Fermilab
ES&H Section

E.P. NOTE 14

CALCULATION OF TRITIUM CONCENTRATIONS RESULTING FROM C0 BEAM ABSORBER OPERATIONS

K. Vaziri and E. Marshall

(July 1998)

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Introduction

A program of study is underway to model tritium production in the soil around different beam absorbers used at the Antiproton target, Main Ring/Tevatron, and the Fixed Target areas. This note is a summary of the modeling and calculations for the Main Ring and Tevatron beam absorber at C0. The computer code CASIM (Va75) was used to model the beam absorber. The Concentration Model (Ma93, Co94, Mal97) was used to predict initial tritium concentrations just outside the walls of the enclosure and final concentration after transport to the aquifer. Results of the initial concentration calculations are compared with the tritium concentrations measured in the sump samples.

Geometry Summary

The geometry used in the CASIM simulations (Figs. 1 and 2) was compiled from civil construction drawings, shielding configuration drawings, and the numerous papers published on the design of this beam absorber. (Refs. 1,2,3, Mu83, To79) For future reference, a copy of the geometry code used in the CASIM simulations is included in the Appendix, as is one of the data files.

In the actual coding phase of this project, some simplifications were made to the geometry so that the code could run efficiently. The C0 absorber is located at a tangent to the Main Ring/Tevatron enclosure. This enclosure is curving away from the absorber enclosure and is not a normal loss point. The possibility of an accidental loss in the Main Ring tunnel in the vicinity of the absorber exists, but given the frequency and the proton intensity, such losses will make negligible contributions to soil activation. This section of the Main Ring tunnel was not included in the geometry. The granular fill as shown in Figures 1 and 2, around the concrete was modeled as a rectangular cross section of equal area (and volume). Experience with CASIM has shown that this level of geometry simplification yields only minor differences in the calculations, which are within the level of the acceptable accuracy associated with the CASIM results.

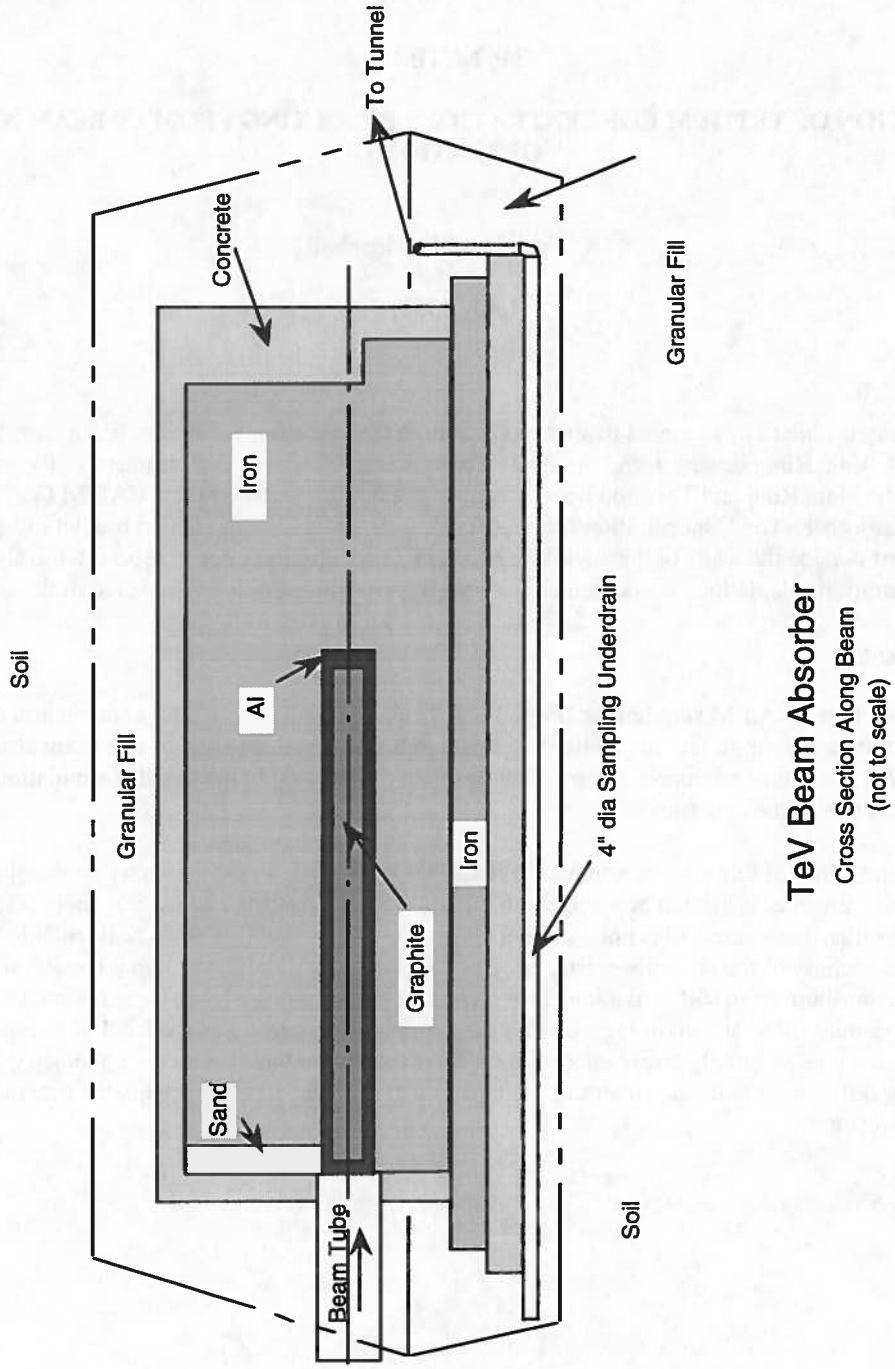
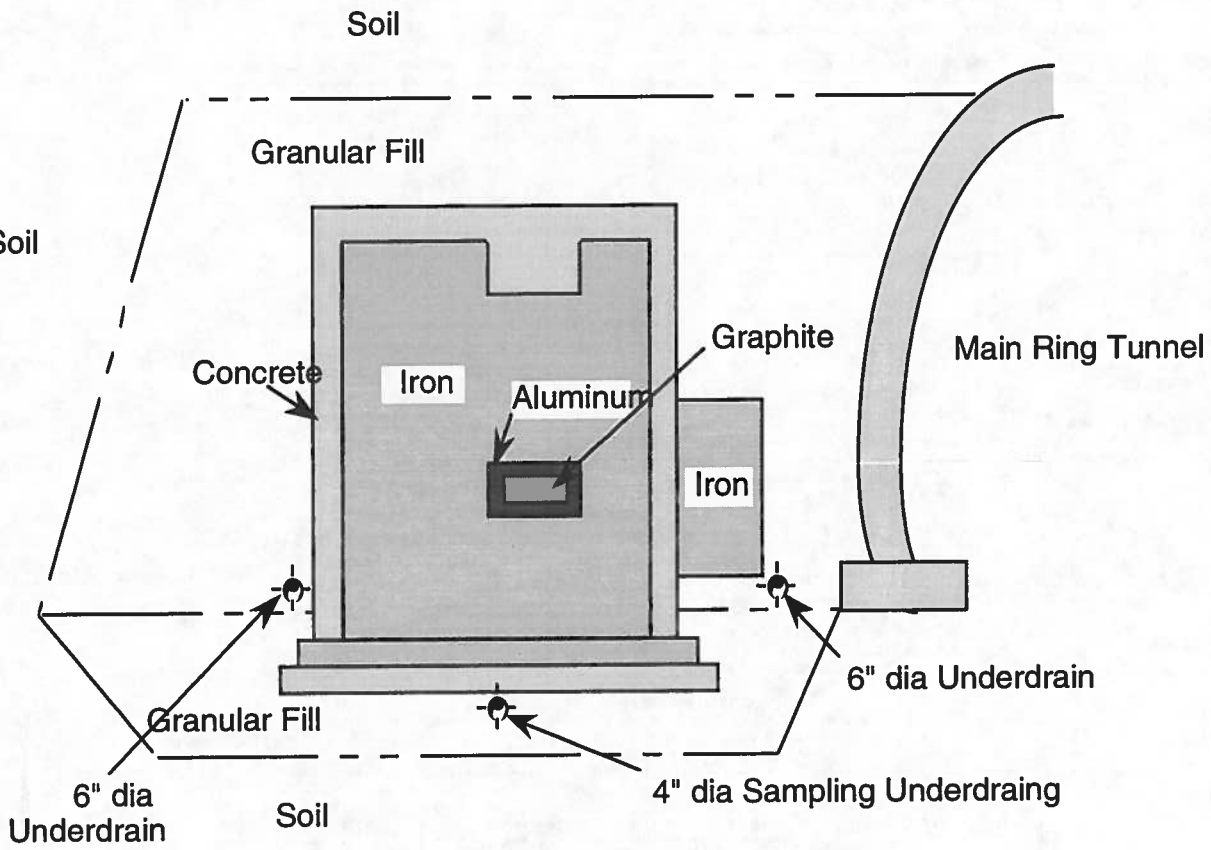


Fig. 1: Cross section along beam axis of C0 beam absorber (not to scale)



TeV Beam Absorber
Cross Section Looking Downstream
(not to scale)

Fig. 2: Cross section of C0 beam absorber looking downstream (not to scale)

Simulations

The values of the proton energies given in Table 1 are, of course, the maximum possible values of each group. The actual values of the proton energies may vary anywhere from 8 GeV to 900 GeV.[a] CASIM simulations were run at 150, 400, 800, 900 GeV, each with 150,000 incident particles to provide sufficient statistics. Figure 3 shows the star density contour plots for a 150 GeV run. The star density value used in the calculations is the maximum value found on the outer surface of the enclosure. This parameter was picked from the tabular output of CASIM.

[a] A study of the available energy history of the protons aborted during Main Ring and the Tevatron operations showed that inclusion of the actual abort energies (if available) rather than the maximum abort energies used in this report, will result in a maximum of 12% reduction in the estimated concentrations. This omission has no impact on our conclusions and is small compared to other uncertainties (private communication with Thornton Murphy).

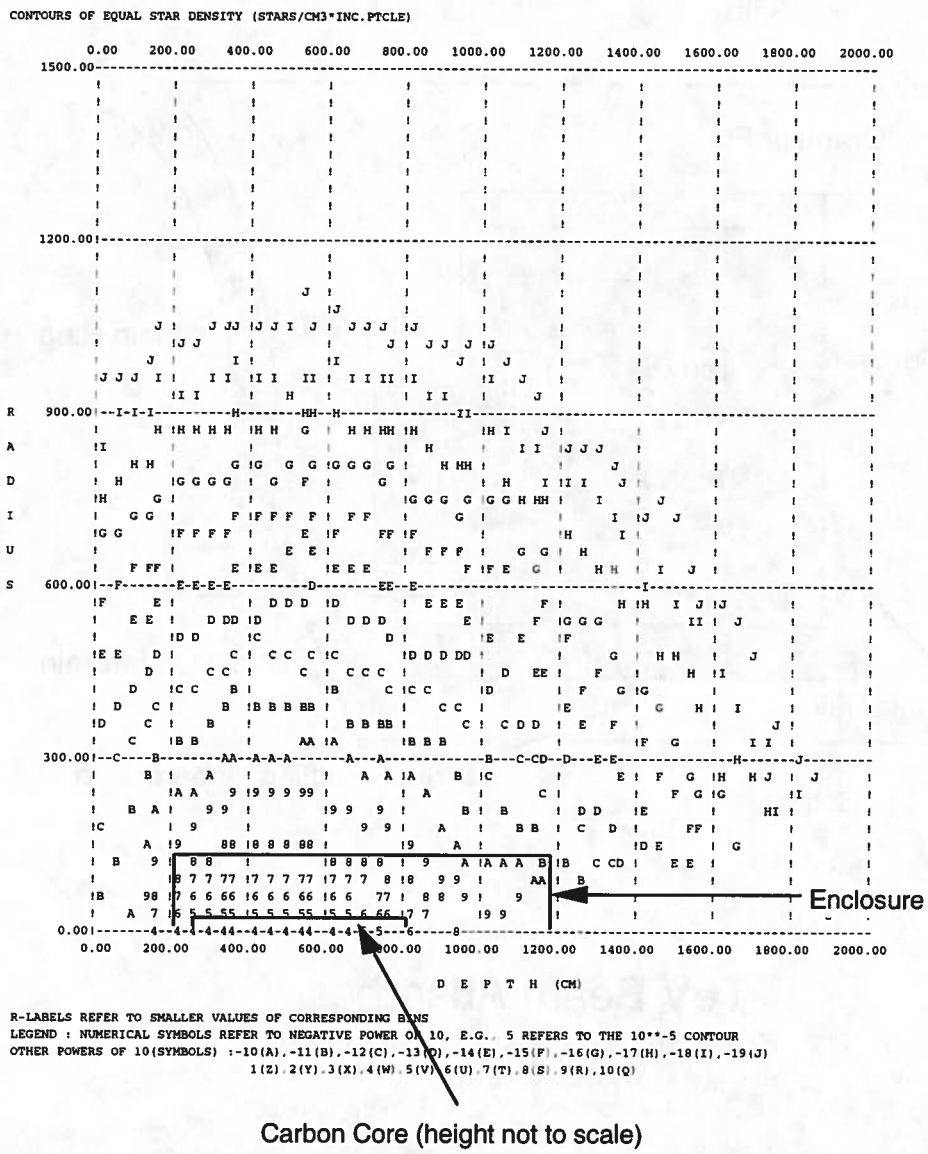


Figure 3: The horizontal axis of this star density contour plot corresponds to the distance along the beam axis or Z. Z=0 is at the entrance to the beam absorber. The vertical axis corresponds to the radial distance from beam center.

Proton Intensity History

The proton intensities and their respective energies are summarized in the Table 1 below (Refs. 4, 5). Activation in aluminum foils is also used as an independent method of measuring the number of protons sent to the beam absorber. There is generally good agreement between the number of protons reported by the accelerator operators, measured using a beam intensity monitor, and that determined from the analysis of the aluminum foils. Whenever the accelerator proton reports were not available, the data from foil analysis were used. With the star density calculated by CASIM and the incident proton intensity history, radionuclide concentrations can be calculated. The radionuclide

of greatest concern is tritium (which has a half-life of 12.3 years) and, therefore, the only radionuclide addressed in this paper.

Table 1: Total number of protons incident on C0 beam absorber. Shaded rows indicates proton intensities obtained using the operating records of the Main Ring and the Tevatron. The unshaded rows are from the foil activation data.

		Energy (GeV)			
Date(from)	Date(to)	150	400	800	900
1/1/97	9/30/97	9.78E+17		2.25E+17	
1/1/96	12/31/96	7.98E+17		1.87E+17	
1/1/95	12/31/95	4.80E+17			
1/1/94	12/31/94	4.57E+17			
1/1/93	12/31/93	4.87E+17			
1/1/92	12/31/92	2.61E+17			
1/1/91	12/31/91	5.90E+17		1.52E+17	
1/1/90	12/31/90	1.02E+18		2.36E+15	
1/1/89	12/31/89	4.24E+17			4.36E+16
1/1/88	12/31/88	3.86E+17		3.14E+16	1.64E+15
1/1/87	12/31/87	7.26E+17		1.22E+17	2.40E+15
1/1/86	12/31/86	1.43E+17			9.46E+14
1/1/85	12/31/85	2.28E+17		1.13E+17	
1/1/84	12/31/84	1.11E+17	1.34E+15	2.37E+16	
9/29/83	12/31/83	3.70E+16	1.26E+16		
	SUM TOTALS	7.12E+18	1.39E+16	8.57E+17	4.86E+16

As Table 1 shows, the majority of the protons sent to the C0 absorber have energies of 150 GeV. One of the important properties of hadronic cascades is that the induced activation can be scaled with proton energy. This scaling follows a well known power law (Co96). Therefore, to simplify the calculations, the intensity of protons at other energies was converted to an equivalent proton intensity at 150 GeV, using

$$I_{equivalent}\ (150\ \text{GeV}) = I_p(E) * \left(\frac{E\ (\text{GeV})}{150\ (\text{GeV})}\right)^{0.8},$$

where E is the proton energy in GeV, Ip is the proton intensity, and $I_{equivalent}$ is the scaled equivalent proton intensity at 150 GeV. The results are given in Table 2.

Table 2: C0 Beam Absorber proton intensity history in equivalent 150 GeV protons.

Date (from)	Date (to)	Number of Equivalent Protons at 150 GeV
1/1/97	9/30/97	1.84E+18
1/1/96	12/31/96	1.51E+18
1/1/95	12/31/95	4.80E+17
1/1/94	12/31/94	4.57E+17
1/1/93	12/31/93	4.87E+17
1/1/92	12/31/92	2.61E+17
1/1/91	12/31/91	1.17E+18
1/1/90	12/31/90	1.03E+18
1/1/89	12/31/89	6.07E+17
1/1/88	12/31/88	5.13E+17
1/1/87	12/31/87	1.20E+18
1/1/86	12/31/86	1.47E+17
1/1/85	12/31/85	6.59E+17
1/1/84	12/31/84	2.04E+17
9/29/83	12/31/83	6.46E+16
	TOTALS	1.06E+19

Concentration Model (CM) calculations

The Concentration Model (CM) allows the estimation of tritium concentrations right at the wall outside the enclosure, as well as final concentrations after transport and migration of the tritium through the till, the till-dolomite interface zone, and to the dolomite aquifer. For all the calculations presented in this report the Concentration Model as given in Mal97 was used.

The parameters for the calculation of the initial tritium concentrations were taken from Ma93. For the transport of radionuclides to the aquifer, a distance of 15.2 meters, given in Table 4 of Ma93, was used. No reduction was assumed for transport through the dolomite and the till-dolomite interface region (See Co94 for justification). It is the conclusion of references Ma93 and Co94 that the best value for the vertical velocity of the tritium from the production point to the aquifer is the "Intermediate Vertical Velocity", which is about 15 cm/year. The fifty-year buildup to saturation assumption was not used . Instead, the calculations included production and decay factors for tritium.

To obtain the average star density for the CM, the method described by Freeman (Fr96), rather than the prescription given in Ma93, was used. With exponential coefficients a=2.5 and b=1, I_R=0.12, I_Z=0.374 (see FR96, page 13, for the definition of these parameters), and S_{ave}/S_{max}=0.045, where S_{max} is the star density right outside the enclosure. This defines the value of S_{ave} over the volume which contains 99% of the total isotope production. However, since the 4" underdrain is only 10" below the floor of the enclosure, one should include only the volume between the floor and the underdrain rather than the 99% volume. Therefore, then, with the same exponential coefficients but with R_2=1.55 (rather than its value 3.6 for the 99% volume), S_{ave}/S_{max}=0.276, six times greater than the above value.

Table 3 shows the estimated annual contributions at the 99% volume (C_0), at the 4" underdrain (C_{sump}) and in the aquifer (C_f). Initial concentrations are not dependent on the vertical velocity.

Table 3: Calculated annual tritium concentrations at the surface, C_0, C_{sump}, and in the aquifer, C_f.

Year	C_0 (pCi/cc)	C_{sump} (pCi/cc)	C_f (pCi/cc)
1997	10.28	62.96	10.8E-02
1996	8.451	51.67	8.84E-02
1995	2.682	16.42	2.81E-02
1994	2.553	15.64	2.67E-02
1993	2.721	16.66	2.85E-02
1992	1.458	8.93	1.53E-02
1991	6.534	40.03	6.84E-02
1990	5.738	35.24	6.00E-02
1989	3.390	20.77	3.55E-02
1988	2.864	17.55	3.00E-02
1987	6.713	41.06	7.02E-02
1986	0.821	5.03	8.59E-03
1985	3.683	22.55	3.85E-02
1984	1.142	6.98	1.19E-02
1983	0.361	2.21	3.78E-03

Comparison to Sump Discharge

Since 1984, the C0 underdrain, the 4" underdrain shown in Fig. 2, has been periodically pumped and sampled. Moreover, since September 1993, about 40 gallons per work-day is being pumped and the sampling has been done on a weekly basis. For comparison, the calculated annual sump concentrations are given in Fig.4. Since the weekly measured sump sample results were available, they are also presented in this Figure. Figure 5 expands the region from November 1992 to the present.

As observed the average predicted tritium concentrations in the sump are in reasonable agreement with the results from the sumps (except for the abnormal rise around 93-94 which will be discussed later). When pumping of the underdrain started in 1993, the average tritium concentration was about 150 pCi/ml. Then in 1994, this concentration decreased and (as shown in Fig. 4) leveled out at approximately 50 pCi/ml. However, sump samples during long shut down periods did not indicate zero tritium concentrations. This seems to imply that the activity in the soil has reached equilibrium and because transport velocities (vertical and transverse) for the radionuclides are fairly low it moves through the soil very slowly. During the beam-off periods, the remaining tritium in the granular region continues to migrate to the vicinity of the underdrain.

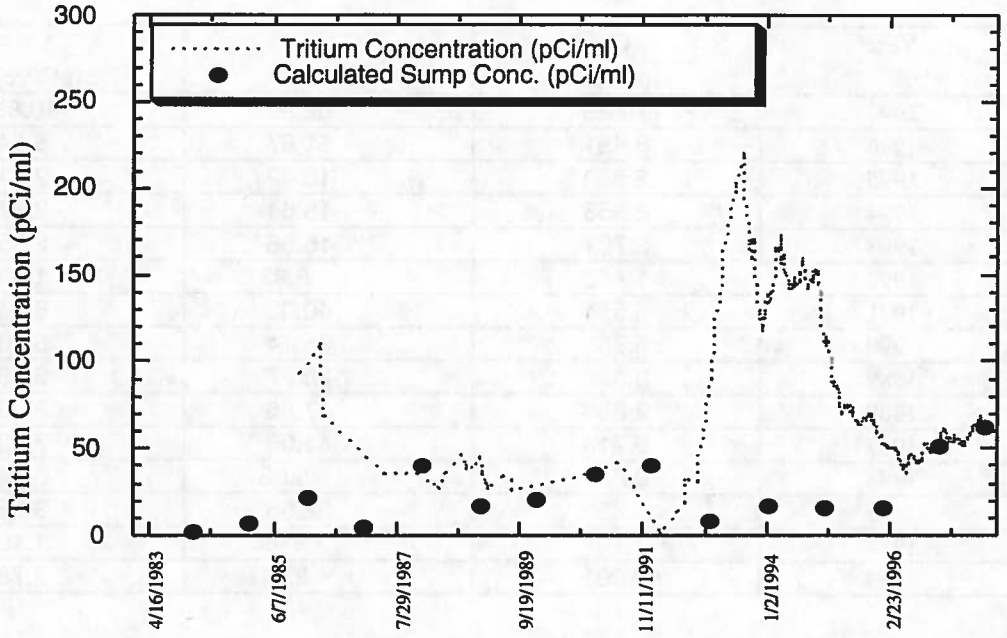


Figure 4: Tritium concentration from samples at the C0 underdrain compared to the estimated annual tritium concentrations.

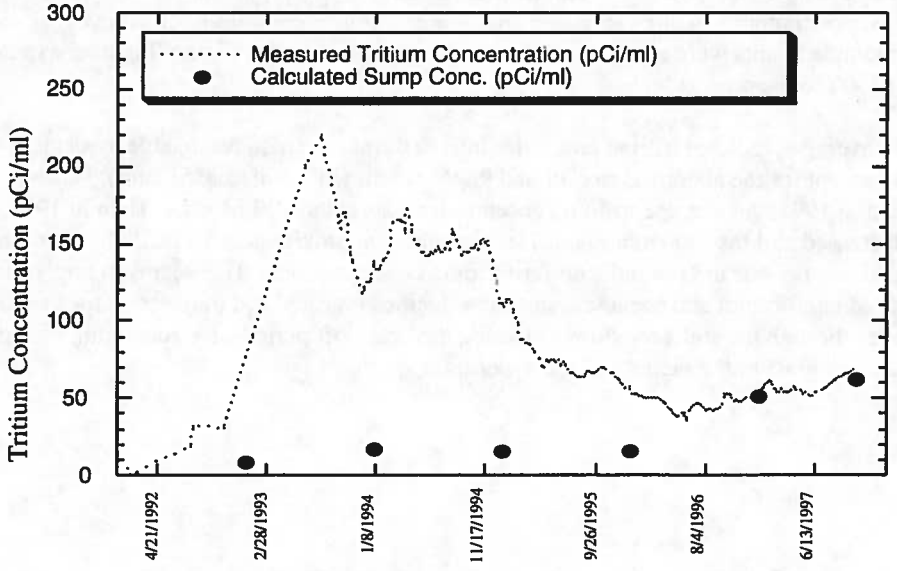


Figure 5: Tritium concentration from samples at the C0 underdrain compared to the CM predictions for the period of October 1992 to present.

Measured tritium concentrations over time were also compared to the proton intensities and the weekly precipitation (Ref.6) for this same time period. We also investigated whether there is a better correlation between the measured concentrations with the product of the proton intensities (which is directly correlated with the predicted concentrations) and precipitation. There is no obvious improvement in correlation beyond what was observed with the proton intensity alone.
The rise in the tritium concentration at the start of the C0 beam absorber operation (Fig.4, 1985-1986 period) is suspected to be due to the initial beam tuning and adjustments. The four fold rise in the sump tritium activity, in 1993-1994, is believed to be due to beam loss on the vacuum pipe in the soil upstream of the absorber, or loss of vacuum in this pipe, and should not be compared with the calculations of C_{sump} described here.

Muons from C0 beam absorber at Butterfield Road

The muon fluence was measured with the Mobile Environmental Radiation Laboratory (MERL, see reference FRCM) on the Hadley Road (service road) at the Fermilab site boundary parallel to the Butterfield Road. The muon profile was determined at positions 10 feet apart. Reference is approximately to a line tangent to the accelerator ring at the C0 beam absorber. Twenty two pulses of about 2.5×10^{13} 800 GeV protons were dedicated to this measurement. Two measurements were made at each location. Figure 6 shows the results. Negative (positive) distances are to the East (West) of the reference point. The muon distribution shows a wide peak, even though the statistical accuracy is poor, centered about 30 feet west of reference point. The maximum value of dose equivalent per proton is $(6\pm3) \times 10^{-17}$ μrem/proton. In 1997, during the Fixed Target operations, a total of 2.25×10^{17} 800 GeV protons were sent to the beam absorber. This would correspond to (13.5± 6.8) μrem/year dose equivalent, to a member of the public sitting at the site boundary in the peak region of the muon cone, all year. Extant experience (El88) show that muons from lower energy protons range out before reaching the site boundary. Original modeling of the muon cone and its emergence angle from the ground (Mu83) indicates that at the site boundary the maximum dose equivalent occurs about 12 meters high in the air, and it is about 13.5 times higher than the ground level value. This corresponds to an annual dose of (182±91) μrem at that elevation.

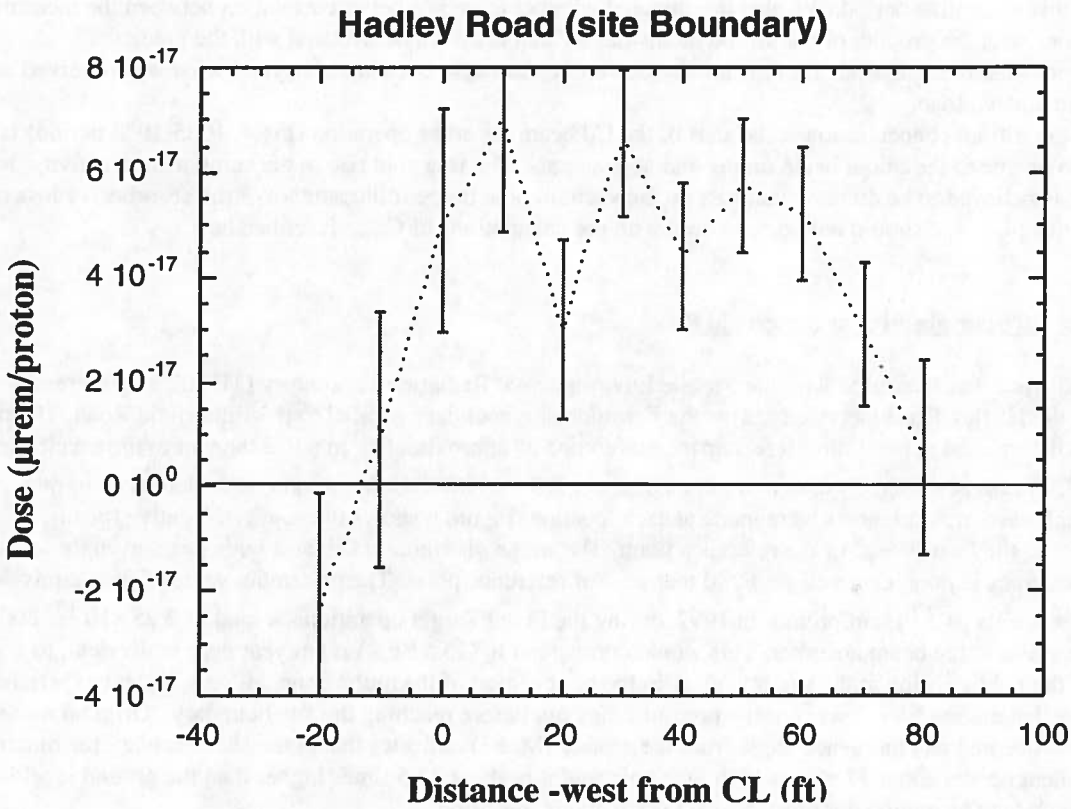


Figure 6: Muon fluence from the C0 beam absorber from the 1997 measurements.

Estimation of the induced tritium activity level in the soil

A knowledge of the induced tritium activity level in undisturbed soil at different radial distances from the absorber will be useful in several ways. This information can be compared with the estimations obtained from the star densities calculated using a CASIM model. Measurements of the activity levels in a soil column placed in a transverse direction to the beam at a loss point may provide a good comparison with results of the model. Similar measurements of the activity in soil in the vicinity of the absorber can provide information about the actual leaching rate and downward migration velocity of the leachates.

Six special cubic soil volumes were added to the C0 beam absorber geometry. The star densities in these special regions of 30cmX30cmX30cm soil volumes were calculated. These volumes were located over the graphite core of the absorber where the star densities are maximal (at z=500 cm). Using these star densities and the yearly proton intensities and including the tritium decay, the present tritium activity concentration have been calculated. Table 4 shows the results of these calculations.

Table 4: Soil tritium activity concentration at heights above the carbon core of the C0 beam absorber.

Height (cm)	Star Density (stars/cm^3)	Tritium Activity Concentration (pCi/cm^3)	Error
398	7.38E-12	1.92E-01	51%
489	4.10E-13	1.06E-02	35%
565	2.16E-14	5.60E-04	39%
665	1.29E-15	3.35E-05	46%
741	8.30E-17	2.15E-06	44%
841	3.54E-17	9.19E-07	85%

Conclusions

Calculations of initial tritium concentrations by use of the CM with S_{ave} at 99% volume and the annual proton intensity tally yields tritium concentration estimates below the yearly average of those observed in the weekly sump samples. However, when the activity is calculated for the underdrain location the agreement seems very reasonable. Both the empirical data and the estimates are well below the DOE tritium concentration guideline of 2000 pCi/ml for surface waters. However, it is apparent that the Concentration Model should be used knowledgeably. Careful treatment of the star density, and saturation assumption improves the predictions. The other parameters used as constants may need to be treated as variables, depending on the geology of the site in question. For example, the values of W and L should be picked to represent the local geological conditions. Inclusion of the annual precipitation does effect this parameter. It is evident that selection of these parameters should be based on the site-specific measurements; use of one recipe for the whole site is not prudent.

There are two other vertical velocities discussed in reference Ma93. One is the high end velocity which is considered very conservative and is about 40 cm/year; the other one is the "modified representative" vertical velocity that was suggested by Woodward-Clyde consultants (Ma93). In the absence of any hydrological data from the area near C0, we were not able to determine which value of vertical velocity best reflects the actual transport velocity of the tritium through the strata. Information from hydrological investigations would allow the selection of the correct vertical transport velocity for the C0 region and provide a record of the actual tritium concentration in the soil below the absorber.

The Main Ring has been dismantled and its magnets will be used in the construction of the Main Injector. Thus, after the Main Injector is on-line, the beam absorber at C0 will no longer receive such high intensities of protons. As such, tritium production in this area will be significantly reduced.

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2. Main Ring Abort System, Abort Plan, Shielding and Beam Pipe Detail. Drawing No. 6-1-64 PA-2.

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4. Tabulation of Off-Site Radiological Parameters. Microsoft Excel™ Spreadsheets maintained by the ES&H Section. 1990-1997.

5. C0 Logbook, maintained by Beams Division ES&H.

6. Precipitation Levels at Fermilab. Data maintained by ES&H Section.

APPENDIX

FORTRAN CODES

APPENDIX

Geometry Coding

```
      SUBROUTINE CASIMGEOM
C **     This version of the C0 absorber has the special volumes in it to
C        figure out the vertical gradient of the activation over
C        the absorber at shower maximum between 300cm and 700cm
C        i.e. at 500cm.
C
C        USER SUBROUTINE DESCRIBING PROBLEM GEOMETRY
C
C        GIVEN ( X,Y,Z ) IN CM, ENTRY USRGEOM RETURNS
C                MATERIAL INDEX N (GE.-1  AND LE.9)
C                MAGNETIC REGION INDEX M (GE.0)
C
C        CONVENTIONS NM=-1 VACUUM WITH MAGNETIC FIELD PRESENT
C                    0 VACUUM  NO  MAGNETIC FIELD PRESENT
C                    1-9 MATERIALS
C                    99 Outside of defined geometry
C
C
      IMPLICIT NONE
      SAVE
C
C========================= Include HIBI.CIN ==========================
C  HIBI
C
      REAL ZLIM, RLIM
C
      COMMON/HIBI/ ZLIM, RLIM
C============================ End Include ============================
C
      INTEGER N, M, KT
C
      REAL X, Y, Z, XM, YM, ZM, R
      REAL RTUN, RMAG, XTAR, YTAR, RPIP
      real x_in_l,x_in_r,x_out_l,x_out_r
      real y_in_u,y_in_d,y_out_u,y_out_d
      real TX_l,TX_r,TY_u,TY_d
      real TX_l2,TX_r2,TY_u2,TY_d2
      real z0,z1,z2,z3,z4,z5,z6,z7
      real AX1,AX2,Ay1,Ay2
      real XG_l,XG_r,YG_u,YG_d
      real r_soil_limit,RLIS,RR
      real Y1u,Y1d,Y2u,Y2d,Y3u,Y3d,Y4u,Y4d
      real Xsl,Xsr,Zsu,Zsd
C
C-----------------------------------------------------------------
C Hard-wire the limits to your geometry here.  This section gets
C called once per Job.  The 'SAVE' above insures that values set
C are retained after the subroutine is exited.
C
       ZLIM=2000.          ! 65.6 feet
       RLIM=1500.            !49.2 feet
C
C
C THIS SECTION IS WHERE THE PROBLEM DIMENSIONS ARE ADJUSTED
```

APPENDIX

Geometry Coding

```
C
   RLIS=RLIM*RLIM
C
   RETURN
C-----------------------------------------------------------
C
C This section gets called whenever CASIM wants to check what material
C a particle is in, given X, Y, Z
C
   ENTRY USRGEOM(X,Y,Z,N,M,KT,XM,YM,ZM)
C
C                X,Y,Z ARE "LAB" COORDINATES
C                XM,YM,ZM      ARE "MAGNET" COORDINATES
C                IN PRESENT EXAMPLE THEY ARE IDENTICAL
C
C Keep these 5 lines here, always.  CASIM needs the counter KT, and needs to
C know when the counter has gone beyond it's limit
   KT=KT+1
   IF(KT.GT.10000) THEN
        N = 99
        RETURN
   ENDIF
C
C Set N=0 until we know if we are in some other material
   N=0
C
C Set M=0 until we know if we are in a field region
   M=0
C
C==================================================================
C
   IF(Z.GE.ZLIM) then
    return
   ENDIF
   IF(Z.LE.0.) RETURN
   KT=KT+1
   IF(KT.GE.5000) RETURN
   RR=X*X+Y*Y
   IF(RR.GE.RLIS) RETURN
   XM=X
   YM=Y
   ZM=Z
C
C THIS SECTION IS WHERE THE PROBLEM GEOMETRY RESIDES
C don't want to use symmetry here
c    AX=ABS(X)
c    AY=ABS(Y)
C
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C THIS SECTION IS WHERE THE PROBLEM GEOMETRY RESIDES
C
C ******  in my input file  ******
C                N=0 Vacuum
C                N=1 is soil
```

APPENDIX

Geometry Coding

```
C                N=2 is concrete
C                N=3 is iron
C                N=4 is aluminum box
C                N=5 is dump material(graphite)
C                N=6 is granular fill
C                N=7 is a rectangular box
C                N=8 is a rectangular box
C                N=9 is a rectangular box
C                N=10 is a rectangular box
CC coordinates w.r.t. beam in z direction
CC start at (0,0,0) at the entrance to the granular fill around the
CC absorber on the beam line
CC ** looking down stream of beam **

      X_IN_l=-114.3        !inside of left wall
      X_IN_r=68.6          !inside of right wall
      X_OUT_l=-127.0       !outside of left wall
      X_OUT_r=81.3         !outside of right wall
      Y_IN_u=116.8         !inside roof
      Y_OUT_u=131.0        !outside roof
      Y_IN_d=-106.7        !inside floor
      Y_OUT_d=-127.0       !outside floor
      TX_r=22.9   !target half width(Al+C)
      TX_l=-22.9  !target half width(Al+C)
      TY_u=15.2   !target half height(Al+C)
      TY_d=-15.2  !target half height(Al+C)
      TX_r2=15.2  !target half width(C)
      TX_l2=-15.2 !target half width(C)
      TY_u2=7.62  !target half height(C)
      TY_d2=-7.62          !target half height(C)
      AX1=81.28      !x-start of iron appendage
      AX2=127.       !x-stop  of iron appendage
      AY1=45.72      !y-up of iron appendage
      AY2=-45.72     !y-down  of iron appendage
      XG_l=-238.56    !left-rectangular equivalent of the granular fill
      XG_r=168.40     !right-rectangular equivalent of the granular fill
      YG_u=180.34     !up-rectangular equivalent of the granular fill
      YG_d=-167.13    !down-rectangular equivalent of the granular fill
      Xsl=-15.       !left x-extent of special box
      Xsr=15.        !right x-extent of special box
      Y1u=856.        !height above core center-special volume 1
      Y1d=826.        !height above core center-special volume 1
      Y2u=680.        !height above core center-special volume 2
      Y2d=650.        !height above core center-special volume 2
      Y3u=504.        !height above core center-special volume 3
      Y3d=474.        !height above core center-special volume 3
      Y4u=328.        !height above core center-special volume 4
      Y4d=298.        !height above core center-special volume 4
      Zsu=485.       !approx. longitudinal US of middle of shower max
      Zsd=515.       !approx. longitudinal DS of middle of shower max
      Z0=129.54       !start of concrete face upstream of absorber
      Z1=160.04   !end of beam pipe-start of iron+aluminum
      Z2=617.24   !end of iron+aluminum-start of iron
      Z3=891.54   !end of iron- start of concrete wall
```

Geometry Coding

```
      Z4=982.94    !end of concrete wall
      Z5=215.94      !start of iron appendage between the dump and tunnel
      Z6=764.54      !end of iron appendage between the dump and tunnel
      Z7=1112.48     !longitudinal End of the granular fill
C     R_SOIL_LIMIT=762.*762.              !25.FT  unprotected soil outer boundary
      R_SOIL_LIMIT=1219.2*1219.2          !40.FT  unprotected soil outer boundary
C***********unprotected soil***************
      IF(RR.LT.R_SOIL_LIMIT)then
          N=1                             !soil
      ELSE
          N=0    ! R>40 ft air(vacuum)
      ENDIF
C+++++++++++ Beam absorber +++++++++++++++++
      if(Z.gt.0.0)then                    !start granular fill
C********** Granular fill in front and around the tunnel
      if(x.gt.XG_l.and.x.lt.XG_r)then
       if(y.gt.YG_d.and.y.lt.YG_u)then
          N=6
       endif
      endif
C************ concrete face with square hole the size of the Al box
      if(z.lt.Z1.and.z.gt.z0)then
       If(x.gt.x_out_l.and.x.lt.x_out_r)then
        if(y.gt.y_out_d.and.y.lt.y_out_u)then
           N=2
        endif
       endif
      endif
C*********** beam pipe hole to absorber **********
      if(z.lt.z1)then
C there is vacuum up to the absorber
       If(x.gt.Tx_l.and.x.lt.Tx_r)then
        if(y.gt.Ty_d.and.y.lt.Ty_u)then
           N=0        !Vacuum pipe
        endif
       endif        !end of beam
      endif
C***********concrete rectangular*****************
      IF(z.ge.Z0.and.z.le.Z4)then
C  Tunnel walls are 5in thick, floor in 8in
C****right SIDE WALLS
      IF(x.ge.x_in_r.AND.x.le.x_out_r)THEN
       IF(y.Gt.y_in_d.AND.y.lt.y_in_u)THEN
                N=2
           ENDIF
      ENDIF
C****left SIDE WALLS
      IF(x.ge.x_out_l.AND.x.le.x_in_l)THEN
       IF(y.Gt.y_in_d.AND.y.lt.y_in_u)THEN
                N=2
           ENDIF
      ENDIF
C**** ROOF
      IF(y.le.y_out_u.AND.y.ge.y_in_u)THEN
```

Geometry Coding

```
      IF(X.Ge.X_out_l.AND.X.Le.X_OUT_r)THEN
                N=2
          ENDIF
    ENDIF
C**** floor
    IF(y.le.y_in_d.AND.y.ge.y_out_d)THEN
      IF(X.Ge.X_out_l.AND.X.Le.X_OUT_r)THEN
                N=2
          ENDIF
    ENDIF
C*****Iron
     if(Z.ge.Z1)then
    IF(y.lt.y_in_u.AND.y.gt.y_in_d)THEN
      IF(X.Gt.X_in_l.AND.X.Lt.X_in_r)THEN
                N=3
          ENDIF
    ENDIF
C--------------ABSORBER REGION-------------------
    if(Z.ge.Z1.AND.Z.le.Z2)then
C*****Absorber core material
     IF(y.le.Ty_u.AND.y.ge.Ty_d)THEN
      IF(x.GE.Tx_l.AND.x.LE.Tx_r)THEN
                N=4      !Aluminum
          ENDIF
     ENDIF
     IF(y.lt.Ty_u2.AND.y.gt.Ty_d2)THEN
      IF(x.GT.Tx_l2.AND.x.LT.Tx_r2)THEN
                N=5      !Graphite
          ENDIF
     ENDIF
    endif !end of the core of the absorber
C---------------------------------
     endif                    !end of iron
C+++++++++++concrete end wall of the c0 beam absorber
     if(z.gt.z3.AND.z.le.z4)then
      if(y.le.y_out_u.AND.y.ge.y_out_d)then
       if(x.le.x_out_r.AND.x.ge.x_out_l)then
                N=2
       endif
      endif
     endif
C************ End of concrete tunnel *****
     ENDIF
C++++++++++++END of granular fill +++++++++++++++++++
     if(z.gt.z7)then
                N=1                !soil
     endif
C++++++++++Iron Appendage between the absorber and the TeV Tunnel
     if(z.gt.z5.and.z.lt.z6)then
      if(x.gt.AX1.and.x.lt.AX2)then
       if(y.gt.AY2.and.y.lt.AY1)then
          N=3
       endif
      endif
```

Geometry Coding

```
      endif
C-------------------------------------------
     endif            !end of granular fill
C::::::::::::::special volumes::::::::::::::::::::::::::
     if(z.gt.Zsu.and.z.lt.Zsd)then
      if(x.gt.Xsl.and.x.lt.Xsr)then
       if(y.gt.Y1d.and.y.lt.Y1u)then
         N=7
       else if(y.gt.Y2d.and.y.lt.Y2u)then
            N=8
          else if(y.gt.Y3d.and.y.lt.Y3u)then
               N=9
c              else if(y.gt.Y4d.and.y.lt.Y4u)then
c                   N=10
       endif
      endif
     endif
C:::::::::: END OF SPECIAL VOLUMES ::::::::::::::::::::
C
C THIS SECTION IS WHERE THE PROBLEM GEOMETRY ENDS
C
     RETURN
     END
```

Data File

```
! The first lines hold the list of customized files you need to run
! your CASIM geometry.  The two listed here are the MINIMUM you need, and
! should always be there.  If you gave the CASIMGEOM file a customized name,
! then you need to edit that name here in place of CASIMGEOM.FOR.
! Add more files as needed, add them as new lines below these two,
! 1 file-name per line, left-justified.
CASIM.FOR
CASIMGEOMS.FOR
GEOMVIEW.FOR
!!!!!!!!!!!! The CASIM Input Deck information starts below this line !!!!!
     1    1000.    0.3      0.12    0.068     1.0    150000
  0  1    1    1 123456789  1.E-18     5.0       5.0
     9
  10.7     21.6     2.25    135.0   12.30     3.62      0.162
  11.4     22.9     2.40    143.0   10.90     3.69      0.171
  26.0     55.8     7.87    288.     1.80     4.97      0.385
  13.0     26.98    2.70    159.95   8.99     3.90      0.199
   6.0     12.01    1.71     86.02  25.15     2.98      0.095
  11.4     22.9     1.92    142.65  13.61     3.69      0.171
  10.7     21.6     2.25    135.0   12.30     3.62      0.162
  10.7     21.6     2.25    135.0   12.30     3.62      0.162
  10.7     21.6     2.25    135.0   12.30     3.62      0.162
!!!!!!!!!!!
```