Fermilab

21 June 1982
TM 1117
1104.200

CASIM Predictions of Meson West Tevatron Target Soil Activation

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A new Meson West Target has been proposed for Tevatron II. The dump design proposed by David Eartly is shown in Figures 1-4. Figure 1 shows a longitudinal side view of the dump and the shield for target produced muons. In Figure 3, the core of the dump is seen to be a copper plate surrounding the beam. The copper is surrounded by iron, which is in turn shielded by concrete. The tunnel is embedded in sand and gravel. The sand and gravel within 3' of the concrete is continuously drained by underdrains. Soil below the top of the underdrains is not considered to be protected (Ref. 1). Activity produced in the unprotected soil below can be leached out, transported to the aquifer, and subsequently reach public water supplies. It is the activation of this unprotected soil which is of particular interest. Since the specific type of beryllium target to be used has not yet been decided, and since it would only reduce the resultant soil activation, I have chosen to ignore it and to presume that all the targetted intensity is lost on the dump.

I have made CASIM (Ref. 2) calculations of the levels of soil activation to be expected using the proposed dump design. Since the activation of the unprotected soil is the major consideration, I made the calculations using rectangular geometry (rather than the usual cylindrical approximation). To improve the statistics of my results, I reflect the lower half through the horizontal plane passing through the beam and divide the result by 2.

The beam parameters used were:

Incident beam: 1000 GeV/c protons
Beam begins to interact: 1.0 cm into dump
Threshold momentum: 0.3 GeV/c
Beam spot size: 1.0 x 1.0 cm

The dump design modeled was:

Backscatter shield: steel 3' high by 5' wide by 6' long. The shield is surrounded by concrete out

to the same distance as the dump (see Figures).

Dump: Copper plate 4" high by 12" wide, centered on beam axis, surrounded by steel. The steel extends 54" east of the beam, 48" west of the beam, and 18" below the beam, with an extra steel plate 4" high by 3' wide centered below the beam underneath the main body of the shield. The length of the dump is 20'.

Concrete: The concrete floor under the dump is 22" thick. Concrete tunnel walls or shield blocks extend 3' laterally on either side of the dump. There are 4' concrete immediately downstream of the dump.

The region of interest for soil activation is the soil below the top of the underdrains, which will be 3' below the bottom of the concrete floor of the dump. The underdrains are emptied by sump pumps.

The number of stars produced in each region of interest were summed in the CASIM run. The procedure of Ref. 3 was used to obtain radionuclide production and subsequent transport to the aquifer. As discussed in Ref. 3, the radionuclides of interest are 3H and 22Na. Their production rates in glacial till are given there as:

$$\begin{aligned} 3H &= 0.075 \text{ leachable atoms/star} \\ 22Na &= 0.003 \text{ leachable atoms/star (15\% of total 22Na production).} \end{aligned} \quad (1)$$

Figure 5 is a plot of star densities as a function of effective radius (R) and distance along the beam axis (Z). The effective radius of the components has been used to show their outlines. Since the actual geometry is rectangular rather than cylindrical, one should use the actual radius to a point of interest to predict the levels at that point using Figure 5. The Z distribution prediction can be considered to be quantitive.

The formula for calculating activities from the number of stars/proton is given by Ref. 3 as:

$$A = NSP/T \times 3.7\ E10, \quad (2)$$

where
- A = activity produced in Curies/year,
- N = number of protons/year,
- S = number of stars/proton in the region of interest,
- P = production rate in atoms/star of leachable radionuclide,
- T = mean lifetime:

T (3H) = 17.7 yr = 5.58 E8 seconds
T (22Na) = 3.75 yr = 1.18 E8 seconds
1 Curie (Ci) = 3.7 E10 decays/second.

Assuming Tevatron running conditions of 180 days/year, 60% duty cycle, 60 spills/hour, and 5 E12 protons/spill on the Meson West Target gives:

$$N = 7.8\ E17 \text{ protons/year.} \tag{3}$$

As discussed in Ref. 3, horizontal transport of the leachable radionuclides happens very rapidly and can therefore be neglected in soil activation estimates. The vertical transport to the Silurian aquifer (V) is estimated to be (Ref. 3):

$$V\ (3H) = 3.6\text{-}7.2 \text{ feet/year} \tag{4}$$
$$V\ (22Na) = 1.6\text{-}3.2 \text{ feet/year.}$$

The elevation of the Silurian aquifer is about 677'. The elevation of the beam is to be 746'; unprotected soil begins at an elevation of about 740'. Thus the radionuclides must travel about 63' vertically to reach the aquifer. The times required with the most conservative transit rates are:

$$3H:\ 63'/(7.2'/\text{year}) = 8.75 \text{ years} \tag{5}$$
$$22Na:\ 63'/(3.2'/\text{year}) = 19.7 \text{ years.}$$

Thus their activities upon reaching the aquifer have been reduced by factors of:

$$P\ (3H) = \exp(-8.75/17.7) = 0.610 \tag{6}$$
$$P\ (22Na) = \exp(-19.7/3.75) = 0.00525.$$

Three separate CASIM runs were made, each using a different random number seed and calculating 200,000 pseudostars. The results were 0.712, 0.540, and 0.332 stars/incident proton in unprotected soil. The average is 0.528; the standard deviation is 0.190 (statistical only). The result can probably be assumed to be accurate within a factor of about three (Ref. 3). Using:

$$S = 0.528 \text{ stars/proton,} \tag{7}$$

Equations 1-3, 6-7, and the factor of 2 from reflection, we predict the activity/year reaching the Silurian aquifer to be:

$$A\ (3H) = \frac{7.8\ E17 \times 0.528 \times 0.610 \times 0.075}{2 \times 5.58\ E8 \times 3.7\ E10} \tag{8}$$

$$= 0.456 \text{ milliCuries/year,}$$

$$A\ (22NA) = \frac{7.8\ E17 \times 0.528 \times 0.00525 \times 0.003}{2 \times 1.18\ E8 \times 3.7\ E10}$$

$$= 0.743 \text{ microCuries/year.}$$

The EPA upper concentration limits on community water systems are:

$$\begin{aligned} 3H&: \ 20 \text{ pCi(picoCuries)/ml} \\ 22Na&: \ 0.2 \text{ pCi/ml.} \end{aligned} \tag{9}$$

The Laboratory has applied this limit to users of individual wells in considering new construction. The minimum consumption per well user is taken as:

$$\text{Consumption} = 40 \text{ gal/day} = 5.55\ E7 \text{ ml/year.}$$

This figure coupled with the activities reaching the Silurian aquifer per year give concentrations (C):

$$\begin{aligned} C\ (3H) &= 0.456 \text{ milliCi}/5.55\ E7 \text{ ml} = 8.2 \text{ pCi/ml} \\ C\ (22Na) &= 0.743 \text{ microCi}/5.55\ E7 \text{ ml} = 0.013 \text{ pCi/ml,} \end{aligned} \tag{10}$$

values well within the legal and more stringent Laboratory limit (Ref. 4).

For a mixture of radionuclides, the weighted sum of the concentrations must be less than 1. This condition is also filled:

$$8.2/20 + 0.013/0.2 = 0.48. \tag{11}$$

It is worth noting that if the underdrains are located 3' lower (i.e. 3' of additional soil are protected), the values of S obtained (Eqn. 7) are 0.0564, 0.0526, and 0.0314, for an average of 0.0468, as opposed to 0.528. Leaching water must travel 3' less to the aquifer (Eqn. 5). The net result (Eqns. 8 and 10) would be 0.0414 millicuries/yr or 0.746 pCi/ml of 3H and 0.0845 microcuries/yr or 0.0015 pCi/ml of 22Na. Thus an additional 3' of protected soil would improve the soil activation problem by about an order of magnitude.

A complete listing of my SUBMIT file for running this job interactively on the CYBER is included as an appendix. It is available as a public file: GET,STM1117/UN=94590.

I wish to thank David Eartly for suggesting this calculation. Don Cossairt, Jack Couch, and Sam Baker made many valuable suggestions. Cossairt's TM-945 (Ref. 5) was particularly useful.

References:

1. S. I. Baker, private communication, 17 June 1982. Based on C. W. Pfingsten and C. N. Baker of Soil Testing Services, "Ground Water Seepage Study, Neutrino and Main Accelerator Laboratory Areas, National Accelerator Laboratory, near Batavia, Illinois", memo to R. E. Pages of Daniel, Urbahn, Seelye, and Fuller, 25 July 1973.

2. A. Van Ginneken, "CASIM: A Program to Simulate Transport of Hadronic Cascades in Bulk Matter", FNAL FN-272, January, 1975.

3. P. J. Gollon, "Soil Activation Calculations for the Anti-Proton Target Area", FNAL TM-816, September 14, 1978.

4. A. L. Read, "Regulations on Exposure from Drinking Water", memo to Division/Department Heads, April 5, 1979.

5. J. D. Cossairt, "Soil Activation Calculations for the Proposed Neutrino Front Hall", FNAL TM-945, January 15, 1980.

West Tevatron Target Dump Model. Reflect through horizontal beam plane. Elevation view.

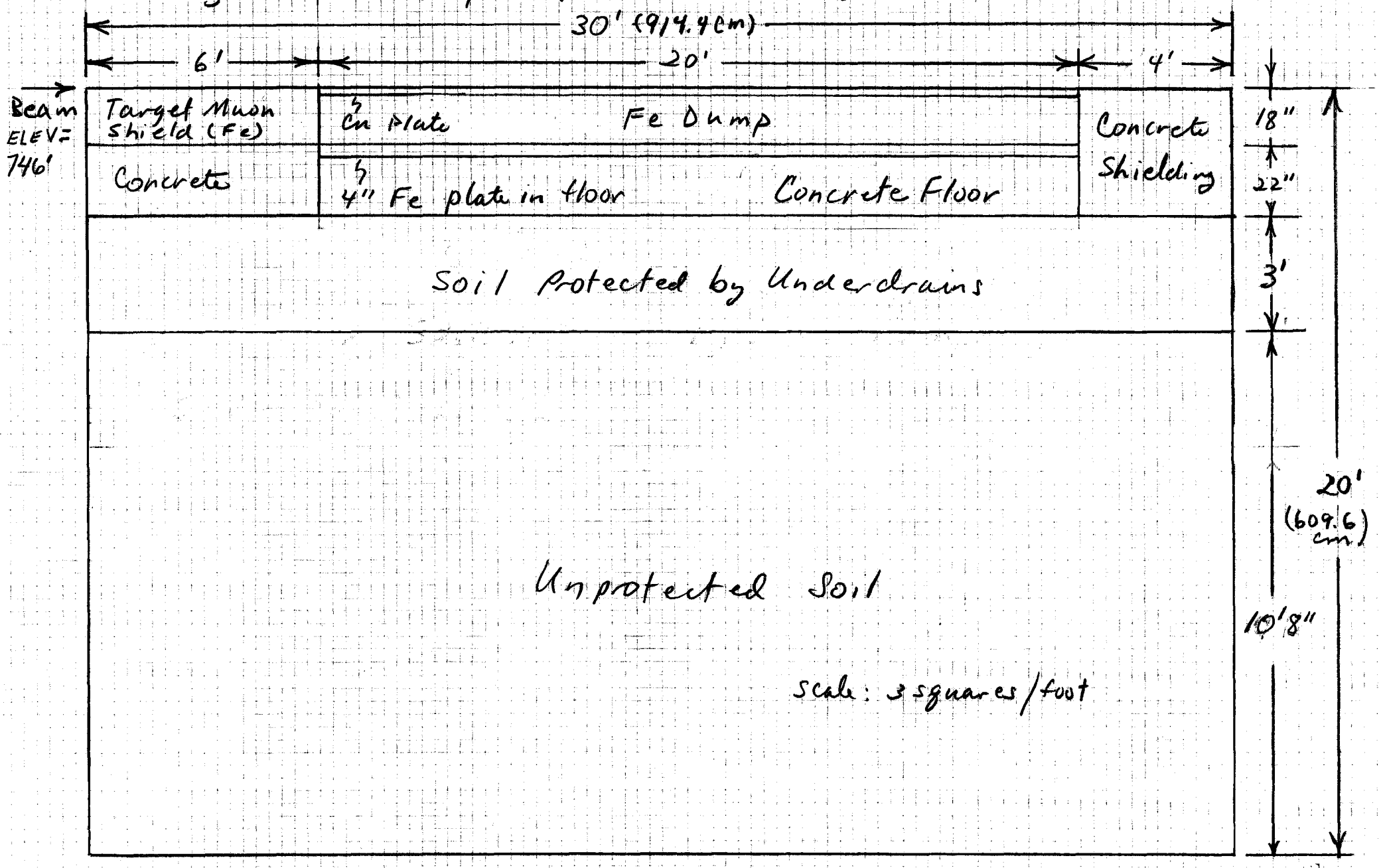


Figure 1

Section through Target Muon Shield. Reflect through horizontal beam plane. Elevation view.

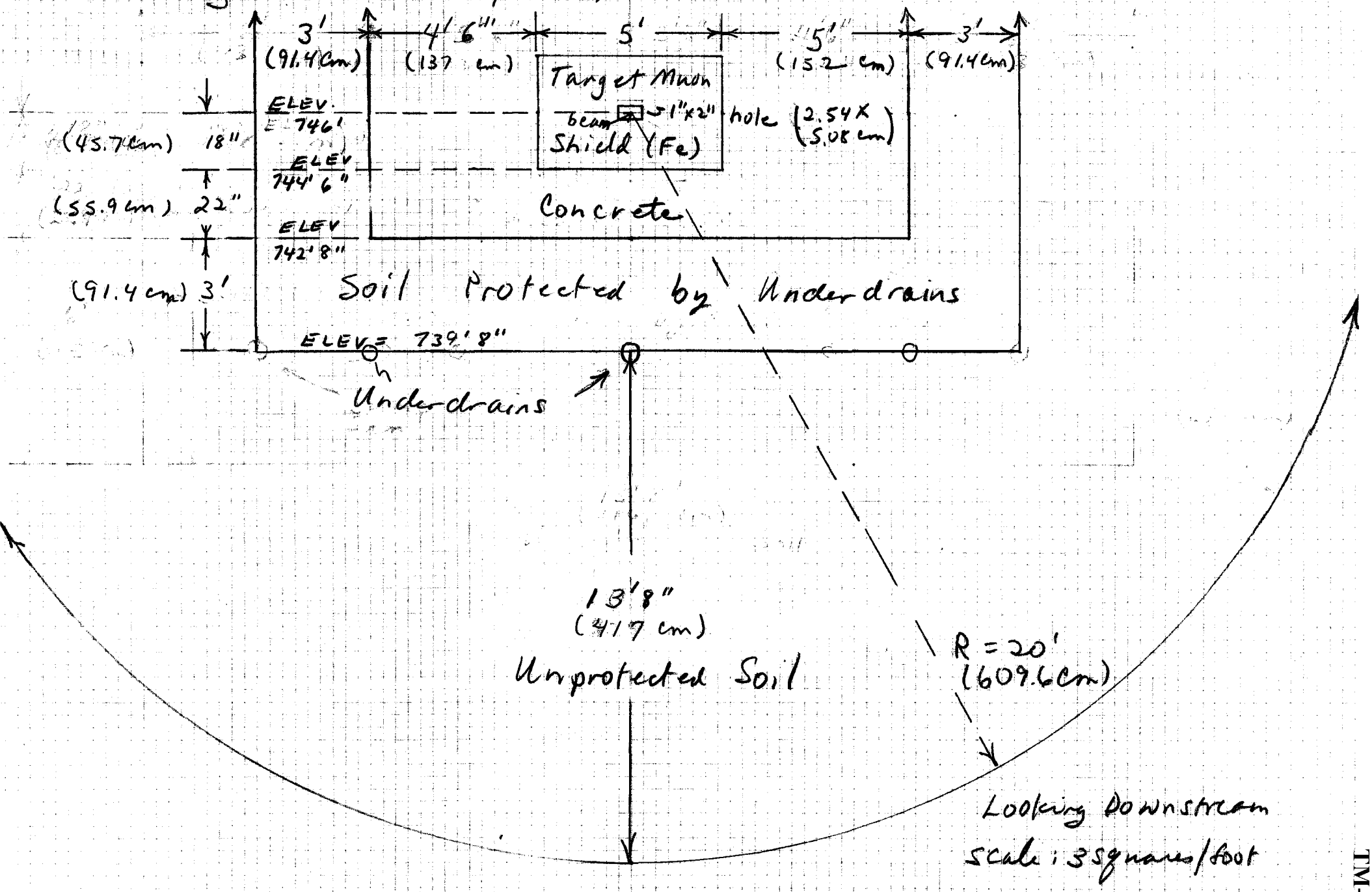


Figure 2

Section through Dump. Reflect through horizontal beam plane.

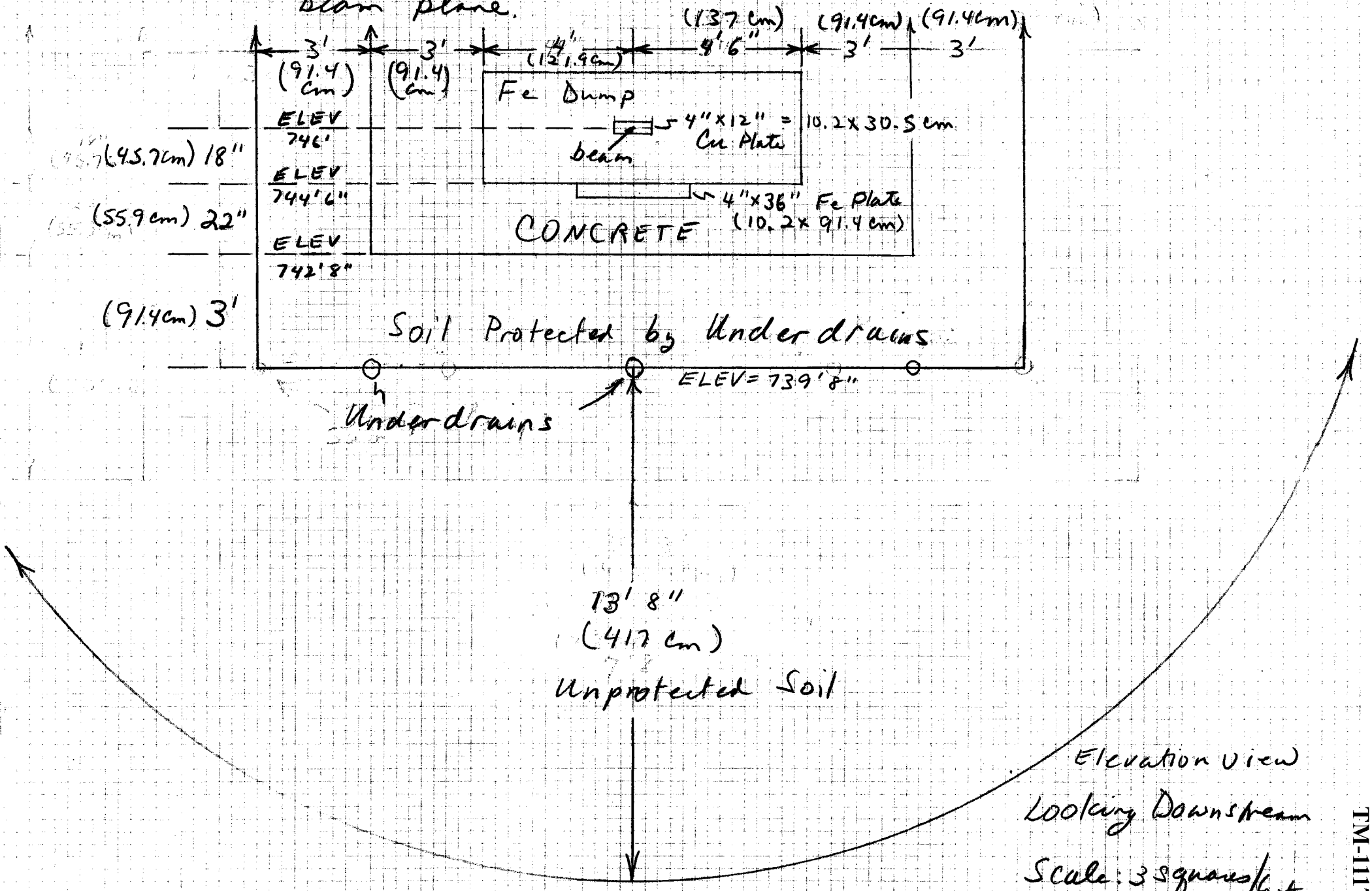


Figure 3

Section through Concrete downstream of Dams. Reflect through horizontal beam plane.

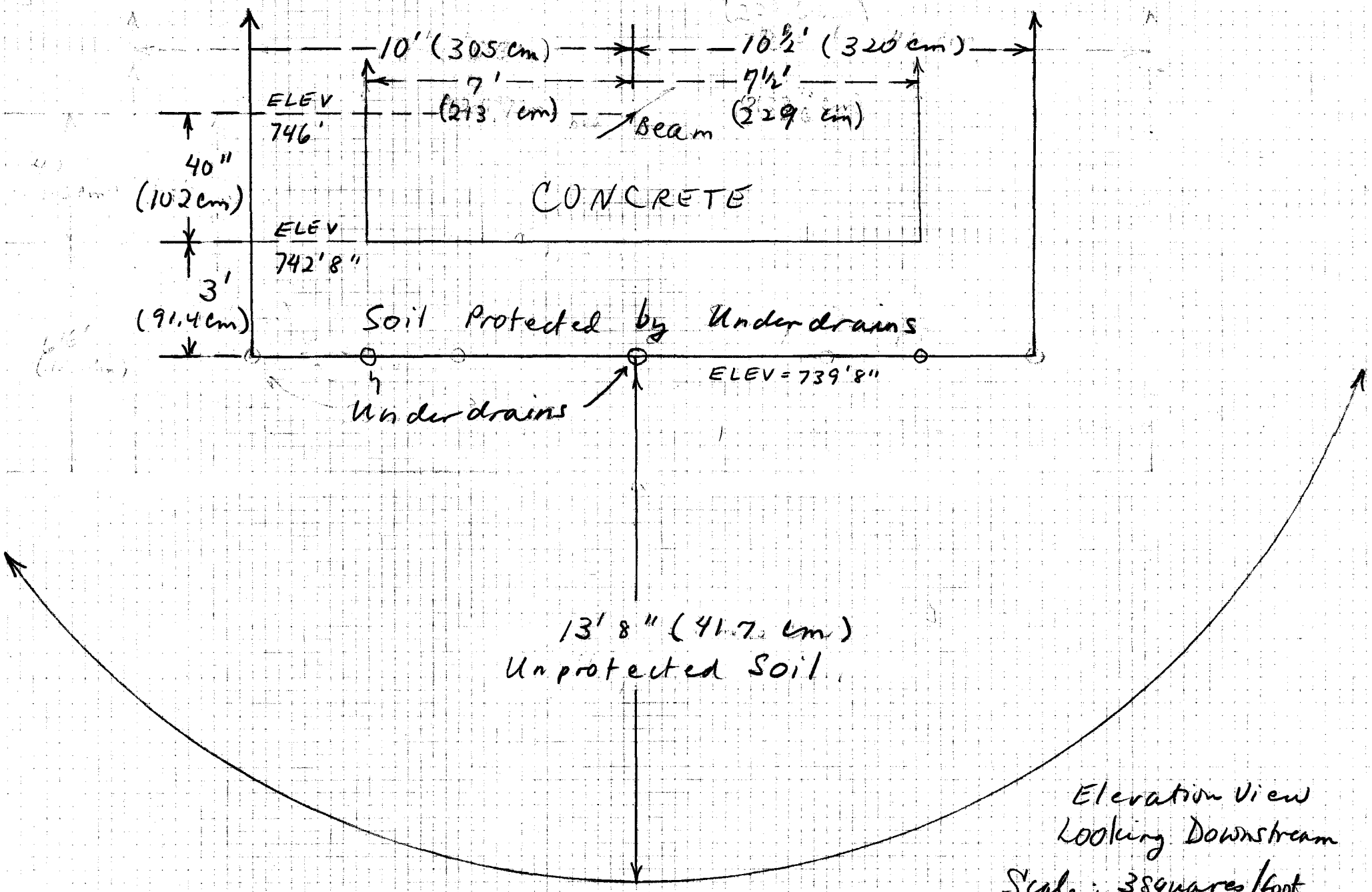
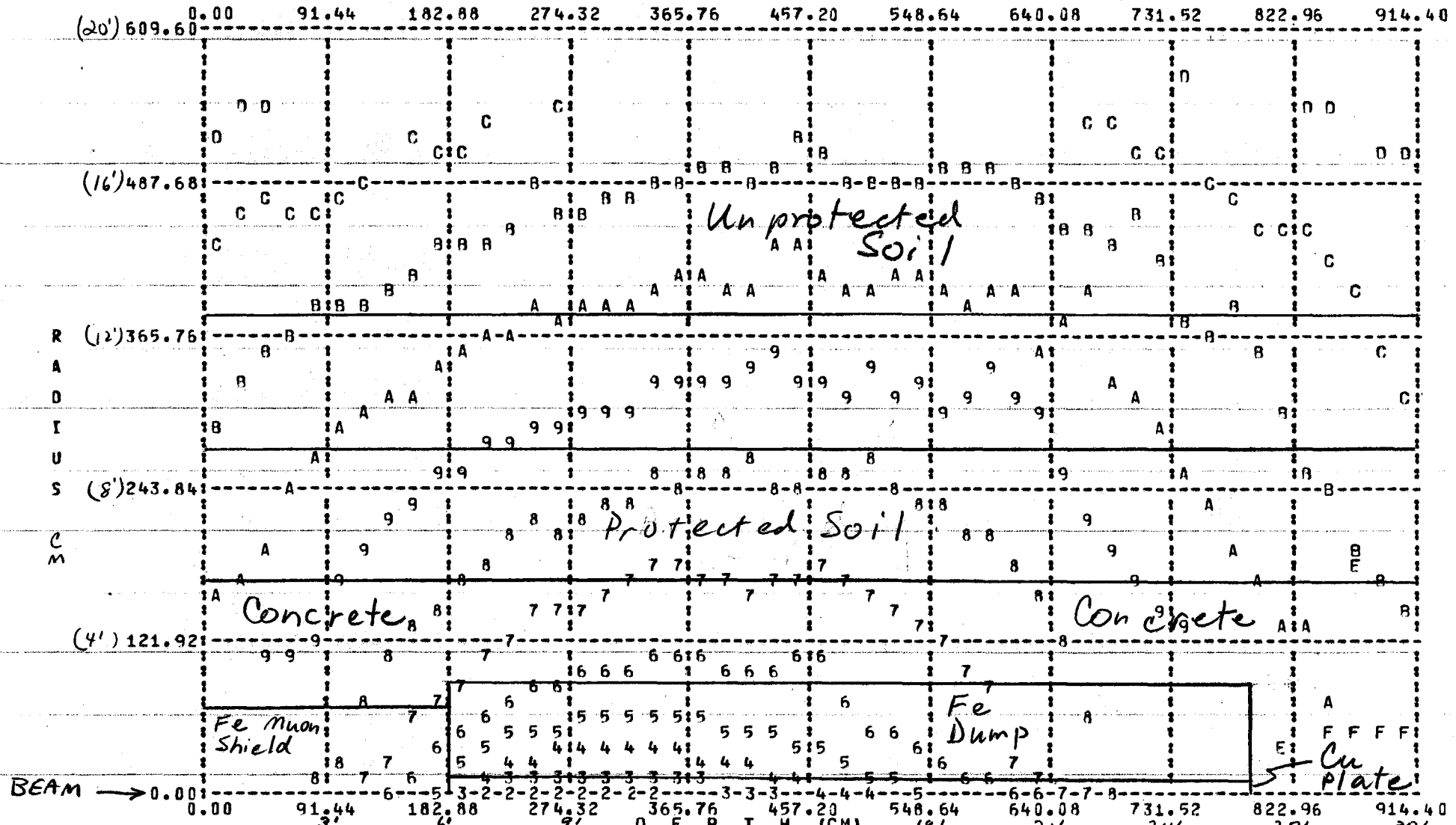


Figure 4

Dump Components drawn in using their effective radius, R_{eff}, vs depth (z). $R_{eff} = \sqrt{\text{height} \times \text{width}/\pi}$

CONTOURS OF EQUAL STAR~~(ENERGY)~~ DENSITY, IN UNITS OF STARS(GEV)/(CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR THE INTEGRAL POWERS OF 10



R-LABELS REFER TO SMALLER VALUES OF CORRESPONDING BINS
LEGEND : NUMERICAL SYMBOLS REFER TO THE NEGATIVE POWER OF 10 OF THE STAR(ENERGY) DENSITY E.G., 5 REFERS TO THE 10**-5 CONTOUR
OTHER POWERS OF 10(SYMBOLS) : -10(A),-11(B),-12(C),-13(D),-14(E),-15(F),-16(G),-17(H),-18(I),-19(J)
1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

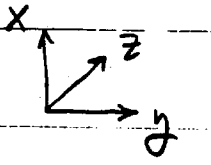
FIGURE 5

```
AGUQ,T7777,HP.
USER,94590,[redacted]  PASSWORD.
CHARGE,G37.
PURGE,TARGET/NA.
DEFINE,OUTPUT=TARGET.
ATTACH,NAME7/UN=LIBR.
NAME7,TEV,MWEST,TARGET,ACTIVE,SOIL.
RETURN,NAME7.
GET,OLDPL=CASTMUD.
UPDATE,F.
FTN,I,PMD,ER,R=2,OPT=1,L.
MAP,PART.
LDSET(PRESET=ZERO)
LGO.
CTIME.
DAYFILE.
REWIND,OUTPUT.
COPY,OUTPUT,TARGET.
REWIND(OUTPUT)
COPYEI(OUTPUT=PRINT)
SKIPEI(OUTPUT)
ROUTE(PRINT,DC=PR)
*.
SKIP(END)
EXIT.
ENDIF(END)
CTIME.
DAYFILE,OP=I.
DAYFILE,CASDF.
REPLACE,CASDF.
```

PRYOR CORP. 14852GB

```
*IDENT.GAUSS
*I CASIM.10
C THIS BLOCK PUTS IN GAUSSIAN SPOTS WITH BSIZ INTERPRETED AS
C SIGMA IN UNITS OF C.1.
      DIMENSION IXSIG(40),IYSIG(40)
      COMMON/GAUSS/IXSIG,IYSIG
*I CASIM.11
      DATA IXSIG,IYSIG/40*0,40*0/
*D CASIM.177,180
      XA=GAUS(0.0,BSIZ)
      YA=GAUS(0.0,BSIZ)
 2998 NNX=5.0*XA/BSIZ   +20.0
      NNY=5.0*YA/BSIZ   +20.00
      IF(NNX.GT.40)NNX=40
      IF(NNY.GT.40)NNY=40
      IF(NNX.LT.1)NNX=1
      IF(NNY.LT.1)NNY=1
      IXSIG(NNX)=IXSIG(NNX)+1
      IYSIG(NNY)=IYSIG(NNY)+1
 3000 CONTINUE
*I CASIM.378
      FUNCTION GAUS(AV,SD)
      A=-6.
      DO 10 I=1,12
   10 A=A+RAN(V)
      GAUS=A*SD+AV
      RETURN
      END
*I 2/14/80.3
      DIMENSION IXSIG(40),IYSIG(40)
      COM ON/GAUSS/IXSIG,IYSIG
*I 2/14/80.17
      WRITE(6,1000)
 1000 FORMAT(1H1,* DISTRIBUTION OF INCIDENT X VALUES.  BSIZ = 5
     1UNITS*/1X,*ZERO = 20 UNITS*)
      WRITE(6,1001)(I,IXSIG(I),I=1,40)
 1001 FORMAT(1X,I5,I10)
      WRITE(6,1002)
 1002 FORMAT(1H1,* DISTRIBUTION OF INCIDENT Y VALUES.  BSIZ = 5
     1UNITS*/1X,*ZERO = 20 UNITS*)
      WRITE(6,1001)(I,IYSIG(I),I=1,40)
*IDENT.STARSUM
*I CASIM.10
      REAL NSTMA(5)
      COMMON/SUM/NSTMA,NNNN
*I 2/14/80.1
      NNNN=MNEW
*I RECORD.10
      REAL NSTMA(5)
      COMMON/SUM/NSTMA,NNNN
*I 2/14/80.19
      NNNN=NNEW
*I BINS.12
      REAL NSTMA(5)
      COMMON/SUM/NSTMA,NNNN
*I BINS.26
      IF(NNNN.GE.NOUT.OR.NNNN.EQ.0)GO TO 26
      IF(NQ.LE.3)NSTMA(NNNN)=NSTMA(NNNN)+W
   26 CONTINUE
*I BINPT.13
      REAL NSTMA(5)
      COMMON/SUM/NSTMA,NNNN
      DATA NSTMA/5*0.0/
*I BINPT.84
```

```
      DO 75 IIII=1,NE
   75 NSTMA(IIII)=NSTMA(IIII)/(NUINC*ENCR(7))
*I BINPT.97
      WRITE(6,95)NSTMA
   95 FORMAT(* STARS/INC.PTCL IN MATERIAL NO. 1-5*,5E10.3,//)
*IDENT.TARGET
*D BINSTA.19,.20
      IF(NGEOM.NE.2) GO TO 500
      IF(((IZ-.5)*ZBL.LT.TUNL).AND.((IR-.5)*RBL.LT.TUNR)) GO TO 560
500   CONTINUE
*D EMSHWR.47
80    CALL HITORM(XB,YB,ZB,NN,DFX,DFY,DFZ)
*D EMSHWR.96
      CALL HITORM(XB,YB,ZB,NL,DEX,DEY,DEZ)
*D EDP.54
      CALL HITORM(XC,YC,ZC,NG,DCX,DCY,DCZ)
*I EDP.73
      J=11
*D EDP.91
      CALL HITORM(XC,YC,ZC,NL,DDX,DDY,DDZ)
*D EDP.131
72    CALL HITORM(XD,YD,ZD,NI,VX,VY,VZ)
*D HITORM.12,.40
C THIS VERSION CALCULATES SOIL ACTIVATION BELOW THE PROPOSED
C  TEVATRON MESON WEST TARGET BOX.  THE SUBMIT FILE IS STARGET,
C  AND THE OUTPUT FILE IS TARGET.  THE CASIMUD VERSION OF
C  CASIM IS USED FOR THE CALCULATION.  I USE AL JONCKHEERE'S UPDATES
C AND DON COSSAIRT'S GAUSSIAN BEAM SPOT; I.E. I INCLUDE BOTH THEIR
C IMPROVEMENTS TO THE PROGRAM.
C
C
C          N=NOUT   =>  OUTSIDE REGION OF INTEREST
C          N=0      =>  VACUUM/AIR
C          N=1      =>  STEEL
C          N=2      =>  CONCRETE
C          N=3      =>  SOIL "PROTECTED" BY A SUMP PUMP
C          N=4      =>  UNPROTECTED SOIL
C          N=5      =>  COPPER PLATE ON BEAM AXIS
C
C
      N=NOUT
      IF(RR.GE.RLIS) RETURN
      IF((Z.LE.0).OR.(Z.GE.ZLIM)) RETURN
C
C
C CALCULATE ABSOLUTE VALUES
      AX=ABS(X)
      AY=ABS(Y)
C REENTRANT CAVITY 1 INCH HIGH BY 2 INCHS WIDE BY 6 FEET LONG
C  INSIDE STEEL 3 FEET HIGH BY 5 FEET WIDE.
      N=0
      IF(Z.GE.182.9) GO TO 100
      IF(AX.GE.1.27.OR.AY.GE.2.54) N=1
C HORIZONTAL (Y) BOUNDARIES OF STEEL (N=1),CONCTRETE (N=2), AND
C   PROTECTED (BY SUMP PUMP) SOIL (N=3).
C   UNPROTECTED (BY SUMP PUMP) SOIL IS N=4.
      IF(AY.GE.76.2) N=2
      IF(Y.LE.-213.OR.Y.GE.229) N=3
      IF(Y.LE.-305.OR.Y.GE.320) N=4
C VERTICAL (X) BOUNDARIES OF STEEL (N=1), 22 INCH THICK CONCRETE
C   (N=2), AND PROTECTED SOIL (N=3).  UNPROTECTED SOIL IS N=4.
C    I REFLECT THROUGH THE HORIZONTAL PLANE TO IMPROVE STATISTICS.
      IF(AX.GE.45.7) N=2
      IF(AX.GT.102) N=3
```



Program dimensions in centimeters.

```
      IF(AX.GT.193) N=4
      RETURN
C
C
C 20 FOOT SOLID DUMP DOWNSTREAM OF REENTRANT CAVITY
C
C
C HORIZONTAL (Y) BOUNDARIES OF STEEL (N=1), CONCRETE (N=2), AND
C   PROTECTED (BY A SUMP PUMP) SOIL (N=3).
C   UNPROTECTED (BY SUMP PUMP) SOIL IS N=4.
C   COPPER (N=5) PLATE 4 IN HIGH BY 12 IN WIDE IS CENTERED ON BEAM
C
100   CONTINUE
      IF(Z.GE.792.5) GO TO 200
      N=5
      IF(AX.GE.5.08.OR.AY.GE.15.2) N=1
      IF(Y.LE.-122.OR.Y.GE.137) N=2
      IF(Y.LE.-213.OR.Y.GE.229) N=3
      IF(Y.LE.-305.OR.Y.GE.320) N=4
C VERTICAL (X) BOUNDARIES OF STEEL.  I REFLECT THROUGH THE HORIZONTAL
C   PLANE TO IMPROVE STATISTICS.
      IF(AY.LE.45.7.AND.AX.GE.55.8) N=2
      IF(AY.GT.45.7.AND.AX.GE.45.7) N=2
      IF(AX.GT.102) N=3
      IF(AX.GT.193) N=4
      RETURN
C
C
C CONCRETE DOWNSTREAM OF DUMP
C
C
C
C HORIZONTAL (Y) BOUNDARIES OF CONCRETE (N=2) AND PROTECTED SOIL (N=3).
C   UNPROTECTED (BY SUMP PUMP) SOIL IS N=4.
C
200   CONTINUE
      N=2
      IF(Y.LE.-213.OR.Y.GE.229) N=3
      IF(Y.LE.-305.OR.Y.GE.320) N=4
C VERTICAL (X) BOUNDARIES.  I REFLECT THROUGH THE HORIZONTAL
C   PLANE TO IMPROVE STATISTICS.
      IF(AX.GT.102) N=3
      IF(AX.GT.193) N=4
      RETURN
```

INPUT DATA FOR THIS RUN:

```
      7777.
         1      1000.        0.3        1.0        1.0     200000          0
         1         0    1.0E-15        3.0       12.0
1717675334021435 7761
         1
     914.4      609.0      183.9
         5
       26.      55.85       7.86       27.4
       11.      23.         2.40       49.
       11.      23.         2.40       49.
       11.      23.         2.40       49.
       29.      63.54       5.96       24.8
```