EP note 2

Environmental Protection Note No. 2
Summary of Subsurface Exploration Near the Neutrino and Meson Target Areas

J. D. Cossairt
D. W. Grobe

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Introduction

The Neutrino Area Target Tube and Meson Area Target Box were used as part of the proton targeting scheme from the beginnings of the Laboratory until 1982. The Neutrino Area targeting since that time has occurred in further upstream in enclosure N01. The proton beams delivered to the Meson Area, once targeted in enclosure M01 are now concentrated in the target piles in the Meson Detector Building. Most of the protons targeted on the Neutrino Area Target Tube and Meson Area Target Box were accelerated by the Main Ring during the pre-Tevatron era. At the time of its design, the philosophy of groundwater protection was that a "bathtub" underneath the target stations would serve to contain the radionuclides produced in the environs of the target tube and prevent their further migration downward to the aquifer. The water collected by underdrains within the bathtubs is received in retention pits and, as necessary, disposed of as radioactive waste. In the terminology used by Fermilab shielding designers, this region of drainage to a bathtub is considered to be "protected soil". Underdrains outside of the bathtub also collect water from "unprotected soil" and discharge it to surface waters via ditches. Surface discharges are allowed at higher concentrations than are permissible in groundwater. Hence, the zone above the underdrains is also "protected", though with somewhat less certainty than that provided by the bathtub. Since hadrons are known to be attenuated exponentially in shielding, some radionuclides are obviously produced in the zone outside of the bathtub. This is a particular concern for the older Neutrino and Meson target areas because at the time of their construction, the design criteria used drinking water concentration guides which were approximately a factor of 25 less stringent than those in use since 1979[1].

Shielding design criteria for all construction at Fermilab since that time has utilized a somewhat arbitrary model developed by Sam Baker which limits groundwater concentrations in "unprotected" soil regions to values within the guidelines for drinking water. In fact, the more stringent limits have led to a design strategy which does not depend upon the use of "bathtubs" but instead uses massive steel and concrete shields within beam enclosures to protect the surrounding soil against radioactivation above specified levels. Obviously, attempts have been made to determine if the radionuclides known to be present in the soil near these older target stations represents a threat to groundwater. The need to do this was enhanced by a 1987 DOE

Environmental Survey finding on this subject. This report summarizes the studies made over the past few years on this subject, both in response to the DOE Survey and predating it.

Propagation Assumptions and Concentration Limits

Studies of radionuclide production cross sections and leaching from Fermilab soil samples have been done which have shown that the principal accelerator-produced radionuclides of concern are ^{3}H and ^{22}Na[2]. Other radionuclides produced are not significantly leached into water and hence do not pose a threat to groundwater. Even for ^{22}Na, only 15 to 20 percent of this nuclide produced in soil is leachable[2]. The model applied at Fermilab since 1978[3] conservatively assumes that all the leachable fraction of the radioactivity produced in an unprotected region will migrate vertically to the aquifer at the rate of 7 ft. per year for ^{3}H and 3.1 ft. per year for ^{22}Na. An allowance is made for radioactive decay which occurs during the vertical migration. Furthermore, it is assumed that upon reaching the aquifer the radionuclides are rapidly transported offsite to the nearest hypothetical private well allowing no further radioactive decay. The activity is then considered to be completely withdrawn from the well diluted in 40 gallons per day taken to be the sole drinking water source for its consumer. This "model" is very nearly a "worst case" scenario. A higher volume community drinking water well would provide much greater dilution.

Concentration limits for ^{3}H and ^{22}Na are much more restrictive for groundwater than for surface water. This is because discharges to surface waters normally could be expected to receive rather large dilution from other sources prior to consumption. The choice to apply drinking water limits to groundwater at the level of the closest aquifer in this manner is admittedly arbitrary, but conservative. The silurian dolomite aquifer, nominally 70 ft. below the surface at Fermilab, is the aquifer nearest to the region containing the radionuclides which is used by individuals in the vicinity of the Laboratory. Local municipalities, in general, use much deeper ones much less likely to be polluted by activation products from Fermilab accelerator operations because of protection by many geological layers.

Table 1 gives derived concentration guides for the ^{3}H and ^{22}Na in surface and drinking waters according to current regulations. Applicable regulations, and the consequent derivation of these limits, are discussed elsewhere.[4] When mixtures of radionuclides are encountered, a weighted-sum condition explained in Reference 4 must be used. In the immediate vicinity of Fermilab, all drinking water is taken from groundwater; no surface waters are so used.

Table 1
Allowable Concentrations (pCi/ml)

Radionuclide	Surface Water	Drinking Water
^{3}H	1000	20
^{22}Na	10	0.2

Thus the principal goal is to assure that concentrations in groundwater at Fermilab which could possibly reach the aquifer are kept below the values shown in the right-hand column. Various studies have been used in recent years to ascertain these concentrations. The results are now described.

45° Sampling Hole Drilled in 1984

In September of 1984, a hole was drilled into the Neutrino berm at 45° from the vertical at DUSAF coordinates (z = 103,505 ft., x = 99,958.3 ft.), essentially at the location of the target used to produce neutrino beams during the physics program conducted during the pre-Tevatron era. A cross section of the neutrino berm showing this sampling hole is presented in Figure 1. This hole is described in the Fermilab Site Environmental Monitoring Report for Calendar Year 1984[5] and private notes[6]. The actual drilling was performed by an outside vendor.[a] The purpose for drilling the hole was to sample the soil searching for radionuclides below the lowest underdrains beneath the target tube which might have been leached from the activated soil and then migrated downward. Samples were analyzed for ^{3}H and ^{22}Na by a outside vendor.[b] This drilling found a peak concentration of 10.8 ± 0.4 pCi/ml of ^{3}H in soil moisture evaporated from a sample taken at the elevation of the lowest underdrain. The evaporation was accomplished by heating the sample to temperatures between 110 and 120 °C until dry but not burned.[7] Less than 1 pCi/ml of ^{3}H was measured in water evaporated from a sample taken at the bottom of the hole, 18 feet below the lowest underdrain. Concentrations of ^{22}Na in soil taken at these two elevations were measured to be 0.056 ± 0.031 and 0.016 ± 0.035 pCi/g, respectively. Given the small leachability into water of the ^{22}Na produced in soil and the relatively low tritium concentrations, it is clear that migration of water from the level of the underdrains to the aquifer would not result in

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[a] Testing Service Corporation, 457 East Gundersen Drive, Carol Stream, IL 60188
[b] Teledyne Isotopes, 1509 Frontage Road, Northbrook, IL 60062

groundwater concentrations above the drinking water limits. The underdrains are collecting tritiated water as expected, yet there is no evidence for significant quantities of radionuclides headed for the aquifer. Confirmation of this is provided by the fact that the maximum concentration of ^{3}H measured in the sump receiving the water from the underdrains during calendar year 1984 was 250 ± 2 pCi/ml, also far below the relevant standard for discharge to surface waters. This sampling hole was sealed after these samples were taken to avoid creating a "short circuit" for water to move rapidly downward from the region of the underdrains.

1988 Monitoring Holes

In response to the 1987 DOE Environmental Survey, more extensive soil sampling in the vadose zone was done to determine the extent of radionuclide production and migration beneath the Neutrino Area Target Tube, the Meson Area Target Box, and the Neutrino Area Primary Beam Dump (NW4). Monitoring wells were, also, installed for future shallow water sampling at these locations. Specifically, three soil borings (denoted S-1061, S-1062, and S-1063) were made near the Meson Area Target Box and one (S-1060) was made near the Neutrino Area Primary Beam Dump. These were drilled at 45° to the vertical in order to reach the area underneath the beamlines without drilling through the "bathtub". Two additional holes (S-1058 and S-1059) were drilled into the berm at 45° in the region of the target hall and decay pipe end of the Neutrino Area Target Tube, respectively. Figure 2 shows the locations of these boring holes along with the one drilled in 1984. The other numbers on this figure denote monitoring wells referred to later. This work was conducted using the services of an outside vendor to drill the holes and to manage the sampling work.[c] The radionuclide analysis was also done by an outside vendor.[d] After the holes were drilled, a casing was installed to convert them into monitoring wells.

Figure 3 shows a cross section view of S-1059 which is typical of the others in its geometric relationship to the appropriate beamline. These holes were drilled to an approximate elevation of 705 ft. above sea level. The soil samples were counted directly for ^{22}Na while the ^{3}H analysis was accomplished by an outside vendor who used a reflux (azeotropic distillation) technique to collect the tritiated water in preparation for liquid scintillation counting. For all holes

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[c] STS Consultants Ltd., 111 Pfingsten Road, Northbrook Illinois 60062, project 25635-XF. The written report is entitled "Subsurface Exploration and Analytical Testing Results at the Neutrino and Meson Experimental Areas Located at the Fermi National Accelerator Laboratory, Batavia, IL".

[d] Controls for Environmental Pollution, Inc. P. O. Box 5351, Santa Fe, New Mexico 87502

except S-1059, ^{3}H results were less than the detection limit of 0.2 pCi/ml; ^{22}Na concentrations were less than the corresponding detection limit of 0.01 pCi/g.

Boring hole S-1059 is located along the decay pipe in the Neutrino Beam Line. Tritium levels found in the evaporated soil moisture ranged from a low of 0.5 ± 0.1 pCi/ml to a maximum of 8.1 ± 0.2 pCi/ml. These are plotted under the label "Distillate" on Figure 3 along with the cross-sectional view of the boring geometry. Although the results are "positive", they are significantly below the groundwater standard that we have used. The first results above the detection limit occurred at the level of the underdrains beneath the bathtub. It was somewhat surprising that the ^{3}H concentrations were as low as they were, given the fact the sump draining the underdrains typically has concentrations averaging around 100 pCi/ml of ^{3}H. Another puzzling feature of the data was the fact that the expected systematic decrease in concentration as a function of sample depth was not observed. To verify the values, three of the samples with the highest tritium concentrations were recounted by the same vendor; the original results were confirmed. Splits of the same samples were also processed at Fermilab by heating the samples and collecting the evaporate (as was done for the 1984 samples). The analysis of the evaporate for ^{3}H was then done by a different vendor[e]. This procedure yielded much higher concentrations, which are also plotted on Figure 3 under the label "Evaporate". These concentrations exceed our groundwater standard for this nuclide, if no further dilution between this point and a hypothetical user of the water is provided, a very improbable circumstance.

Given the lack of decrease in the concentrations as a function of depth, it was suspected that this single well may have had its lower levels contaminated from above during the drilling process. To check this, water (not soil) samples were taken directly from near the bottom of the the cased S-1059 hole. An initial sample was taken from the standing water in the casing. The second was taken after the hole was pumped dry and recharged from slits in the bottom five feet of the casing. The results for ^{3}H were values of 29 pCi/ml in the standing water and 134 pCi/ml in the recharge water. Similar results are still being found as this sampling continues to date as given in Table 2.

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[e] International Technology Corporation, 1550 Bear Creek Road, Oak Ridge, TN 37831

Table 2

^3H in Water Samples Taken from S-1059

Date	Conditions	Concentrations (pCi/ml)
4/3/89	0.5 gal. purged, well allowed to recharge before sampling	25.8
5/4/89	4.6 gal. purged, well allowed to recharge before sampling	134.0
5/16/89	sample of standing water	58.5
8/21/89	sample of standing water before purging	81.0
8/23/89	4.5 gal. purged, allowed to recharge for two days	83.0

As a part of the same drilling project, three deep wells also shown in Figure 2 were installed to monitor the groundwater quality of the limestone bedrock aquifer. These reach elevations near 670 feet above sea level and are denoted S-1055 (676 ft.), S-1056 (669 ft.), and S-1057 (669 ft.). No tritium has been detected in any of these three wells down to a detection limit of 1.0 pCi/ml.

The drilling subcontractor stated a conclusion concerning hydrogeologic conditions related to the likelihood of downward migration of the radionuclides:

> "The results of the exploration program for this project showed that the hydrogeological conditions on site would likely inhibit significant and rapid contaminant migration through the subsurface. While both the neutrino and meson beams have internal safeguards to contain contaminants, the thick, low permeability silty clays across the study area may constitute another barrier to the spread of contamination. Silt, sand and gravel lenses were encountered in several borings, most significantly below the meson berm and below the neutrino beam dump areas. However, the lateral and vertical extent of these units could not be determined. While these units could be a conduit for contaminant migration, such lenses are often found to be discontinuous and highly localized. The monitoring wells were designed to monitor the groundwater in these porous layers. The three deep wells may similarly be used to monitor groundwater quality in the uppermost section of the limestone bedrock."

1989 Monitoring Holes

In order to resolve the questions raised by the results from well S-1059, further drilling was done in late summer, 1989. Extra precautions were taken because of concerns about the contamination problems suspected in the 1989 drilling. Three more soil borings were completed and monitoring holes were installed in each. These three wells (S-1087, S-1088, and S-1089) are in the immediate vicinity of S-1059 and are shown on Figure 4. Each hole was drilled at 45 to 50° from the vertical to approximately the same depth as S-1059. The 1988 vendor accomplished the drilling.[f] This time, each well was cased with an 8 inch steel casing as the drilling progressed through the saturated zone in the vicinity of the underdrains to minimize infiltration of water. This casing was installed to limit the migration of water downward as the well was drilled and hence decrease the potential for developing a significant "short circuit" downward. In the process fifty-five soil samples were collected and sent for analysis using heat to collect evaporate as was done in the latter samples collected in 1988. Analysis results were discouraging in that due to low soil moisture content the vendor was unable to achieve the required sensitivity of 1 pCi/ml for ^{3}H. Instead, a threshold of 15 pCi/ml (barely below our groundwater concentration guide) was realized. Still, only one of the holes, S-1087, indicates the presence of ^{3}H.

In Figure 5, the concentrations of ^{3}H are graphed as a function of distance west of the beamline and are shown along with the drilling geometry for this monitoring hole . It appears that there are pockets of detectable ^{3}H just below the outer underdrain and also near the bottom of the hole. It is possible that the latter is a "puddle" due to a small amount of contamination from the drilling process. It is interesting that the maximum concentration was found nearly precisely at the point closest to the beam centerline. This is evidence for lack of significant movement of the radionuclides downward. Future sampling results of water taken from this well will continue to monitor this. The subsurface exploration also identified two significant water-bearing layers in the subsurface that correspond to the elevations where the pocket of ^{3}H was detected. The first is a shallow perched water table within the underdrain material in the Neutrino target containment area and the second is a sandy clay and silt lens encountered about 32 ft below grade level. After completion of the soil sampling, monitoring wells were installed at various depths: one shallow

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[f] STS Consultants Ltd., 111 Pfingsten Road, Northbrook Illinois 60062, project 25635-XH. The written report is entitled "Report of Subsurface Exploration and and Monitoring Well Installation at the Neutrino Experimental Area, Fermi National Accelerator Laboratory, Batavia, IL".

(S-1088, sealed at about 730 ft.), one intermediate (S-1089, sealed at about 724 ft.), and one deep (S-1087 sealed at about 706 ft.). Water samples will be collected from these monitoring holes routinely. The first results obtained early in 1990 are listed in Table 3.

Table 3 ^{3}H in Water Samples Taken from Wells Drilled in 1989

Well	Date	Conditions	Concentrations (pCi/ml)
S-1087	1/29/90	Before purging water by bailing	<3.0
S-1088	1/29/90	Before purging water by bailing	4.7 ± 1.2
S-1089	1/29/90	Before purging water by bailing	4.7 ± 1.1
S-1087	2/5/90	Recharge water	<3.0
S-1088	2/5/90	Recharge water	4.4 ± 1.1
S-1089	2/5/90	Recharge water	5.7 ± 1.3

As one can see, these concentrations are all quite comfortably below our groundwater concentration guide even for S-1087, the hole closest to S-1059.

The drilling subcontractor reported some additional conclusions concerning the hydrogeological conditions in this region of the Neutrino Area: The upper layers contained gray silty clay and clayey silt. These were underlain by more porous brown sandy silt and and silty fine sand which appears to surround the underdrain. Below the underdrain level are natural undisturbed sediments consisting of a thick unit of gray silty clay with trace sand and gravel content and some cobbles. Between 714 ft. and 707 ft. above sea level, a sequence of softer, wet to saturated sediments were found and these were underlain by a very hard, gray silty clay with trace sand and gravel. The results of "falling head permeability tests" indicated hydraulic conductivities ranging between 3 X 10^{-8} cm/sec to 5 X 10^{-8} cm/sec for samples collected at elevations between 721 ft. to 713 ft. These conductivities correspond to an approximate maximum movement of less than 3/4 inch per year. Such small hydraulic conductivities are characteristic of glacial tills in this region. Studies by the Illinois State Geological Survey conducted as a part of the SSC siting study found values of conductivities in this layer ranging from 1 X 10^{-8} to 1 X 10^{-6} cm/sec.[9] Even the highest value would correspond to a movement of only about 1 ft/year.

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9 Illinois State Geological Survey, Department of Energy and Natural Resources, "Geotechnical Summary to the Proposal to Site the Superconducting Super Collider in Illinois" prepared by Harza Engineering Company with assistance of ISGS, 1988.

Conclusions

Several conclusions can be drawn from this work. First, it seems quite clear now that the extraction of ^3H from the soil samples by reflux (azeotropic distillation), at least by the particular vendor involved with the 1988 samples, gave values which were low by typically a factor of 35. The evaporation by heating seems to be a much more reliable and sensitive method of extracting this radionuclide from soil samples. However, even if the quoted detection limit of 0.2 pCi/ml represented actual values 35 times higher (7 pCi/ml), well S-1059 would still have been the only one with concentrations of concern with respect to our groundwater concentration guide.

A second conclusion is that drilling monitoring holes without installing casings as the drilling proceeds has a considerable risk of providing a "short circuit" for downward movement of contamination. Such a phenomenon is the best explanation for the questionable 1988 results concerning well S-1059.

A third conclusion is that no evidence for concentrations of radionuclides of concern that exceed our groundwater concentration guide below the approximate level of the underdrains, except for the now questionable results from S-1059 and the "puddle" found at the bottom of S-1087 at the time of its initial installation. This "puddle" has now disappeared, apparently having been removed by the pumping associated with the sampling procedure. Thus, even without considering the leaching process necessary to actually remove and transport the radioactivity, additional dilution processes, and finite downward migration velocities, no significant risk to any drinking water supplies exists. The hydrogeological information identified in these studies supports this conclusion with additional evidence for a very slow, or even negligible, migration rate of water from the vicinity of these target stations to underlying aquifers. The migration times are indicated to be quite long compared with the radioactive half-lives of both ^3H (12.3 years) and ^{22}Na (2.6 years).

A final conclusion is that the wells presently installed provide the means to adequately monitor any conceivable migration of radionuclides. No additional monitoring wells are needed, or are even advisable.

References

1. Memo tó Division/Section heads from A. L. Read dated April 5, 1979, " Regulations on Exposure from Drinking Water."

2. T. B. Borak, M. Awschalom, W. Fairman, F. Iwami, and J. Sedlet, "The Underground Migration of Radionuclides Produced in Soil Near High Energy Proton Accelerators," *Health Physics* **23** (1972) 679-687.

3. P. J. Gollon, "Soil Activation Calculations for the Antiproton Target Area", TM-816, September, 1978.

4. J. D. Cossairt, Environmental Protection Note No. 1, " Derived Concentration Guides for Accelerator-Produced Radionuclides in Surface Water Discharges and Drinking Water", March, 1990.

5. S. I. Baker, Fermilab Site Environmental Report for Calendar Year 1984, May 1, 1985.

6. S. I. Baker, private notes.

7. S. I. baker, private communication, February, 1990.

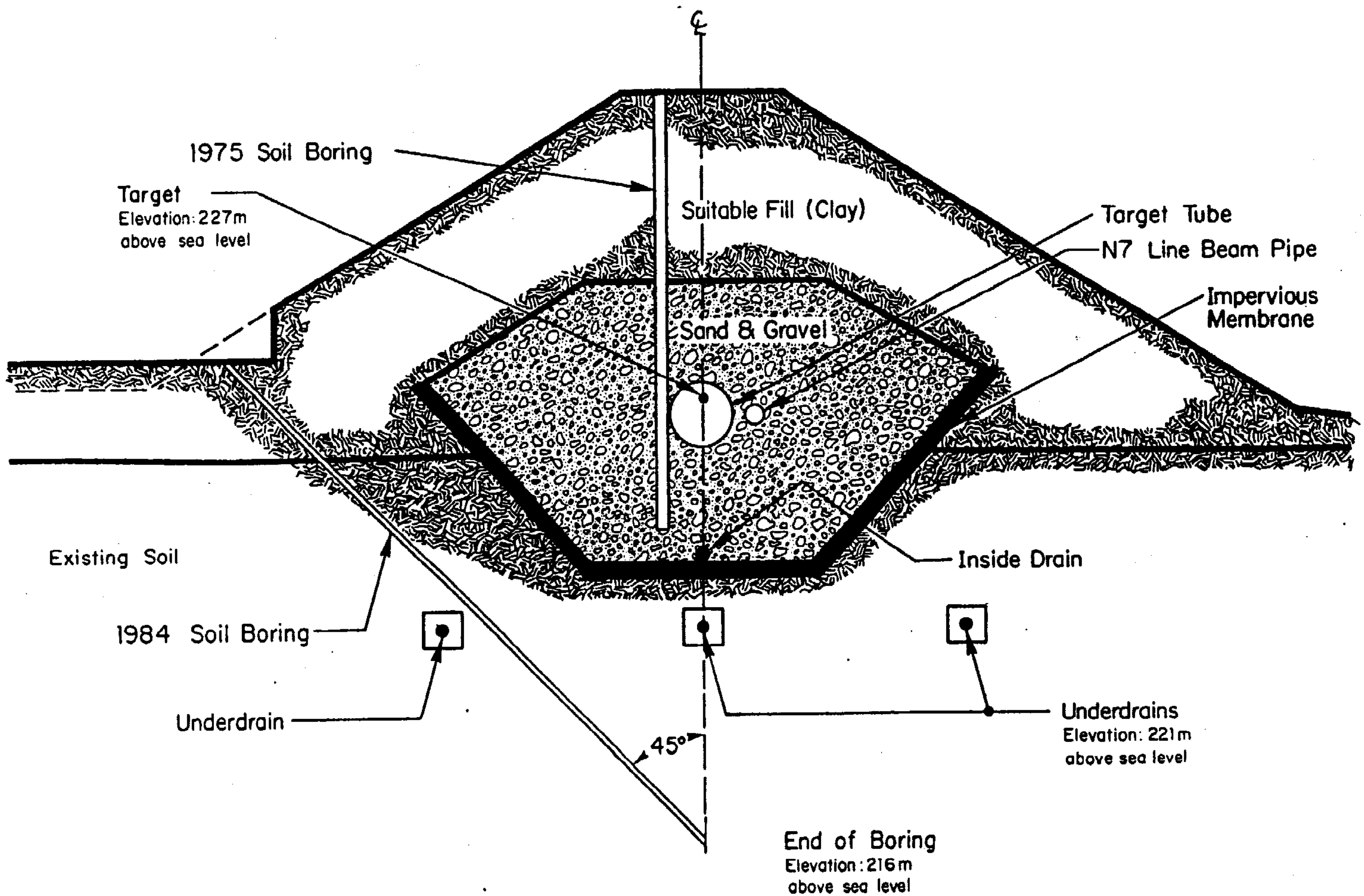


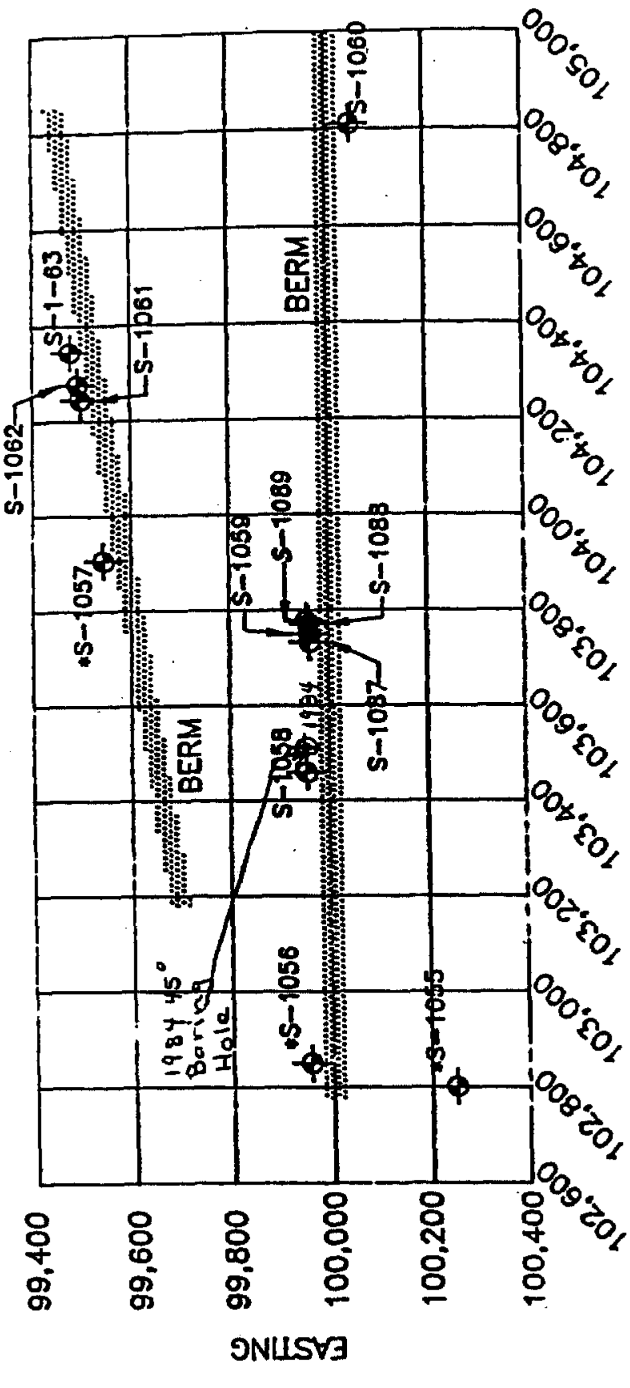
Figure 1 Geometry of the soil boring drilled in 1984 near the Neutrino Area Target. The view is that of the "beam's eye".

Attachment II

MONITORING WELL AND BORING LOCATION DIAGRAM

FERMI NATIONAL ACCELERATOR LABORATORY

FOR ENVIRONMENTAL SAFETY GROUP



1984 BH BORING	99,958.3 EASTING	103,585 NORTHING	750 ELEV.
*S-1055	100250.0	102800.0	746.2'
*S-1056	99955.0	102850.0	752.4'
*S-1057	99544.6	103905.8	750.6'
S-1058	99952.7	103459.7	750.4'
S-1059	99958.9	103749.9	747.5'
S-1060	100049.0	104810.1	751.4'
S-1061	99498.9	104243.7	753.4'
S-1062	99492.9	104274.6	754.1'
S-1063	99477.3	104344.6	757.3'
S-1087	99959.4	103731.8	946.0'
S-1088	99960.0	103770.9	945.6'
S-1089	99953.7	103777.5	944.6

* = BEDROCK WELL

Figure 2 Plan view of the Neutrino and Meson Areas showing the locations of the boring holes drilled in 1988 along with the one installed in 1984.

STS Consultants Ltd. Consulting Engineers	BORING LOCATION DIAGRAM ANGLE HOLES AT NEUTRINO TARGET AREA FERMI NATIONAL ACCELERATOR LABORATORY BATAVIA , ILLINOIS	DRAWN BY	GRS	10–
		CHECKED BY	DLG	10–
		APPROVED BY		
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		STS DRAWING NO. 25635–XH		

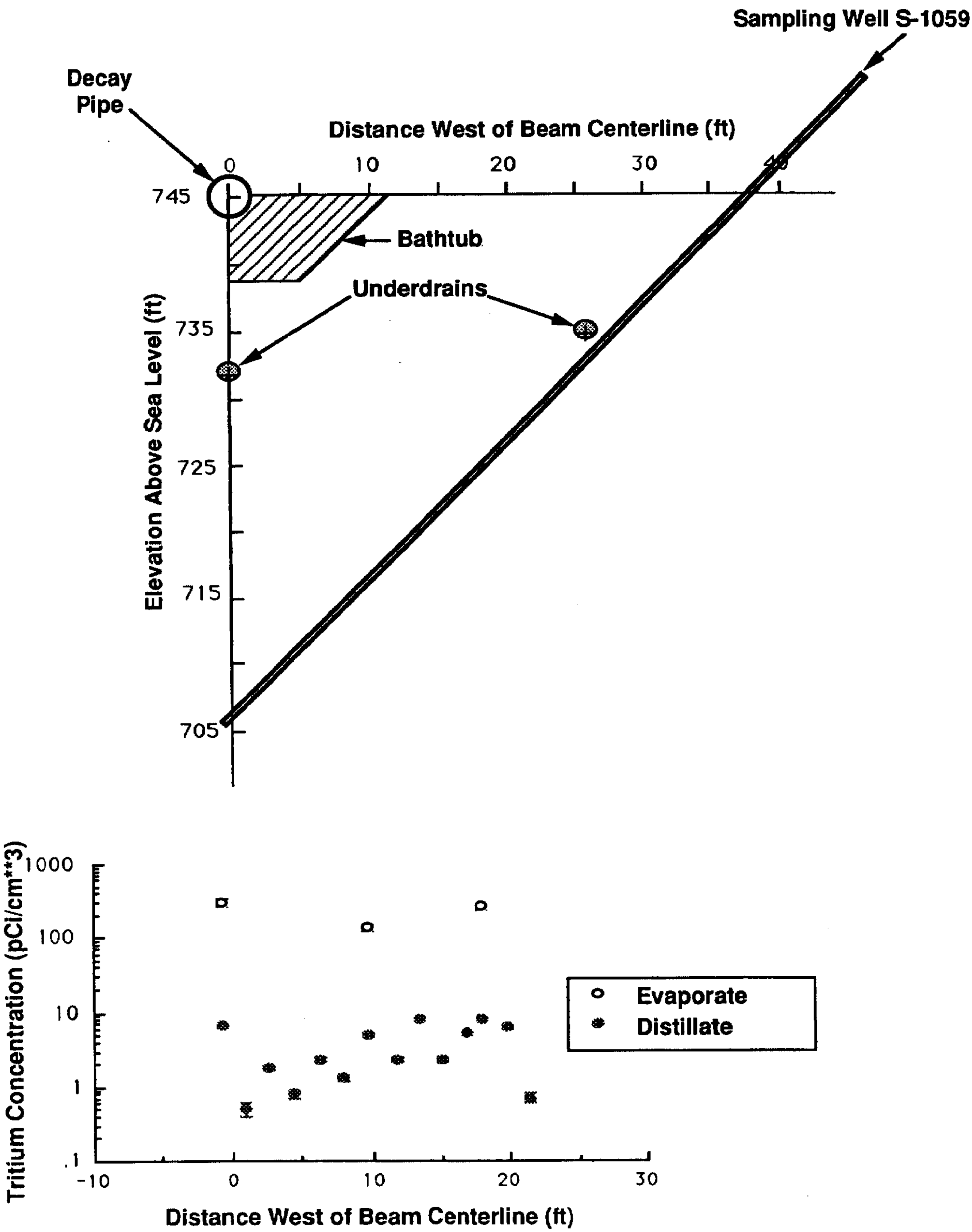
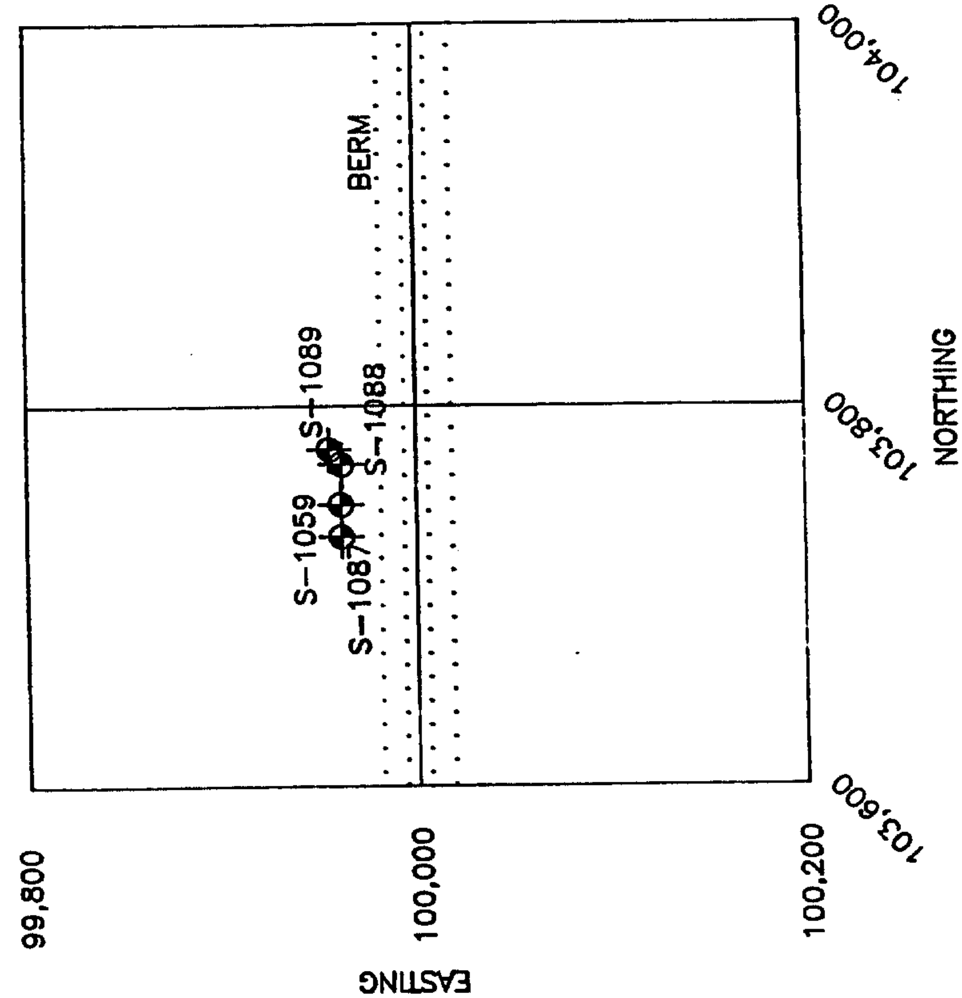


Figure 3 Cross Section of the Neutrino Berm at the location of sampling well S-1059 (drilled in 1988) along with plots of the results of the tritium analyses using two different methods as a function of distance west from beam center.

Attachment III

MONITORING WELL AND BORING LOCATION DIAGRAM
FERMI NATIONAL ACCELERATOR LABORATORY
FOR ENVIRONMENTAL SAFETY GROUP



PROJECT NORTH

BORING	EASTING	NORTHING	ELEV.
S-1059	99958.9	103749.9	747.5'
S-1087	99959.4	103731.8	946.0'
S-1088	99960.0	103770.9	945.6'
S-1089	99953.7	103777.5	944.6

Figure 4 Plan view showing the holes drilled near the Neutrino Berm in 1988 and 1989.

STS Consultants Ltd. Consulting Engineers	BORING LOCATION DIAGRAM ANGLE HOLES MESON AND NEUTRINO TARGET AREA FERMI NATIONAL ACCELERATOR LABORATORY BATAVIA, ILLINOIS	DRAWN BY	GRS	10-
		CHECKED BY	DLG	10-
		APPROVED BY		
		SCALE 1" = 100'	FIGURE NO. 2	
		STS DRAWING NO. 25635-XH		

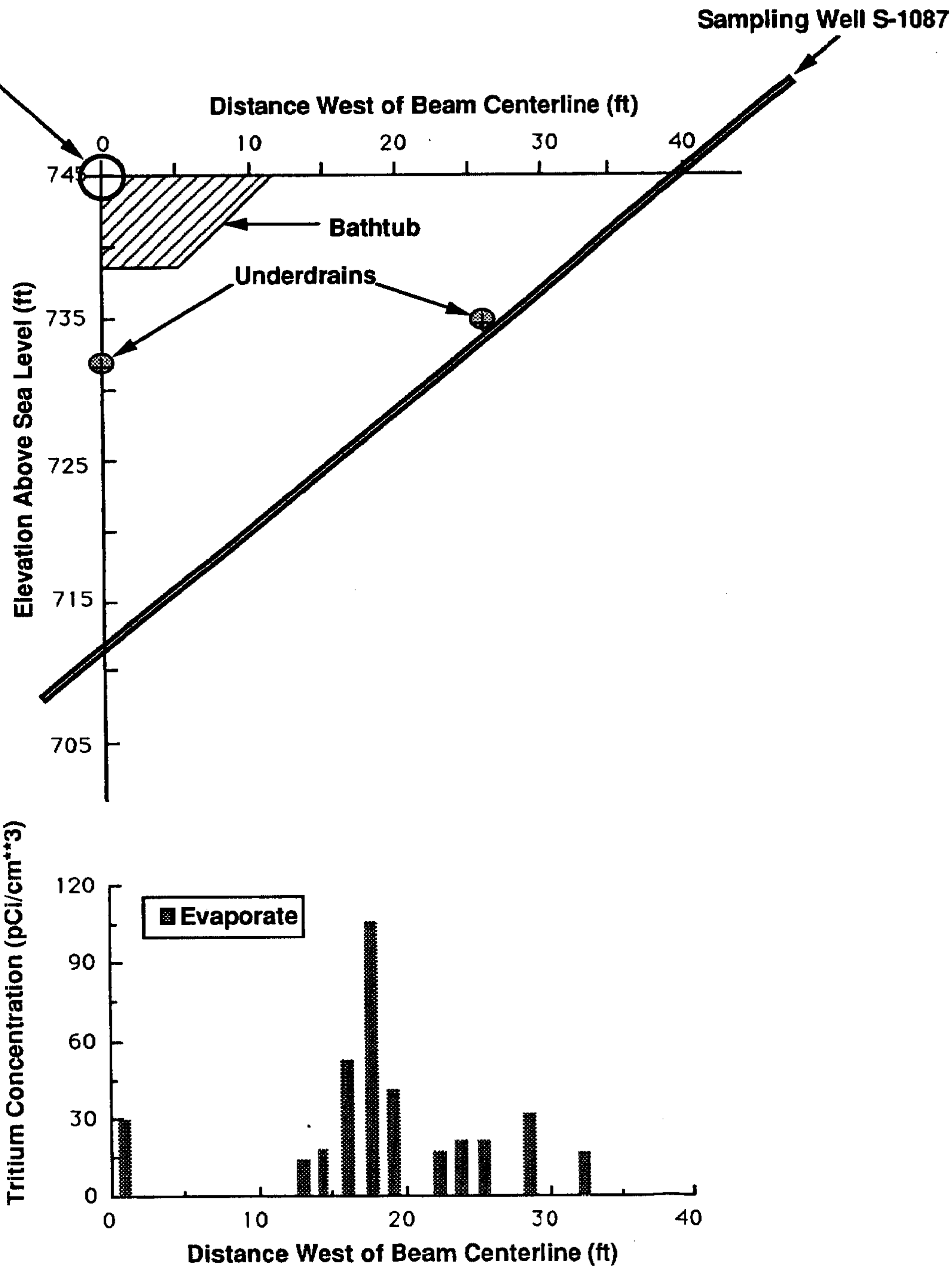


Figure 5 Cross Section of the Neutrino Berm at the location of sampling well S-1087 (drilled in 1989) along with plots of the results of the tritium analysis as a function of distance west from beam center.