



AN ESTIMATE OF THE GROUND WATER
ACTIVATION DUE TO MESON AREA OPERATION

T. E. Toohig
August 23, 1978

I. Introduction

During the six-month Mesopause the proton beam targeting configuration in the Meson Area will be modified to allow targeting of two, and ultimately three, independent proton beams. It is anticipated that the proton beam to produce the M5/M6 beams will be targeted in the existing Target Box. The protons for M2/M3/M4 will be targeted for the most part in the Target Box, but will be transmitted to the Detector Building for high intensity targeting in the M2 cave. Targeting for the M1 beam line will be in the 300-foot area for pion production or in the Detector Building for direct proton experiments. In the light of this changed target configuration the question of radioactive contamination of the ground water system must be re-examined.

The ground water control system around the Target Box is illustrated in Figure 1 from the construction drawings. This system was designed for operation at 400 GeV, 10^{13} protons/sec

continuous operation. Historically (1975, 1976), the targeted intensity has been 10^{11} protons/sec with a scheduled $\sim 2 \times 10^{12}$ ppp, so the Area has been operating at a level of two orders of magnitude below the intensity on which the ground water system was designed.

For Tevatron operation the targeting parameters for the Meson Area, as specified for the Research Division, are:

1. 10^{13} protons/min at 1000 GeV
2. 5000 hrs/yr operation
3. Half of the flux on the M1 system, half distributed between the M2 and M6 systems
4. M1 targeting is half for pions (300' area) and half for protons (Detector Building)

The nuclides of importance in the ground water calculation are Na^{22} and H^3 . Both have half-lives sufficiently short to have a significant production cross-section and sufficiently long to have a potential for moving off-site before decaying.

The original ground water studies, in common with similar studies for the SPS, (see TM-284A) concluded that H^3 was not a significant contaminant. As a result, detailed calculations were published only for Na^{22} contamination. The present calculation will be valid for all contaminants.

TABLE 1

Relevant Nuclides in Soil Activation Studies

<u>Nuclide</u>	<u>Production Reaction</u>	<u>Half-Life</u>
C ¹¹	C ¹² (n, 2n) C ¹¹	20.4 min
Na ²⁴	Na ²⁵ (n, 2n) Na ²⁴	15 hr
	Al ²⁷ spallation	162 days
Na ²²	Na ²³ (n, 2n) Na ²²	53.3 days
	Al ²⁷ spallation	2.6 yr
Ca ⁴⁵		221 days
Be ⁷	O ¹⁶ spallation	313 days
Mn ⁵⁴		401 days
H ³	O ¹⁶ spallation	12.3 years

II. Activation

Detailed calculations do not exist for the Meson Area system. The approach used here will be to scale from the existing system, keeping in mind that the calculations indicate that the original ground water control system was already very conservative.

1. M5/M6 Targeting, M2/M3/M4 Targeting

This targeting takes place in the present ground water control system (cf. Fig. 1). Referring to the targeting

assumptions with Introduction, the probability of ground water activation by Na²² production is reduced by

a. $\frac{10^{13} \text{ p/sec}}{10^{13} \text{ p/min}} = 60$

b. $\frac{8766 \text{ hrs/yr}}{5000 \text{ hrs/yr}} = 1.7$

c. $\frac{\text{Assumed } M(400 \text{ GeV})/M(30 \text{ GeV})}{\text{Experimental } M(1000 \text{ GeV})/M(30 \text{ GeV})} = 2.2$

Relative reduction in contamination = 224

Therefore, the potential contamination of the ground water system by Tevatron targeting at the present Target Box position is reduced by a factor of ≈224 relative to the original design, which was already very conservative.

2. M1 Targeting in the Detector Building

The proton beam in the Detector Building is 4 feet above the floor of the building. The floor is an 8-inch slab. This four feet would be filled with steel when the proton beam is targeted in the Detector Building (cf. P605). The contamination at this position relative to the Target Box design is:

a. Factors due to targeted beam, as above, for
Target Box = 224

- b. Shielding effectiveness of 4' Fe vs
10' Soil = 1.2
 - c. Geometric Factor ($\frac{1}{r}$) = .46
- Net Reduction in Contamination Relative to
Target Box Design = 124

3. M1 Upstream Targeting

Figure 2 is a cross-section of the new construction in the 300-foot area. This cross-section applies from 269' (Front End Hall) to 363'. The beam will be targeted and collimated in this region. The M1 beam as illustrated, is four feet above the floor of the enclosure as in the case discussed for the Detector Building.

4. M1 Dump

The beam will be dumped in the 500-foot area where the cross section is as shown in Figure 3, with 2.5 feet of steel beneath the target.

Relative to the canonical Target Box, the shielding at 500' is:

- a. Target Box factors 224
- b. Shielding effectiveness 2.5' Fe vs
10' sand and gravel 0.75

c. Geometric factor	0.25
Net Relative Effectiveness	42

Scaling for the relative amounts of beam targeted in each position we have an overall relative effectiveness factor.

$$\begin{aligned}
 \text{REF} &= \frac{1}{\text{Relative Activation}} \\
 &= \frac{1}{\sum_{\text{all targets}} \frac{\text{Beam Fraction}}{\text{Effectiveness Factor}}}
 \end{aligned}$$

$$\begin{aligned}
 \text{REF} &= \frac{1}{\frac{.5}{224} + \left(\frac{2/3 \times .25}{124} + \frac{1/3 \times .25}{42} \right) + \frac{.25}{124}}
 \end{aligned}$$

REF = 132

The amount of potential activation, relative to the already conservative Meson Area design, is reduced by a factor of 132.

REFERENCES

1. Ground Water Studies

23 March 1973: G. B. Stapleton and R. H. Thomas (Pergamon Press Report). "The Effect of Sorption on the Migration of Be^7 from a High Energy Accelerator Constructed on a Chalk Site".

June, 1971. G. B. Stapleton and R. H. Thomas. "Estimation of the Induced Radioactivity of the Ground Water System in the Neighborhood of a Proposed 300 GeV High Energy Accelerator Situated on a Chalk Site".

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October, 1970. R. H. Thomas. UCRL20131. "Possible Contamination of Ground Water System by High Energy Proton Accelerators".

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2. Hadron Cascades

Calculations

June, 1971. M. Barbier and R. Hunter, CERN 71-13. "Systematics of Extra-Nuclear Cascades in Shields".

FOR BERM, FINISHED GRADE
ELEVATIONS AND DETAILS SEE
CIVIL DRAWINGS.

SUITABLE BERM
MATERIAL

S OF TARGET BOX SEE

BANK RUN S
COMPACTED

EL. 757'-0"

10'-0"
MIN.

ELEVATION 733.0

IMPERVIOUS LAYER SEE
SPECIFICATIONS.

UNSUITABLE
REMOVED

SEAL IMPREVIOUS L
AROUND BASE P'S

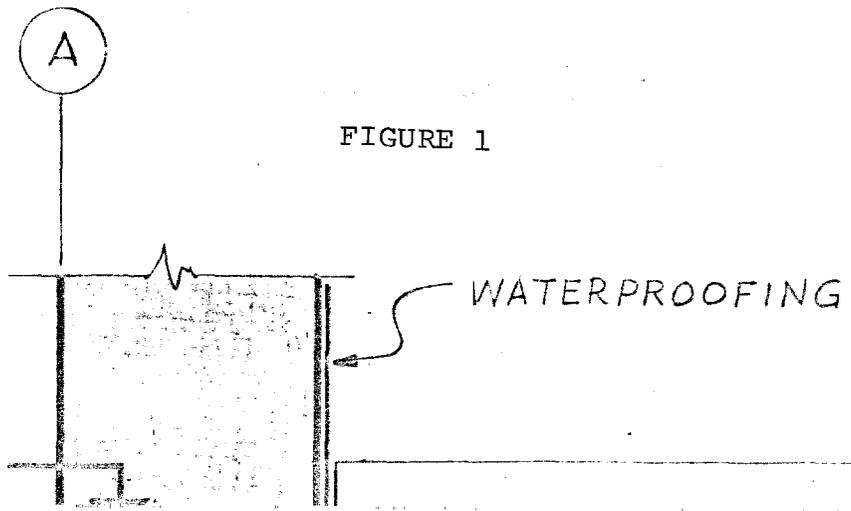
CAISSONS TO ROCK

SECTION

B
PS-1

SCALE: 1/16" = 1'-0"

FIGURE 1



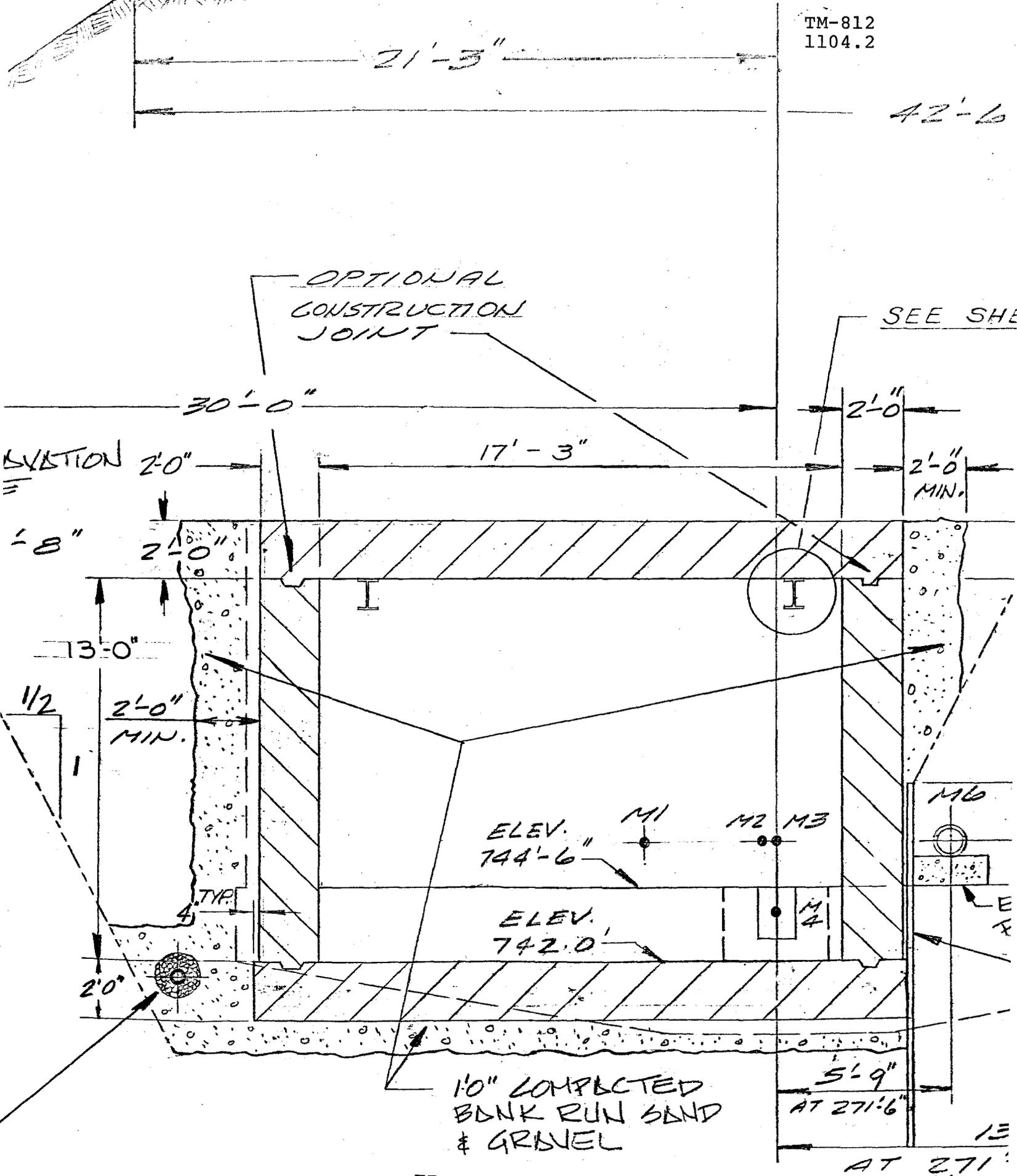


FIGURE 2
TYPICAL EXCAVATION DETAIL
- SCALE 1/4" = 1.0"

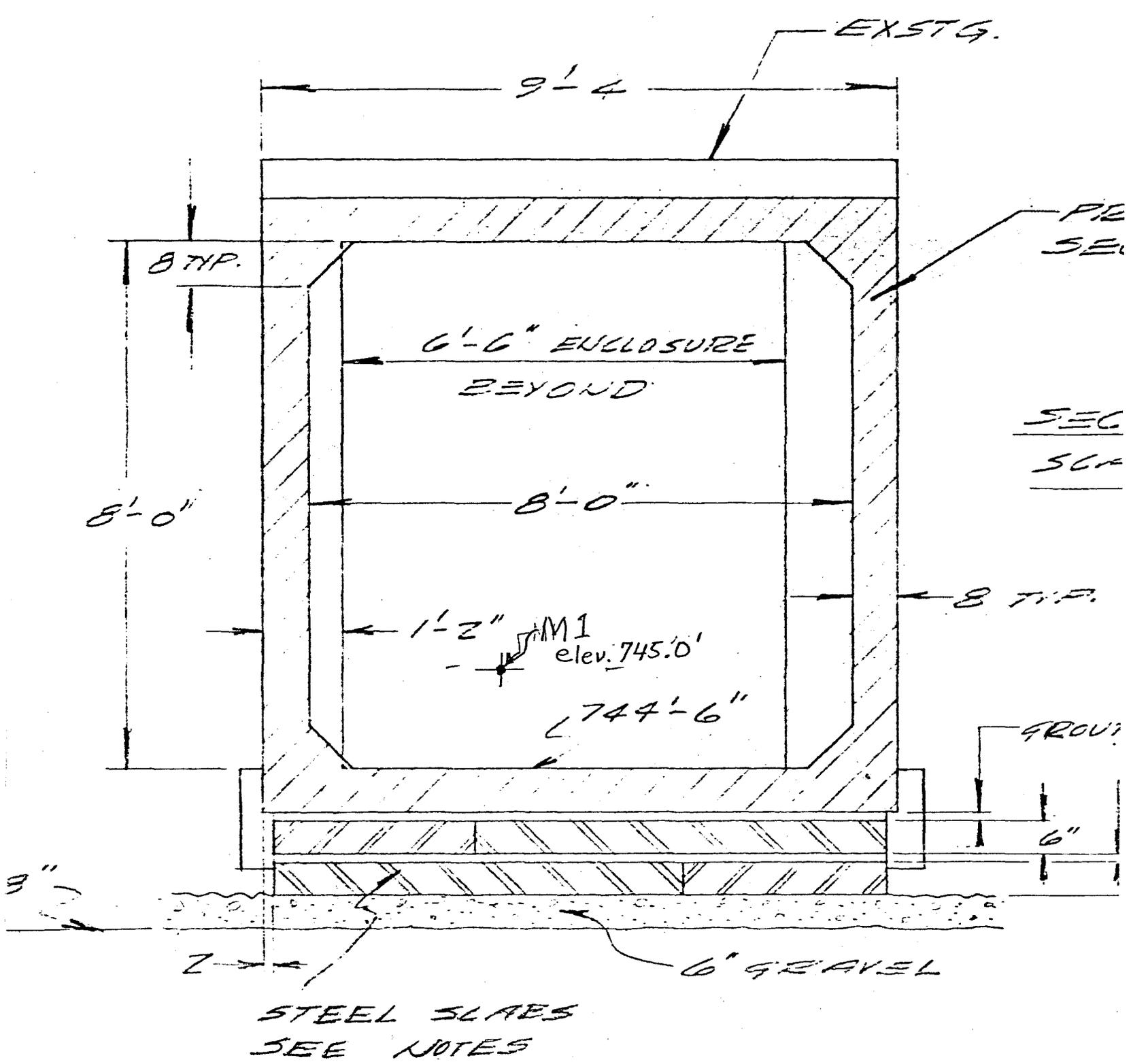


FIGURE 3



GROUND WATER PROTECTION IN THE MESON AREA
FOR TEVATRON OPERATION

T. E. Toohig
September 21, 1978

I. Introduction

Major modifications to the targeting system for the Meson Area require a re-examination of the question of the possible contamination of the ground water system by radiation. The question is complicated at the present time by new EPA regulations lowering the concentration guidelines for tritium by a factor of 50. This note will consist of two parts. In the first, a comparison will be made between the present ground water protection system as designed, and the multiple targeting system being designed for the Meson Area. In the second part, the level of tritium concentration at the 70-foot aquifer will be estimated, using the original design parameters as a calibration of the original target box system.

Figures 1 and 2 illustrate the present ground water protection system around the Meson Target Box. The design parameters for the system were:^{1,2}

10^{13} p/sec interacting

400 GeV

Continuous operation (8766 hrs/yr)

In Table I are listed nuclides relevant for ground water contamination studies. Of these, Na^{22} and H^3 have half-lives sufficiently short to be produced in significant quantities and sufficiently long to have a potential for reaching the site boundary before decaying away.

In Table II, the composition of Fermilab soils is detailed.

II. The Effectiveness of the Revised Meson Targeting System
Relative to the Original Design

A. Introduction

During the six-month Mesopause the proton beam targeting configuration in the Meson Area will be modified to allow targeting of two, and ultimately three, independent proton beams. It is anticipated that the proton beam to produce the M5/M6 beams will be targeted in the existing Target Box. The protons for M2/M3/M4 will be targeted for the most part in the Target Box, but will be transmitted at times to the Detector Building for high intensity targeting in the M2 cave. Targeting for the M1 beam line will be in the 300-foot area for pion production or in the Detector

Building for direct proton experiments. In the light of this changed target configuration, the question of radioactive contamination of the ground water system must be re-examined.

A cross-sectional view of the Target Box construction is given in Figure 3, taken from the as-built construction drawings. This system was designed for operation at 400 GeV, 10^{13} protons/sec, continuous operation, as noted above*.

For Tevatron operation the targeting parameters for the Meson Area, as specified by the Research Division, are:

1. 10^{13} protons/min at 1000 GeV
2. 5000 hrs/yr operation
3. Half of the flux on the M1 system, half distributed between the M2 and M6 systems
4. M1 targeting is half for pions (300' area) and half for protons (Detector Building)

The original ground water studies for Fermilab (see

*Note: Historically (1975, 1976) the targeted intensity has been 10^{11} protons/sec with a scheduled $\sim 2 \times 10^{12}$ ppp, so the Area has been operating at a level of two orders of magnitude below the intensity on which the ground water system was designed.

TM-284A), in common with similar studies for the SPS, concluded that H^3 was not a significant contaminant. As a result, detailed calculations were published only for Na^{22} contamination. The present calculation, since it is purely relative, will be independent of any specific nuclide.

B. Activation Calculations

Detailed calculations do not exist for the Meson Area system. The approach used here will be to scale from the existing system. From the Neutrino experience, which is documented (cf. TM-284A, TM-292⁴), it is reasonable to assume that the original ground water control system was already very conservative. However, this assumption will be examined in Part III below.

1. M5/M6 Targeting, M2/M3/M4 Targeting

This targeting takes place in the present Target Box with its ground water control system (Figure 1). Referring to the targeting assumptions in the Introduction, from considerations of energy and intensity, the probability of ground water activation relative to the design is reduced by

$$a. \frac{10^{13} \text{ p/sec}}{10^{13} \text{ p/min}} = 60$$

b. $\frac{8766 \text{ hrs/yr}}{5000 \text{ hrs/yr}} = 1.7$

c. Multiplicity ($\propto E^{0.7}$) $\frac{(400 \text{ GeV})}{(1000 \text{ GeV})} = 0.53$

Relative reduction in contamination due to changes
in targeting parameters = 54

2. M1 Targeting in the Detector Building

The proton beam in the Detector Building is 4 feet above the floor of the building. The floor is an 8-inch slab. This four feet would be filled with steel when the proton beam is targeted in the Detector Building (e.g., P605). The contamination at this position relative to the Target Box design is:

a. Factors due to targeted beam parameters,
as above, for Target Box = 54

b. Shielding effectiveness of 4' Fe
+ 8" concrete vs 18" Fe and 9' of
sand and gravel = $\frac{1000 \text{ gm/cm}^2}{850 \text{ gm/cm}^2} = 1.2$

c. Geometric Factor ($\frac{1}{r}$) = .4

Net Reduction in contamination relative to Target
Box design, if all the beam were targeted in the
Detector Building = 29

3. M1 Upstream Targeting

Figure 2 is a cross-section of the new construction in the 300-foot area. This cross-section applies from 269' (Front End Hall) to 363 '. The beam will be targeted and collimated in this region. The M1 beam, as illustrated, is four feet above the floor of the enclosure as in the case discussed for the Detector Building.

a. Targeting factors, as above = 54

b. Shielding: 4' Fe + 18" concrete
vs Target Box = $\frac{1061 \text{ gm/cm}^2}{850 \text{ gm/cm}^2}$ = 1.2

c. Geometric factor = .5

Net Reduction = 32

4. M1 Dump

The beam will be dumped in the 500-foot area where the cross section is, as shown in Figure 3, with 2.5 feet of steel and 8" of concrete beneath the target.

Relative to the canonical Target Box, the shielding at 500' is:

a. Targeting factors = 54

b. Shielding effectiveness: 2.5' Fe +
8" concrete vs Target Box =
 $\frac{643 \text{ gm/cm}^2}{850 \text{ gm/cm}^2}$ = 0.76

$$c. \text{ Geometric factor } \left(\frac{1}{r}\right) = .30$$

$$\text{Net Relative Effectiveness} = \boxed{12}$$

Scaling for the relative amounts of beam targeted in each position we have an overall Relative Effectiveness Factor.

$$\begin{aligned} \text{REF} &= \frac{1}{\text{Relative Activation}} \\ &= \frac{1}{\frac{\text{Beam Fraction}}{\text{Effectiveness Factor}} \text{ all targets}} \end{aligned}$$

$$\text{REF} = \frac{.5}{54} + \left(\frac{2/3 \times .25}{32} + \frac{1/3 \times .25}{12} \right) + \frac{.25}{29}$$

$$\boxed{\text{REF} = 33}$$

The amount of potential activation, relative to the original Meson Area design, is reduced by a factor of 33, given the distribution of targeting locations and intensities specified in Research Division Tevatron planning.

It remains to determine the effectiveness of the original design. This will be calculated in Part III.

III. An Estimate of the Tritium Produced in the Ground Water Due to Meson Operation

To calibrate the original Meson Ground Water System with respect to tritium, a calculation can be made using data from

the CERN shielding experiment. An alternate approach to the same problem may be made using the BNL side shield data.

A. Use of CERN Data

1. Saturated Activity

The results of the CERN experiment indicate that the observed activity is to first order due only to neutron activation. Measurements were made of the particle flux as a function of position in the shield, using a variety of detectors, with different thresholds. These yielded the neutron energy spectrum as a function of position.

$$\phi_{E>E_0}(r,z) = \frac{a}{r} \phi_0 e^{-(r-a)/\lambda} e^{-z/\mu}$$

where:

$\phi_{E>E_0}(r,z)$ = the neutron flux density of neutrons greater than energy E_0 at (r,z)

ϕ_0 = neutron flux density ($E>E_0$) at $r = a, z = 0$

a = effective radius of target cavity

λ = neutron flux relaxation length in the transverse direction

μ = neutron flux relaxation length in the longitudinal direction

Renormalizing the CERN data to the edge of the "bathtub"

$$a \approx a_{\text{Cern}} = 390 \text{ cm}$$

$$\phi_0(E > 20 \text{ MeV}) = \phi_0^{\text{Cern}} e^{-t/\lambda}$$

where t is the radial amount of material between the target and the edge of the bathtub = 6" steel, 9'6" sand and gravel (neglecting the shielding under the train).

$$\begin{aligned} \phi_0 &= (6 \times 10^5 / \text{cm}^2\text{-sec}) e^{-\frac{6409 \text{ m/cm}^2}{1149 \text{ m/cm}^2}} e^{-64} \\ &= 2.2 \times 10^3 / \text{cm}^2\text{-sec} \end{aligned}$$

The saturated activity for nuclides produced in water outside the bathtub is , for $\sigma = 1 \text{ mb}$, and assuming the angle subtended by the irradiated zone = $\frac{\pi}{3}$,

$$S_0 = 1.33 \times 10^{-20} \mu\text{Ci ml}^{-1} \text{mb}^{-1} \text{GeV}^{-1} \text{sec}^{-1}$$

The total activity, at saturation, Q_0 is

$$Q_0 = 3.62 \times 10^{-19} \text{ curies mb}^{-1} \text{GeV}^{-1} \text{sec}^{-1}$$

For 400 GeV, 10^{13} p/sec, continuous

$$S_0 = 1.60 \times 10^{-3} \mu\text{Ci/ml}$$

$$Q_0 = 0.44 \mu\text{Ci}$$

2. Actual Levels

The actual buildup of activity is modified by the residence time of the water in the radiation zone and the decay of the nuclide enroute to the aquifer and the site boundary.⁸ The residence time is given by:

$$T = \frac{fV}{RA} \text{ years}$$

where

f = fraction of water by volume = 30%

R = annual rainfall entering ground water = 1/3 m

V = volume of activation zone (1/6 cyl); r = a,

$$L = 3, t = 3\lambda$$

A = surface area of activation

$$\text{volume} = ((2\lambda + 6\lambda) \cdot 3\mu)$$

$$T = \frac{.36 \times 152 \text{ m}^3}{.3 \text{ m/yr} \times 220 \text{ m}^3}$$

$$= .69 \text{ years}$$

$$S' = S_o (1 - e^{-\frac{.693 \times .69}{12.3}}) = .038S_o = 6.1 \times 10^{-5} \text{ } \mu\text{Ci/ml}$$

The activity at the aquifer is further modified by the decay of the tritium in moving from the radiation zone to the aquifer.

$$S = S' e^{-\frac{.693 \text{ d/v}}{\tau}}$$

where

d = distance to the aquifer = 70 ft

v = velocity of the nuclides in the aquifer =
= 1 m/yr⁵

τ = tritium half-life

So finally,

$$S = S_0 (1 - e^{-\frac{.693T}{\tau}}) e^{-\frac{.693 d/v}{\tau}}$$

$S = 1.04 \times 10^{-6} \text{ } \mu\text{Ci/ml}$
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as compared with the Concentration Guide

$$S_{cg} = 20 \times 10^{-6} \text{ } \mu\text{Ci/ml}$$

It should be noted (cf Figure 6) that an ion exchange column (the glacial till is effectively such) tries to restore equilibrium as quickly as possible. A short term (relative to the 12.3 year half-life) increase in the soil irradiation will be held near the top of the column and be smeared out rather than move through the column as a pulse.

It should also be noted that the actual operating experience (1975, 1976) for the Meson Area averages 10^{11} p/sec, two orders of magnitude less than the design parameters on which the calculations above are based.

IV. Conclusion

The Meson Area ground water protection system as designed is adequate also for the reduced EPA guidelines, even for the very high beam currents originally specified. Under actual running conditions for the proposed distributed targeting for Tevatron operation, the system is several orders of magnitude more conservative than the EPA standards.

REFERENCES

1. Private Communication, J. R. Orr (Head of Meson at the time Meson Area was designed).
2. Memo: D. Theriot to T. E. Toohig, October 24, 1975.
3. T. E. Toohig, TM-284A, March, 1971. A Calculation of the Na^{22} Produced in the Soil and in Ground Water in the Vicinity of the Neutrino Laboratory of NAL".
(Note: This TM is the basis for the design of the Neutrino System.)
4. M. Awschalom, TM-292, March, 1971. "Calculation of the Radionuclide Production in the Surroundings of the NAL Neutrino Laboratory".
(Note: This is a post-factum analysis responding to TM-284.)
5. G. B. Stapleton, R. H. Thomas, RPP/A83, "Estimation of the Induced Radioactivity of the Ground Water System in the Neighborhood of a Proposed 300 GeV High Energy Accelerator Situated on a Chalk Site".
6. R. H. Thomas, UCRL-20131. "Possible Contamination of Ground Water System by High Energy Proton Accelerators".
7. S. Baker, Fermilab 78/27. "Environmental Monitoring Report, CY 1977". Tritium moves with the same velocity as the ground water.
8. C. A. Mawson, "Consequences of Radioactive Disposals into the Ground Progress in Nuclear Energy", Health Physics Vol. 2, part 1 (Pergamon Press).

TABLE I

Relevant Nuclides in Soil Activation Studies

<u>Nuclide</u>	<u>Production Reaction</u>	<u>Half-life</u>	<u>Cross Section</u>
-C ¹¹	C ¹² (n,2n) C ¹¹	20.4 min	
Na ²⁴	Na ²⁵ (n,2n) Na ²⁴	15 hrs	
-Be ⁷	O ¹⁶ (n, spallation) Be	53 days	10 mb ¹
Ca ⁴⁵	Ca ⁴⁴ (n,γ) Ca ⁴⁵	153 days	1100 mb
Mn ⁵⁴	Fe ⁵⁴ (n,p) Mn ⁵⁴	278 days	500 mb
	Mn ⁵⁵ (n, 2n) Mn ⁵⁴		1100 mb
-Na ²²	Na ²³ (n, 2n) Na ²²	2.6 yr	70 mb
	Al ²⁷ (n, spallation) Na ²²		20 mb
-H ³	O ¹⁶ (n, spallation) H ³	12.3 yr	30 mb ¹

¹UCRL-20131, p.8

- In Fermilab Soil

TABLE II

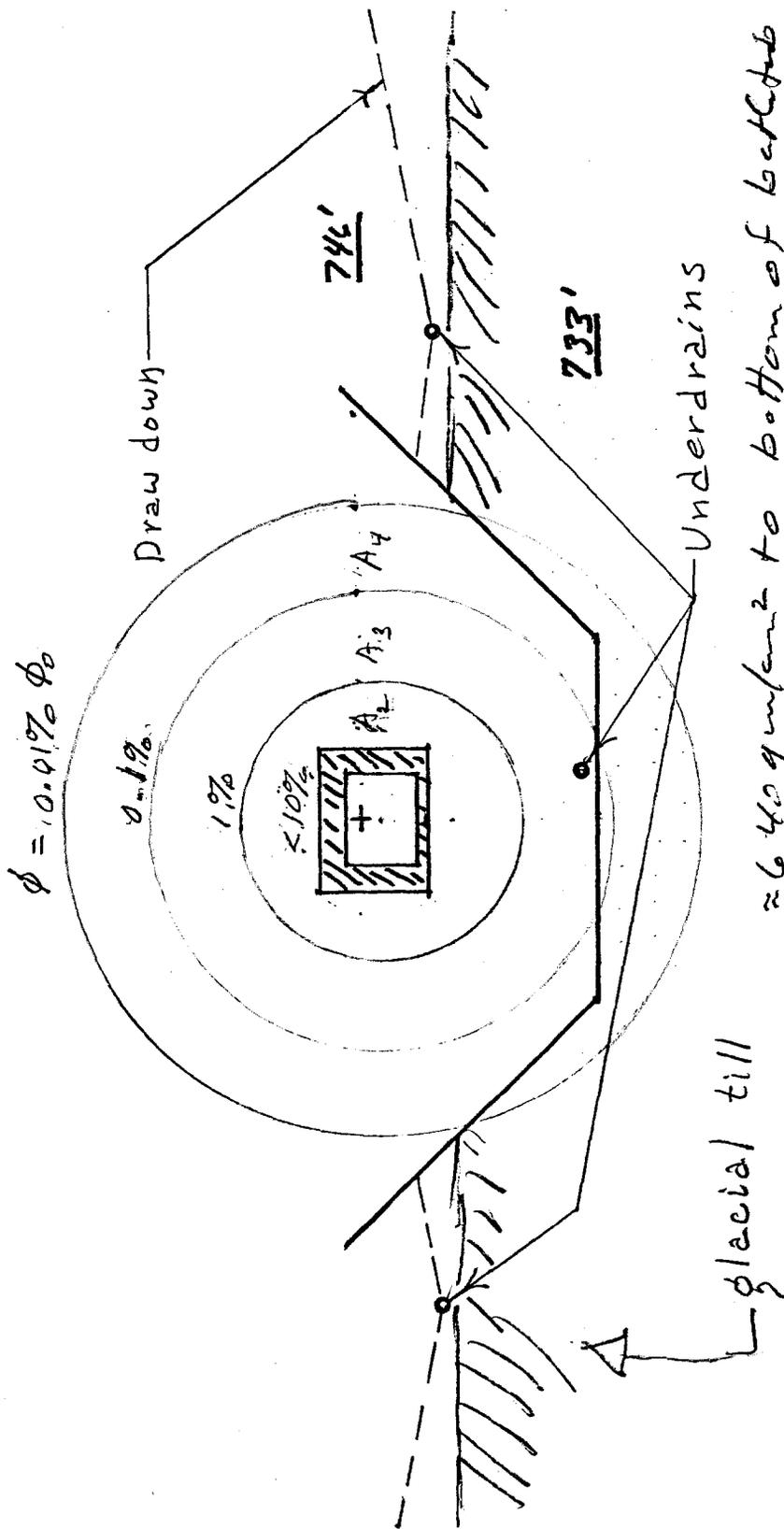
Composition By Weight of FNAL Soils

1. Average Soil

<u>Element</u>	<u>A</u>	<u>Percent by Weight</u>	<u>Atoms/gm</u>
Oxygen	16	55.00	2.07×10^{22}
Silicon	28	22.80	4.9×10^{21}
Aluminum	27	5.51	1.23×10^{21}
Carbon	12	3.32	1.66×10^{21}
Hydrogen	1	1.23	7.37×10^{21}
Iron	56	2.91	3.14×10^{20}
Calcium	40	6.08	9.14×10^{20}
Magnesium	25	2.09	5.18×10^{20}
Sodium	23	0.40	1.04×10^{20}
Potassium	39	0.52	8.0×10^{19}

2. Glacial Till

		<u>Dry</u>	<u>Moist</u>	
Oxygen	16	50.80	56.50	2.13×10^{22}
Silicon	28	25.70	21.80	4.7×10^{21}
Aluminum	27	6.20	5.30	1.2×10^{21}
Carbon	12	3.70	3.20	1.5×10^{21}
Hydrogen	1	-	1.70	1.0×10^{22}
Iron	56	3.30	2.80	3.1×10^{20}
Calcium	40	6.80	5.80	8.7×10^{20}
Magnesium	25	2.40	2.00	5.0×10^{20}
Sodium	23	0.45	0.38	1.0×10^{20}
Potassium	39	0.58	0.49	7.7×10^{19}



MESON TARGET BOX

Figure 1

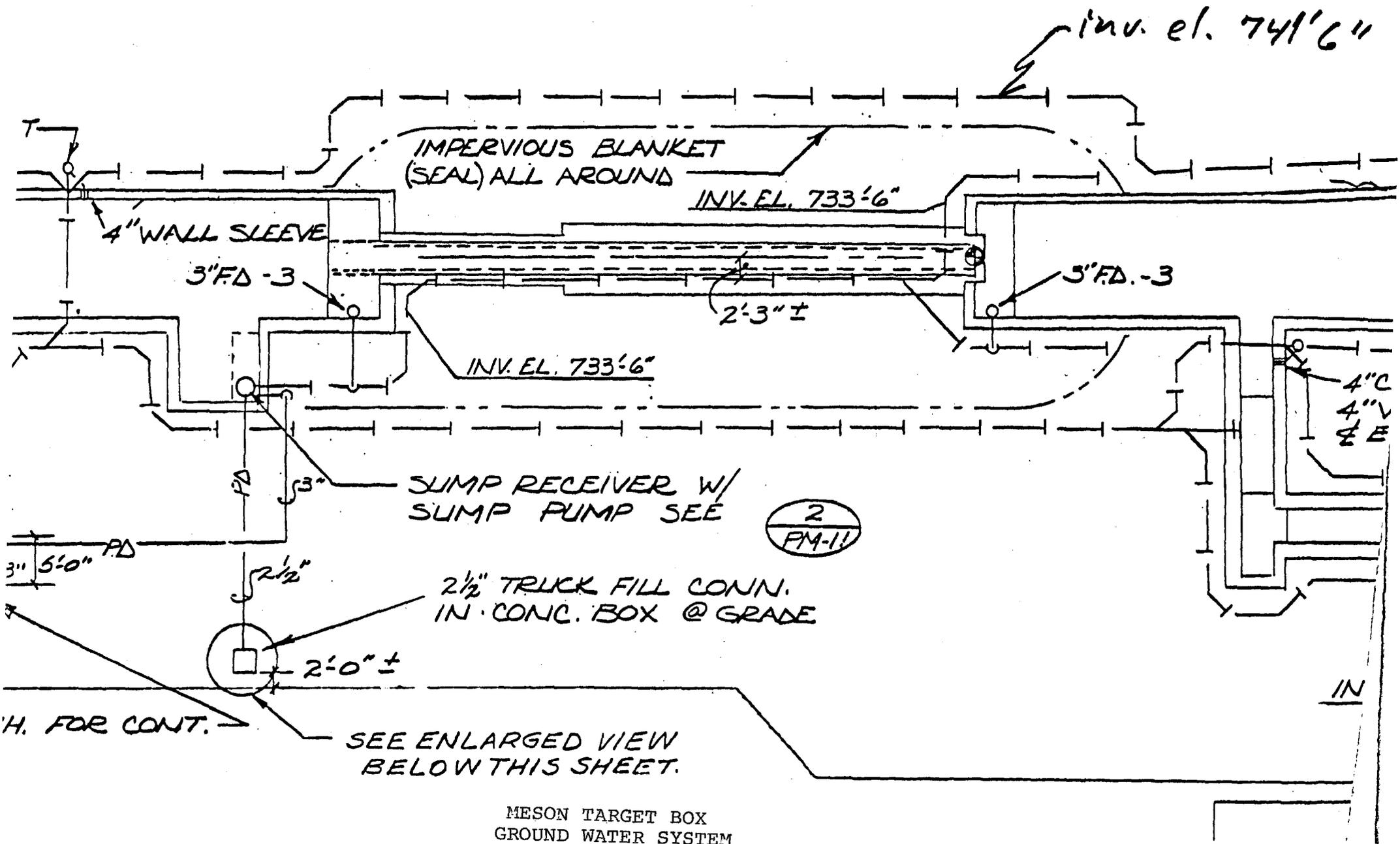
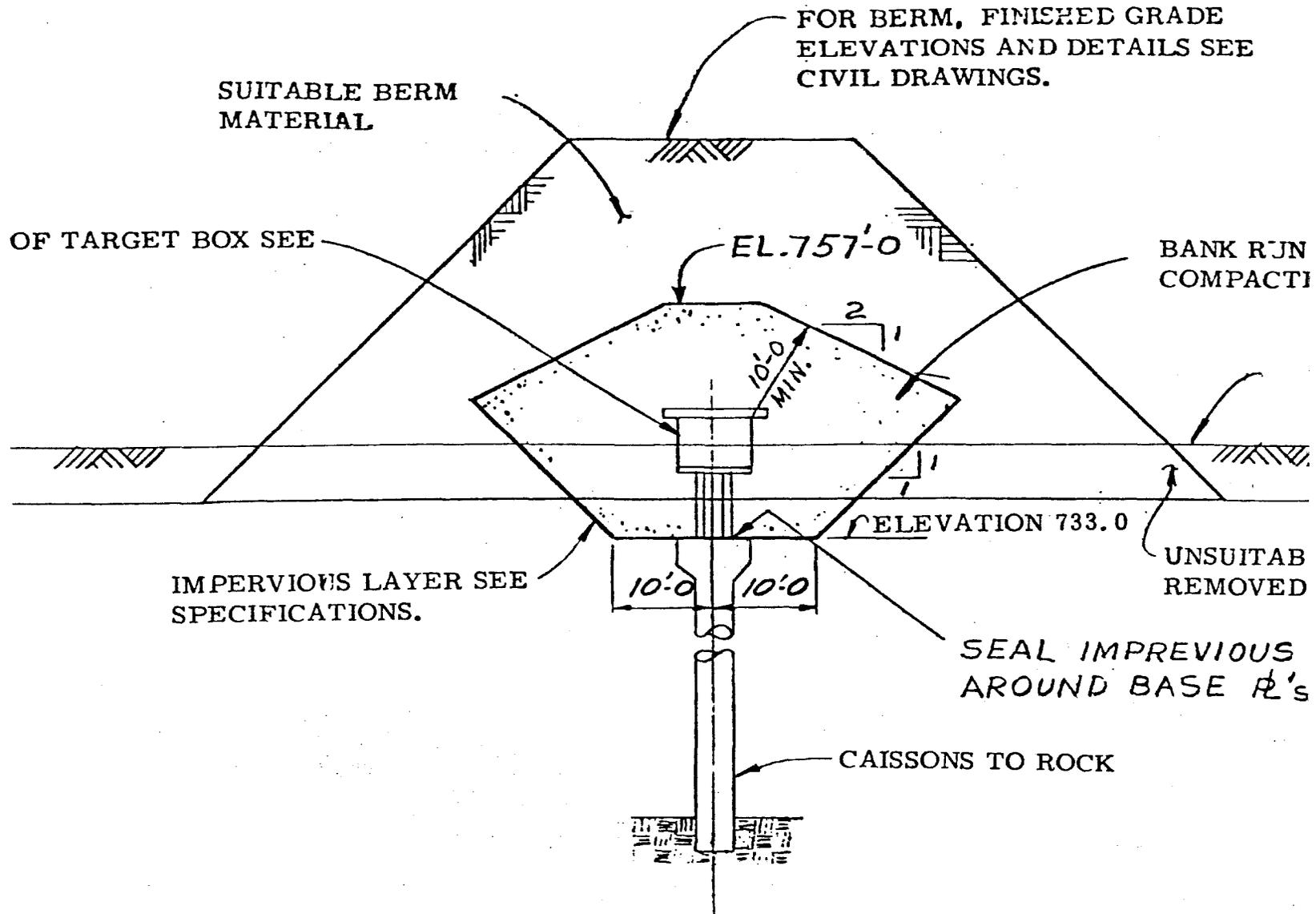


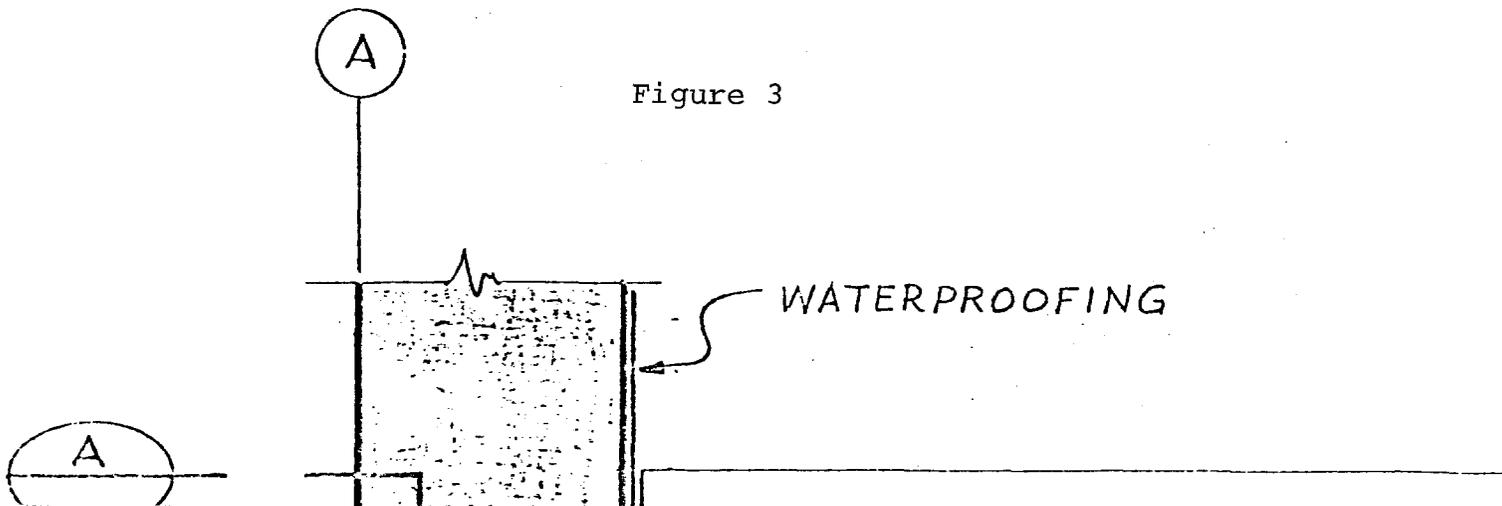
Figure 2

-17-
TM-812A
1104.2



SECTION B
 SCALE: 1/16" = 1'-0" PS-1

Figure 3



21'-3"⁻¹⁹⁻

42-6

OPTIONAL
CONSTRUCTION
JOINT

SEE SH

30'-0"

17'-3"

2'-0"

2'-0"
MIN.

SECTION 2'-0"

8"

2'-0"

3'-0"

2'-0"
MIN.

1/2

TYP

ELEV.
744'-6"

M1

M2

M3

ELEV.
742'-0"

M4

M6

2'-0"

1'-0" COMPACTED
BANK RUN SAND
& GRAVEL

5'-9"
AT 271'-6"

AT 271

Figure 4

TYPICAL EXCAVATION DETAIL
SCALE 1/4" = 1'-0"

EXIST'G.

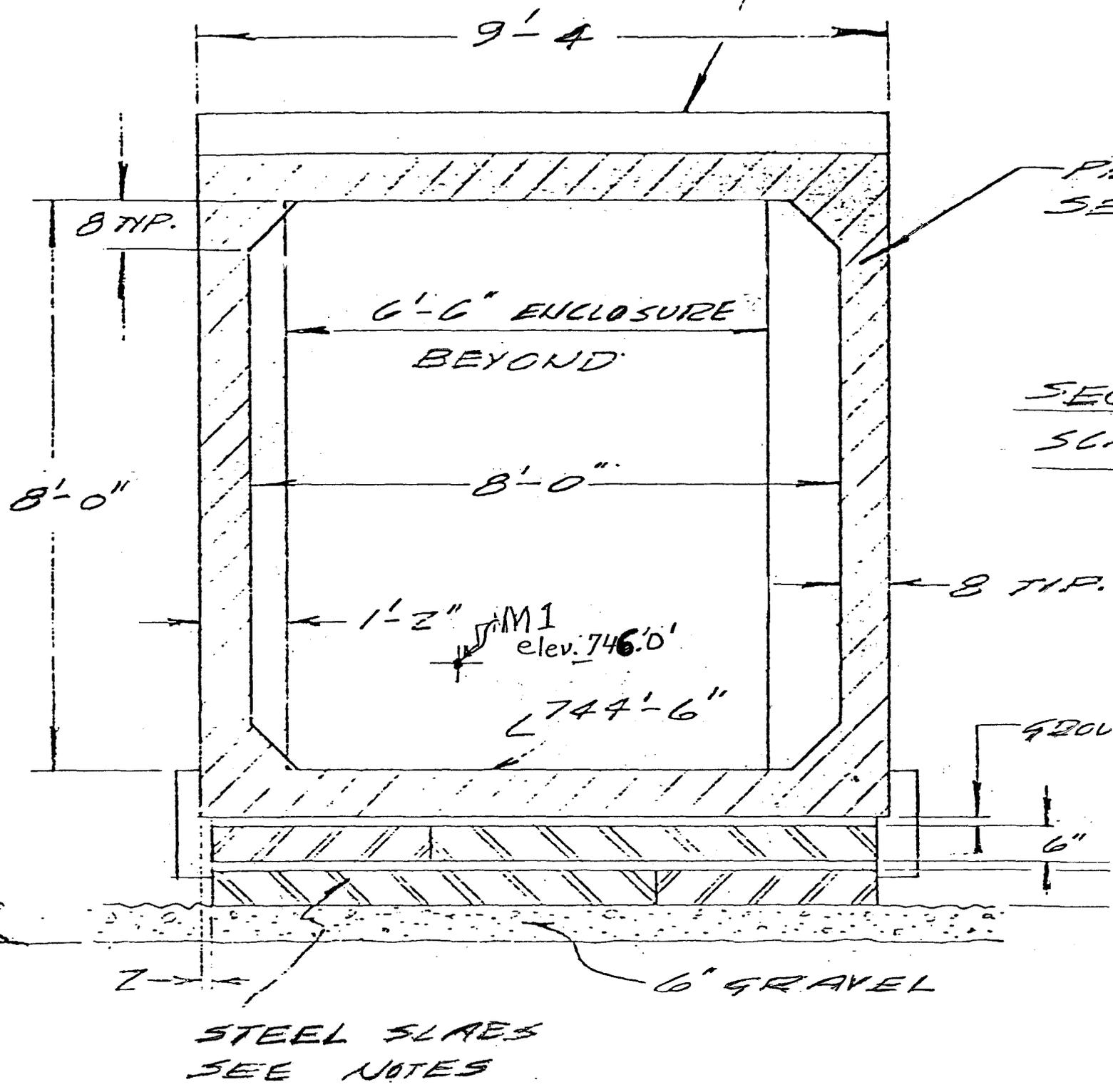


Figure 5

REPARTITION DU DEBIT DE DOSE AU CONTACT (mrad/h) DU LIT MELANGE LM2/1 EN FONCT ON DE LA HAUTEUR DES RESINES

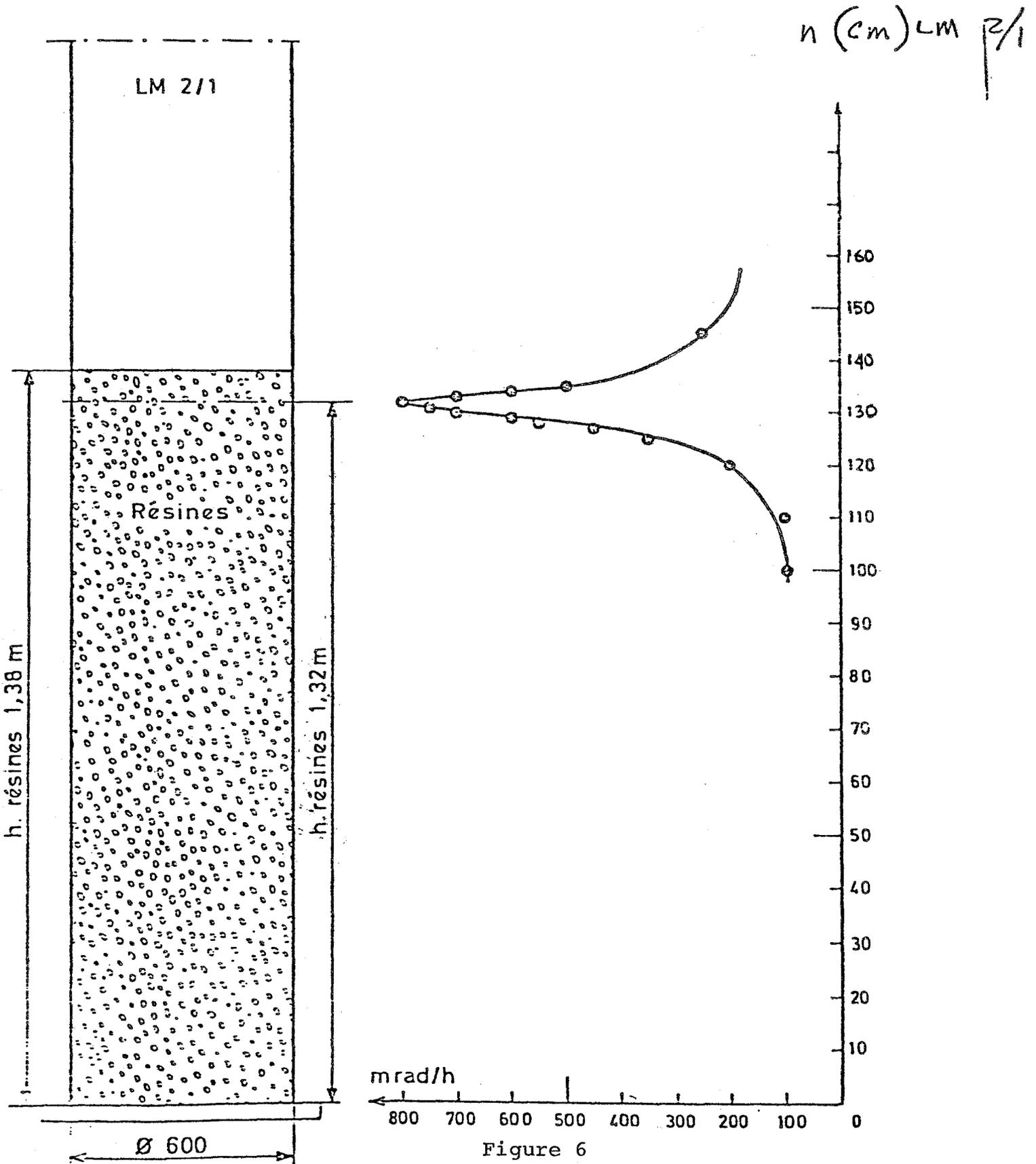


Figure 6