FERMILAB-LU-179

Fermilab Linac Dumps

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1 Introduction

A study is made of the thermal and radiation effects in existing Linac Dumps when irradiated by 200 and 400 MeV protons, 7.5x10^{12} protons per pulse for a period of 24 hours with pulse repetition rate of 15 Hz. A cross section showing the cross section of the dumps is shown in Fig. 1[1]. The main body of the dumps is solid cylindrical steel casting. The casting is then placed in a heavy concrete monoblock of square cross section. The important dimensions are shown on the drawing. The berm is about 3 meters above center of the Momentum Dump. The beam enters through a hole along the axis. It is stopped along the side wall of the hole, which slopes at an angle of 3^0 with respect to the beam direction in order to spread out the area that the beam hits[2] (see Fig. 2). Figures 3, 4, 5 and 6 show relative locations of the dumps with respect to the Linac Tunnel, Booster Gallery and Tunnel, as well as elevations of the berm and beam pipes.

2 Temperature of the Dump

I have calculated the temperature distribution as a function of time and position inside the Linac Dump based on the following assumptions:

1. A 400 MeV proton beam has a Gaussian density distribution. The beam size is $2\sigma_x$, $2\sigma_y$, where $\sigma_x = 0.3cm$ horizontal and where $\sigma_y = 2.0cm$ vertical. During momentum measurements at present[3], Fig. 7., the beam size at Momentum Wire is $\sigma_x = 0.35cm$, $\sigma_y = 4.32cm$ and $\sigma_x = 1.23cm$, $\sigma_y = 2.69cm$ during normal operations.

2. The local energy deposition density in the dump is identical to the beam density distribution at the moment of pulse arrival and should be considered as the initial temperature distribution.

3. Because of the slanted dump wall, $l = 2\sigma_y \tan(3^0)$, and the radiation length for Fe, $\lambda = 1.75cm$, we have an instantaneous line source which liberates heat Q per length l.

The temperature distribution $T(r,t)$ at later times is found as the solution of the heat equation

$$\frac{\partial T}{\partial t} = D(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r})$$

where

$$D = \frac{\kappa}{C\rho},$$

κ the thermal conductivity, C the heat capacity and ρ the density.

The solution has to satisfy the initial condition $T(0,r) = f(r)$, where $f(r)$ is the initial temperature distribution, and the boundary condition

$$\frac{\partial T}{\partial r} + hT|_{r=R} = 0$$

The temperature distribution[4,5]

$$T(r,t) = \frac{Q}{4\pi\rho l C D(t_0+t)} e^{-\frac{r^2}{4D(t_0+t)}}$$

is the solution of heat equation where

$$t_0 = \frac{\sigma_r^2}{16D\ln 2}$$

is fixed by initial distribution, $T(r,0) = f(r)$. The boundary condition can be satisfied by the appropriate choice of the image source.

I have calculated the temperature as a function of time at two positions in two extreme cases, Fig. 8;

1. the steel extends to infinity, case $h = \infty$, solid lines,

2. there is no heat exchange between steel and concrete, case $h = 0|_{r=50cm}$ and the image source at position r=100 cm, dotted lines.

The upper curves correspond to the temperature at the center and the lower curves to the temperature at $r = 50$ cm. The real temperature of the central spot and at r=50 cm should be between the solid and dotted lines, probably somewhat below the dotted lines if the steel and the concrete are in good thermal contact. In these calculations I have used $\rho = 7.43\frac{gr}{cm^3}$, $C = 447J/kg^0K$ and D=0.227 cm^2/sec for steel. The corresponding values for concrete are; $\rho = 3.8\frac{gr}{cm^3}$, $C = 880J/kg^0K$ and D=0.007 cm^2/sec. Fig. 9 shows the temperature of the center as a function of time during the first 15 and 150 pulses.

The dynamical thermal stress created in the dump due to its rapid heating was not studied.

3 Dump Shielding

I have calculated radiation shielding properties of the Linac Dumps using the MARS10[6] simulation code. MARS10 is a Monte Carlo program for inclusive simulation of 3-dimensional hadronic and electromagnetic cascades in matter. As input to the calculations I have used:

1. the radius of the steel to be 45 cm, concrete 90 cm and soil 3 meters,
2. the geometry of the dump with slanted incident wall, meshed in 100 regions,
3. the Gaussian proton beam both with 200 MeV and 400 MeV, $\sigma_x = \sigma_y = 0.5cm$,
4. the 12x10^6 incident particles for 200 MeV beam and the 4x10^6 incident particles for 400 MeV beam, with 1 MeV energy cut.
5. the Fe density, $\rho = 7.86$, concrete density[1], $\rho = 3.8$, and $\rho = 2.1\frac{gr}{cm^3}$, Fermilab soil density[7],

Table 1 lists region numbers and their correspondence to input geometry. Tables 2-4 summarize the results of the calculations for 200 MeV and Tables 5-7 for 400 MeV.

4 Conclusion

Although the temperature calculations are done using relatively crude approximations it has been found that the hottest spot in the dump is $\sim 500^0C$ after one hour, well below the melting temperature of the steel ($\geq 1400^0C$), even in the case of $\sigma_x = 0.3cm$ and $\sigma_y = 0.5cm$ and 15 Hz repetition rate.

The energy deposition and dose rate calculated for the case of 200 MeV protons on the top of the berm have large error (as can be seen from Table 2.) even for the $12x10^6$ incident particles (10^6 particles $\sim$ 24 hours of the CPU time on FNAL Vax). The calculation of the dose rate for 400 MeV beam gives $1.2x10^{-19}$ Rem per proton (error is $\sim$ 58%) on the top of the berm (4.05+0.25 meters from the center of the dump) and $3.4x10^{-18}$ Rem per proton (error is $\sim$ 58%) in the Booster Tunnel ($\sim$ 3.05 + 0.25 meters from the center of the beam).

5 References

1. M. Awschalom, Linac shielding: Expected Beam Losses, Design Criteria, TM-236, May 5, 1970

2. Booster Staff, Booster Synchrotron, TM-405, Jan. 1970

3. C. Schmidt, Fermilab, unpublished.

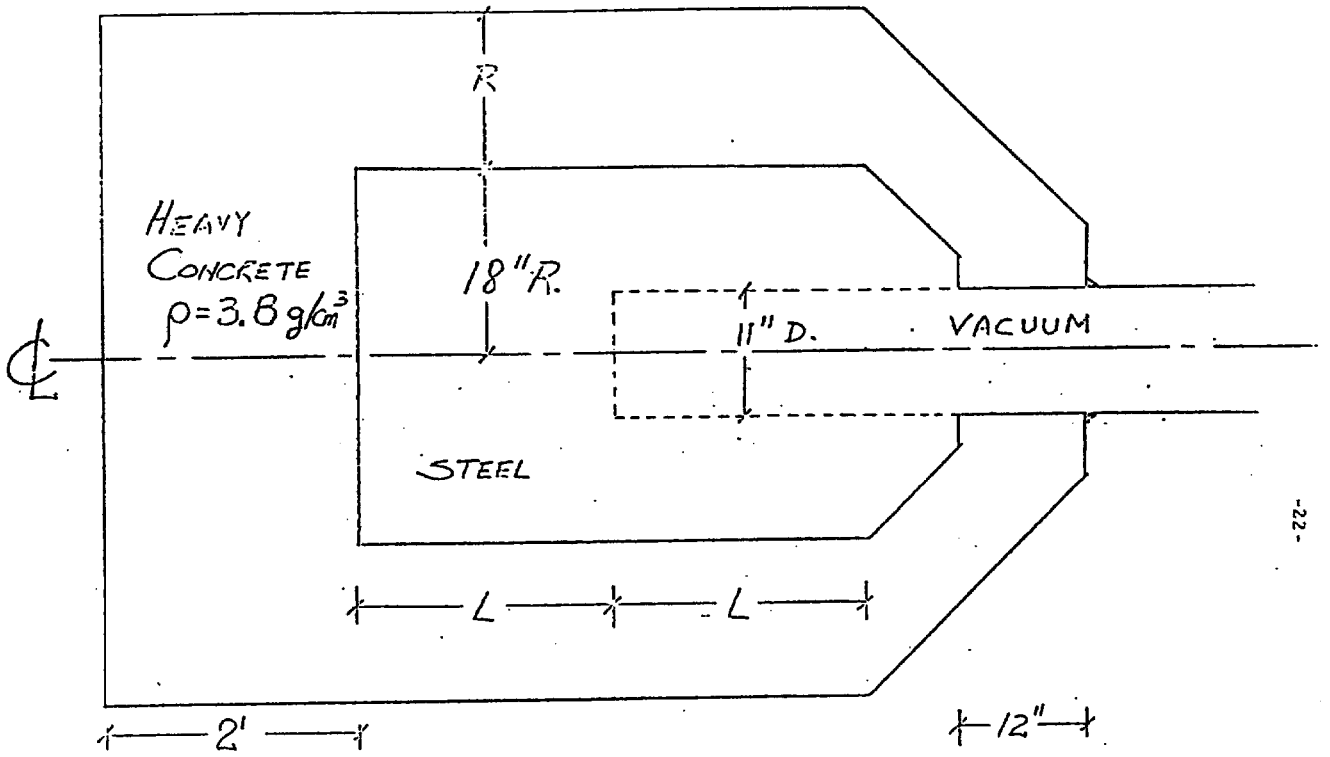
4. H. S. Carslaw and J. C. Jaeger, Conduction of Heat in Solids, Oxford Uni. Press, 1959,

5. V. Visnjic, Calculation of the Temperature Distribution in the Antiproton Target, PBAR Note-492, Dec. 7,1990

6. N. V. Mokhov, The MARS10 Code System: Inclusive Simulation of Hadronic and Electromagnetic Cascades and Muon Transport, FN-509, March 20, 1989

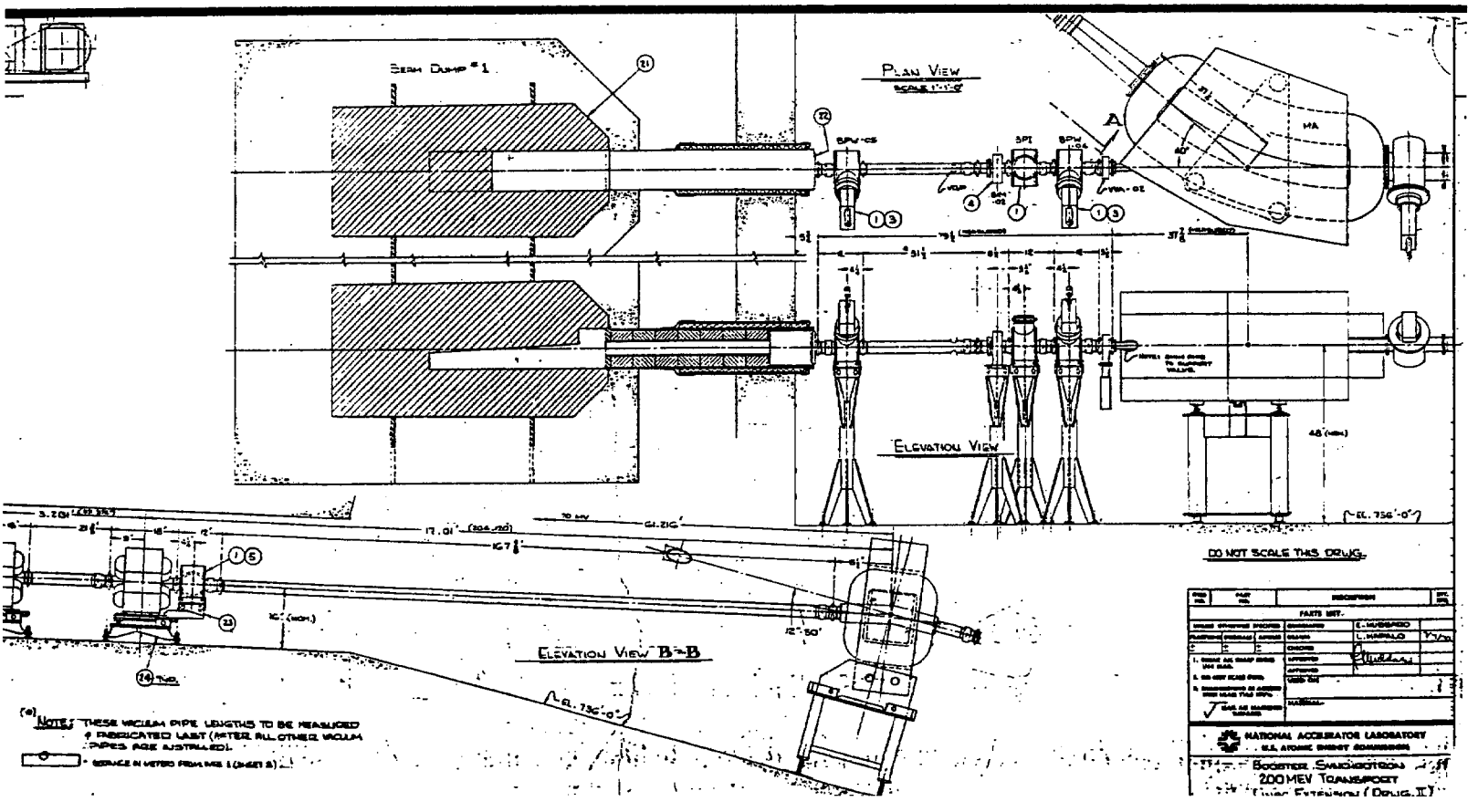
7. W. Fairman, W. Hranka, J. Sedlet, M. Awschalom, T. B. Borak, The Extraction and Transport of Radionuclides Produced in Soil by High Energy Hadrons, TM-247, June 24, 1970

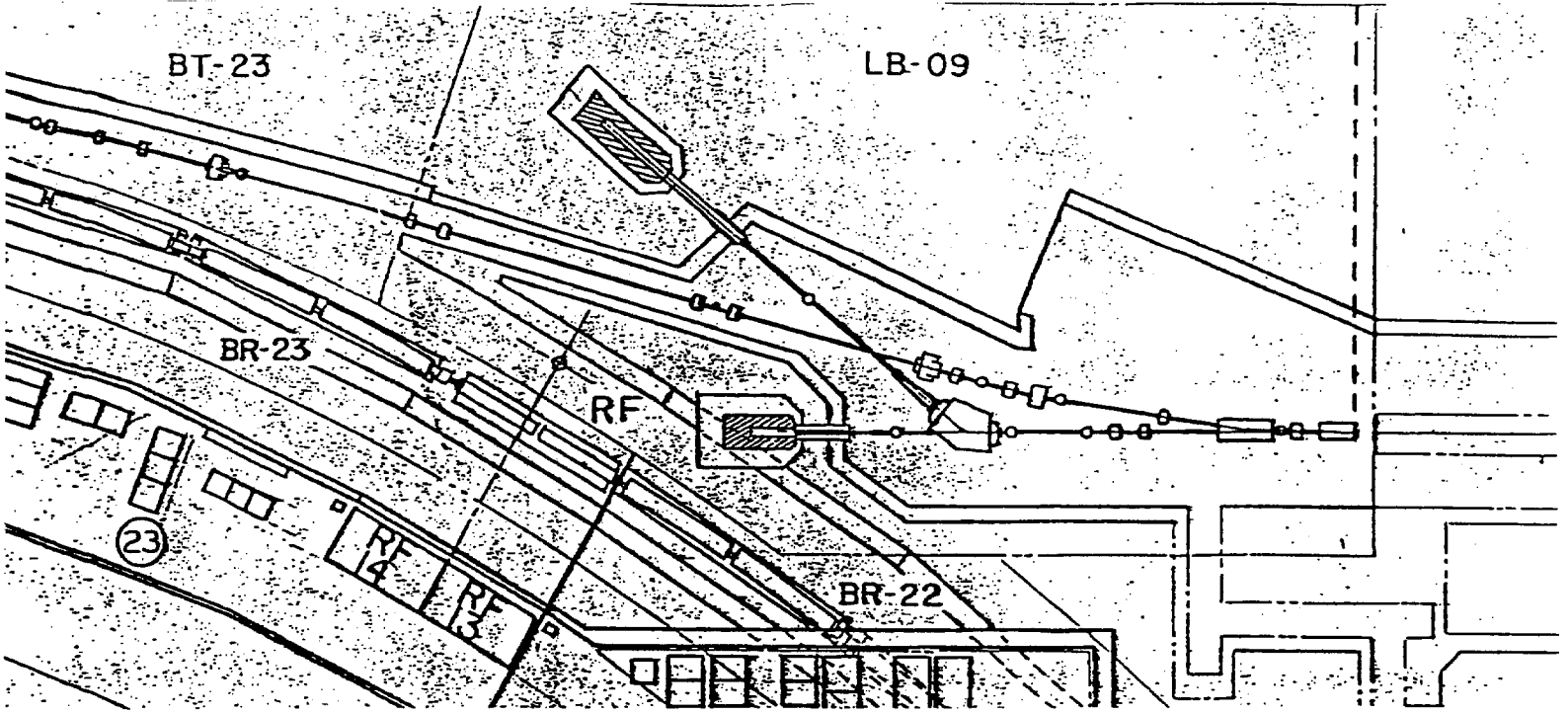
Figures 1. and 2.



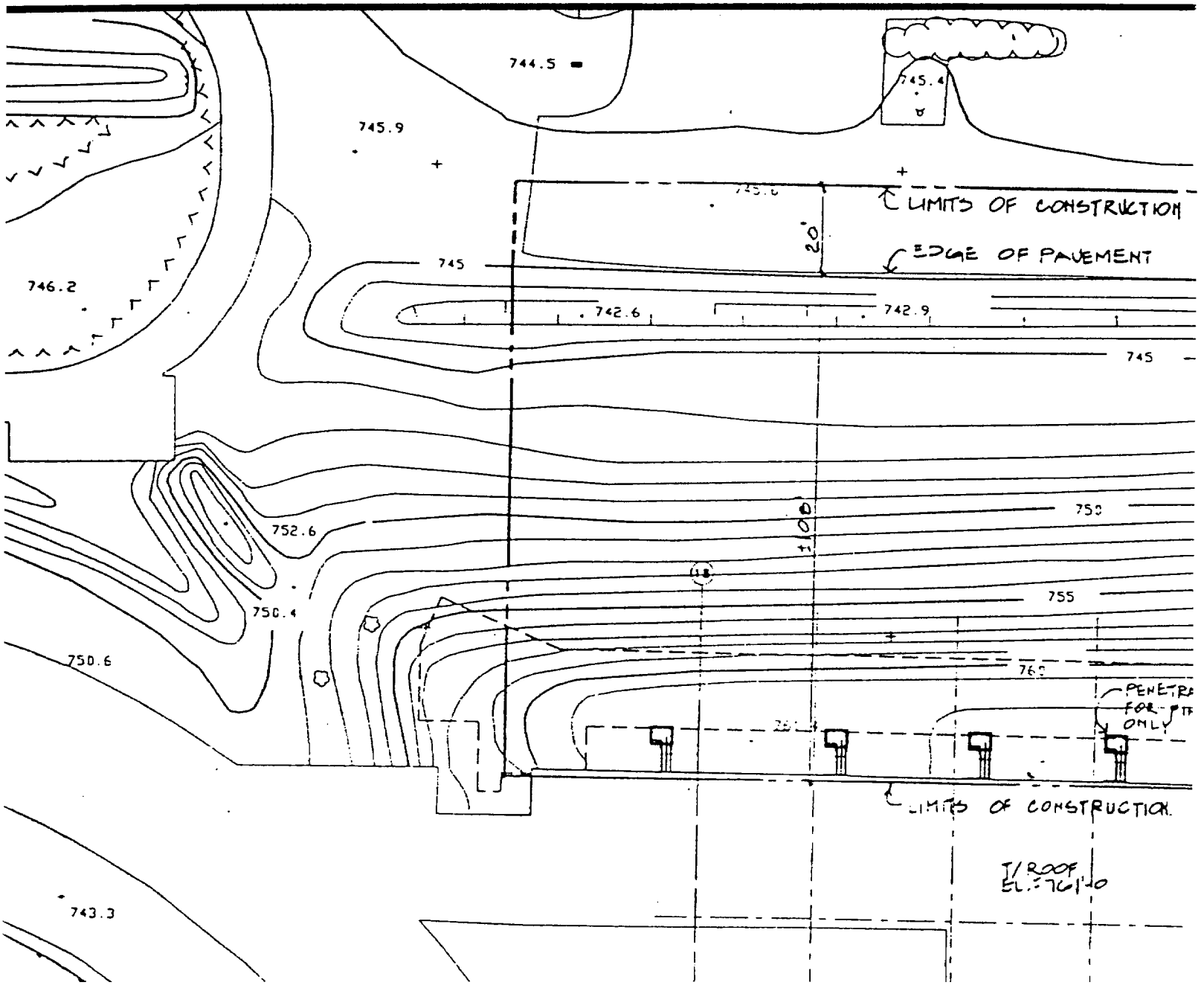
	L	R
DUMP #1	3 ft	1½ ft
DUMP #2	4 ft	1½ ft

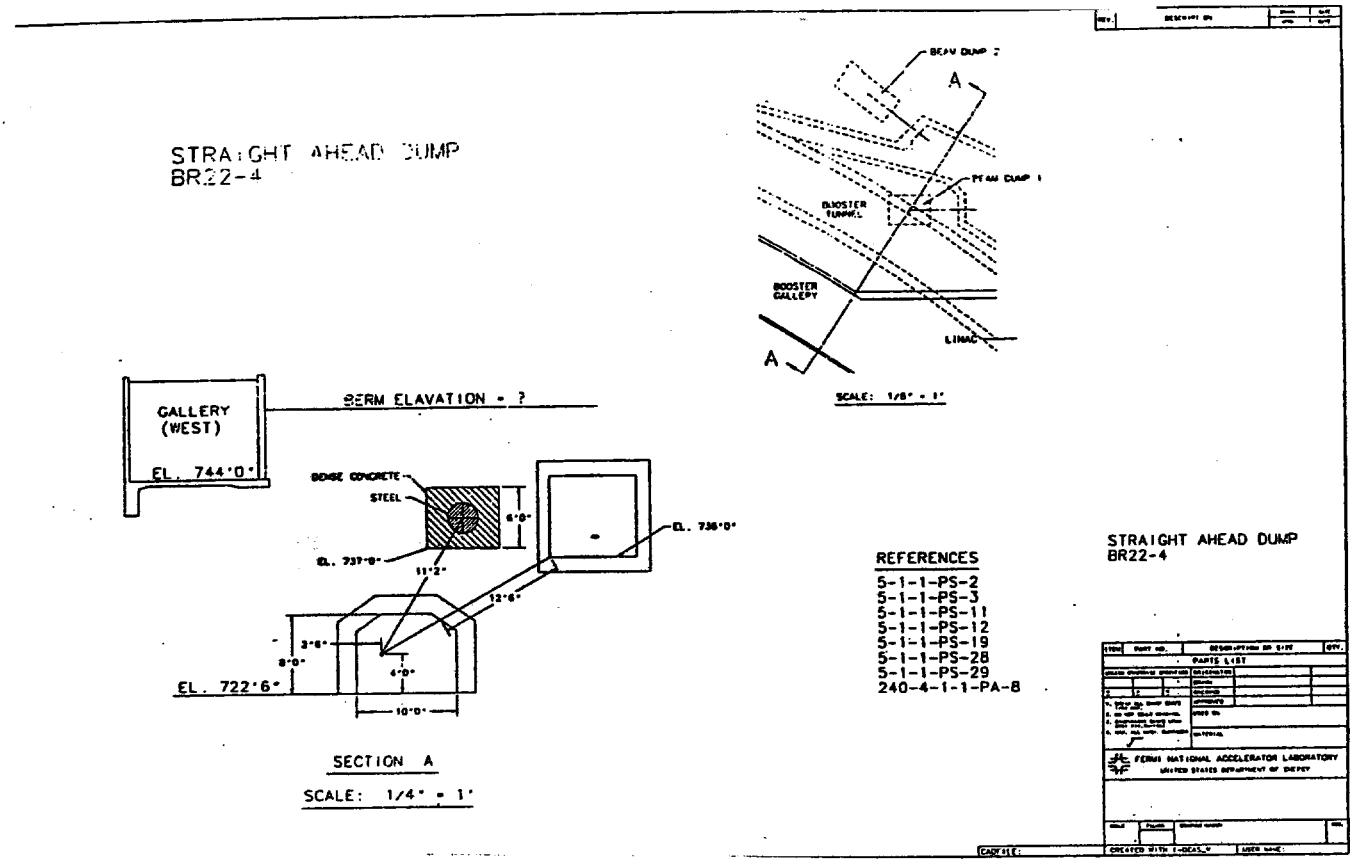
200 MeV,
LINAC BEAM DUMPS.

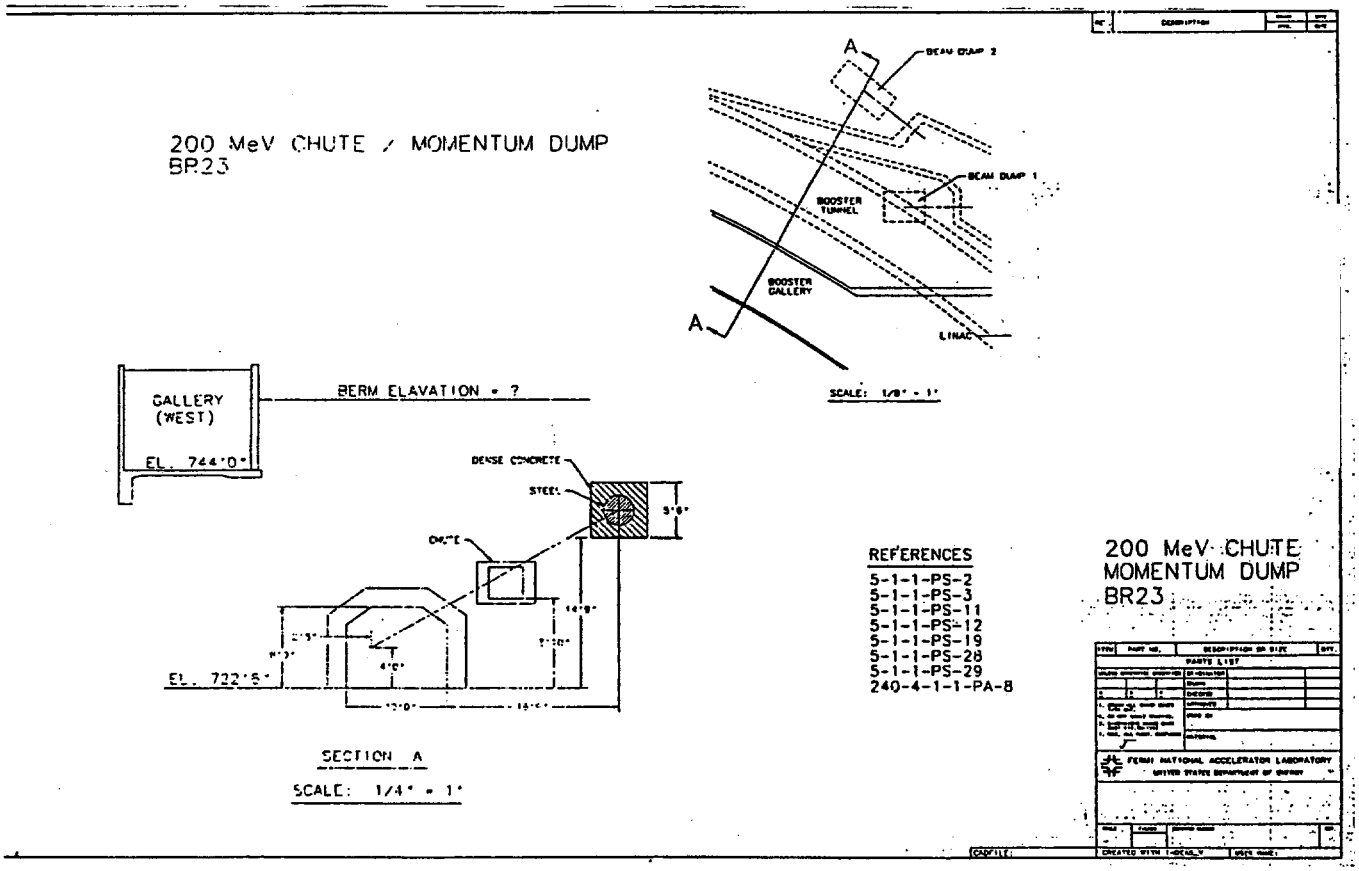




Figures 3. and 4.







Figures 5. and 6.

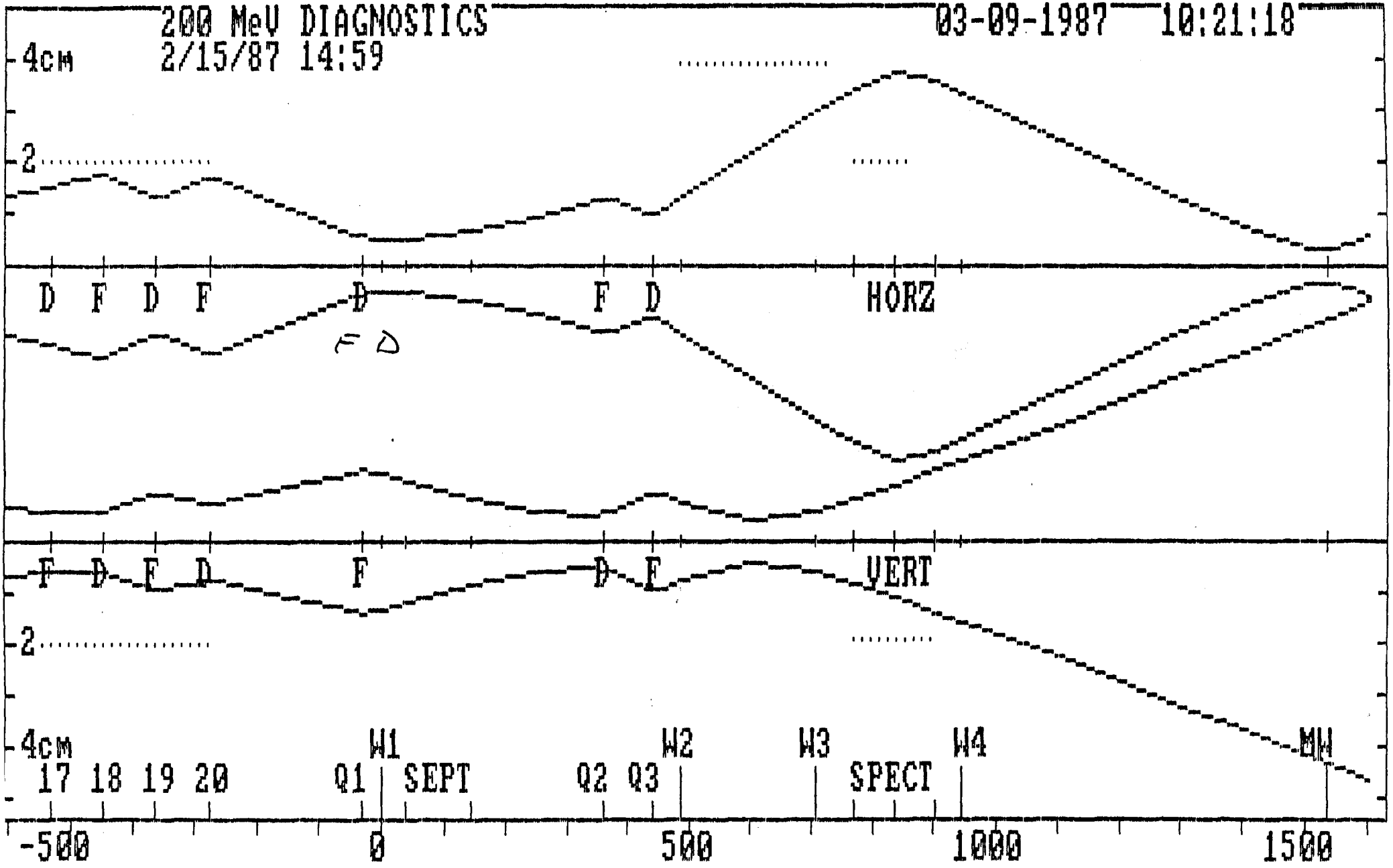

200 MeV DIAGNOSTICS
03-09-1987 10:21:18
4cm
2/15/87 14:59
2
D F D F D F D HORZ
F D
F D F D F D F VERT
2
4cm
W1 W2 W3 W4 MH
17 18 19 20 Q1 SEPT Q2 Q3 SPECT
-500 0 500 1000 1500

Figure 7.

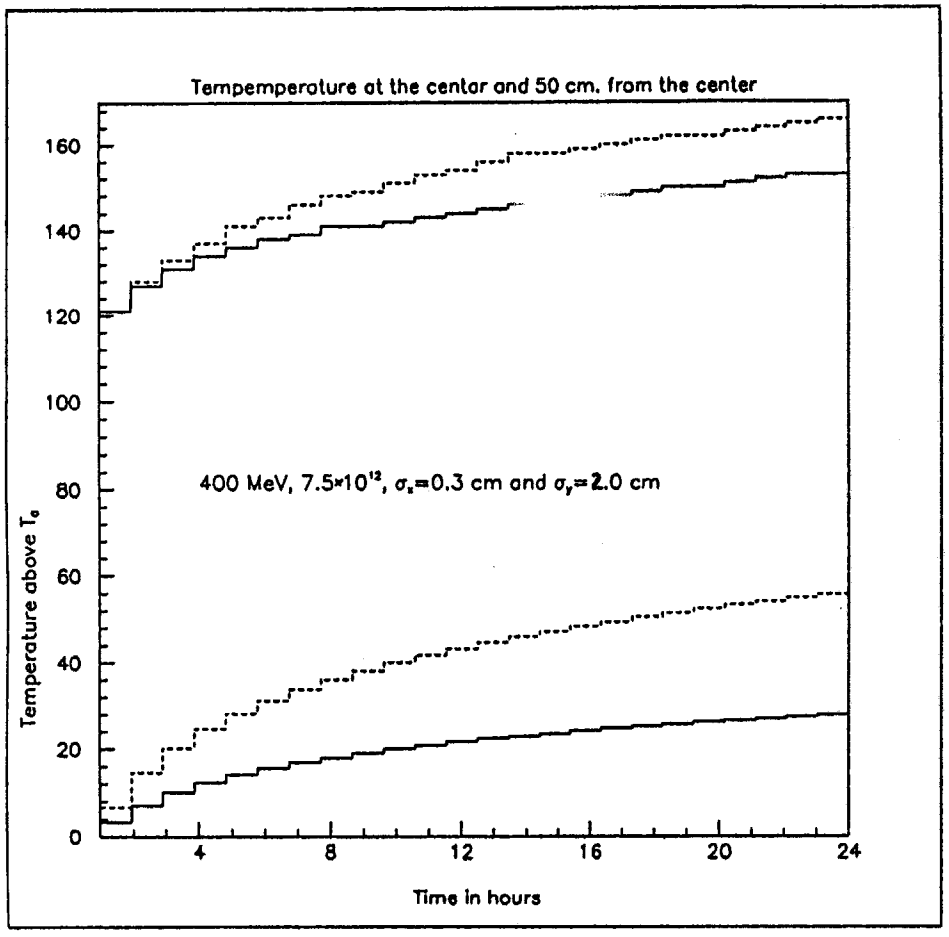


Figure 8.

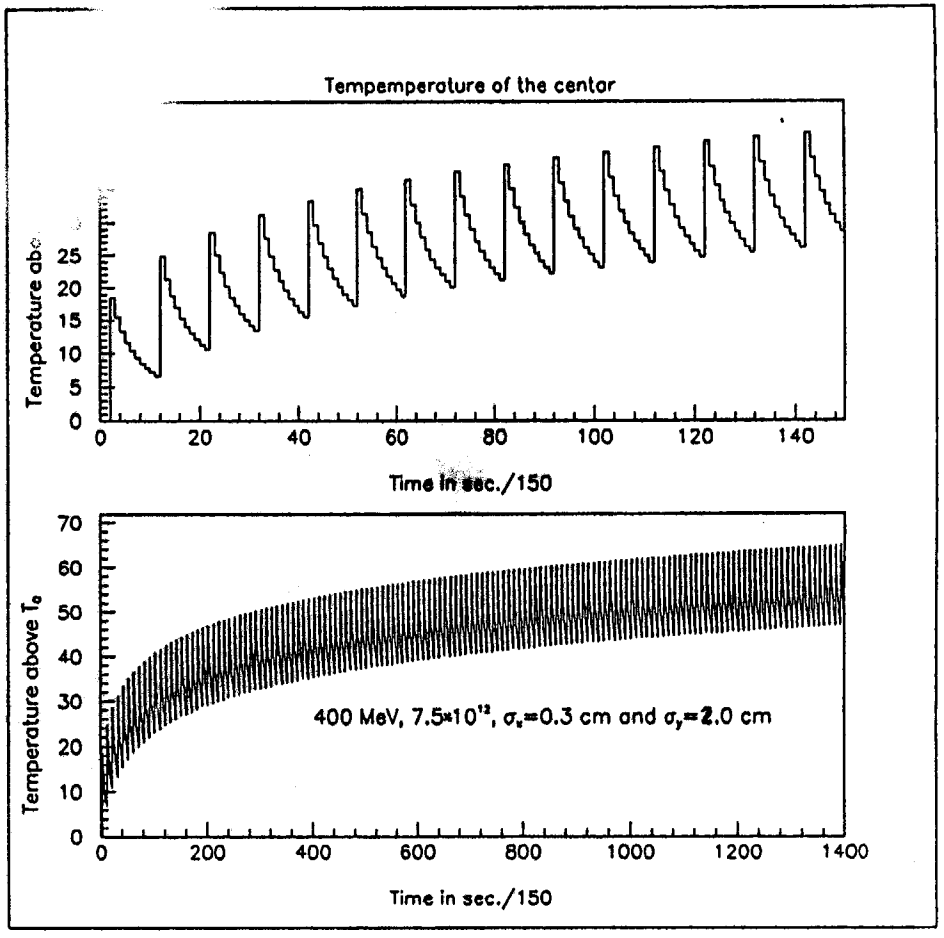
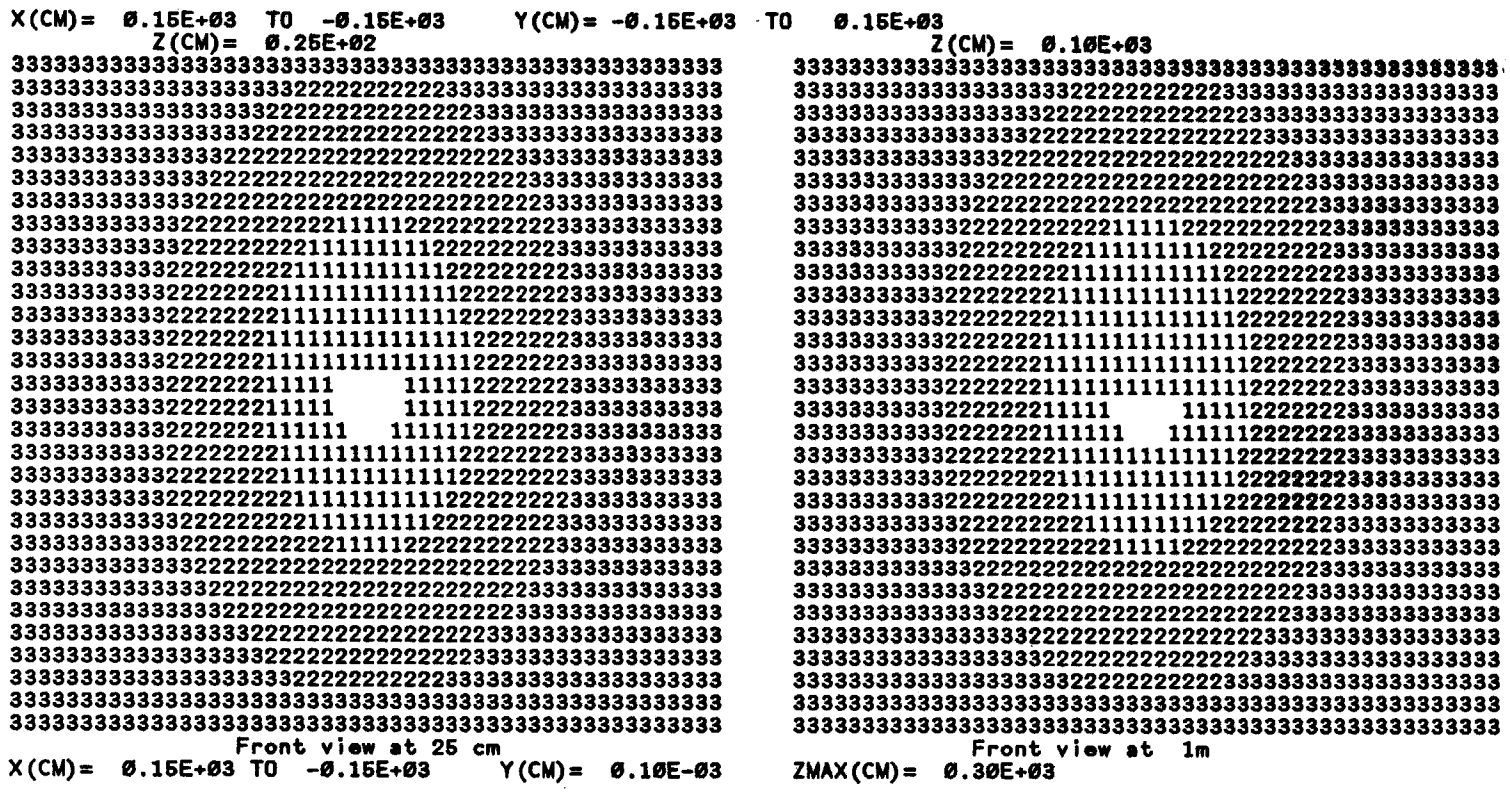


Figure 9.



Figures 10 and 11

**********200 MEV PROTONS**********

THE LIST OF REGION NUMBERS AND THEIR CORRESPONDENCE TO STANDARD GEOMETRY SECTOR COORDINATES

RADIUS, CM

Z, CM IM MAG	0.000E+00	0.225E+02	0.450E+02	0.900E+02	0.139E+03	0.187E+03	0.236E+03	0.284E+03	0.333E+03	0.381E+03	0.430E+03
0.000E+00	1	11	21	31	41	51	61	71	81	91	
0.200E+02	2	12	22	32	42	52	62	72	82	92	
0.560E+02	3	13	23	33	43	53	63	73	83	93	
0.920E+02	4	14	24	34	44	54	64	74	84	94	
0.128E+03	5	15	25	35	45	55	65	75	85	95	
0.164E+03	6	16	26	36	46	56	66	76	86	96	
0.200E+03	7	17	27	37	47	57	67	77	87	97	
0.235E+03	8	18	28	38	48	58	68	78	88	98	
0.270E+03	9	19	29	39	49	59	69	79	89	99	
0.285E+03	10	20	30	40	50	60	70	80	90	100	
0.300E+03											

STEEL

CONC.

SOIL

R

Z

Table 1.

TOTAL ENERGY DEPOSITION AND ERROR, GEV/G P.P.

REGION NUMBER		1	2	3	4	5	6	7	8	9	10
0		0.00E+00	0.17E-07	0.33E-06	0.14E-07	0.47E-09	0.24E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.21E-10	0.65E-10	0.19E-10	0.26E-11	0.55E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10		0.00E+00	0.79E-10	0.38E-09	0.34E-09	0.90E-10	0.13E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.52E-12	0.18E-11	0.18E-11	0.85E-12	0.29E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20		0.00E+00	0.80E-11	0.29E-10	0.33E-10	0.15E-10	0.38E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.20E-12	0.43E-12	0.46E-12	0.31E-12	0.15E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30		0.00E+00	0.81E-12	0.19E-11	0.23E-11	0.16E-11	0.79E-12	0.19E-12	0.71E-13	0.67E-28	0.00E+00
	+/-	0.00E+00	0.61E-13	0.98E-13	0.11E-12	0.95E-13	0.64E-13	0.23E-13	0.16E-13	0.00E+00	0.00E+00
40		0.00E+00	0.18E-12	0.35E-12	0.41E-12	0.35E-12	0.17E-12	0.11E-12	0.58E-13	0.00E+00	0.00E+00
	+/-	0.00E+00	0.22E-13	0.39E-13	0.41E-13	0.41E-13	0.18E-13	0.20E-13	0.14E-13	0.00E+00	0.00E+00
50		0.00E+00	0.59E-13	0.62E-13	0.11E-12	0.59E-13	0.56E-13	0.58E-13	0.31E-13	0.13E-18	0.00E+00
	+/-	0.00E+00	0.12E-13	0.10E-13	0.23E-13	0.10E-13	0.14E-13	0.16E-13	0.17E-13	0.11E-18	0.00E+00
60		0.00E+00	0.11E-13	0.67E-14	0.22E-13	0.33E-13	0.13E-13	0.17E-13	0.81E-14	0.00E+00	0.00E+00
	+/-	0.00E+00	0.44E-14	0.24E-14	0.98E-14	0.11E-13	0.42E-14	0.74E-14	0.36E-14	0.00E+00	0.00E+00
70		0.00E+00	0.72E-14	0.38E-14	0.83E-14	0.51E-14	0.13E-14	0.17E-14	0.29E-14	0.00E+00	0.00E+00
	+/-	0.00E+00	0.36E-14	0.18E-14	0.69E-14	0.28E-14	0.53E-15	0.73E-15	0.12E-14	0.00E+00	0.00E+00
80		0.00E+00	0.38E-15	0.12E-14	0.21E-19	0.18E-18	0.12E-17	0.35E-15	0.57E-15	0.00E+00	0.00E+00
	+/-	0.00E+00	0.19E-15	0.12E-14	0.15E-19	0.11E-18	0.12E-17	0.34E-15	0.50E-15	0.00E+00	0.00E+00
90		0.00E+00	0.29E-14	0.11E-15	0.00E+00	0.00E+00	0.00E+00	0.26E-15	0.55E-16	0.00E+00	0.00E+00
	+/-	0.00E+00	0.21E-14	0.11E-15	0.00E+00	0.00E+00	0.00E+00	0.18E-15	0.55E-16	0.00E+00	0.00E+00

Z

r

Table 2.

DOSE EQUIVALENT, REM P.P.

REGION NUMBER	1	2	3	4	5	6	7	8	9	10
0	0.00E+00	0.37E-12	0.59E-11	0.47E-12	0.46E-13	0.23E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.93E-14	0.41E-13	0.35E-13	0.87E-14	0.12E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	0.84E-15	0.31E-14	0.33E-14	0.14E-14	0.37E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.84E-16	0.20E-15	0.25E-15	0.16E-15	0.76E-16	0.21E-16	0.70E-17	0.84E-32	0.00E+00
40	0.00E+00	0.21E-16	0.33E-16	0.39E-16	0.31E-16	0.20E-16	0.12E-16	0.50E-17	0.00E+00	0.00E+00
50	0.00E+00	0.53E-17	0.67E-17	0.10E-16	0.58E-17	0.52E-17	0.43E-17	0.26E-17	0.16E-22	0.00E+00
60	0.00E+00	0.15E-17	0.91E-18	0.17E-17	0.36E-17	0.18E-17	0.11E-17	0.88E-18	0.00E+00	0.00E+00
70	0.00E+00	0.52E-18	0.43E-18	0.47E-18	0.64E-18	0.16E-18	0.28E-18	0.40E-18	0.00E+00	0.00E+00
80	0.00E+00	0.47E-19	0.13E-18	0.35E-23	0.29E-22	0.15E-21	0.59E-19	0.82E-19	0.00E+00	0.00E+00
90	0.00E+00	0.47E-19	0.14E-19	0.00E+00	0.00E+00	0.00E+00	0.33E-19	0.69E-20	0.00E+00	0.00E+00

Z

r

Table 3.

LEAKAGE:	BACKWARD	FORWARD	SIDE
HADRONS LEAKAGE ENERGY, GEV:	0.6244E-04	0.8621E-06	0.3561E-07
NUMBER OF LEAKAGE PARTICLES:	0.2534E-02	0.1430E-04	0.1068E-05

LOW-ENERGY NEUTRONS LEAKAGE ENERGY, GEV: 0.503E-04
PHOTON AND ELECTRON LEAKAGE ENERGY, GEV: 0.000E+00
TOTAL LEAKAGE ENERGY, GEV: 0.114E-03
ENERGY BALANCE: ETOT= 0.1634E+00 GEV, ETOT/EO= 0.81701

LEAKAGE SPECTRA OF PARTICLES: PARTICLES/GEV

ENERGY SCALE, GEV	UPSTREAM PLANE			DOWNSTREAM PLANE			THE EXTERNAL CYLINDER		
	P	N	PI+/-	P	N	PI+/-	P	N	PI+/-
0.100E-02									
	0.16E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.137E-02									
	0.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.187E-02									
	0.23E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.255E-02									
	0.25E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.348E-02									
	0.25E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.475E-02									
	0.21E-02	-0.46E-11	0.00E+00	0.00E+00	-0.75E-14	0.00E+00	0.00E+00	-0.82E-17	0.00E+00
0.649E-02									
	0.48E-02	0.11E+00	0.00E+00	0.00E+00	0.27E-04	0.00E+00	0.00E+00	0.61E-06	0.00E+00
0.886E-02									
	0.39E-02	0.12E+00	0.00E+00	0.00E+00	0.53E-04	0.00E+00	0.00E+00	0.26E-06	0.00E+00
0.121E-01									
	0.44E-02	0.87E-01	0.00E+00	0.00E+00	0.89E-04	0.00E+00	0.00E+00	0.18E-06	0.00E+00
0.165E-01									
	0.33E-02	0.62E-01	0.00E+00	0.00E+00	0.32E-04	0.00E+00	0.00E+00	0.13E-03	0.00E+00
0.226E-01									
	0.27E-02	0.40E-01	0.00E+00	0.00E+00	0.91E-04	0.00E+00	0.00E+00	0.12E-05	0.00E+00
0.308E-01									
	0.18E-02	0.26E-01	0.00E+00	0.19E-05	0.43E-03	0.00E+00	0.00E+00	0.16E-05	0.00E+00
0.421E-01									
	0.99E-03	0.13E-01	0.00E+00	0.00E+00	0.98E-04	0.00E+00	0.00E+00	0.46E-05	0.00E+00
0.575E-01									
	0.42E-03	0.48E-02	0.00E+00	0.00E+00	0.11E-03	0.00E+00	0.00E+00	0.19E-05	0.00E+00
0.785E-01									
	0.93E-04	0.11E-02	0.00E+00	0.00E+00	0.82E-04	0.00E+00	0.00E+00	0.28E-05	0.00E+00
0.107E+00									
	0.13E-04	0.18E-03	0.00E+00	0.00E+00	0.35E-04	0.00E+00	0.00E+00	0.91E-06	0.00E+00
0.146E+00									
	0.14E-05	0.12E-04	0.00E+00	0.00E+00	0.13E-04	0.00E+00	0.00E+00	0.15E-06	0.00E+00
0.160E+00									
	0.00E+00	0.47E-05	0.00E+00	0.00E+00	0.58E-05	0.00E+00	0.00E+00	0.86E-07	0.00E+00
0.173E+00									
	0.00E+00	0.16E-05	0.00E+00	0.00E+00	0.25E-05	0.00E+00	0.00E+00	0.19E-07	0.00E+00
0.187E+00									
	0.00E+00	0.22E-06	0.00E+00	0.00E+00	0.41E-06	0.00E+00	0.00E+00	0.30E-08	0.00E+00
0.200E+00									
SUM, PARTICLES	0.14E-03	0.24E-02	0.00E+00	0.21E-07	0.14E-04	0.00E+00	0.00E+00	0.11E-05	0.00E+00

Table 4.

********** 400 MEV PROTONS **********

TOTAL ENERGY DEPOSITION, GEV/G P.P.

REGION NUMBER		1	2	3	4	5	6	7	8	9	10
0		0.00E+00	0.15E-07	0.37E-06	0.91E-07	0.37E-08	0.21E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.38E-10	0.29E-09	0.11E-09	0.23E-10	0.64E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10		0.00E+00	0.30E-09	0.17E-08	0.21E-08	0.70E-09	0.11E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.27E-11	0.10E-10	0.13E-10	0.76E-11	0.29E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20		0.00E+00	0.43E-10	0.16E-09	0.21E-09	0.12E-09	0.40E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	+/-	0.00E+00	0.11E-11	0.26E-11	0.32E-11	0.25E-11	0.15E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30		0.00E+00	0.69E-11	0.13E-10	0.19E-10	0.16E-10	0.10E-10	0.40E-11	0.16E-11	0.43E-18	0.00E+00
	+/-	0.00E+00	0.49E-12	0.60E-12	0.95E-12	0.98E-12	0.79E-12	0.52E-12	0.27E-12	0.40E-18	0.00E+00
40		0.00E+00	0.15E-11	0.28E-11	0.39E-11	0.31E-11	0.26E-11	0.14E-11	0.40E-11	0.14E-23	0.00E+00
	+/-	0.00E+00	0.18E-12	0.31E-12	0.41E-12	0.31E-12	0.35E-12	0.20E-12	0.32E-11	0.14E-23	0.00E+00
50		0.00E+00	0.25E-12	0.79E-12	0.83E-12	0.10E-11	0.94E-12	0.38E-12	0.40E-12	0.00E+00	0.00E+00
	+/-	0.00E+00	0.49E-13	0.14E-12	0.19E-12	0.20E-12	0.24E-12	0.89E-13	0.96E-13	0.00E+00	0.00E+00
60		0.00E+00	0.10E-12	0.29E-12	0.17E-12	0.16E-12	0.13E-12	0.25E-12	0.76E-13	0.96E-18	0.00E+00
	+/-	0.00E+00	0.42E-13	0.76E-13	0.57E-13	0.54E-13	0.39E-13	0.93E-13	0.32E-13	0.96E-18	0.00E+00
70		0.00E+00	0.81E-14	0.42E-13	0.23E-13	0.41E-13	0.24E-13	0.55E-13	0.20E-13	0.12E-18	0.00E+00
	+/-	0.00E+00	0.30E-14	0.17E-13	0.84E-14	0.22E-13	0.15E-13	0.33E-13	0.96E-14	0.12E-18	0.00E+00
80		0.00E+00	0.23E-13	0.49E-13	0.44E-13	0.18E-13	0.12E-13	0.14E-13	0.74E-15	0.00E+00	0.00E+00
	+/-	0.00E+00	0.19E-13	0.35E-13	0.27E-13	0.11E-13	0.80E-14	0.10E-13	0.58E-15	0.00E+00	0.00E+00
90		0.00E+00	0.87E-17	0.17E-14	0.69E-13	0.11E-14	0.57E-14	0.97E-15	0.83E-16	0.00E+00	0.00E+00
	+/-	0.00E+00	0.87E-17	0.11E-14	0.66E-13	0.90E-15	0.43E-14	0.57E-15	0.83E-16	0.00E+00	0.00E+00

Table 5.

DOSE EQUIVALENT, REM P.P.

REGION NUMBER	1	2	3	4	5	6	7	8	9	10
0	0.00E+00	0.51E-12	0.89E-11	0.28E-11	0.27E-12	0.17E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.33E-13	0.17E-12	0.19E-12	0.60E-13	0.93E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	0.44E-14	0.16E-13	0.20E-13	0.11E-13	0.34E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.65E-15	0.13E-14	0.18E-14	0.15E-14	0.91E-15	0.32E-15	0.14E-15	0.54E-22	0.00E+00
40	0.00E+00	0.14E-15	0.26E-15	0.35E-15	0.29E-15	0.23E-15	0.11E-15	0.17E-15	0.17E-27	0.00E+00
50	0.00E+00	0.28E-16	0.76E-16	0.65E-16	0.90E-16	0.67E-16	0.34E-16	0.41E-16	0.00E+00	0.00E+00
60	0.00E+00	0.91E-17	0.23E-16	0.19E-16	0.18E-16	0.12E-16	0.21E-16	0.97E-17	0.12E-21	0.00E+00
70	0.00E+00	0.11E-17	0.41E-17	0.34E-17	0.46E-17	0.36E-17	0.39E-17	0.20E-17	0.15E-22	0.00E+00
80	0.00E+00	0.18E-17	0.35E-17	0.31E-17	0.26E-17	0.12E-17	0.95E-18	0.92E-19	0.00E+00	0.00E+00
90	0.00E+00	0.11E-20	0.25E-18	0.38E-17	0.17E-18	0.83E-18	0.12E-18	0.10E-19	0.00E+00	0.00E+00

Table 6.

LEAKAGE:	BACKWARD	FORWARD	SIDE
HADRONS LEAKAGE ENERGY, GEV:	0.2801E-03	0.1598E-04	0.4625E-06
NUMBER OF LEAKAGE PARTICLES:	0.8699E-02	0.1946E-03	0.6000E-05

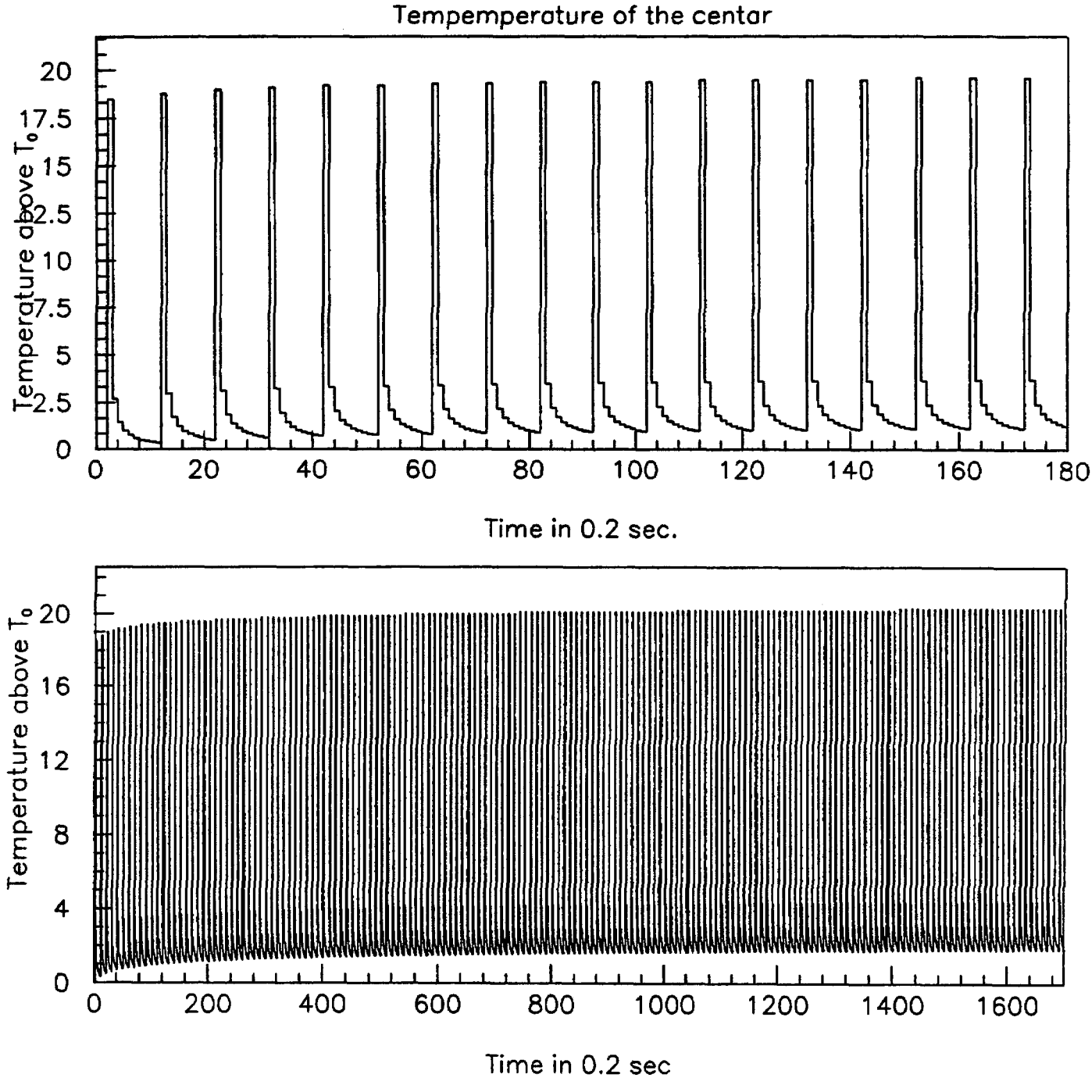
LOW-ENERGY NEUTRONS LEAKAGE ENERGY, GEV: 0.161E-03
PHOTON AND ELECTRON LEAKAGE ENERGY, GEV: 0.000E+00
TOTAL LEAKAGE ENERGY, GEV: 0.458E-03
ENERGY BALANCE: ETOT= 0.2261E+00 GEV, ETOT/EO= 0.56537

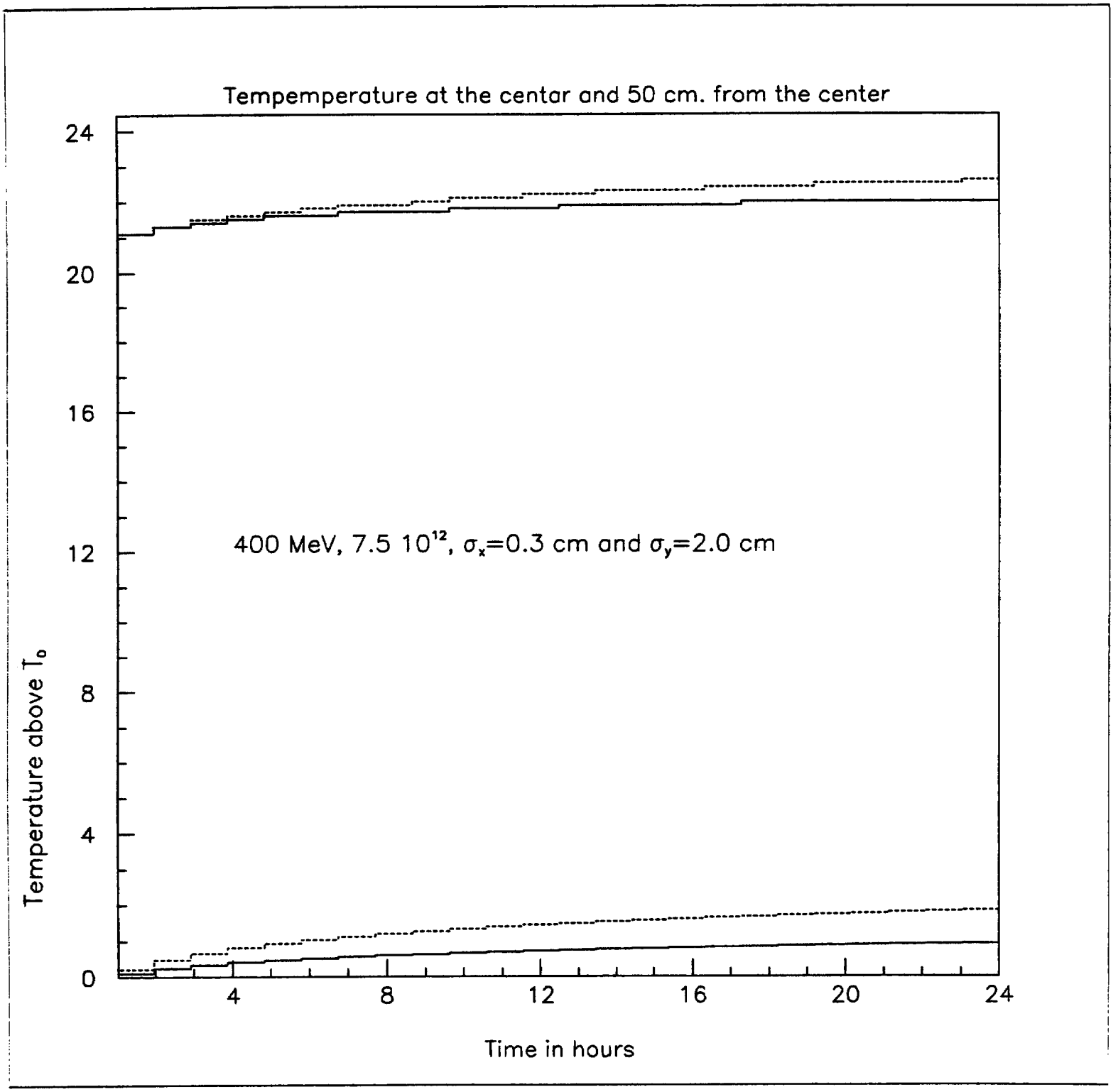
LEAKAGE SPECTRA OF PARTICLES: PARTICLES/GEV

ENERGY SCALE, GEV	UPSTREAM PLANE			DOWNSTREAM PLANE			THE EXTERNAL CYLINDER		
	P	N	PI+/-	P	N	PI+/-	P	N	PI+/-
0.100E-02	0.48E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.142E-02	0.34E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.202E-02	0.10E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.288E-02	0.30E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.409E-02	0.38E-02	-0.44E-12	0.00E+00	0.00E+00	-0.13E-14	0.00E+00	0.00E+00	-0.18E-16	0.00E+00
0.583E-02	0.16E-02	0.21E+00	0.00E+00	0.00E+00	0.64E-03	0.00E+00	0.00E+00	0.22E-04	0.00E+00
0.829E-02	0.46E-02	0.32E+00	0.00E+00	0.00E+00	0.17E-02	0.00E+00	0.00E+00	0.54E-04	0.00E+00
0.118E-01	0.47E-02	0.25E+00	0.00E+00	0.00E+00	0.39E-03	0.00E+00	0.00E+00	0.80E-04	0.00E+00
0.168E-01	0.61E-02	0.19E+00	0.00E+00	0.00E+00	0.16E-02	0.00E+00	0.00E+00	0.76E-05	0.00E+00
0.239E-01	0.52E-02	0.12E+00	0.00E+00	0.00E+00	0.15E-02	0.00E+00	0.00E+00	0.17E-04	0.00E+00
0.339E-01	0.31E-02	0.90E-01	0.00E+00	0.00E+00	0.21E-02	0.00E+00	0.00E+00	0.90E-04	0.00E+00
0.483E-01	0.21E-02	0.49E-01	0.00E+00	0.00E+00	0.15E-02	0.00E+00	0.00E+00	0.36E-04	0.00E+00
0.687E-01	0.85E-03	0.17E-01	0.00E+00	0.00E+00	0.14E-02	0.00E+00	0.00E+00	0.24E-04	0.00E+00
0.977E-01	0.25E-03	0.43E-02	0.00E+00	0.00E+00	0.68E-03	0.00E+00	0.00E+00	0.46E-04	0.00E+00
0.139E+00	0.30E-04	0.59E-03	0.00E+00	0.66E-05	0.27E-03	0.00E+00	0.00E+00	0.70E-05	0.00E+00
0.198E+00	0.16E-05	0.45E-04	0.00E+00	0.00E+00	0.12E-03	0.00E+00	0.00E+00	0.84E-06	0.00E+00
0.281E+00	0.00E+00	0.84E-05	0.00E+00	0.00E+00	0.41E-04	0.00E+00	0.00E+00	0.18E-06	0.00E+00
0.311E+00	0.70E-06	0.44E-05	0.00E+00	0.00E+00	0.21E-04	0.00E+00	0.00E+00	0.21E-07	0.00E+00
0.341E+00	0.00E+00	0.39E-07	0.00E+00	0.00E+00	0.92E-05	0.00E+00	0.00E+00	0.59E-08	0.00E+00
0.370E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.19E-05	0.00E+00	0.00E+00	0.11E-09	0.00E+00
0.400E+00									
SUM, PARTICLES	0.28E-03	0.84E-02	0.00E+00	0.39E-06	0.19E-03	0.00E+00	0.00E+00	0.60E-05	0.00E+00

Table 7.

400 MeV, 7.5×10^{12} protons, 1800 pulses/hour σ_x=0.3 cm σ_y=2.0 cm




Tempemperature at the centar and 50 cm. from the center
24
20
16
12
8
4
0
400 MeV, 7.5 10^12, σx=0.3 cm and σy=2.0 cm
Temperature above To
4
8
12
16
20
24
Time in hours