EXP-205

Booster Long 13 Irradiation Studies

6/30/98

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INTRODUCTION

Extraction from the Booster to the Main Ring occurred at Long Straight 13. The nature of the extraction process was such that 1% to 2% of the beam was lost in this region. There was an appreciable amount of beam extracted as shown in Table I, which gives the yearly integrated intensities from 1973 to 1997. A simple model of the extraction losses was set up by Chandra Bhat utilizing the program CASIM. A sample output I shown in figure 1 which gives contours of stars/cm3 in the dirt, also schematically depicted are the three six feet deep sampling holes which were drilled to map out this cascade.

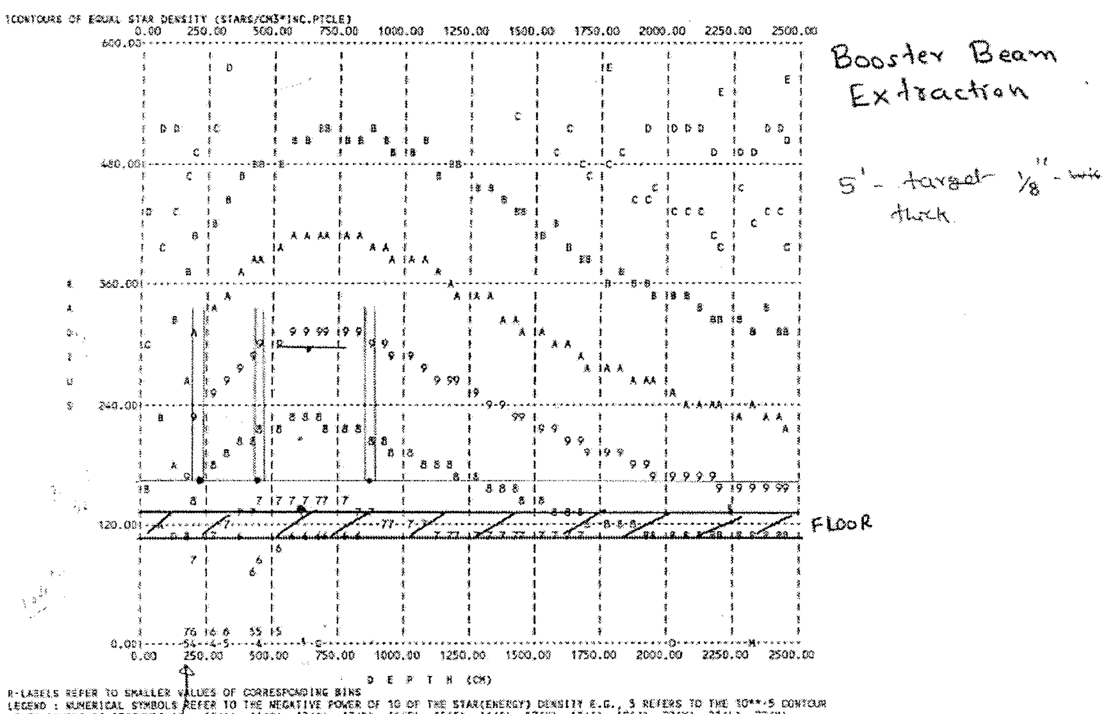

Figure 1. Sample CASIM output for Booster extraction. The target is at z = 150 cm.

YEAR	INTENSITY (1E19) PROTONS
1973	
1974	1.48
1975	1.95
1976	2.33
1977	3.00
1978	2.51
1979	3.25
1980	1.36
1981	2.00
1982	2.24
1983	.003
1984	.131
1985	.608
1986	.152
1987	1.31
1988	.737
1989	.557
1990	.501
1991	.725
1992	1.07
1993	.971
1994	1.36
1995	1.68
1996	.871
1997	1.13

TABLE I. BOOSTER YEARLY INTEGRATED INTENSITY

As a check we did a survey of the concrete floor every foot starting at Booster magnet 12-3 and figure 2 shows the results also with location of the sampling holes.

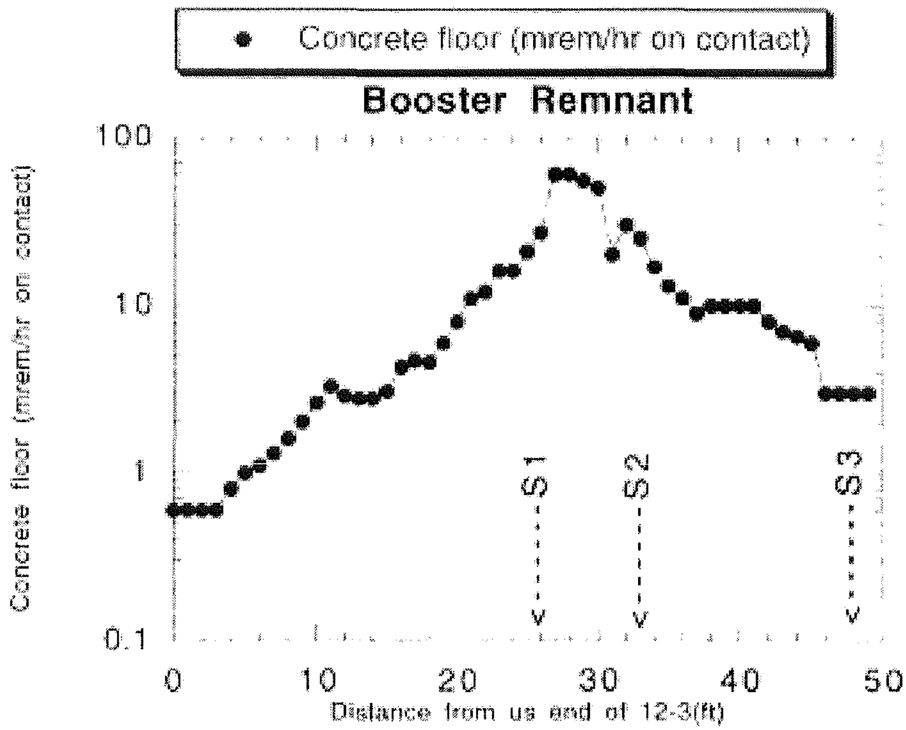

Figure 2. Longitudinal radiation survey in the vicinity of MPO1. The sampling holes are marked

This survey (and a survey of the magnets themselves) shows that losses start occurring well upstream of the extraction septum MP01 while the model assumes all the losses started at MP01, however the bulk of the losses did occur on the septum and as we will observe, the predicted activation in the top sample of hole S2 by the model is in reasonable agreement with the experimental data. Figure 3 gives a cross section of the Booster tunnel along with an indication of the location of the sampling holes and the location of the aquifer.

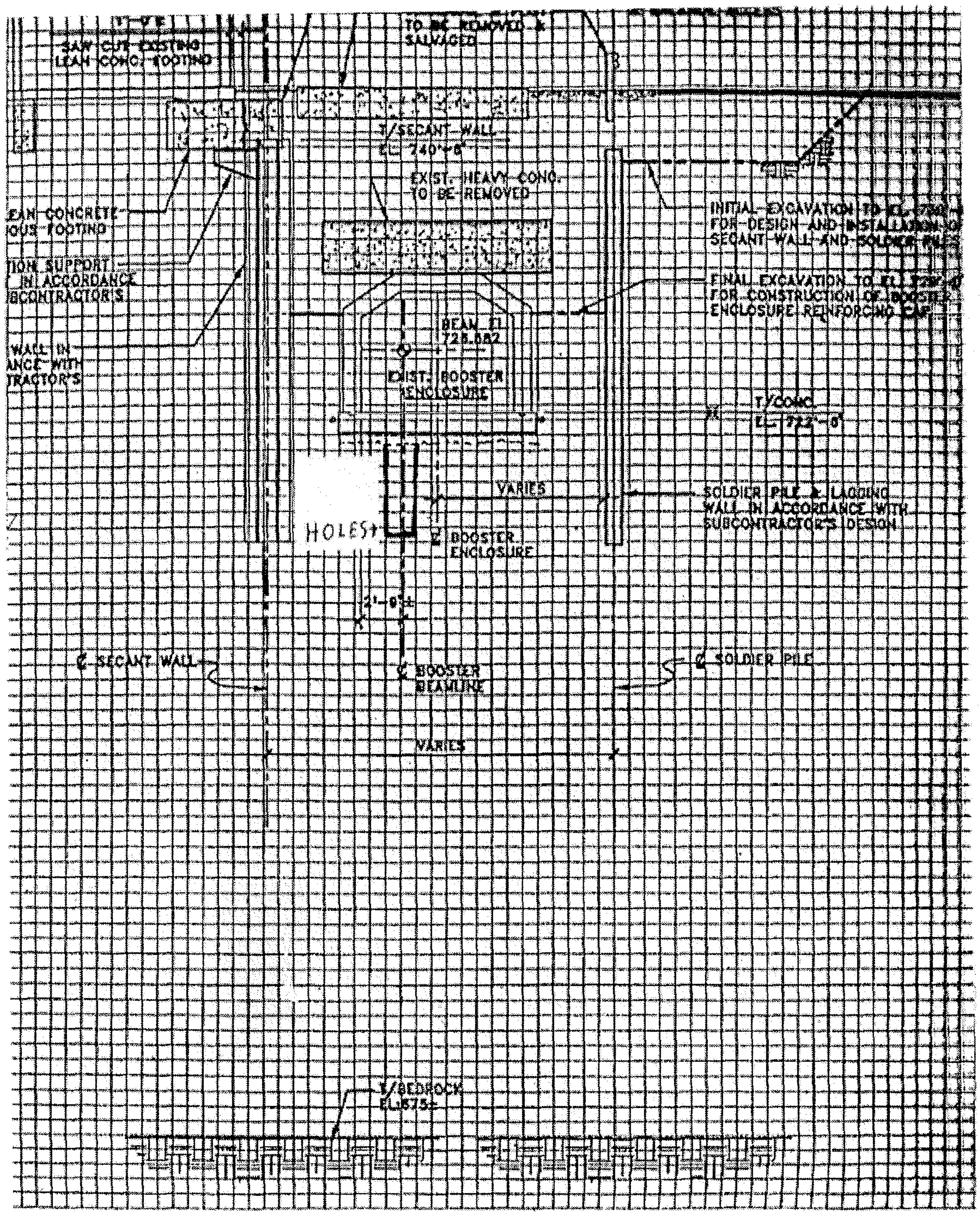

Figure 3. Booster tunnel schematic

DATA ANALYSIS

The core borings were analyzed by the Fermilab ES$H section for radionuclide production in a spacing of approximately one foot increments. The raw data is given in appendix 1. When dealing with real life samples of dirt one can not have exact reproducibility of lengths and spacing; however a great deal of effort was taken to examine 6" samples every foot, and the data appears to behave reasonably. Examining the production of Sodium 22 depicted in figure 4 we see that the pattern is roughly what one would expect from figure 2, i.e. the amount of Na22 in holes S1 and S2 is approximately equal and much larger than in S3.

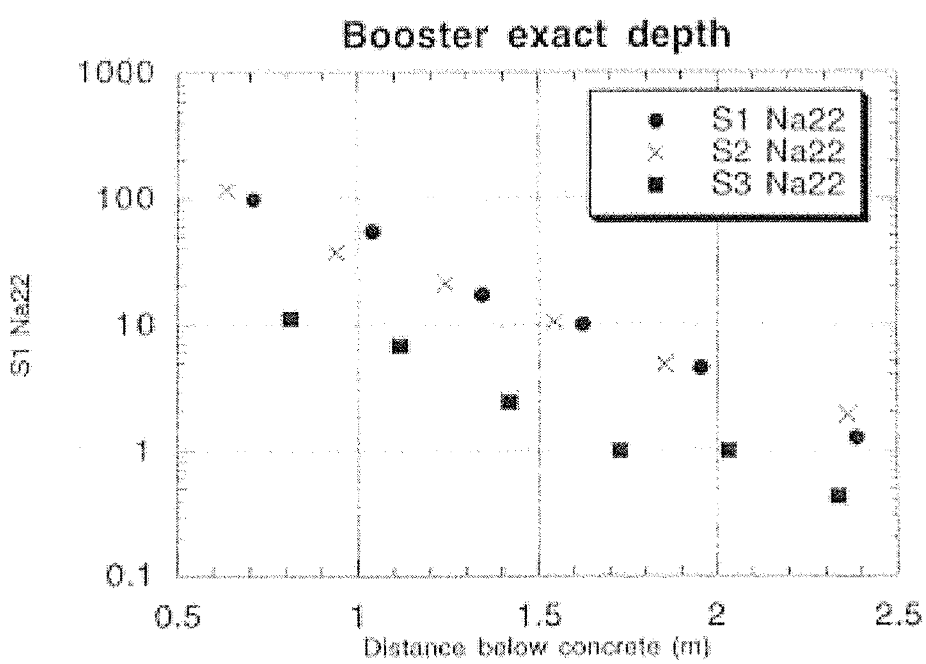

Figure 4. Spatial pattern of Na22 production in the three sampling holes.

CASIM predicts that the distribution of star density in a thick shield goes as exp[-2.5*r] where r is in meters. Hence one would expect that if there were no migration of nuclides then the pattern of activation would follow this simple exponential. Figure 5 shows the spatial distribution of three nuclides from hole S2 compared to this simple functional form and there is a clear relationship that indicates that the parameterization is reasonable and that there has been no migration of these nuclides.

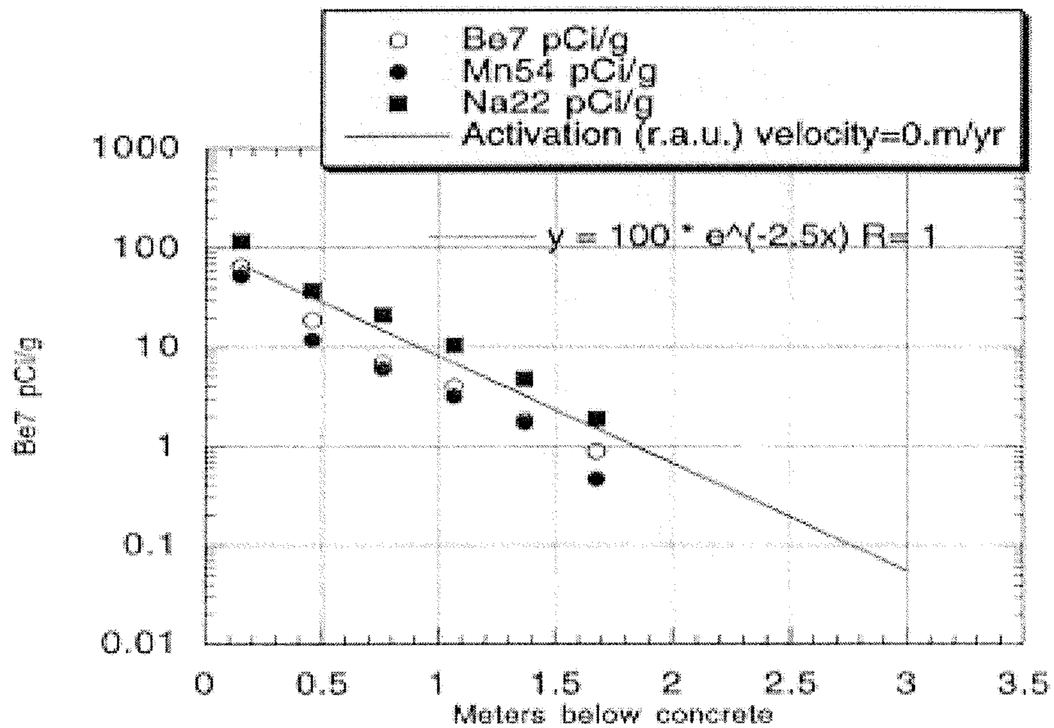

Figure 5. Nuclide Spatial Pattern in hole S2 compared to CASIM pattern prediction

There is an interesting observation that one can draw from the experimental data as shown in figure 6. It is apparent that one can estimate the production of certain other isotopes once one has predicted the Na22 production for regions in a thick shield. This is from the fact that the ratios shown in figure 6 are nearly flat over the region sampled even though the momentum spectrum and particle composition varies along the cascade.

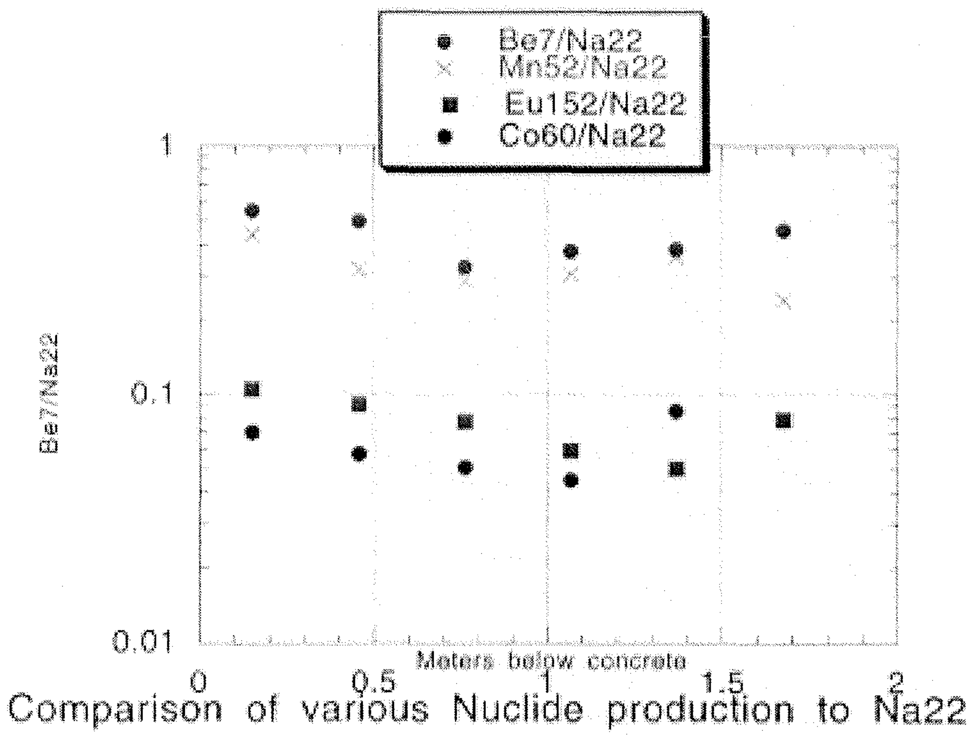

Figure 6. Comparison of the production of various nuclides to Na22 in hole S2 as a function of depth.

The data for tritium production in holes S1 and S2 are presented in figure 7 along with the parameterization used for the other nuclides. It is obvious that the exponential is not a good representation of the spatial pattern of the tritium. This is evidence for vertical migration of the tritium.

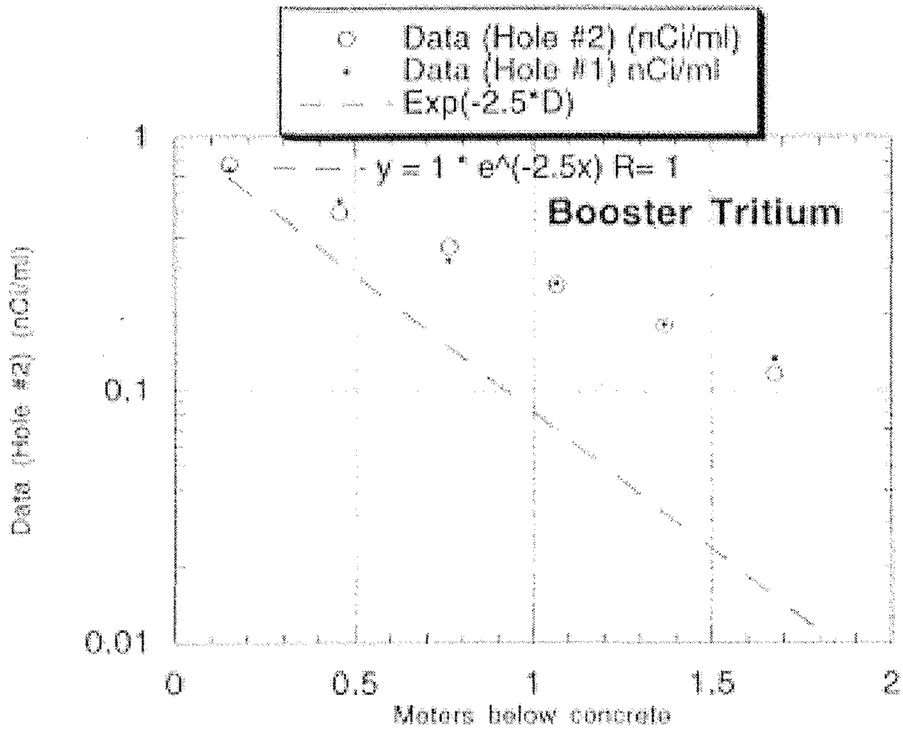

Figure 7. Tritium spatial production compared to a simple exponential parameterization.

We will discuss the analysis of the migration after first discussing the absolute calculation of nuclide production in the top sample of hole S2. In discussing the production of nuclides from accelerator operations one needs to incorporate the time history of the intensity as documented in Table I. We have made a simplifying assumption of uniform irradiation for the nuclide production, however we have used varying lengths of time in calculating the average intensity based upon the behavior of the build up factors shown in figure 8.

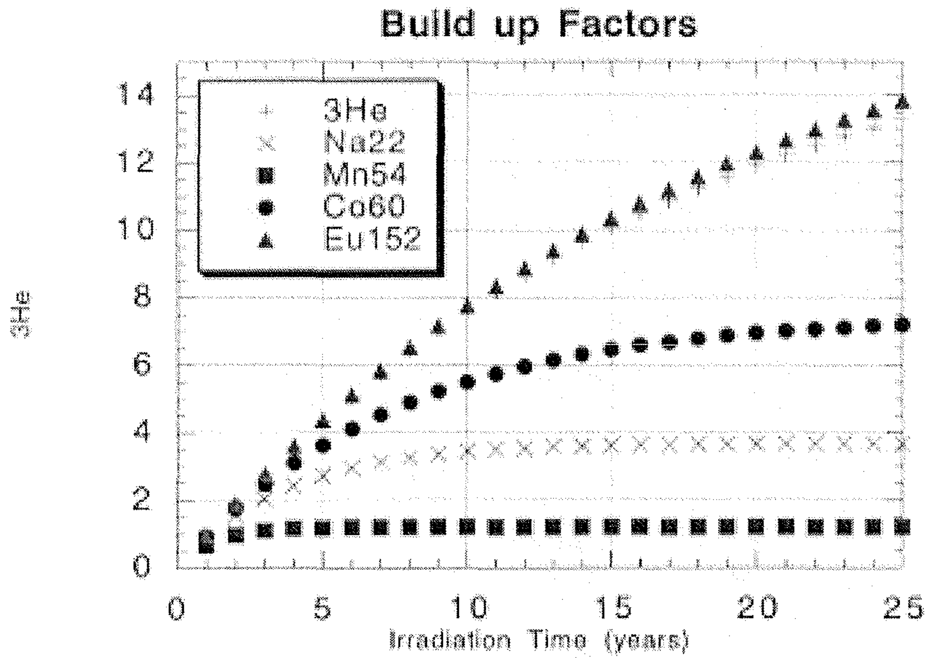

Figure 8.

Table II gives the results for several isotopes along with two different assumptions for the length of time for the tritium irradiation because of the obvious downward migration of the tritium from the top:

A_i= specific activity per gram (pCi/gm) = (BFi/ τ_i)*N*S* K_i/(1.17E6* ρ)

N = the average number of protons per year for the appropriate irradiation time, T N.B. remember there is an assumed loss of .02 (1E19 protons)

S = the number of stars per cubic centimeter per proton in the unprotected region: 7E-8.

K_i = the probability per star that an atom of nuclide I will be produced

τ_i = the mean lifetime of nuclide I (yr)

1.17E6 = converts disintegrations per second into picoCuries (.037) and years into seconds (3.15E7)

ρ = density of soil, 2.25 g/cm^3

BFi = build-up factor = $\tau_i * (1 - e^{-T/\tau_i}) * e^{-Tc/\tau_i}$

Tc = cool down time, or time from end of irradiation to the start of the counting, actually the counts have been corrected for this

Nuclide	K_i	τ_i(yr)	T(yr)	N(E19)	BFi	BFi/ τ_i	A_i	Data
H3	.075	17.5	10	.9	7.63	.436	156	269
H3	.075	17.5	24	1.33	13.1	.746	395	269
Na22	.02	3.68	10	.9	3.5	.95	91	118
Mn54	.004	1.21	5	1.2	1.2	1	25	52
Co60	.003	7.45	24	1.33	7.19	.97	20.6	8.3
Eu152	.01	18.8	24	1.33	13.8	.73	51.5	12.4

Table II. Parameters in calculation of specific activity, A_i.

Figure 9 shows the comparison of the predicted versus experimental nuclide production in the top sample of hole S2. The agreement over the range of data is impressive considering that this was not a controlled experiment. The agreement shows that we have some handle on the modeling and the intensity history since this is an absolute calculation.

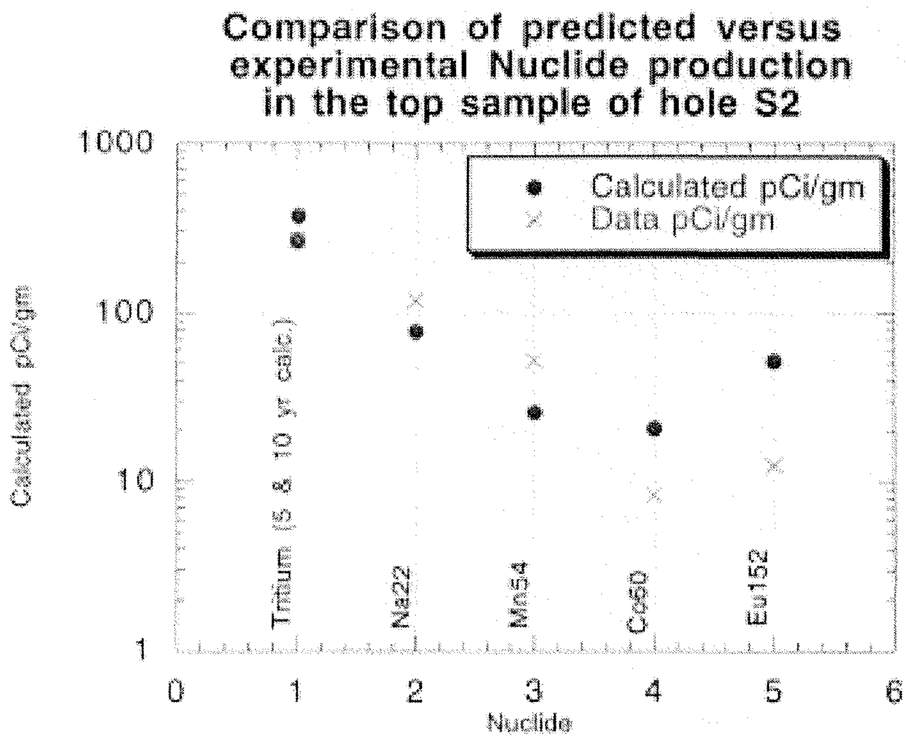

Figure 9.

There are two points for tritium with two differing assumptions about the length of irradiation. This is the top sample and any migration would lead to a diminution in expected specific activity. Please note for tritium that this is the amount produced in the soil and the concentration reported by the Analysis Laboratory is the result of boiling off the water (hence the difference between 777 pCi/ml and 269 pCi/gm, i.e. there has been a volume correction applied to the data for comparison to the CASIM prediction).

One unknown in considering the spatial pattern of the tritium is the vertical migration rate. We have attempted to determine this factor by examining the spatial pattern of the tritium at one point in time (namely the day the core samples were taken). A crude model showed that the spatial pattern could take very different shapes depending on the assumed migration rate, hence a sophisticated model incorporating the irradiation history, an improved cascade simulation utilizing MARS, and differing migration rates was developed. The results are shown in figure 10 comparing the model, with different vertical migration rates, to the experimental data for Hole S2. As shown before the results are clearly inconsistent with a zero migration rate, but they are also clearly inconsistent with a rate of .15m/yr. A reasonable number is .03 m/yr that gives a shape which resembles the data; there is a discrepancy with the first point but the overall pattern clearly approximates the data better than the other two curves shown. Also the top sample is the one in which horizontal migration might be most important due to the construction of the Booster tunnel. A copy of the FORTRAN program used for this study is included in Appendix II.

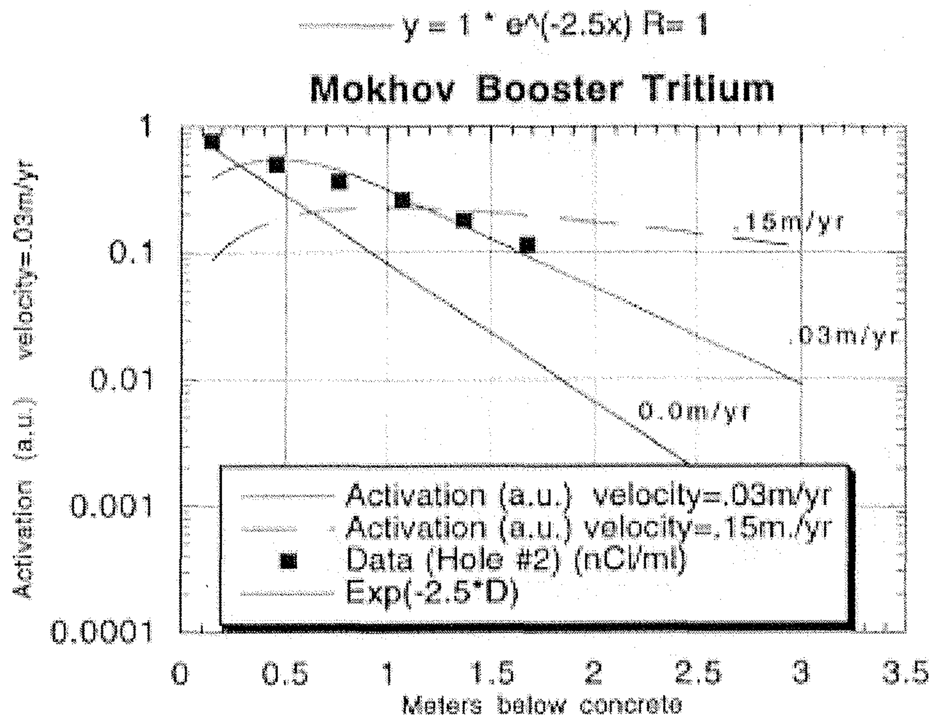

Figure 10. A comparison of the experimental spatial distribution of tritium to a model which has the vertical migration rate as an adjustable parameter. Three different rates are shown

CONCLUSION

One aspect of this study has been the study of the production of non-migrating nuclides and further study may in fact yield better values for the K parameter (the probability per star that an atom of the particular nuclide will be produced. Also the results of this study can give experimental numbers for the production of other nuclides when the amount of Na22 has been calculated.

However the most important part of this study has been the determination of the amount of tritium produced by extraction from the Booster and the experimentally determined migration rate. If we look at the top sample result in hole S2 of 777 pCi/ml of tritium and use the experimentally determined rate of migration and the depth to the aquifer of 13.1m, we calculate that the concentration will have decayed away to 1.1E-8 pCi/ml. If we look at the bottom sample, which is 11.3 m away from the aquifer, we calculate that the 116 pCi/ml will have decayed to 5.2E-8 pCi/ml. Our conclusion is that the rate of migration determined over the 24 year irradiation history of the Booster extraction point is small enough that there is no problem with migration of tritium to the aquifer.

APPENDIX I.
ACTIVATION ANALYSIS REPORTS

Fermilab
ES&H Section/AAL

Activation Analysis Lab Report

LSC Analysis Report

issued by Steven Benesch

Date: Nov. 6, 1997

Work Request #: 97-293 *Priority Sample*

Submitted by: D. White on 10/31/97

Workbook #: LSC 2750-2, page 150-151

Two (2) water samples distilled from soil borings from the Beams Division, ES&H group were analyzed on 11/5/97 for tritium content on a Packard model 2750TR/LL Tri-Carb LSC analyzer as noted on the Work Request listed above. The numbers quoted below represent the arithmetic average of 2 determinations counted for 60 minutes each, and the error is the standard deviation of those measurements or the statistical error, whichever is larger. Sample activity is reported as of the date of counting in pCi/ml from the distillate that was recovered from the sample.

Sample ID #	Work Req. #	Sample Description	Radionuclide	Activity (pCi/ml)
971030TL01	97-293w1	MP01 Soil Boring 22"-28" Distillate	^{3}H	777 ± 5
971030TL02	97-293w2	MP01 Soil Boring 90"-96" Distillate	^{3}H	116 ± 2

cc: T. Busch, MS-371
T. Leveling, MS-371
C. Moore, MS-341
V. Cupps
S. Benesch
AAL Folder

BD-MP01 Soil Borings.97-293 skb

Fermilab
ES&H Section/AAL

Activation Analysis Lab Report

LSC Analysis Report

issued by Steven Benesch

Date: Dec. 22, 1997

Work Request #: 97-303 *Priority Handling* - Complete Report

Submitted by: M. Ferguson on 11/4/97

Workbook #: LSC 2750-3, page 25-26, 27-28, 29-30 & 31-32

Seventeen (17) water samples distilled from soil borings from the Beams Division, ES&H group. They were analyzed on the dates noted below for tritium content on a Packard model 2750TR/LL Tri-Carb LSC analyzer as noted on the Work Request listed above. The numbers quoted below represent the arithmetic average of 2 determinations counted for 60 minutes each, and the error is the standard deviation of those measurements or the statistical error, whichever is larger. Sample activity is reported as of the date of counting in pCi/ml from the distillate that was recovered from the sample.

Sample ID #	Work Req. #	Sample Description	Radionuclide	Activity (pCi/ml)
Samples Analyzed On 12/1/97				
971030TL03	97-303-1	MP01 S2 Soil Boring 34"-40" Distillate	^{3}H	500 ± 3
971030TL04	97-303-2	MP01 S2 Soil Boring 46"-52" Distillate	^{3}H	369 ± 3
971030TL05	97-303-3	MP01 S2 Soil Boring 58"-64" Distillate	^{3}H	260 ± 1
971030TL06	97-303-4	MP01 S2 Soil Boring 70"-76" Distillate	^{3}H	180 ± 2
Samples Analyzed On 12/11/97				
971030TL07	97-303-5	MP01 S2 Soil Boring 82"-90" Distillate	^{3}H	132 ± 1
971030TL14	97-303-C	MP01 S1 Soil Boring 26"-30" Distillate	^{3}H	738 ± 4
971030TL15	97-303-D	MP01 S1 Soil Boring 38"-44" Distillate	^{3}H	561 ± 3
971030TL16	97-303-E	MP01 S1 Soil Boring 50"-56" Distillate	^{3}H	325 ± 2
971030TL17	97-303-F	MP01 S1 Soil Boring 62"-66" Distillate	^{3}H	263 ± 1
971030TL18	97-303-G	MP01 S1 Soil Boring 74"-80" Distillate	^{3}H	182 ± 1
971030TL19	97-303-H	MP01 S1 Soil Boring 92"-96" Distillate	^{3}H	88.8 ± 0.8
Samples Analyzed On 12/17/97				
971030TL08	97-303-6	MP01 S3 Soil Boring 29"-35" Distillate	^{3}H	147 ± 1
971030TL09	97-303-7	MP01 S3 Soil Boring 41"-47" Distillate	^{3}H	117 ± 1
971030TL10	97-303-8	MP01 S3 Soil Boring 53"-59" Distillate	^{3}H	88.9 ± 0.9
971030TL12	97-303-A	MP01 S3 Soil Boring 77"-83" Distillate	^{3}H	48.7 ± 0.6
Samples Analyzed On 12/19/97				
971030TL11	97-303-9	MP01 S3 Soil Boring 65"-71" Distillate	^{3}H	64.8 ± 0.7
971030TL13	97-303-B	MP01 S3 Soil Boring 89"-95" Distillate	^{3}H	38.3 ± 0.5

cc: T. Busch, MS-371 T. Leveling, MS-371 G. Lauten, MS-371 C. Moore, MS-341
V. Cupps S. Benesch D. Cossairt R. Walton
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BD-MP01 Soil Borings 97-303 skb

Fermilab
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Activation Analysis Laboratory
Gamma Analysis Report

issued by Steven Benesch

Report Date: Nov. 6, 1997
Work Request #: 97-293 ***Priority Handling***
Submitted by: D. White on 10/31/97
Workbook #: Ge #8, page 65-69

MP01 Soil Boring Samples

Two (2) soil samples submitted by Beams Division, ES&H Group were analyzed for accelerator-produced radionuclides. Each sample was distilled and the distillate counted for 64,800 seconds and the dried soil was counted for 7,200 seconds. Both samples were counted at 1.2234 cm on detector Ge(Li)#1. The soil samples contained levels of ^{40}K above the normal detector background levels. Because ^{40}K can be produced by the accelerator as well as being in the natural background, no determination can be made as to the source of this activity. The ^{40}K activities listed below are shown with the natural background level removed and the activity calculated on the above background values.

The following table lists the radionuclides detected in the sample, along with the corresponding specific activity. If a sample activity has been reported it has been corrected back to the time of sampling.

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity (pCi/ml)
971030TL01	97-293w1	MP01 Soil Boring 22"-28" Distillate	125ml poly	32.0 ml	11/3/97 @ 15:17		None Detected

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Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity (pCi/g)
971030TL01	97-293s1	MP01 Soil Boring 22"-28" Dried Soil 15.3% Moisture	125ml poly	159.6 g	11/4/97 @ 09:46	^{7}Be	65.5 ± 11.5
						^{54}Mn	52.4 ± 9.1
						^{60}Co	8.33 ± 1.04
						^{22}Na	118 ± 21
						^{152}Eu	12.4 ± 1.3
						^{51}Cr	4.33 ± 1.84
						^{59}Fe	1.11 ± 0.24
						^{46}Sc	6.94 ± 0.86
						^{134}Cs	1.17 ± 0.19
						^{40}K	17.5 ± 3.2

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity(pCi/ml)
971030TL02	97-293w2	MP01 Soil Boring 90"-96" Distillate	125ml poly	32.0 ml	11/4/97 @ 14:57		None Detected

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity(pCi/g)	
971030TL02	97-293s2	MP01 Soil Boring 90"-96" Dried Soil 13.6% Moisture	125ml poly	138.9 g	11/05/97 @ 10:31	^{7}Be	0.88 ± 0.37	S 2
						^{54}Mn	0.46 ± 0.08	
						^{22}Na	1.91 ± 0.35	
						^{40}K	21.4 ± 4.1	

cc: T. Leveling, MS-371   T. Busch, MS-371   C. Moore, MS-341
V. Cupps   S. Benesch   AAL Folder

Fermilab
ES&H Section/AAL

Activation Analysis Laboratory
Gamma Analysis Report
issued by Steven Benesch SKB

Report Date: Dec. 22, 1997
Work Request #: 97-303 ***Priority Handling***
Submitted by: M. Ferguson on 11/4/97
Workbook #: Ge #8, page 70-76, 80-98

Complete Report – MP01 Soil Boring Samples

Seventeen (17) soil samples, submitted by Beams Division ES&H Group, were analyzed for accelerator-produced radionuclides. Each sample was distilled and the dried soil was counted for 7,200 seconds at 1.2234 cm on detector Ge(Li)#1. The soil samples contained levels of ^{40}K above the normal detector background levels. Because ^{40}K can be produced by the accelerator as well as being in the natural background, no determination can be made as to the source of this activity. The ^{40}K activities listed below are shown with the natural background level removed and the activity calculated on the above background values.

The following table lists the radionuclides detected in the sample, along with the corresponding specific activity. If a sample activity has been reported it has been corrected back to the time of sampling.

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity(pCi/g)
971030TL03	97-303-1	MP01 Soil Boring 34"-40" Dried Soil 13.6% Moisture	125ml poly	135.0 g	11/25/97 @ 08:26	^{7}Be	18.7 ± 3.9
						^{54}Mn	12.0 ± 2.1
						^{60}Co	2.14 ± 0.30
						^{22}Na	37.3 ± 6.5
						^{152}Eu	3.38 ± 0.42
						^{46}Sc	1.91 ± 0.31
						^{134}Cs	0.48 ± 0.11
						^{40}K	20.5 ± 4.1
971030TL04	97-303-2	MP01 Soil Boring 46"-52" Dried Soil 14.7% Moisture	125ml poly	148.4 g	11/26/97 @ 07:32	^{7}Be	6.89 ± 2.03
						^{54}Mn	6.08 ± 1.09
						^{60}Co	1.06 ± 0.17
						^{22}Na	21.0 ± 3.7
						^{152}Eu	1.62 ± 0.25
						^{46}Sc	0.96 ± 0.20
						^{40}K	25.0 ± 4.7

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity(pCi/g)
971030TL05	97-303-3	MP01 Soil Boring 58"-64" Dried Soil 14.4% Moisture	125ml poly	134.5 g	11/25/97 @ 10:52	^{7}Be	3.98 ± 1.40
						^{54}Mn	3.23 ± 0.59
						^{60}Co	0.47 ± 0.10
						^{22}Na	10.5 ± 1.9
						^{152}Eu	0.62 ± 0.14
						^{46}Sc	0.63 ± 0.13
						^{40}K	19.8 ± 3.8
971030TL06	97-303-4	MP01 Soil Boring 70"-76" Dried Soil 14.5% Moisture	125ml poly	154.9 g	12/1/97 @ 15:29	^{7}Be	1.85 ± 0.95
						^{54}Mn	1.74 ± 0.33
						^{60}Co	0.41 ± 0.08
						^{22}Na	4.80 ± 0.87
						^{152}Eu	0.24 ± 0.10
						^{46}Sc	0.41 ± 0.08
						^{40}K	23.0 ± 4.3
971030TL07	97-303-5	Booster MP01 S2 Soil Boring 82"-90" 15.2 % Moisture	125ml poly	151.5 g	12/2/97 @ 15:10	^{54}Mn	0.71 ± 0.15
						^{22}Na	2.22 ± 0.42
						^{152}Eu	0.15 ± 0.09
						^{40}K	24.2 ± 4.5
971030TL08	97-303-6	Booster MP01 S3 Soil Boring 29"-35" 14.6 % Moisture	125ml poly	153.2 g	12/15/97 @ 10:11	^{7}Be	5.77 ± 1.77
						^{54}Mn	3.44 ± 0.63
						^{60}Co	0.76 ± 0.14
						^{22}Na	11.2 ± 2.0
						^{152}Eu	1.36 ± 0.20
						^{46}Sc	0.85 ± 0.17
						^{134}Cs	0.17 ± 0.09
						^{40}K	24.7 ± 4.6
971030TL09	97-303-7	Booster MP01 S3 Soil Boring 41"-47" 12.8 % Moisture	125ml poly	184.9 g	12/17/97 @ 15:16	^{7}Be	2.88 ± 1.22
						^{54}Mn	1.82 ± 0.35
						^{60}Co	0.40 ± 0.09
						^{22}Na	6.82 ± 1.22
						^{152}Eu	0.61 ± 0.12
						^{46}Sc	0.31 ± 0.11
						^{40}K	18.9 ± 3.6

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity(pCi/g)
971030TL10	97-303-8	Booster MP01 S3 Soil Boring 53"-59"	125ml poly	141.9 g	12/15/97 @ 14:29	^{54}Mn	1.04 ± 0.21
		15.1 % Moisture				^{22}Na	2.42 ± 0.46
						^{40}K	22.9 ± 4.3
971030TL11	97-303-9	Booster MP01 S3 Soil Boring 65"-71"	125ml poly	164.8 g	12/18/97 @ 15:16	^{54}Mn	0.37 ± 0.09
		14.7 % Moisture				^{22}Na	0.99 ± 0.23
						^{40}K	25.0 ± 4.6
971030TL12	97-303-A	Booster MP01 S3 Soil Boring 77"-83"	125ml poly	157.7 g	12/16/97 @ 15:41	^{54}Mn	0.23 ± 0.09
		12.7 % Moisture				^{22}Na	0.99 ± 0.21
						^{40}K	18.5 ± 3.5
971030TL13	97-303-B	Booster MP01 S3 Soil Boring 89"-95"	125ml poly	221.1 g	12/19/97 @ 14:48	^{54}Mn	0.10 ± 0.06
		6.0 % Moisture				^{22}Na	0.43 ± 0.11
						^{40}K	8.66 ± 1.8
971030TL14	97-303-C	Booster MP01 S1 Soil Boring 26"-30"	125ml poly	129.0 g	12/4/97 @ 09:22	^{7}Be	46.0 ± 8.7
		23.1 % Moisture				^{54}Mn	28.5 ± 5.0
						^{60}Co	6.11 ± 0.79
						^{22}Na	98.4 ± 17.2
						^{152}Eu	11.1 ± 1.2
						^{46}Sc	5.68 ± 0.77
						^{134}Cs	1.02 ± 0.21
						^{40}K	15.9 ± 3.4
971030TL15	97-303-D	Booster MP01 S1 Soil Boring 38"-44"	125ml poly	147.1 g	12/9/97 @ 14:55	^{7}Be	31.9 ± 6.1
		21.5 % Moisture				^{54}Mn	14.2 ± 2.5
						^{60}Co	2.50 ± 0.34
						^{22}Na	54.3 ± 9.5
						^{152}Eu	5.21 ± 0.61
						^{46}Sc	2.51 ± 0.39
						^{134}Cs	0.61 ± 0.14
						^{40}K	18.1 ± 3.5

Sample ID #	WR #	Location	Container	Mass/Vol.	Count Date	Radionuclide	Activity(pCi/g)
971030TL16	97-303-E	Booster MP01 S1 Soil Boring 50"-56" 21.0 % Moisture	125ml poly	158.6 g	12/4/97 @ 15:04	^{7}Be	5.80 ± 1.74
						^{54}Mn	3.96 ± 0.72
						^{60}Co	0.61 ± 0.12
						^{22}Na	17.3 ± 3.0
						^{152}Eu	1.59 ± 0.23
						^{46}Sc	0.67 ± 0.16
						^{40}K	15.3 ± 3.0
971030TL17	97-303-F	Booster MP01 S1 Soil Boring 62"-66" 21.5 % Moisture	125ml poly	178.2 g	12/10/97 @ 14:56	^{7}Be	3.80 ± 1.32
						^{54}Mn	1.71 ± 0.33
						^{60}Co	0.30 ± 0.08
						^{22}Na	10.0 ± 1.8
						^{152}Eu	0.69 ± 0.15
						^{46}Sc	0.48 ± 0.13
						^{40}K	10.3 ± 2.2
971030TL18	97-303-G	Booster MP01 S1 Soil Boring 74"-80" 17.4 % Moisture	125ml poly	145.5 g	12/9/97 @ 10:56	^{7}Be	1.30 ± 1.00
						^{54}Mn	1.17 ± 0.24
						^{60}Co	0.23 ± 0.06
						^{22}Na	4.52 ± 0.82
						^{152}Eu	0.23 ± 0.12
						^{46}Sc	0.40 ± 0.15
						^{40}K	21.3 ± 4.0
971030TL19	97-303-H	Booster MP01 S1 Soil Boring 92"-96" 14.6 % Moisture	125ml poly	149.4 g	12/11/97 @ 15:06	^{54}Mn	0.35 ± 0.11
						^{22}Na	1.25 ± 0.27
						^{40}K	25.5 ± 4.8

cc: T. Leveling, MS-371 T. Busch, MS-371 G. Lauten, MS-317 C. Moore, MS-341
V. Cupps S. Benesch D. Cossairt R. Walton AAL Folder

APPENDIX II.
MARS FORTRAN CODE

```fortran
      program grwater
*************************************************************************
* Fermilab Booster operation during 23 years
* 13-Nov-1997
*************************************************************************
      implicit double precision (a-h,o-z)
      parameter (nisot=9)
      character*80 title
      character*10 isonam
      character*1  unith,tunel
      dimension isonam(nisot),thalf(nisot),unith(nisot),decay(nisot)
      dimension aleach(nisot),wl(nisot),produc(nisot),conc(nisot)
      dimension xmax(nisot),qq(nisot)
      dimension tunel(2),tfact(2)
      dimension xx(20)
      data title/'Activation in dirt around the FNAL Booster septum'/
      data t0/23.d0/
*
*  produc is the atoms produced per star (>50 MeV)
*
      data produc/
     1              0.05d0     ,                 !  H3
     2              0.003d0    ,                 !  Be7
     3              0.011d0    ,                 !  Na22
     4              0.006d0    ,                 !  Ca45
     5              0.0005d0   ,                 !  Sc46
     6              0.004d0    ,                 !  Mn54
     7              0.001d0    ,                 !  Co60
     8              0.01d0     ,                 !  Eu152
     9              0.0006d0   /                 !  Eu154
      data isonam/
     1 'H-3       ','Be-7      ','Na-22     ','Ca-45     ','Sc-46     ',
     2 'Mn-54     ','Co-60     ','Eu-152    ','Eu-154    '/
      data thalf /
     1  12.3500d+00, 53.3000d+00, 2.60000d+00, 163.000d+00, 83.8000d+00,
*      H-3          Be-7         Na-22        Ca-45        Sc-46
     2  312.000d+00, 5.27000d+00, 13.3000d+00, 8.80000d+00/
*      Mn-54        Co-60        Eu-152       Eu-154
      data unith /
     1 'y',          'd',          'y',          'd',          'd',
*      H-3          Be-7         Na-22        Ca-45        Sc-46
     2 'd',          'y',          'y',          'y'/
*      Mn-54        Co-60        Eu-152       Eu-154
      data aleach /
     1  1.d0,         3.d-4,        0.15d0,       0.05d0,       0.02d0,
*      H-3          Be-7         Na-22        Ca-45        Sc-46
     2  0.04d0,       0.03d0,       0.03d0,       0.03d0/
*      Mn-54        Co-60        Eu-152       Eu-154

      data wl/0.5d0,8*1.d0/    ! ???

      data tunel/'y','d'/
      data tfact/1.0d0,2.73972d-3/

      data xx/0.1524d0,0.4572d0,0.762d0,1.0668d0,1.3716d0,1.6764d0,
     & 1.9812d0,2.286d0,3.d0,4.d0,5.d0,6.d0,7.d0,8.d0,9.d0,10.d0,
     & 20.d0,30.d0,50.d0,100.d0/

      data rho/2.25d0/    ! g/cm**3 - dirt density
      data atte/129.d0/   ! g/cm**2 - attenuation length

C      data velo/0.15d0/  ! m/yr     - water velocity
      data velo/0.030d0/  ! m/yr     - water velocity

      data prot/1.d0/     ! protons
C- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
      open(unit=10,file='BOOSTER.OUT',status='unknown')

      aksi=100.d0*rho/atte    ! m**-1

      write(10,100)title,t0,rho,velo,atte,prot
 100  format(1x,a80/' immediately after T0=',f5.1,
     &' years of irradiation'//
     &' rho  (g/cm^3)=',f8.3,'    velo (m/yr)=',f6.3/
     &' atte (g/cm^2)=',f8.3,'    prot=     ',e10.3/
     &' tau=T0, if T0<x/v;  tau=x/v, if T0>x/v'/)
*  Loop over depth
      do l=1,20
         x =xx(l)
         ex=exp(-aksi*x)
         xv=x/velo
         tau =xv
         if(xv.gt.t0) tau=t0
*  Loop over the different isotopes
         tot=0.d0
         do nis=1,nisot
            if(l.eq.1) then
*  Find the half-life unit
               do munit=1,2
                  if(unith(nis).eq.tunel(munit)) go to 6
               end do
               write(*,*)' Unknown half-life unit for isotope',nis
               stop
 6             taul=thalf(nis)*tfact(munit)/log(2.0d0)

               alam=1.d0/taul
               decay(nis)=alam
               eta =aksi*velo-alam
               akv =aksi*velo/alam
               xmax(nis)=-velo*log(akv)/(alam*(1.d0-akv))
               qq(nis)=produc(nis)*aleach(nis)*prot/wl(nis)
            end if
            conc(nis)=qq(nis)*ex*(exp(eta*tau)-1.d0)/eta
            tot=tot+conc(nis)
         end do
         if(l.eq.1) then
            write(10,101)isonam,produc,thalf,unith,aleach,wl,xmax
 101        format(8x,'Isotope       ',4x,9a10/
     &                8x,'Atoms/star    ',9f10.4/
     &                8x,'Half-time     ',9f10.4/
     &                8x,'Units         ',9(4x,a1,5x)/
     &                8x,'Leaching      ',9f10.4/
     &                8x,'Wl            ',9f10.4/
     &                8x,'xmax (m)      ',9f10.4//
     &                5x,'x (m)    tau (yr)',38x,'Concentration (a.u.)',
     $                42x,'Total'/)
         end if
         write(10,102)x,tau,(conc(nis),nis=1,nisot),tot
 102     format(1x,f10.4,f7.2,2x,9e10.3,e12.3)
      end do
      stop
      end
```