrains was $(2.7 \pm 1.1) \times 10^{-6}$ μCi per gram of wet soil. From the abort target results above, the expected activity in water should be approximately the same. The concentrations are far below those in the water collected by the underdrains. Therefore, the underdrains are effective in collecting the radioactive water. Therefore, the inventory of radioactivity heading toward the aquifer is small. The concentrations are well below the standard for community water supplies.[7]

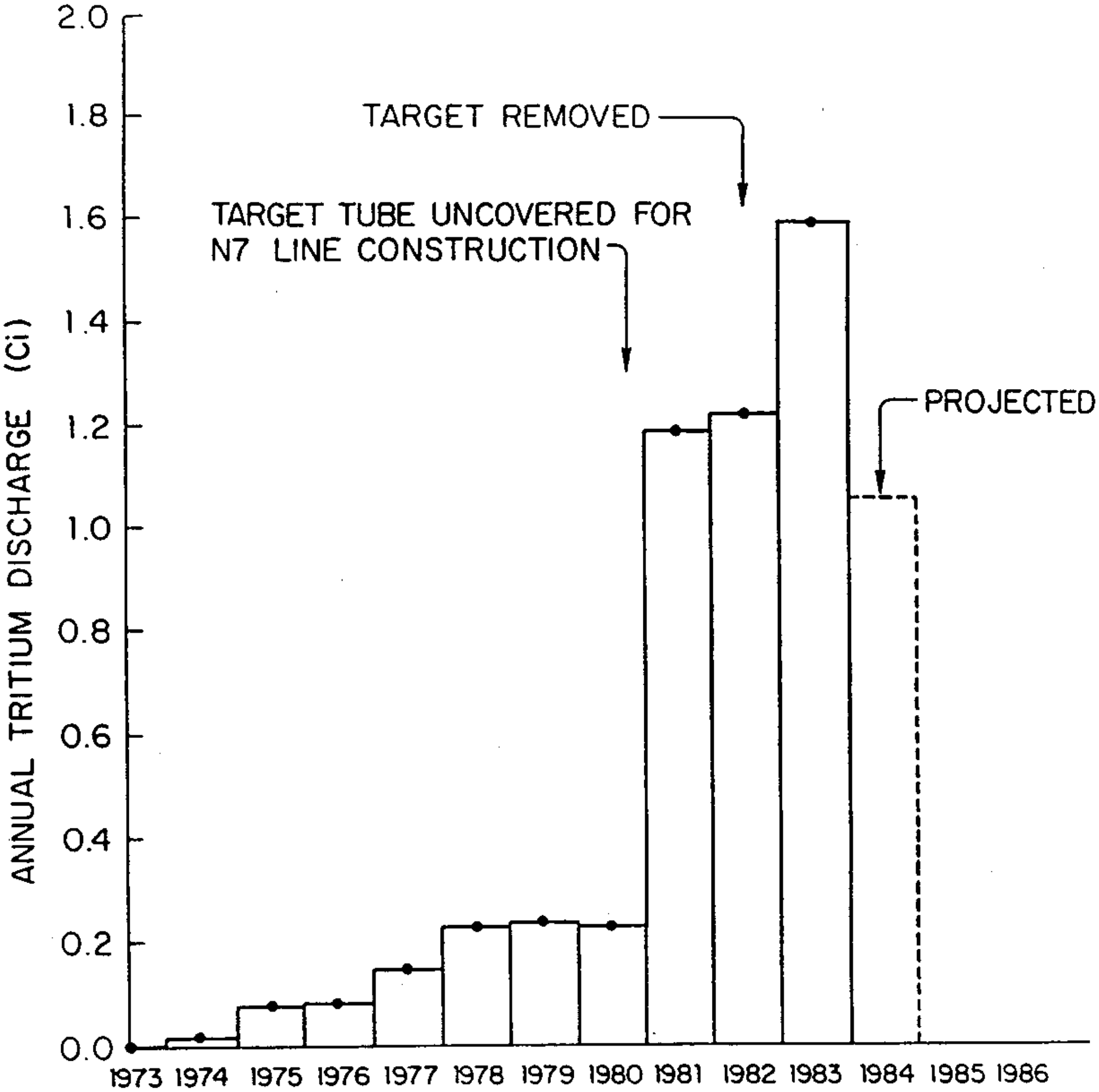

FIGURE 5. Target Tube Underdrain Releases

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