A Design Study of the MI40 Beam-Abort Dump

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Design of the MI beam-abort dump and its study from the point of view of radiation safety has been made. The Main Injector beam dump is planned to be built at MI40 straight section and will be at an elevation of about 714ft. This will be much closer to the aquifer than any previous beamdumps in the Fermilab site. Hence additional attentions should be given about the design and radiation shieldings of the beamdump. Starting from the C0 tevatron beamdump design[1] an optimum size of the beamdump has been investigated by varying the quantities of the dump materials and their transverse geometries to achieve total radiation dose above the berm of the beadump and the total number of stars in the uncontrolled soil to be atleast a factor of two below the acceptable limit. Provision has also been made to have a beam hole through the iron core of the beamdump (which will be used for a special high energy neutrino physics experiment). To have ability for future easy access around the beamdump a stand-alone type of beamdump is planned to design. This design is also in favour of reducing ground water contamination. A conceptual design of the beamdump is shown in the Fig.1a. Figs.1b and 1c show the floor plans both for longitudinal and transverse views. Monte Carlo codes CASIM[2] and MUSIM[3] have been used to estimate ground water contamination, prompt neutron radiation at the surface level, on-site and off-site muon doses. To get better statistics cylindrical geometry has been used throughout. These programs have also been used to optimize the geometry of the beam dump. Table I gives the beam intensity used in our estimations for ground water contamination and muon dose. We have assumed about 20% larger average annual aborted beam than PSAR limit for ground water and muons. While for prompt neutron radiation we assume about a factor of three larger beam intensity than the allowed limit. Table II gives the size and approximate volume of each material needed to build the beam dump. Recently it has been found that the alluminium core cooling box will not be large enough if 1'X1'X9' is used, instead a 1.5'X1.5'X9' size box is needed. By including these changes further calculations have been made which suggests no significiant changes in the amount of dump materials. Table III gives the number of stars in each material and the energy depositions. Table IV gives the calculated ground water activation, radiation dose and annual proton intensity limits based upon present EPA guide lines. Most of the calculations have been carried out at 150 GeV incident proton beam and the results have been interpolated using energy scaling as mentioned below. Figs. 2 and 3 display contours of equal radiation dose (in rem or star/cc) arising from neutrons and muons. Notice that the calculations related to the prompt neutrons have been done only upto 30 meters along the beam direction while for muons the calculations goes upto 200 meters. Fig. 4 displays the estimated muon dose at the earth surface.

Induced radioactivity has also been estimated using the star density data in the various region of the beamdump. Table V gives danger parameters[4] and the stars to flux conversion factors[5] used in the estimation of the residual radioactivity. Table VI gives induced radioactivity at various spots of the beam dump as marked in the Fig. 1a.

Assumptions :

Table I. Proton beam intensity used in the evaluations.

Type of Beam loss	Protons Aborted	
	Presently Used	PSAR Limit[6]
Annual Ground Water	4.0E18 @150GeV	3.1E18 @8GeV 3.1E18 @120GeV 0.3E18 @150GeV
Accidental (for prompt radiation dose calculations)	1.5E17 @150GeV p/hr (i.e., 1E14/pulse aborted for 1hr with a rep. rate of 1pulse /2.4s)	5.4E16 @150GeV (i.e., 3E13/pulse)

Some additional assumptions used in the estimation of radiation dose :

A) Conversion from CASIM Star density to Radiation Dose :

1.0star/cc of soil = 1.0E-5 rem/cc (from FERMILAB ES&H Radiological Control Manual[7]).

B) Most of the calculations have been performed at E_p = 150 GeV and then the star densities as a function of energy of the incident beam is obtained by scaling it as, E**.75

C) Beam spot size (which is not important here) is $\sigma_x=\sigma_y=0.1$cm

D) Operating time per year = 6000hour/year.

Discussions and Conclusions

The number of protons used in the calculations for ground water radioactive nuclei contamination is about 20% larger than the design limit of annual aborted beam of 3.24E18/year @150GeV (this intensity is obtained by normalizing 8 and 120GeV annual aborted beam intensities to 150GeV). This gives a total ground water contamination of .33E17($\pm$18%)stars/year as shown in Table 3 as compared with EPA limit of 2.44E17stars/year. Hence the allowed annual proton intensity limit on beam dump is 2.93E19. We use this limitting value of proton intensity in estimating residual radioactivity (which is about a factor of nine larger than PASR limit of 3.24E18p/year@150GeV) as shown in Table VI.

Using these calculations we have also made estimates on the extent of the berm on the beam dump. From the point of neutron radiation , the additional berm of about 8ft (i.e. total uncontrolled soil of 22ft) which is planned for entire MI ring enclosure is sufficient to keep the radiation level far below 1.0mrem/hr for unlimitted occupancy limit. For muons it is found that no additional shielding is necessary.

Thus from our study we find both ground water contamination and radiation limits suggest that the beam dump design presented here is a safe design for beam dump up to about a factor of nine beam intensity larger than PASR limit.

A Comment about the Geometry of the Beam Dump:

In reality constructing a beam dump with rectangular geometry is more economical than cylindrical beam dump. Since all the radiation shielding calculations have been done here in cylindrical geometry we use constant vlume criteria to go from cylindrical geometry to ractangular geometry parameters. In doing so the transverse thickness of any shielding material will be smaller by 15% (maximum) in some directions (e.g., up,down, left and right). Hence an additional shielding may have to be added to compensate for it.

Table II. Geometry of the beam dumps. Follow the Figure 1.

Material#	Cylindrical Geometry(ft)	Volume of the Material	Design Size @
C	L= 8.0 R= 0.28	1.94cubic ft	L=8.0ft H=W=6in
Al (A)	L=9.0 R= 0.28 to .56	7cubic ft	L=9.0ft H=W=0.5 to 1.0ft
(B)	L=9.0 R= 0.28 to .84	18.25cubic ft	L=9.0ft H=W=0.5 to 1.5ft
Fe (A)	L=20.0 R=0.56 to 3.94	971cubic ft	L= 20.0ft H=W=1.0 to 7.0ft
(B)	L=20.0 R=0.84 to 3.94	958cubic ft	L= 20.0ft H=W=1.5 to 7.0ft
Concrete surrounding the Iron	L=32.0 R=3.94 to 7.90	197 cubic yard	L= 32.0ft H=W=7.0 to 14.0ft
Concrete in the outer Wall	2ft thick wall all around		2ft thick wall all around
Soil	L= 98ft for neutrons L=656.0 for muons R= 13.77 to 36.		L=98ft for neutron L=656ft for Muons Soil above the Beam Dump = 22ft

(A) represents 1'x1' alluminium core cooling box and (B) for 1.5'X1.5' alluminium core cooling box.

@ H = height, W= width and L = length

Table III. Comparison of Stars and Energy Deposition (GeV) in various materials of the MI beam dump explained in Table II. Each material is divided into up and down to check the symmetry of the calculations. The errors statistical in nature and are coming from Monte Carlo calculations. The results are for per proton at 150GeV.

Material	Stars/ Energy[@]	Up/ Down	Number of Stars/energy	
			Up and Down	Total Stars/Energy[*]
Carbon	Stars	Up	29.7(±.2%)	59.4(±.2%)
		Down	29.7(±.2%)	
	Energy			44.7(±.2%)GeV
Alluminium	Stars			
	(A)	Up	20.7(±.4%)	41.6(±.2%)
		Down	20.9(±.2%)	
	(B)	Up	33.1(±.1%)	66.2(±.2%)
		Down	33.1(±.2%)	
	Energy			28.1(±.1%)GeV
Iron[#]	Stars			
	(A)	Up	74.4(±.2%)	148.5(±.3%)
		Down	74.1(±.3%)	
	(B)	Up	62.6(±.3%)	124.8(±.4%)
		Down	62.2(±.4%)	
	Energy	Up	21.3(±.1%)GeV	
	(R=17.2	Down	21.1(±.3%)GeV	
	to 32cm)			57.7(±.2%)GeV
	Energy		14.6(±.3%)	
	(R=32			
	to 120cm)			

Table III continued....

Material	Stars/ Energy	Up/ Down	Number of Stars/energy "12" seed1	
			Up and Down	Total Stars/Energy
Concrete surrounding the Iron	Stars	Up Down	.244(±5%) .194(±5%)	0.367(±4%)
	Energy			.321(±3%)GeV
Concrete in the outer wall	Stars	Up Down	0.0119(±12%) 0.0093(± 8%)	0.0212(±8%)
Uncontrolled Soil	Stars	Up Down	0.0033(±14% 0.0050(±28%)	0.0083(±18%)
	Energy			6.5E-4(±28%)GeV

@ (A) represents 1'x1' alluminium core cooling box and (B) for 1.5'X1.5' alluminium core cooling box.

* It can be seen that the sum of the energy deposition is about 130GeV which is smaller than incident particle energy(150GeV). This difference is arising because the average binding energy of 8MeV per nucleon (which is not being converted into heat)will not expilcity appear in the total energy deposition.

In this case the Iron is segmented into mainly two parts: 1) iron from R= 17.2cm to 32cm which has been further divided into up and down, and 2) iron from R=32cm to 120cm. This sort of segmentation helps us to understand where exactly significant energy of the beam is deposited.

Table IV. An evaluation of ground water and radiation dose for MI Beam dump.

Concern	Beam dump (see table 1 for geometry)
Ground Water activation (Allowed Limit 2.44E17st/year)	0.333E17 (stars/year) (A) (±18%) .572E17 (stars/year) (B) (±17%)
Maximum Radiation Dose - Worst case (Allowed Limit min. Occp. Limit= 2.5mrem/hour - no Occp. limit= .25mrem/hr)	1.5E-3(mrem/hr) (1E-23rem/p @150GeV)
On-site muons* Accidental (Limit= 2.5mrem/hr)	.015mrem/acc.(±25%) (1E-22rem/p @150GeV)
Off-site muons) Annual (mrem/year) (Limit= 170mrem/year)	≤1.5E-4 (1E-26Rad/p @150GeV)
Annual Proton Intensity limit (@150GeV)	2.93E19p@150GeV/year

[@] (A) represents 1'x1' alluminium core cooling box and (B) for 1.5'X1.5' alluminium core cooling box.

* Figs. 2b display results in radiation dose in units of Rad/incident proton for muons. Note that rem = Rad for muons.

An Evaluation of the Induced Radio Activity In and Around the Beam Dump

An estimation of the residual radioactivity is made for the various region of the beam dump essentially adopting the method outlined in the Fermilab Radiation Guide[7]. The radiation dose is given by,

$$\dot{D}\ (\text{rad/hr}) = \Omega/4\pi \times \Phi \times \text{d}$$
$$= \Omega/4\pi \times \text{conversion factor} \times (\text{star/cc}) \times \text{Beam intensity/sec} \times \text{d}$$

where d is danger parameter[4] and Φ is the hadron flux. The conversion factors have been evaluated by A. Van Ginneken [5] for concrete and iron as a function of radii and energies and we use those results here. The star densities are taken from the figs. 2a-c. The values of danger parameters and necessary conversion parameters are listed in Table V. We have also estimated the residual radioactivity adopting the method outlined by Gollon[8] which gives activity smaller by 20% or more. Hence to be more conservative we omit later estimations.

Table V Danger Parameters[4] and conversion factor[5] for the materials of the beam dump. Al and C are assumed to have conversion factors similar to concrete.

Material	Irradiation time (day)	Cooling time (day)	Danger Parameter (rad/hr)	Conversion Factor (Hadrons/cm/ stars/cm3)
C	360	1	7.0E-10	200
Al	360	1	1.7E-8	200
Fe(r=17cm to r=120cm)	360	1	3.5E-8 ,,	70 at 17cm 150 at 120cm
Concrete	360	1	7.2E-9	400
C	360	7	6.5E-10	400
Al	360	7	3.0E-9	400
Fe	360	7	2.0E-8 ,,	70 at 17cm 150 at 120cm
Concrete	360	7	1.5E-9	400
C	30	1	2.2E-10	400
Al	30	1	3.0E-10	400
Fe	30	1	2.4E-8 ,,	70 at 17cm 150 at 120cm
Concrete	30	1	6.0E-9	400
C	30	7	2.0E-10	400
Al	30	7	3.0E-10	400
Fe	30	7	1.2E-8 ,,	70 at 17cm 150 at 120cm
Concrete	30	7	2.2E-10	400

Table VI. An evaluation of induced radioactivity for MI Beam dump. Geometry factor = 1/2 at contact[1]. Number of Protons are limitted by ground water, i.e. 2.93E19p/year which gives 1.36E12/s.

Description	No. of Stars/ proton/2sec	Dose Rate on Contact (rad/hr)	
		T_i=360days T_c=1day (7days)	T_i=30days T_c=1day (7days)
CARBON			
Front	1.0E-3	95 (88)	30 (26)
Back	1.0E-3	95 (88)	30 (26)
ALLUMINIUM BOX			
Top Front	1.0E-4	232 (40)	4. (4.0)
Top Back	1.0E-4	232 (40)	4..0 (4.0)
IRON CORE			
Front	1.0E-6	1.6 (1.)	1. (.6)
Middle Top	1.0E-7	.16 (.1)	.1 (.06)
Middle Top of Al box	1.0E-4	160 (100)	100 (60.0)
Back	1.0E-8	3.6E-3 (1.0E-3)	2.4E-3 (12.0E-4)
CONCRETE SURROUNDING THE IRON CORE			
Top of the steel	0.5E-7	1. (.20*"A")	.83*"A" (.03*"A")
A (as in Fig.1a)	1.0E-9	2.0E-3 (,,)	,, (,,)
B ,,	1.0E-6	2.0 (,,)	,, (,,)
C ,,	1.0E-10	2.0E-4 (,,)	,, (,,)
D ,,	0.5E-8	1.0E-1 (,,)	,, (,,)
E ,,	1.0E-11	2.0E-5 (,,)	,, (,,)
F ,,	1.0E-9	2.0E-3 (,,)	,, (,,)
G ,,	1.0E-11	2.0E-5 (,,)	,, (,,)
H ,,	1.0E-9	2.0E-3 (,,)	,, (,,)
CONCRETE IN THE OUTER WALL			
I (as in Fig.1a)	1.0E-11	2.E-5 (,,)	,, (,,)
J ,,	0.5E-12	1.E-6 (,,)	,, (,,)
K ,,	0.4E-9	8.E-4 (,,)	,, (,,)
L ,,	1.0E-12	2.E-6 (,,)	,, (,,)
M ,,	0.5E-11	1.E-5 (,,)	,, (,,)

"A" implies the values for radiation dose in case of T_i=360days and T_c=1day.

REFERENCES

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2. A. Van Ginneken, CASIM, (private communication)
3. A. Van Ginneken, MUSIM, Fermilab FN-594 (1992)
4. M. Barbier, "Induced Radioactivity" (1969)
5. A. Van Ginneken and M. Awschalom, "High energy particle Interactions in large Targets" VOL. 1, (1983).
6. Preliminary Safety Analysis Report, (PSAR) dated 4-21-1992.
7. ESH Radiaological Control Manual FERMILAB
8. J.Donald Cossairt, Fermilab-TM-1834 (1993),Induced Radioactivity at Accelerators, page 21.

MI BEAM ABORT DUMP

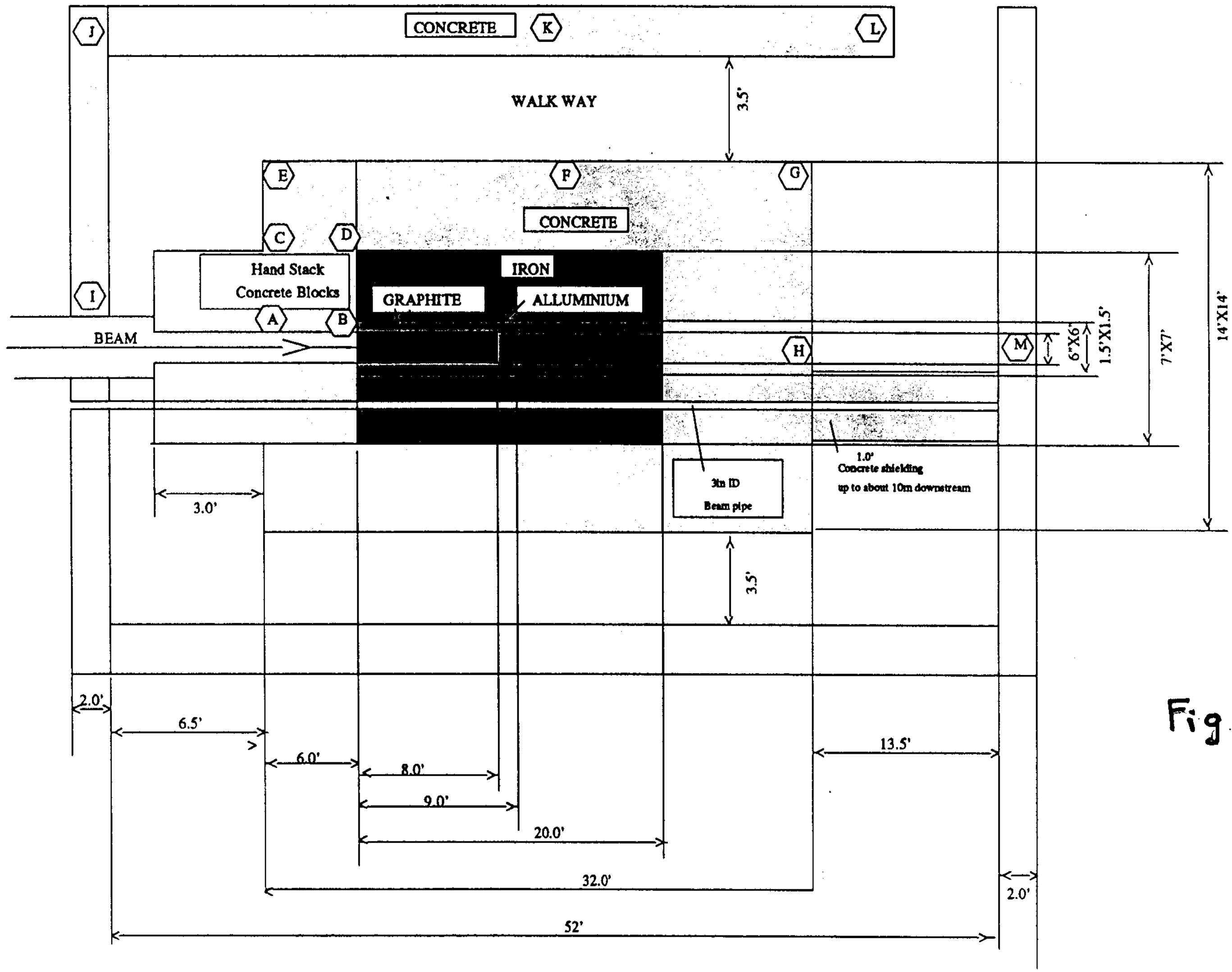
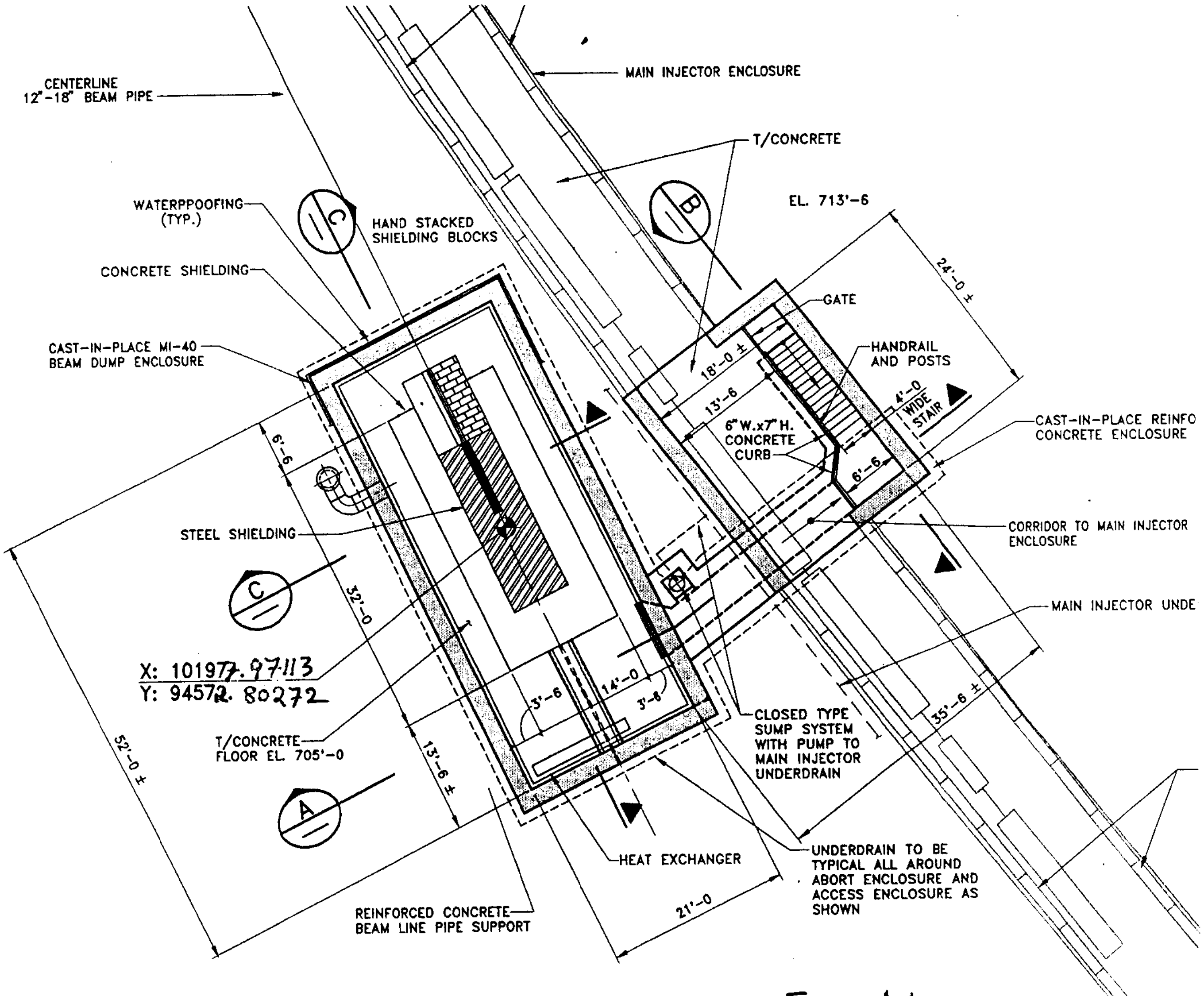
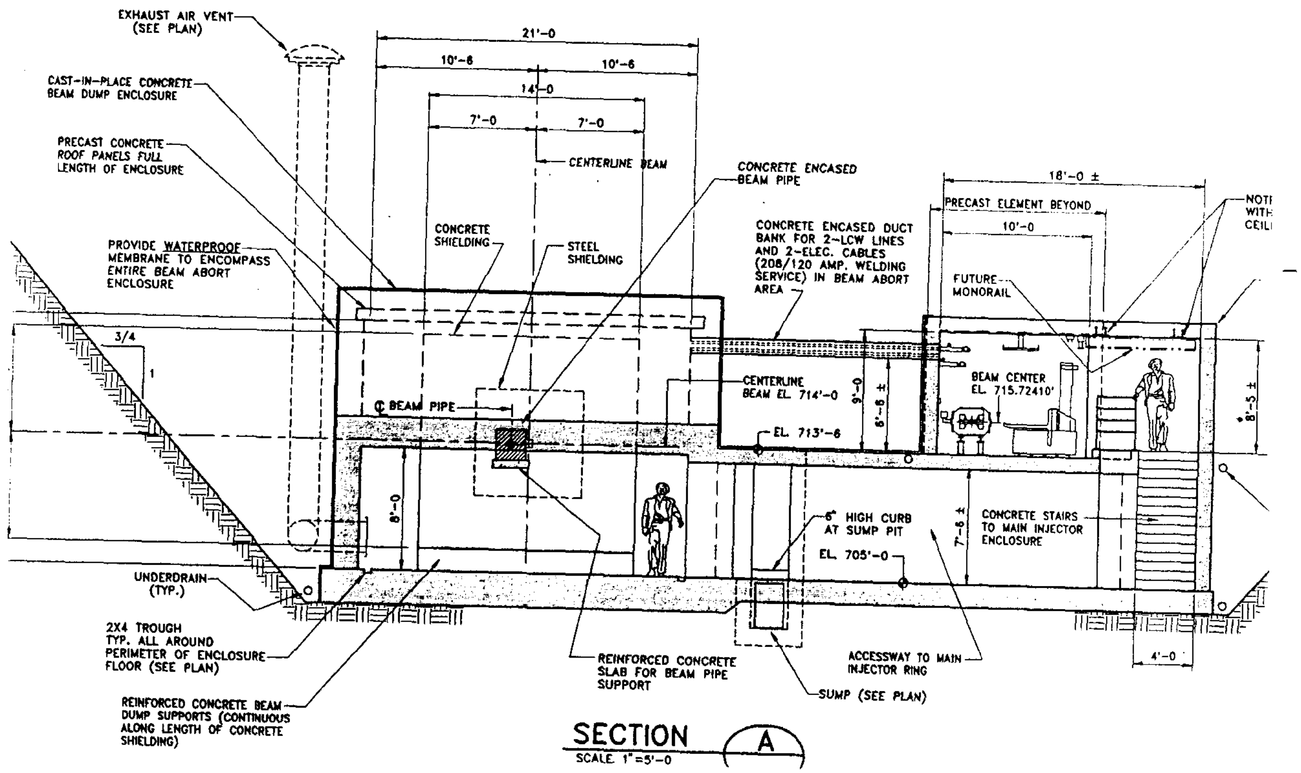


Fig. 1a



CENTERLINE
12"-18" BEAM PIPE
MAIN INJECTOR ENCLOSURE
T/CONCRETE
EL. 713'-6
WATERPPOOFING (TYP.)
HAND STACKED SHIELDING BLOCKS
CONCRETE SHIELDING
CAST-IN-PLACE MI-40 BEAM DUMP ENCLOSURE
GATE
HANDRAIL AND POSTS
24'-0 ±
18'-0 ±
13'-6
6"W.x7"H. CONCRETE CURB
4'-0 WIDE STAIR
CAST-IN-PLACE REINFO CONCRETE ENCLOSURE
6'-6
CORRIDOR TO MAIN INJECTOR ENCLOSURE
STEEL SHIELDING
32'-0
MAIN INJECTOR UNDE
X: 101977.97113
Y: 94572. 80272
14'-0
3'-6
3'-8
T/CONCRETE FLOOR EL. 705'-0
CLOSED TYPE SUMP SYSTEM WITH PUMP TO MAIN INJECTOR UNDERDRAIN
35'-6 ±
52'-0 ±
13'-6 ±
HEAT EXCHANGER
UNDERDRAIN TO BE TYPICAL ALL AROUND ABORT ENCLOSURE AND ACCESS ENCLOSURE AS SHOWN
21'-0
REINFORCED CONCRETE BEAM LINE PIPE SUPPORT

Fig. 1b



SECTION A
SCALE 1"=5'-0

Fig 1c

CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10

M140 BEAM DUMP WITH 3" ID BEAM PIPE THROUGH IRON CORE AL BOX 12"x12"

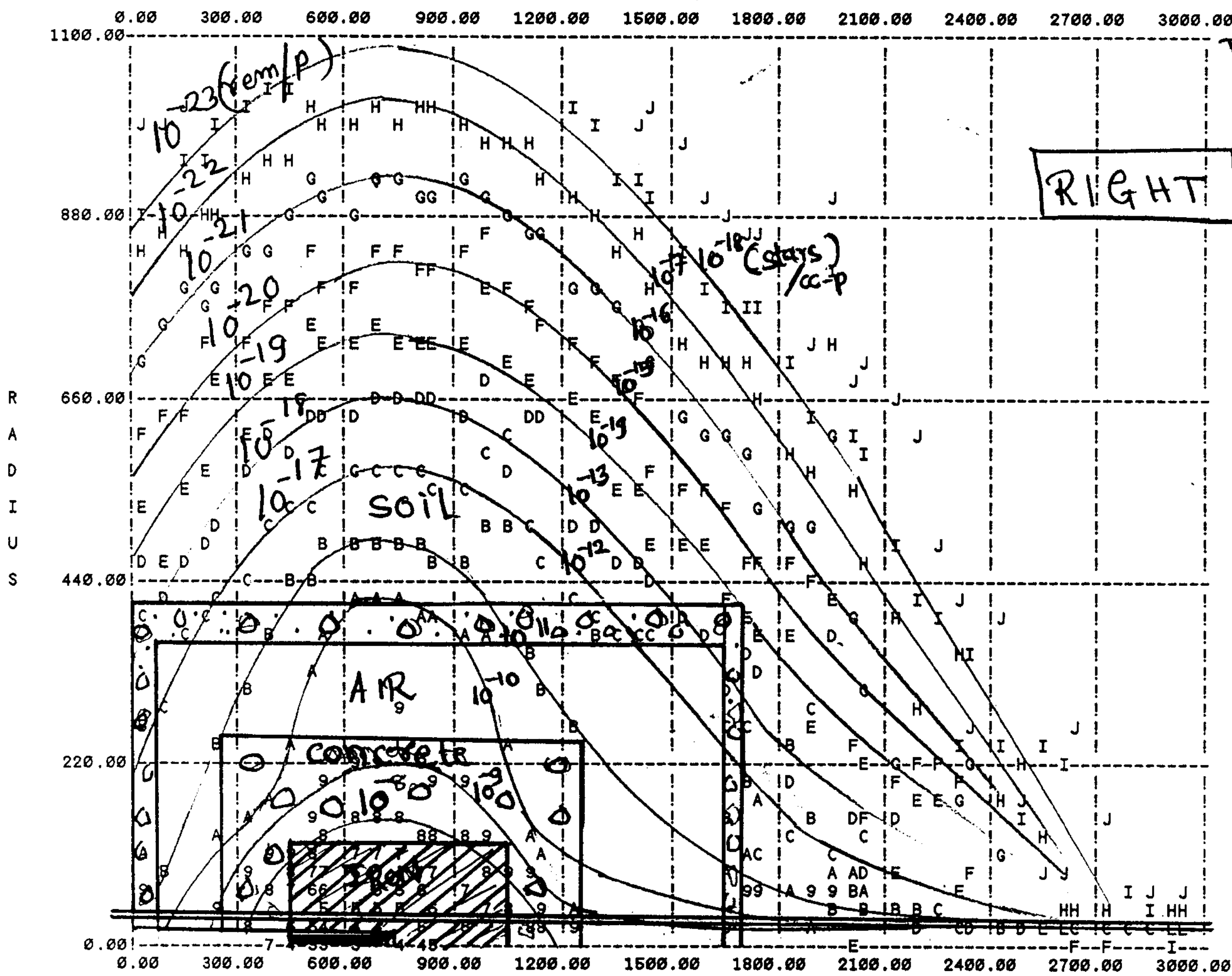


Fig 2a

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)

CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10

M140 Beam Dump, with 3" I.D. Beam hole.
AL = 18' x 18' Box.

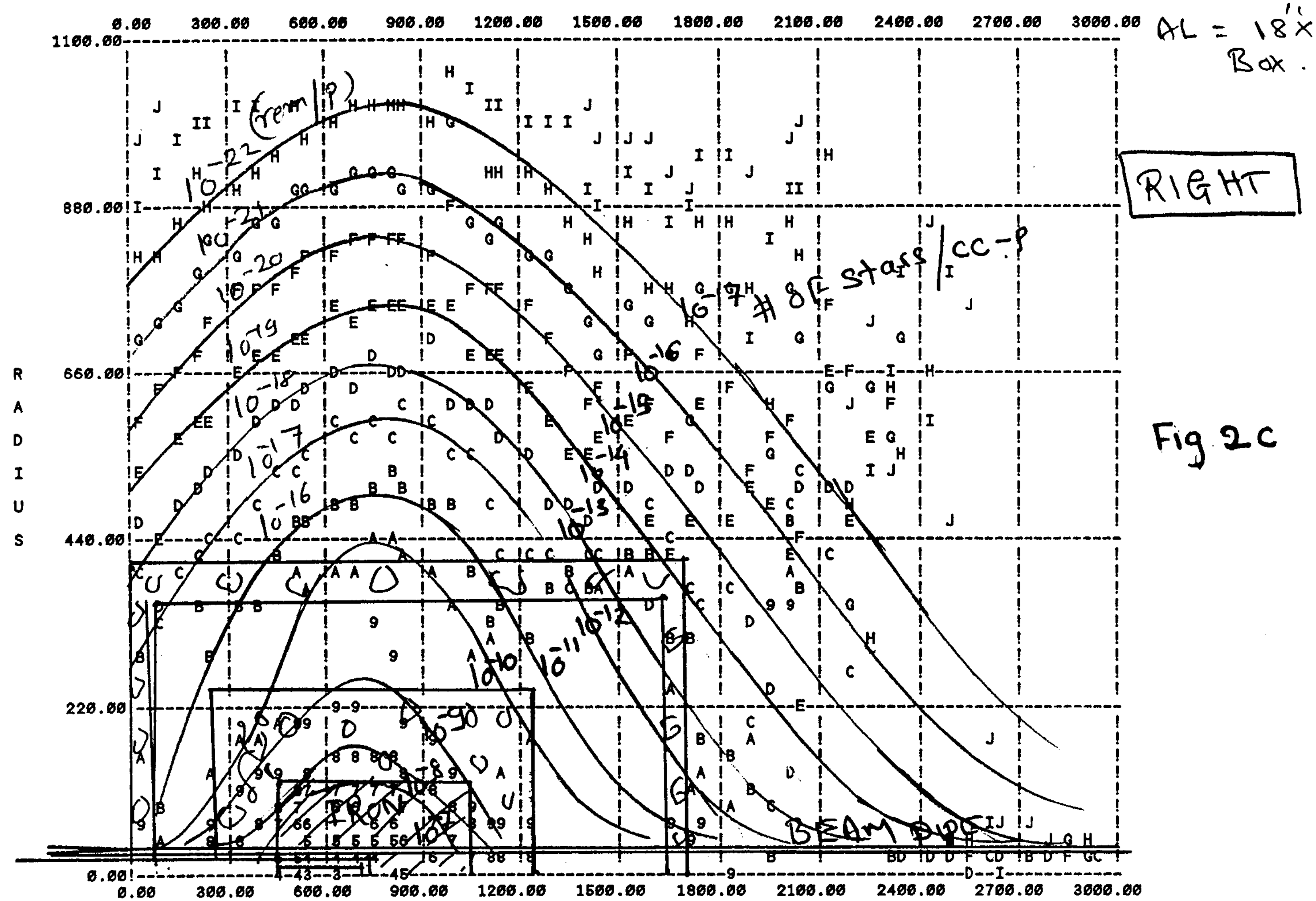


Fig 2c

R-LABELS REFER TO SMALLER VALUES OF CORRESPONDING BINS
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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)

CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10

MI 40 BEAM DUMP

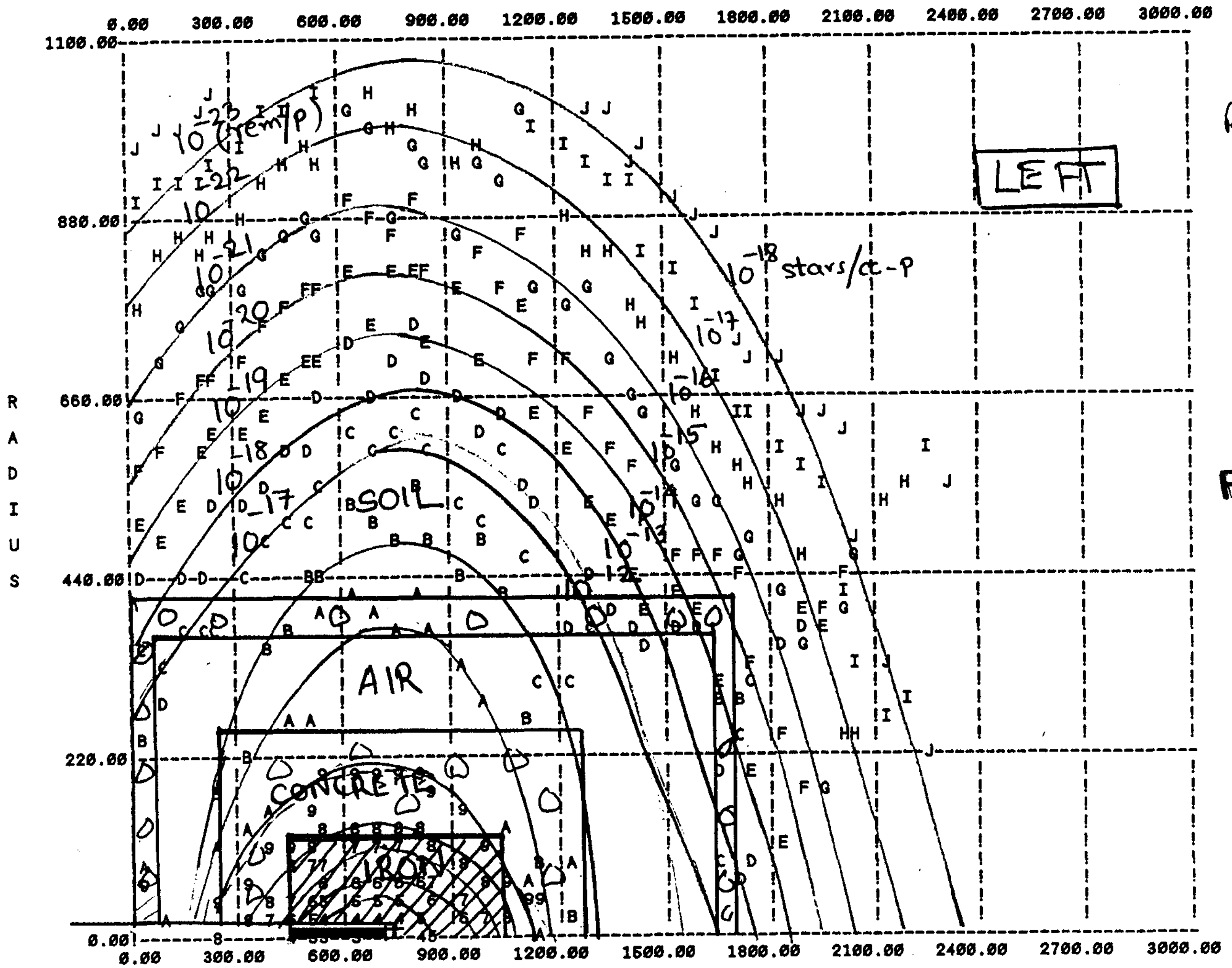

Fig 2b

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)

CONTOURS OF EQUAL ABSORBED DOSE (RAD/INC.PTCLE)
CONTOURS ARE SHOWN FOR INTEGRAL POWERS OF 10

μ- Dose Contours 7/2/93
MI Beam Dump

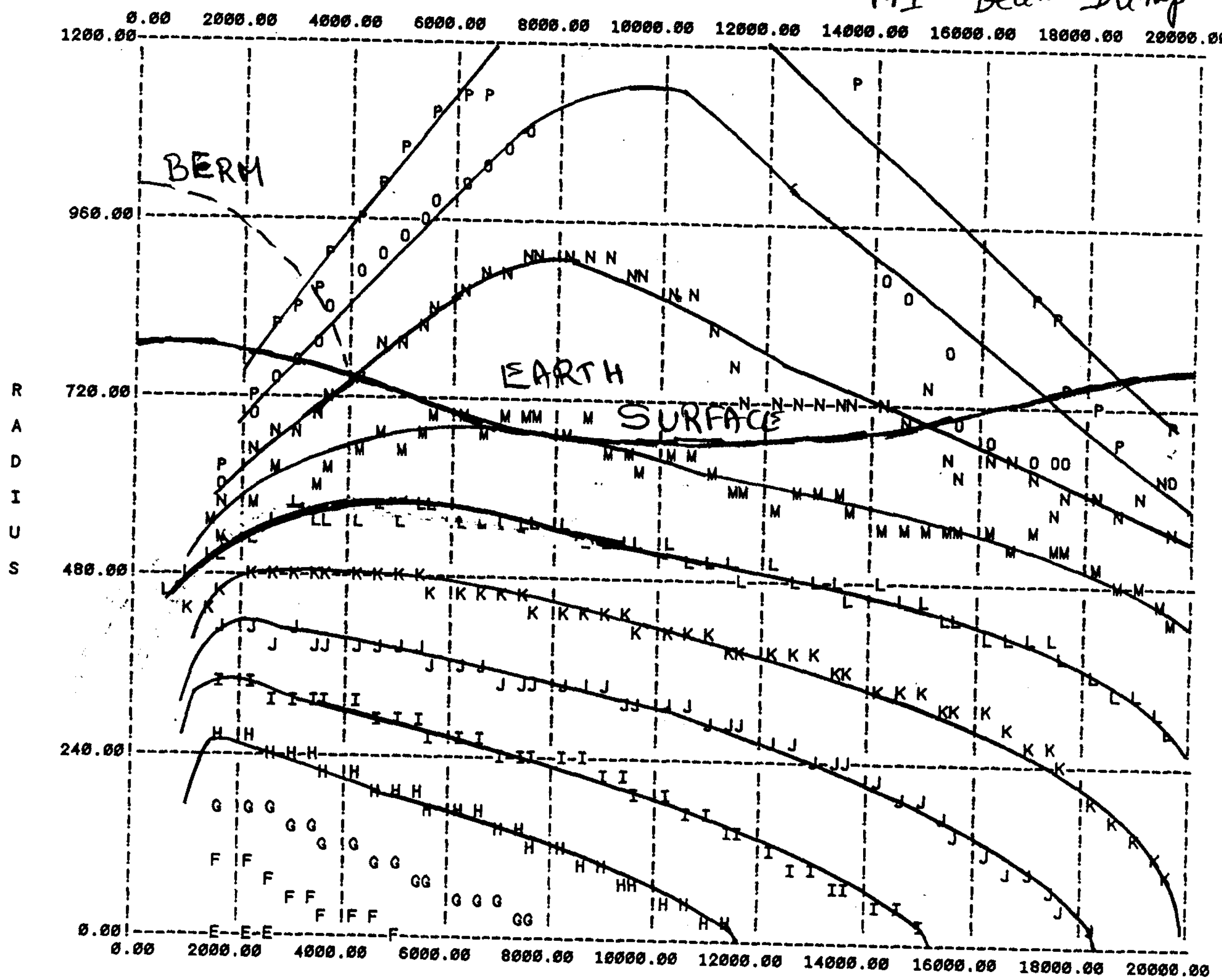

Fig. 3

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),-20(K),-21(L),-22(M)
-23(N),-24(O),-25(P) 1(Z),2(Y),3(X),4(W),5(V),6(U),7(T),8(S),9(R),10(Q)

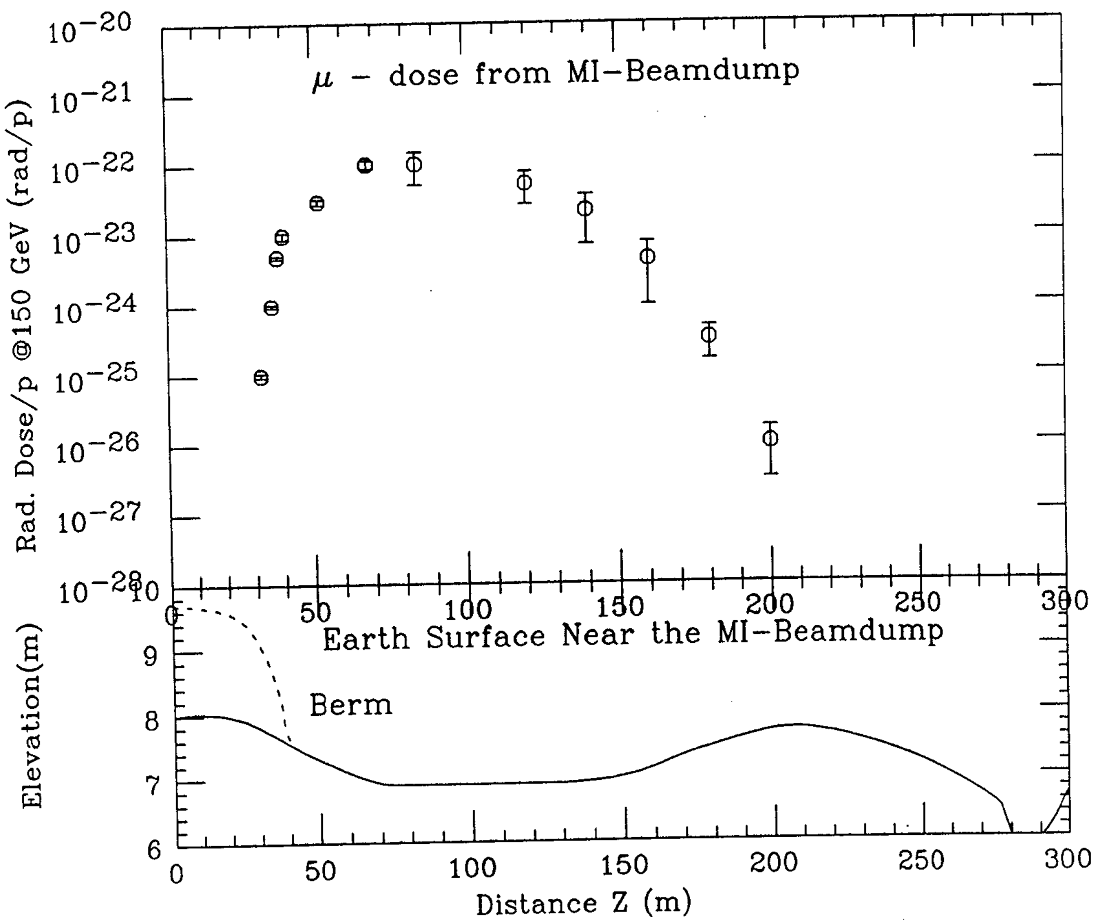
μ − dose from MI−Beamdump
Rad. Dose/p @150 GeV (rad/p)
Earth Surface Near the MI−Beamdump
Berm
Elevation(m)
Distance Z (m)

Fig 4