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RADIATION SHIELDINGS FOR MI CULVERTS

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The radiation shielding aspects of MI Culvert have been re-investigated from the point of view of recent changes in the culvert sizes. A preliminary estimate was made by Van Ginneken[1] for a few culverts assuming culverts size of 3ft ID and only with approximate geometries since the details on the culverts were not available (and finalized). Presently it has been decided that one needs to use 4ft ID pipings for most of the large culverts and center to center distance will be 7ft. This increase in size changes the radiation shielding criteria considerably. The radiation levels at the exits of a culvert are evaluated using a special code CASPEN2[2] which is a version of CASIM. For calculations we assume a cylindrical beam enclosure of size 5.77ft radius(R_{tun}) and that the beam is lost in an iron target of radius 4in. placed at the center of the tunnel. The base of the culvert is $x_1$ft ($=T+R_{tun}$; T is the physical thickness of the shielding from the ceiling of the beam line enclosure to the base of the culvert) from the beam. The Fig.1 gives locations of all culverts around the MI which are having multiple inlets and outlets. Other culverts having 24in ID are not shown here. Fig 2(a) shows the model used in CASPEN2 to evaluate radiation dose at the mouth for a single culvert. A total shielding of 24.5ft soil equivalent is assumed for the entire ring. Also , the cross-talk due to a finite thickness of the soil between two culverts is neglected but the cross-talk due to large angle overlap of radiation at a distance d from the exits of adjacent culverts is important and have been estimated using a model shown in the Fig 2(b). For center to center distance between two culverts is equal to 7ft, we find that the radiation due to cross-talk will add up at the following distances and their values are:

For two Culverts Cross-talk Occur at d = 0.75L ,
Dose Rate = 0.65(Dose at the Mouth)

For three Culverts Cross-talk Occur at d = 2.5L,
Dose Rate = 0.24(Dose at the Mouth)

where L is the longitudinal distance from beam line and the end-of-culvert (EOC) also called distance between the point of highest radiation and the EOC. The radiation is assumed die off according to $1/r^2$.

For many culverts the bare soil(and/or concrete) may not be enough to provide necessary radiation shieldings required for the unlimited occupancy. Then one may have to replace some amount of the soil/concrete between the culverts and beam enclosure-ceiling by high density material like steel. The effective reduction in radiation is given by the expression

$$X = .84 * ln\alpha$$

for steel. Where X(ft) is the thickness of the steel to reduce the radiation by a factor α. This is a good approximate relation (within 6%) for earth shielding from 10ft to 20ft thickness (T). This assumes the nuclear interaction length for iron is 0.55ft.

To estimate radiation dose at the EOCs of the culverts we assume beam losses as prescribed in PSAR[3]. The beam losses under different scenario are listed in Table I

Table I. Proton beam intensity used in the evaluations

Type of Beam loss	PSAR Limit
Operational (Annual)	1.0E19 @8GeV 4.1E18 @120GeV
Accidental (per accident)	5.7E16 @8GeV 8.5E15 @120GeV

Some additional assumptions used in the calculations of radiation dose :

A) The Beam is lost entirely by a 4in iron target causing radiation in the culvert. Soil is the shielding material between culverts and the ceiling of beam line enclosure(.i.e. figures 3-8 are for soil shielding).

B) Conversion from CASIM or CASPEN2 Star density to Radiation Dose :

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

C) Most of the calculations have been performed at E_p = 120 GeV and then the star densities as a function of energy of the incident beam is obtained by scaling it as, E**.75

D) Beam spot size (which is not important here) is σ_x=σ_y=0.1cm

Table II gives the results of the calculations of radiation dose for culverts around MI. Only in the case of the culvert#1 we have made estimations of radiation for 3ft ID as well as 4ft ID culverts and compared their results. Comments and recommendations have also been made for each culvert. The culverts 2,4 and 6 are at different angles with respect to the beam direction. Therefore the forward and backward radiation doses have been treated differently and they are considerably different. For culvert#1 the angle is only about 85deg. Hence we treated both forward and backward radiation dose to be the same. For culverts with 24in ID, the results are presented at the end of the Table II.

The Fig.3-6 display radiation dose as a function of distance along the beam (Z) for different culverts. The upstream and downstream radiation levels are shown separately for culverts 2,4,and 6 in figures. The Figs. 7a and 7b display maximum dose as a function of L for four different culverts. Depending upon the angle of the culvert with respect to the beam direction the downstream end radiation level is an order of magnitude larger than upstream end radiation in some cases. The curves corresponding to each culvert is only to guide the eyes. The results of calculations for culvert#1 with 3ft ID culverts are also shown in Figs.3b and 7b. The markers A and B in these plots essentially indicate proposed physical locations of EOC. (In case of an orianted culvert with multiple inlets and outlets we assume that the lengths of the inlets or outlets are same as that of the one in the middle.) Maximum radiation level per proton loss verses the length of the culvert for 24in culverts are shown in Fig. 7c. The two horizontal lines indicate radiation dose per proton at 120GeV corresponding to 1.0mrem/accident (unlimited occupancy limit) and 10.0mrem/accident (minimal occupancy limit). As shown in the above Table I the number of proton per accident at 120GeV (which is worst case) is assumed to be 8.5E+15 in drawing these lines in Figs. 7.

Initially the reduction of the radiation dose as a function of the length of the culvert is fairly steep and at large distances reduction is slow. On an average, additional culvert lenght increase of 8ft yields a factor of two reduction in the radiation dose at the EOC. A conservative estimate at large distances is that an additional 11ft of the culvert is necessary to reduce the radiation dose by a factor of two.

REFERENCES

1. A. Van Ginneken, A letter to T.Pawlak, Jan.27, 1992
2. A. Van Ginneken, CASPEN2, Fermilab FN-571 (1991)
3. Preliminary Safety Analysis Report, (PSAR) dated 4-21-1992.

Table II Radiation estimates for Culverts in MI under accidental conditions. Beam is at an elevation of 715.724ft and tunnel ceiling is at 721.5ft. For normal operations, mrem/hour can be obtained by multiplying the values in the table by 0.08 and 0.03 for 120GeV and 8GeV cases respectively.

Culvert, Length, T*	Description	Radiation at the EOC (mrem/accident)	
		Culvert size 3ft ID Exits A and B	Culvert size 4ft ID Exits A and B
Culvert#1 Length=105ft (36ft(A)+69ft(B)) T = 7.28ft Theta= 85deg	Single Culvert with Soil shielding	43(A)@120GeV 5.9(B)@120GeV 38(A)@8GeV 5.2(B)@8GeV	77(A)@120GeV 8.5(B)@120GeV 68(A)@8GeV 7.4(B)@8GeV
No. of culverts =3 U.S elev.= 728.96ft D.S. elev.= 728.60ft	Single Culvert with 2ft Steel shield betn. tunnel and the culvert	5.2(A)@120GeV .7(B)@120GeV 4.6(A)@8GeV .6(B)@8GeV	9.4(A)@120GeV 1.0(B)@120GeV 8.2(A)@8GeV .87(B)@8GeV
	Three Culverts with 2ft of steel shield betn. tunnel and the culverts	5.2(A)@120GeV .7(B)@120GeV 4.6(A)@8GeV .6(B)@8GeV	9.4(A)@120GeV 1.0(B)@120GeV 8.2(A)@8GeV 0.87(B)@8GeV

Comments	We find that the radiations at the EOCs A and B of culvert#1 are rather high even with additional 2ft iron shielding underneath the culverts. Also the radiation dose due to cross-talk is important on the side of shorter leg (i.e. at exit A which is only 36ft). Here the cross-talk due to two culverts occur at about 27ft and due to three culverts occur at about 90ft down stream of the culverts. We find that to achieve the radiation level below unlimited occupancy limit without altering the culverts we may need to add a total steel of thickness 3.7ft between the ceiling of the beam enclosure and the base of the culverts. This is not economical. Increasing the length of the culverts to 150ft is also not economical. In practice there are many ways to achieve minimal occupancy limit. One of the possible way is to use 3ft ID culverts instead of 4ft ID with 2ft steel shielding underneath. This gives a radiation dose of about 4mrem/hr. This require displaying warning signs.

* T, physical thickness of the shielding from the ceiling of the beam line enclosure to the base of the culvert.

Table II continued ...

Culvert, Length, T*	Description	Radiation at the EOC culvert(mrem/accident) Culvert size 4ft ID Exits A and B
Culvert#2 Length=115ft (53ft(A)+62ft(B)) T = 12.75ft Theta= 42deg No. of culverts =7 Option 1 U.S elev.= 734.35ft D.S. elev.= 734.15ft	Single Culvert with Soil shielding	.12(A)@120GeV 1.0(B)@120GeV .10(A)@8GeV .87(A)@8GeV
	Seven Culverts with Soil shielding	.12(A)@120GeV 1.0(B)@120GeV .10(A)@8GeV .87(A)@8GeV

Comments and Conclusions	We find that the radiation at upstream end, i.e. EOC "A" of culvert#2 is below the unlimited occupancy limits of 1mrem/accident. No further shielding other than 24.5ft earth berm is necessary. At EOC "B", the calculated radiation level is right on unlimited occupancy limit. A few feet of extenstion may be necessary. The contributions due to cross-talk is small.

Table II continued ...

Culvert, Length, T*	Description	Radiation at the EOC culvert(mrem/accident) Culvert size 4ft ID Exits A and B
Culvert#4 Length=52 ft (29ft(A)+23ft(B)) T = 16.46ft Theta = 60deg No. of culverts = 3 U.S elev.= 738.01ft D.S. elev.= 737.90ft	Single Culvert with Soil shielding	.03(A)@120GeV .25(B)@120GeV .03(A)@8GeV 0.22(B)@8GeV
	Three Culverts with Soil shielding	.03(A)@120GeV .25(B)@120GeV .03(A)@8GeV 0.22(B)@8GeV

Comments	We find that the radiation shielding in this case is adquate and no additional shielding is necessary.

Table II continued ...

Culvert, Length, T*	Description	Radiation at the EOC culvert(mrem/accident) Culvert size 4ft ID Exits A and B
Culvert#6 Length=65ft (30ft(A)+35ft(B)) T = 10.54ft Theta = 75deg No. of culverts =5 U.S elev.= 732.10ft D.S. elev.= 731.97ft	Single Culvert with Soil shielding	6.8(A)@120GeV 25.5(B)@120GeV 6.0(A)@8GeV 22.5(B)@8GeV
	Five Culverts with Soil shielding	6.8(A)@120GeV 25.5(B)@120GeV 6.0(A)@8GeV 22.5(B)@8GeV
	Five Culverts with 2ft of steel shieldings	.63(A)@120GeV 2.35(B)@120GeV .54(A)@8GeV 2.05(A)@8GeV

Comments and Conclusions	The radiation levels at EOCs A and B of culvert#6 are quite high. To reduce below the allowable limits at B without changing the culvert lengths one needs a 3ft steel shielding, which gives a factor of 35 reduction. An alternative to this is to add 2.0ft of iron and increase B side from 35ft to 60ft leaving A side as it is.

Table II continued ...

Culvert, Length, T*	Description	Radiation at the EOC culvert(mrem/accident) Culvert size 24in ID
Culvert at 100 Length=40ft (20ft(A)+20ft(B)) T = 19ft, Theta = 90deg No. of culverts =1 U.S elev.= 740.60ft D.S. elev.= 740.40ft	Single Culvert with Soil shielding	.02(A) @120GeV .002(A) @8GeV
Culvert at 228 Length=42ft (21ft(A)+21ft(B)) T = 16.5ft, Theta = 90deg No. of culverts =1 U.S elev.= 738.2ft D.S. elev.= 737.8 ft	Single Culvert with Soil shielding	.1(A) @120GeV .01(A) @8GeV
Culvert at 316 Length=50ft (25ft(A)+25ft(B)) T = 14.35ft, Theta =90deg No. of culverts =1 U.S elev.= 736.00ft D.S. elev.= 735.70ft	Single Culvert with Soil shielding	0.17(A) @120GeV .02(A) @8GeV
Culvert at 402 Length=60ft (30ft(A)+30ft(B)) T = 11.35ft, Theta = 90deg No. of culverts =1 U.S elev.= 733.60ft D.S. elev.= 732.10ft	Single Culvert with Soil shielding	1.3(A) @120GeV 0.1(A) @8GeV
Culvert at 635 Length=31ft (15.5ft(A)+15.5ft(B)) T = 19.95ft, Theta = 90deg No. of culverts =1 U.S elev.= 741.50ft D.S. elev.= 741.40ft	Single Culvert with Soil shielding	.05(A) @120GeV .005(A) @8GeV

Comments and Conclusions	Almost all culverts with 24in ID pipes are safe except the one near location 402. Here we recommend to extend the culvert to 35ft from 30ft symmetrically to attain radiation dose below the unlimited occupancy limit.

Conclusions

The radiation levels at the EOC for culvers#1 and 6 are quite high. To achieve unlimitted occupancy one needs to add considerably large amount of shielding (especially in the case of culvert#1). For culvert#1 even to get minimum occupancy limit we have to add 2ft of steel shielding and reduce the culvert sizes to 3ft ID from 4ft ID. With the present design the culvert#4 is safe while for culvert#2 we have to increase the length of the downstream legs of the culvert by about 6ft.

In case of culverts with 24in ID we have radiation dose below unlimited occupancy limit for almost all cases except the one at location 402, where the extension of the culvert or adding iron shielding is necessary. For these cases in general if culvert elevation is above 736ft and length of the culvert is more than 40ft we have unlimited occupancy without any additional changes in the culvert geometry. The curve in Fig.8 represents this result in a general way for 24in ID culverts. Those culverts which satisfy the conditions corresponding to the region above the curve in Fig.8 do not need any additional shieldings. While others need additional shieldings.

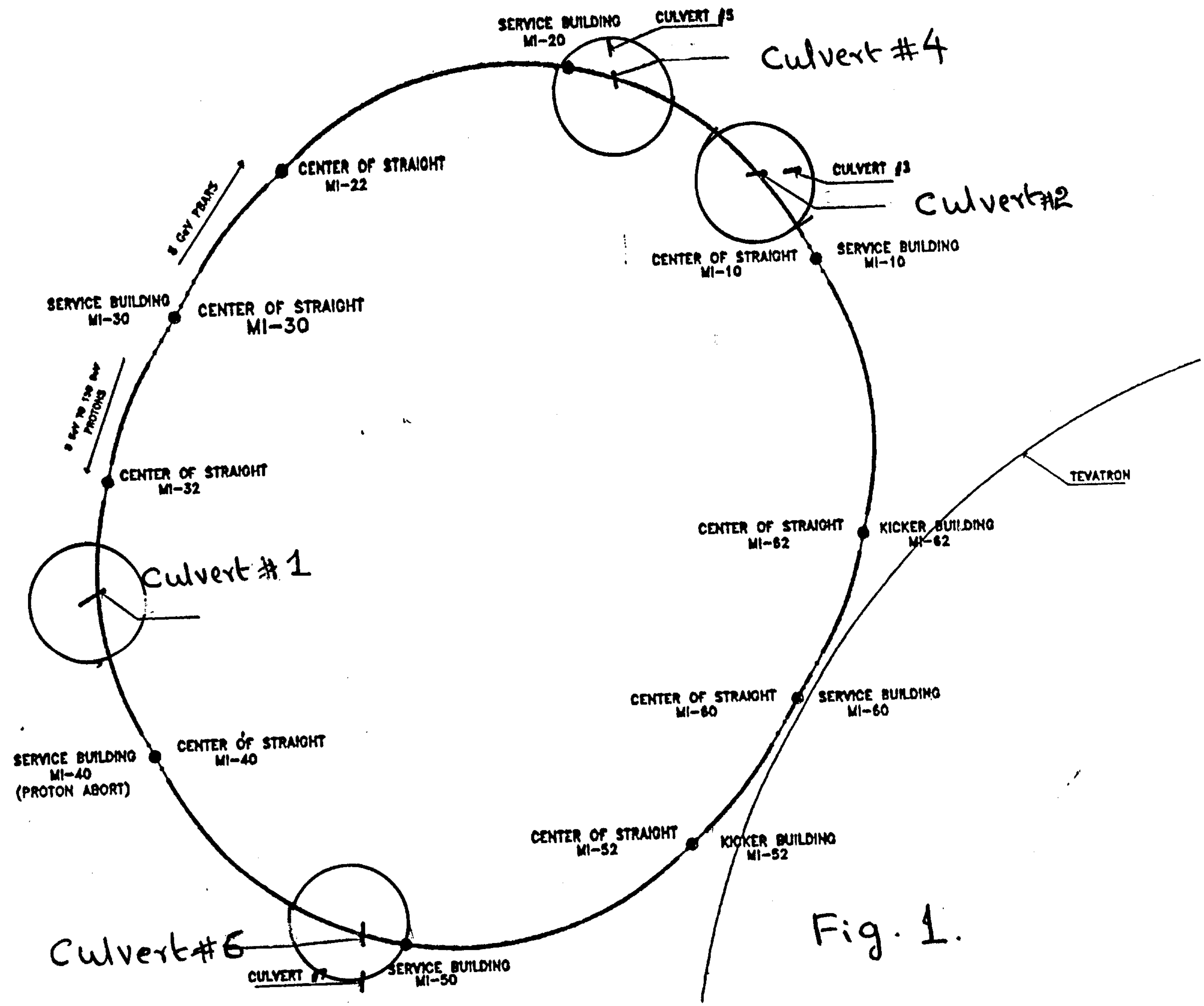

SERVICE BUILDING
MI-20
CULVERT #5
Culvert #4
CULVERT #3
Culvert #2
CENTER OF STRAIGHT
MI-22
GeV PBARS
SERVICE BUILDING
MI-30
CENTER OF STRAIGHT
MI-30
PROTONS
CENTER OF STRAIGHT
MI-32
CENTER OF STRAIGHT
MI-10
SERVICE BUILDING
MI-10
TEVATRON
CENTER OF STRAIGHT
MI-62
KICKER BUILDING
MI-62
Culvert #1
CENTER OF STRAIGHT
MI-60
SERVICE BUILDING
MI-60
SERVICE BUILDING
MI-40
(PROTON ABORT)
CENTER OF STRAIGHT
MI-40
CENTER OF STRAIGHT
MI-52
KICKER BUILDING
MI-52
Culvert #6
CULVERT #7
SERVICE BUILDING
MI-50

Fig. 1.

MI Culverts : Model used in CASPEN2

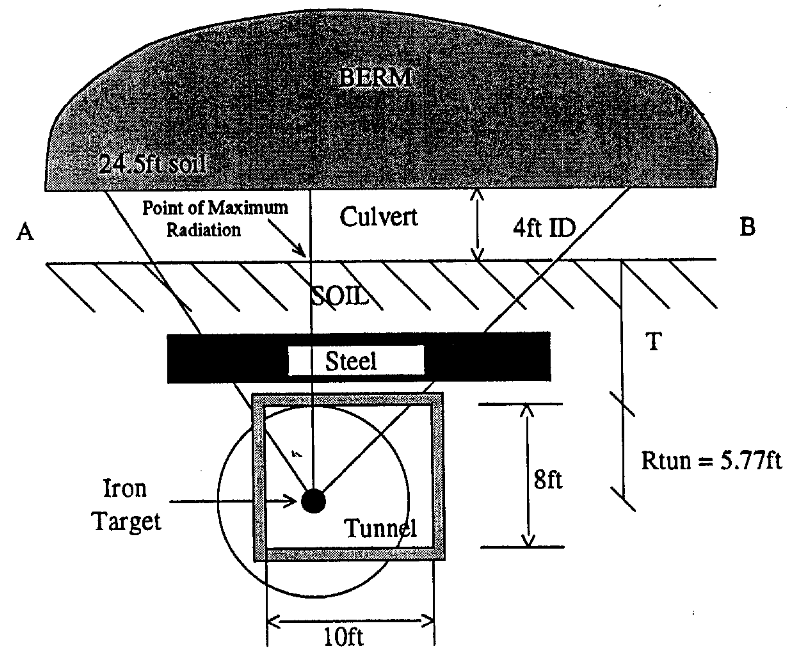


Fig 2(a)

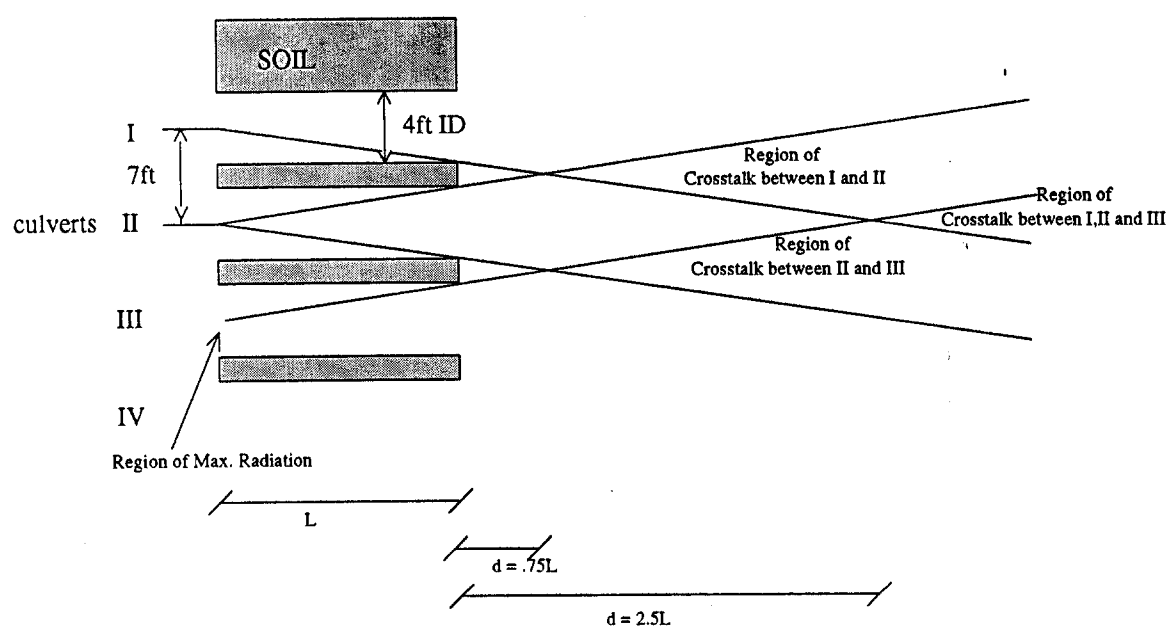
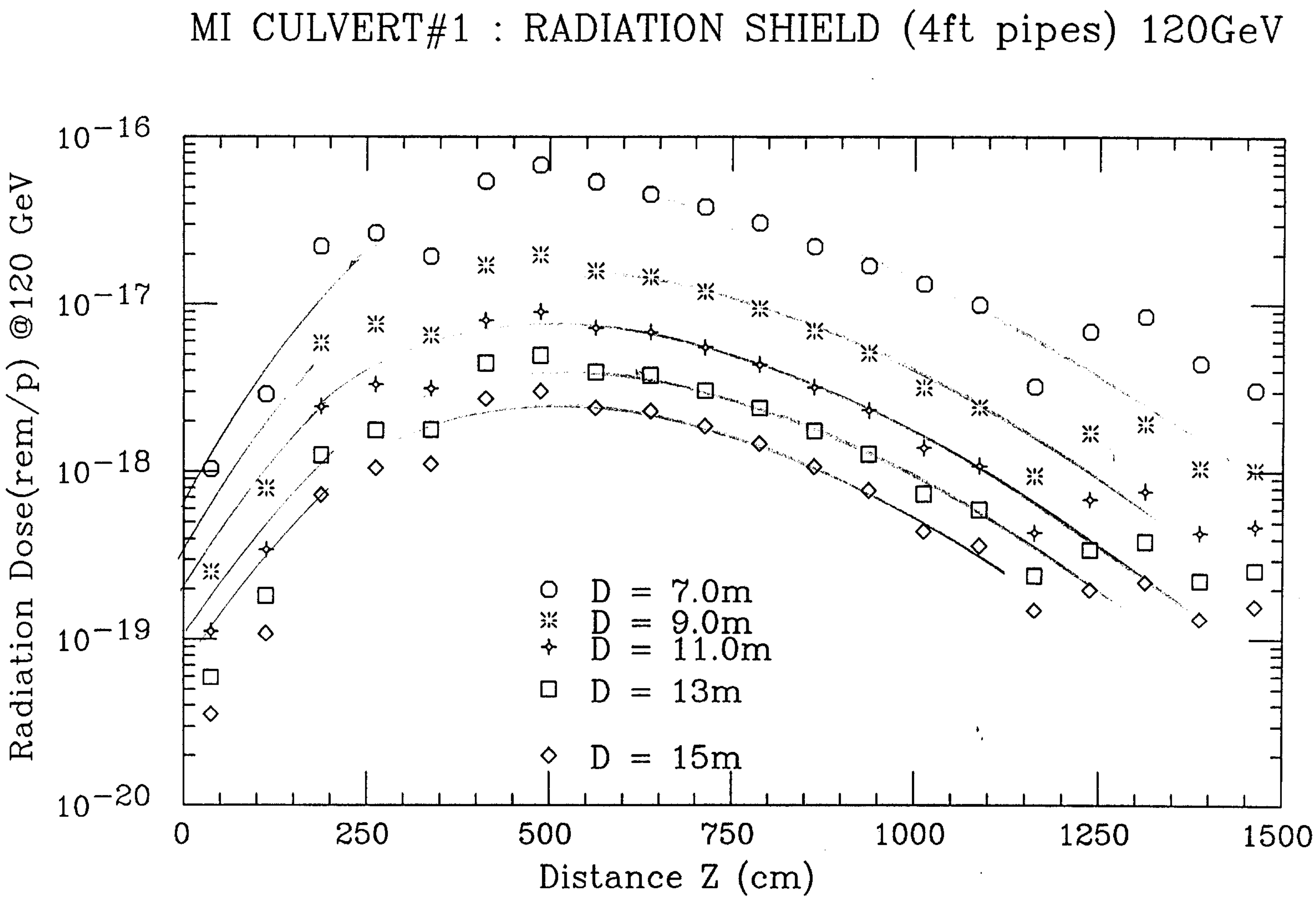
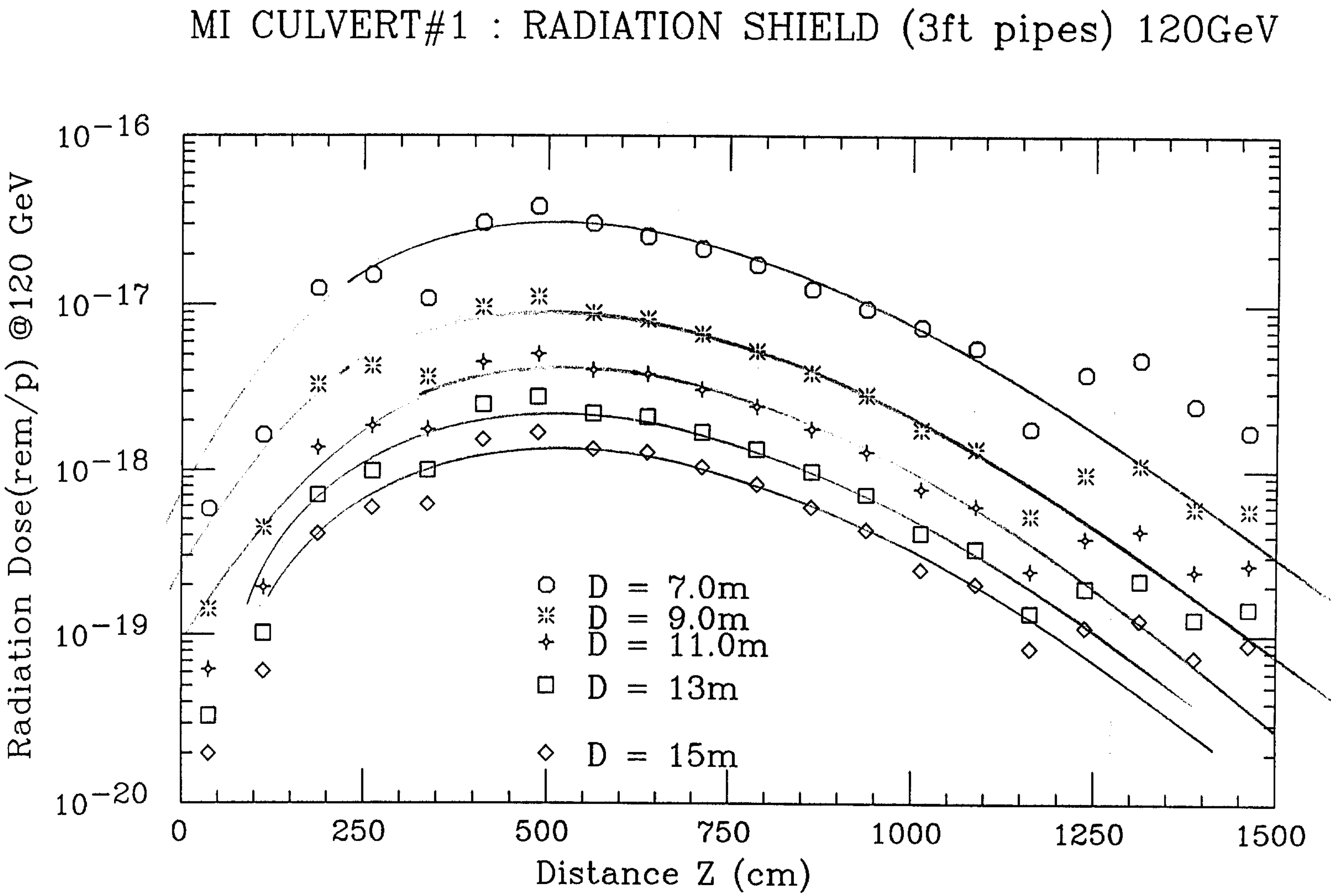


Fig 2(b)



D=Distance betn. the EOC and the pt. of Highest Radiation

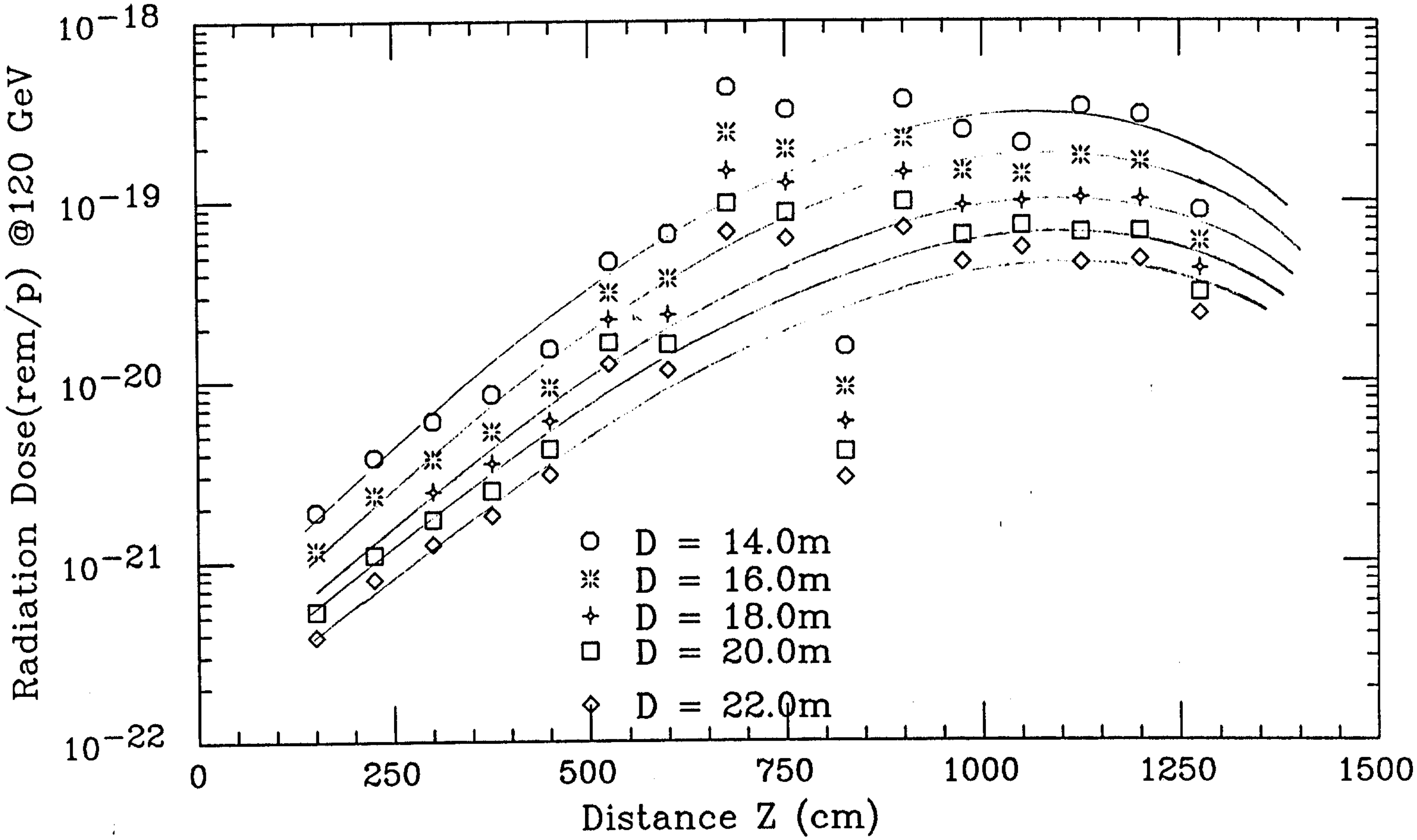
Fig. 3(a)



D=Distance betn. the EOC and the pt. of Highest Radiation

Fig. 3(b)

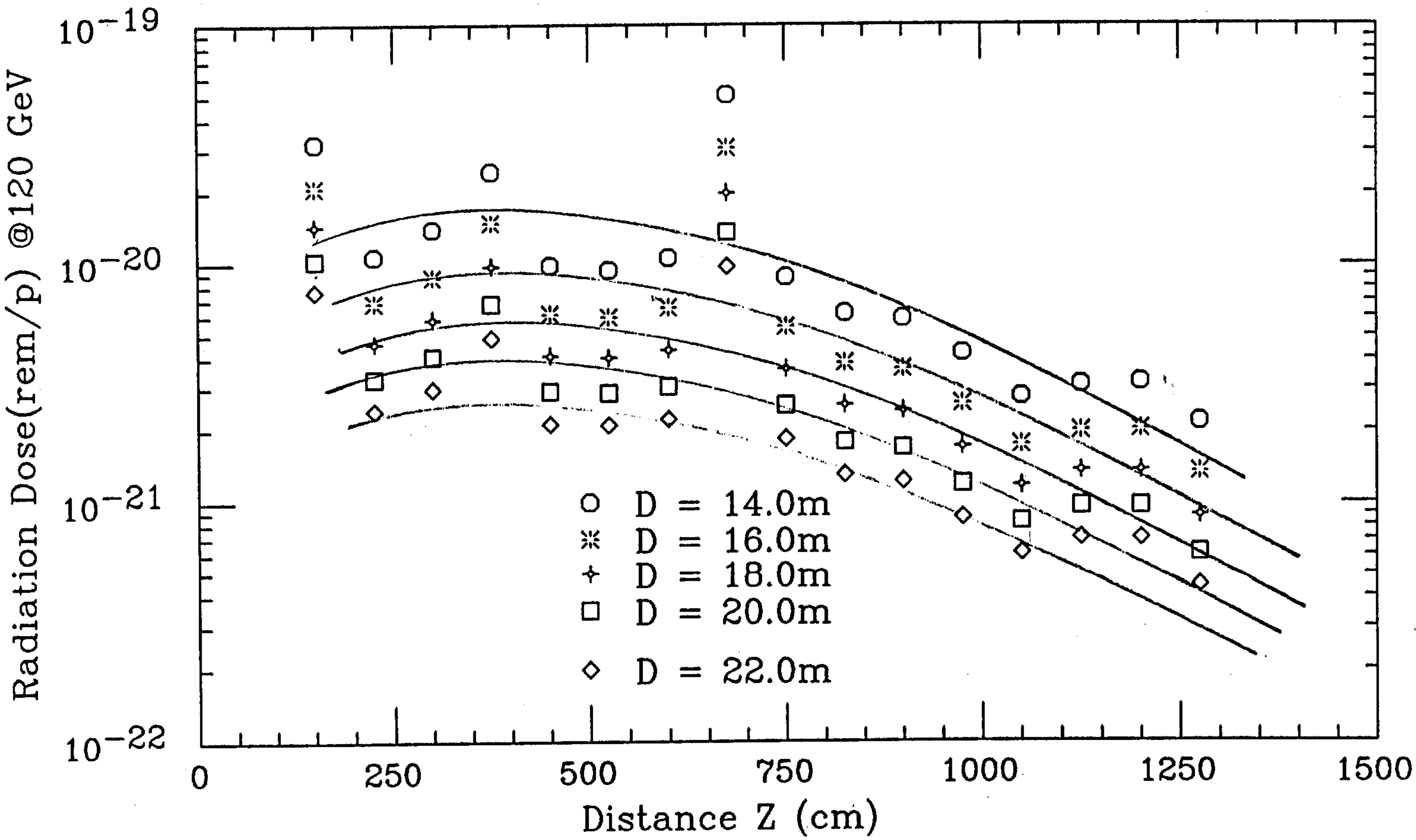
MI CULVERT#2 : 4ft ID, E=120GeV, 42°(FORWARD)



D=Distance betn. the EOC and the pt. of Highest Radiation

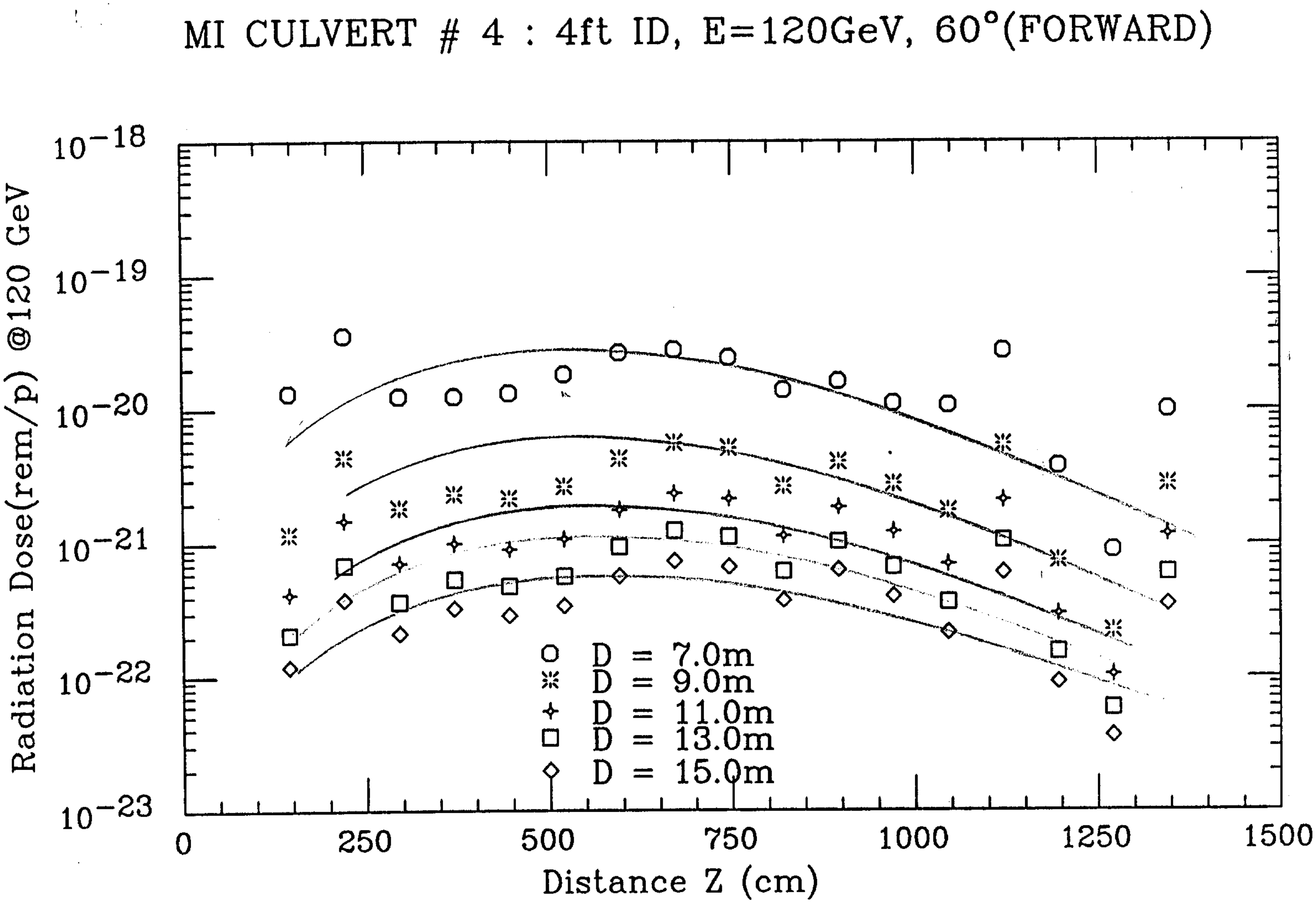
Fig. 4a

MI CULVERT#2 : 4ft ID, E=120GeV, 42°(BACKWARD)



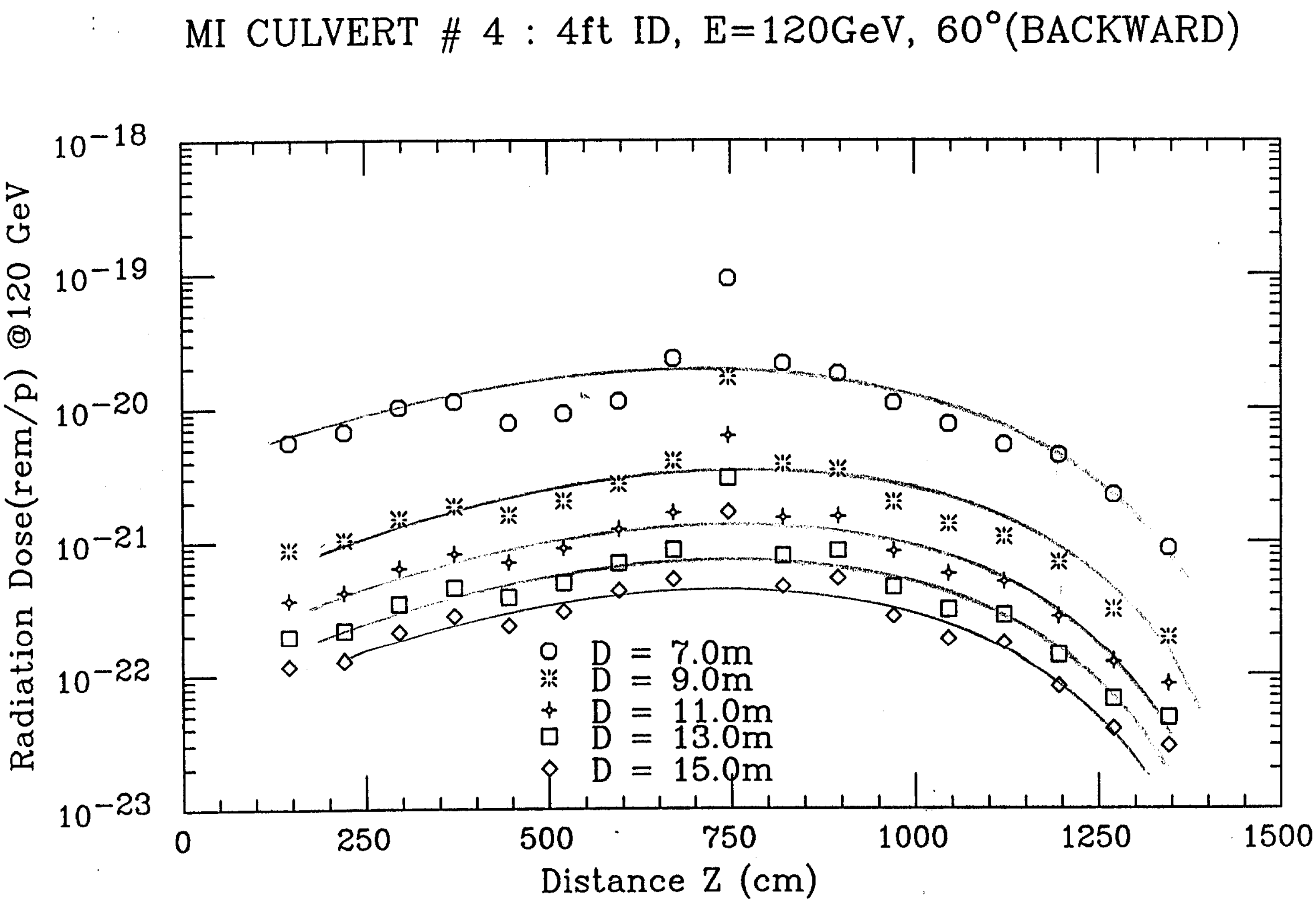
D=Distance betn. the EOC and the pt. of Highest Radiation

Fig. 4 b



D=Distance betn. the EOC and the pt. of Highest Radiation

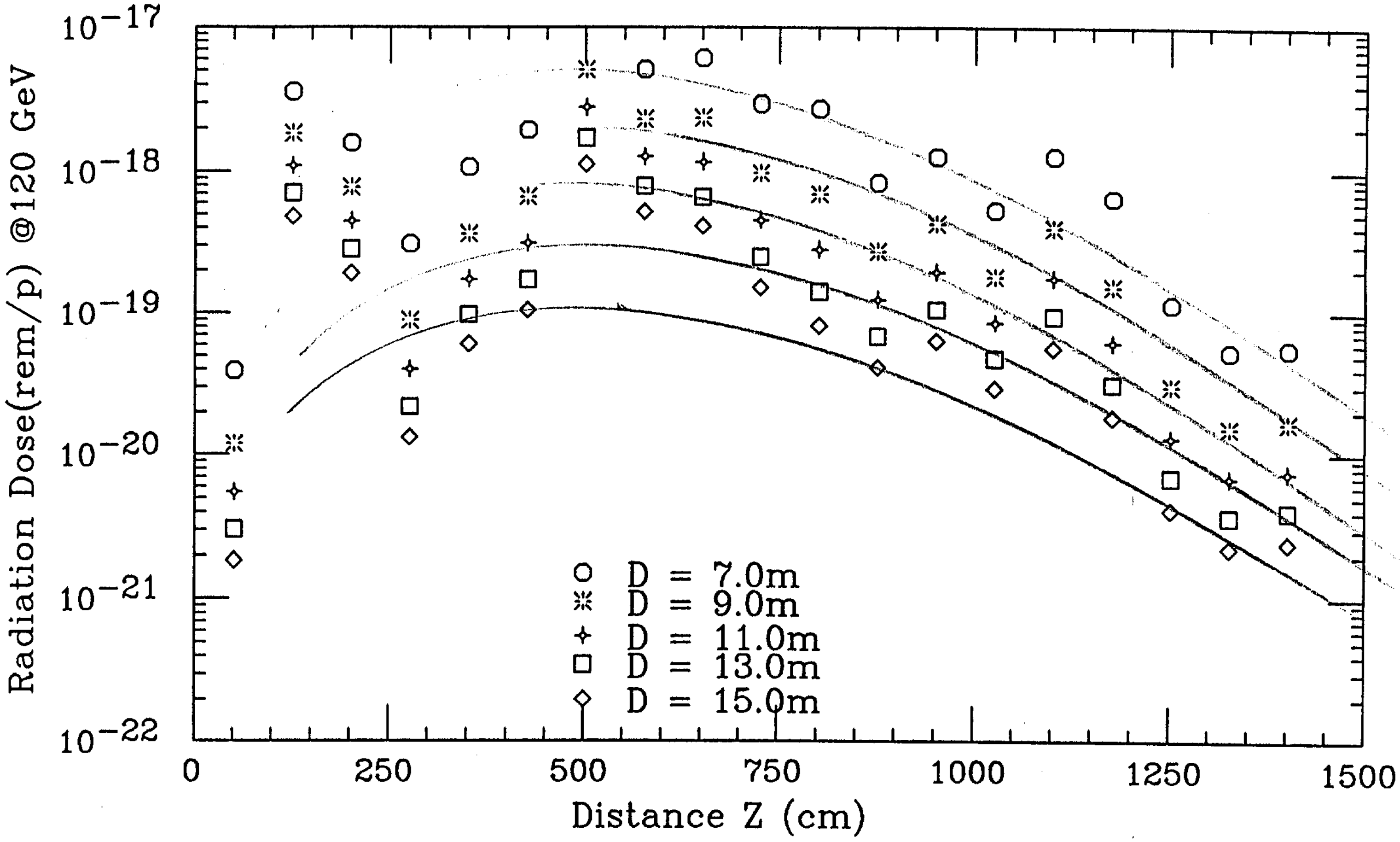
Fig 5a



D=Distance betn. the EOC and the pt. of Highest Radiation

Fig. 5b

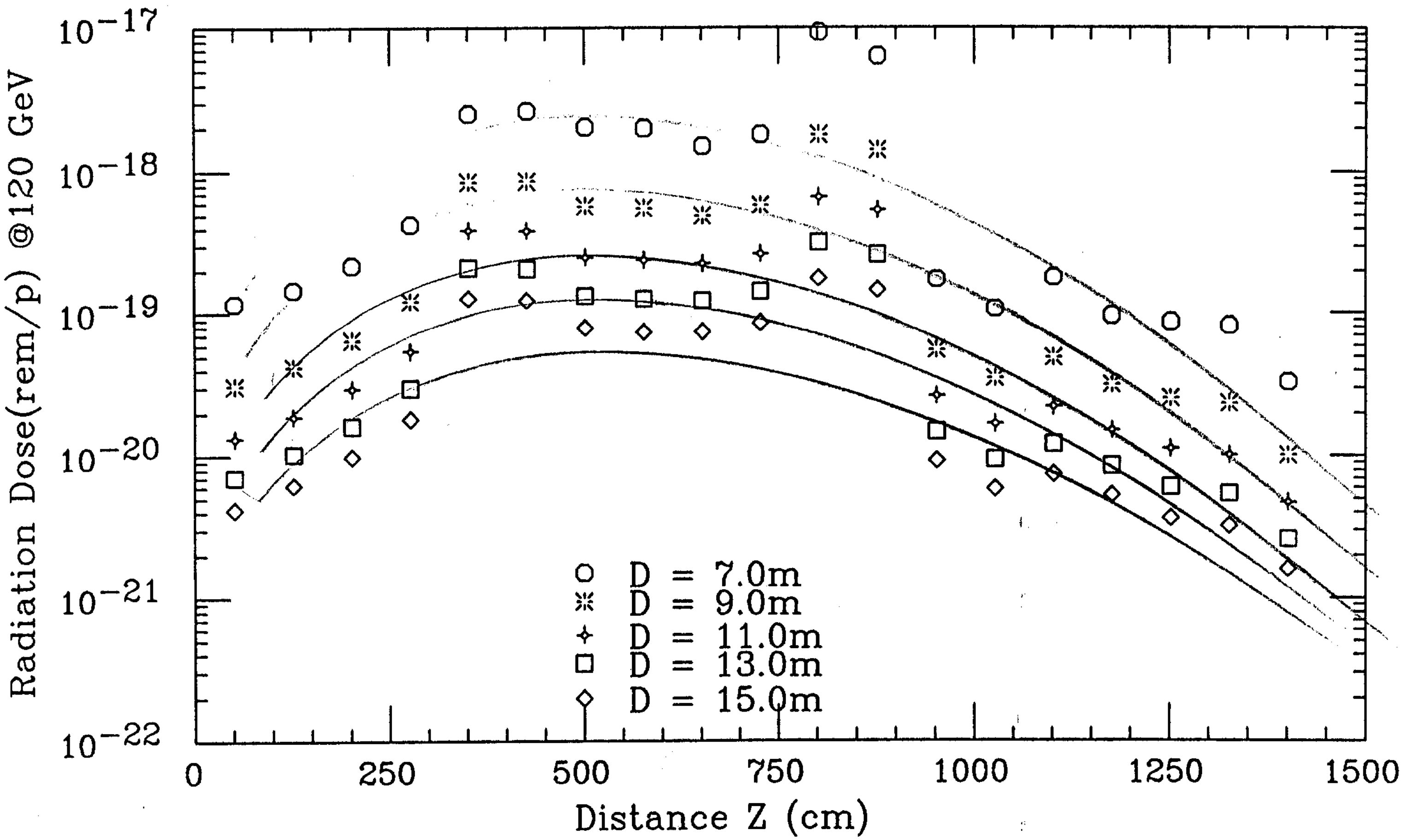
MI CULVERT6 : 4ft ID, E=120GeV, 75°(FORWARD)



D=Distance betn. the EOC and the pt. of Highest Radiation

Fig. 6a

MI CULVERT6 : 4ft ID, E=120GeV, 75°(BACKWARD)



D=Distance betn. the EOC and the pt. of Highest Radiation

Fig. 6 b

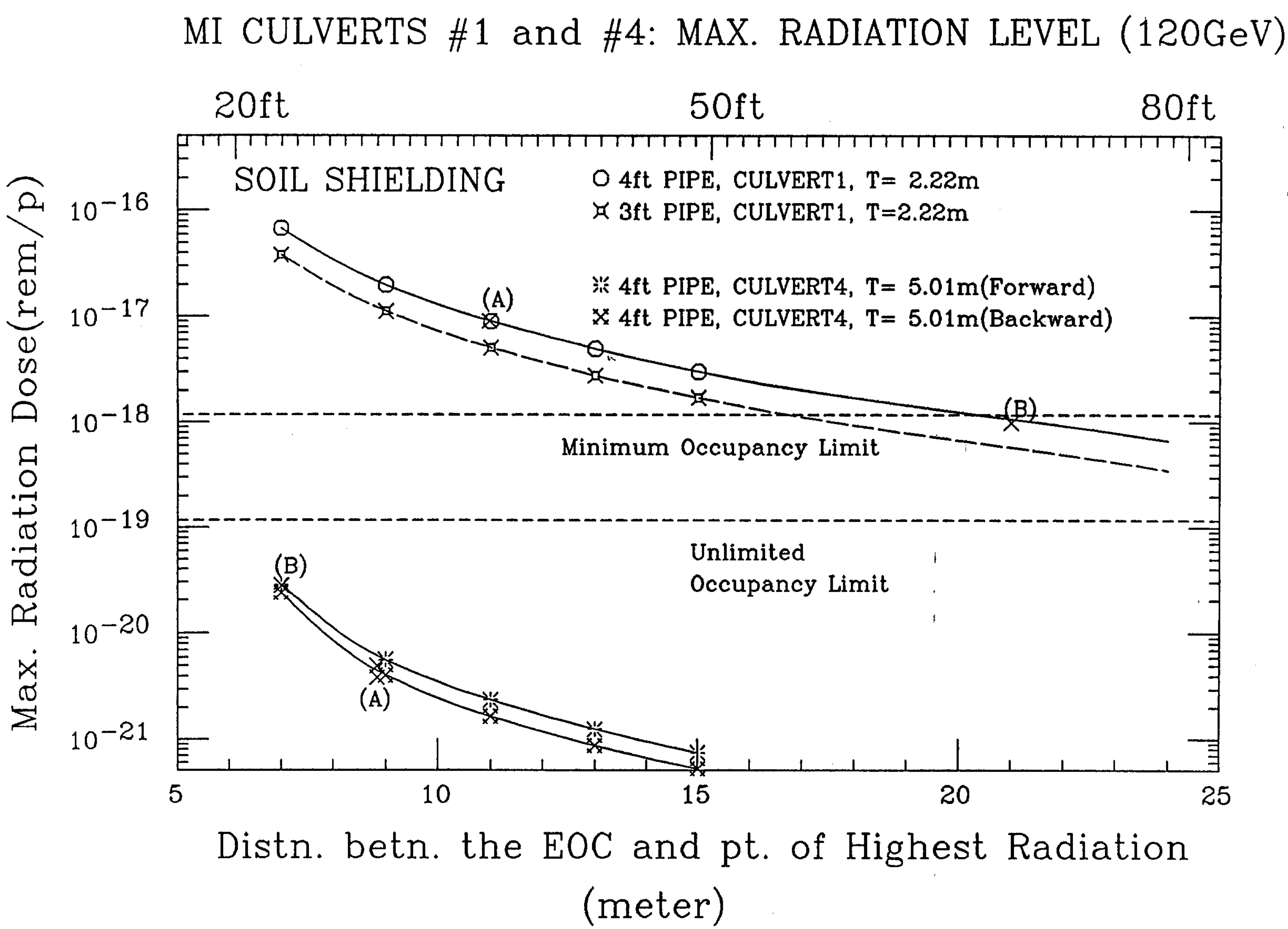

MI CULVERTS #1 and #4: MAX. RADIATION LEVEL (120GeV)
20ft
50ft
80ft
SOIL SHIELDING
4ft PIPE, CULVERT1, T= 2.22m
3ft PIPE, CULVERT1, T=2.22m
4ft PIPE, CULVERT4, T= 5.01m(Forward)
4ft PIPE, CULVERT4, T= 5.01m(Backward)
(A)
(B)
Minimum Occupancy Limit
Unlimited
Occupancy Limit
(B)
(A)
Max. Radiation Dose(rem/p)
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
5
10
15
20
25
Distn. betn. the EOC and pt. of Highest Radiation
(meter)

Fig. 7a

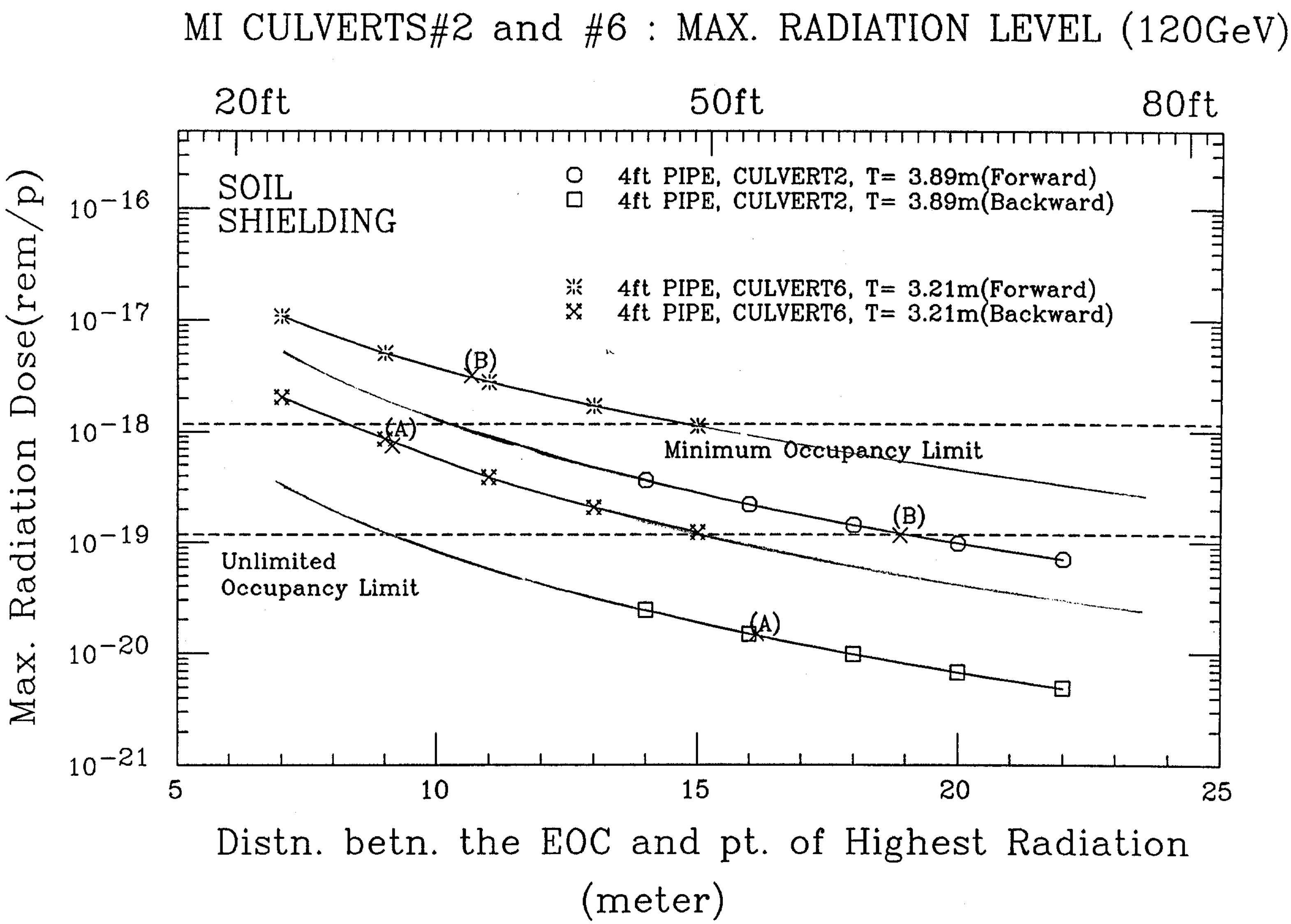

MI CULVERTS#2 and #6 : MAX. RADIATION LEVEL (120GeV)
20ft
50ft
80ft
SOIL
SHIELDING
4ft PIPE, CULVERT2, T= 3.89m(Forward)
4ft PIPE, CULVERT2, T= 3.89m(Backward)
4ft PIPE, CULVERT6, T= 3.21m(Forward)
4ft PIPE, CULVERT6, T= 3.21m(Backward)
(B)
(A)
Minimum Occupancy Limit
(B)
Unlimited
Occupancy Limit
(A)
Max. Radiation Dose(rem/p)
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
5
10
15
20
25
Distn. betn. the EOC and pt. of Highest Radiation
(meter)

Fig. 7 b

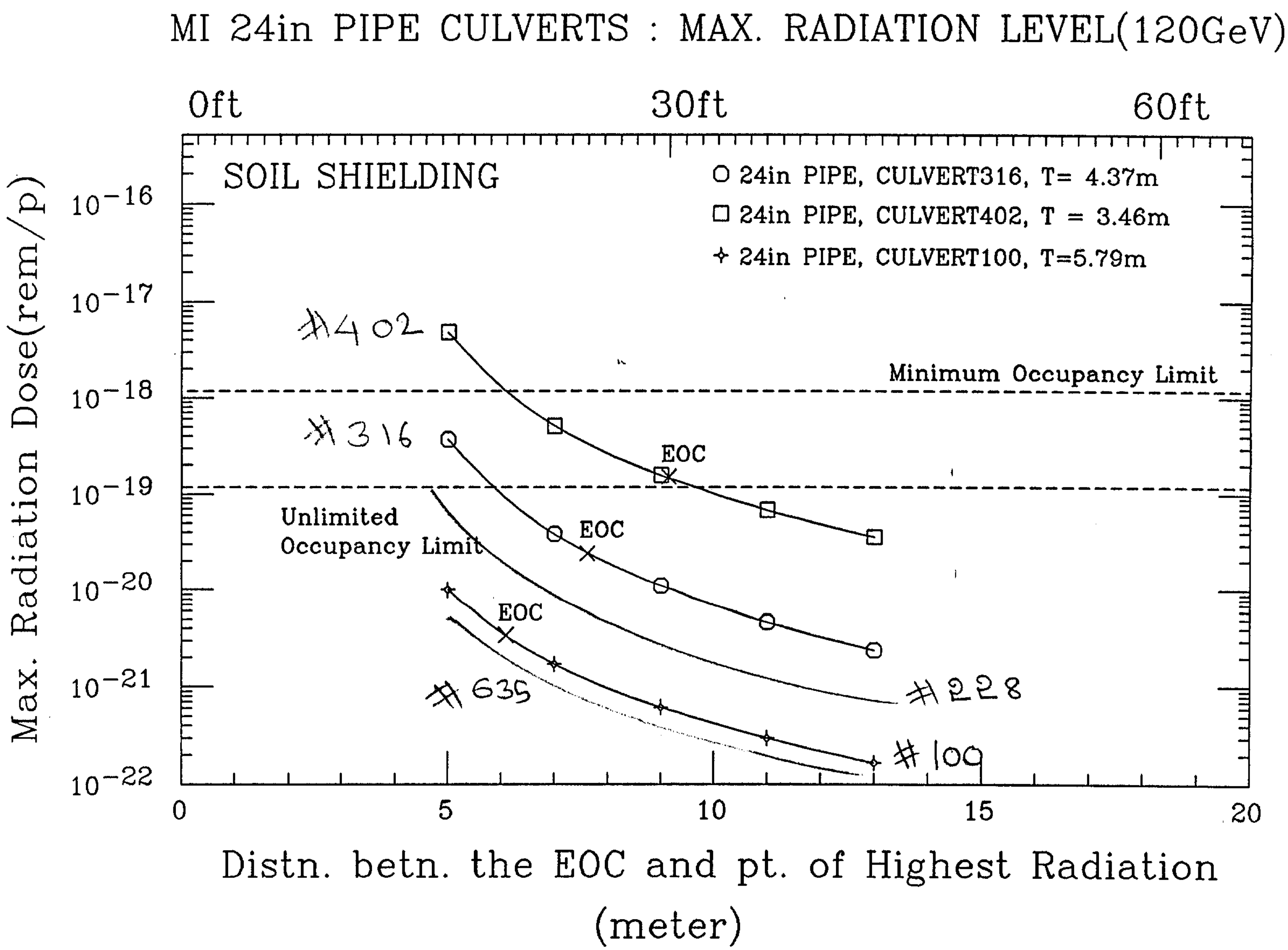

MI 24in PIPE CULVERTS : MAX. RADIATION LEVEL(120GeV)
0ft
30ft
60ft
SOIL SHIELDING
○ 24in PIPE, CULVERT316, T= 4.37m
□ 24in PIPE, CULVERT402, T = 3.46m
✧ 24in PIPE, CULVERT100, T=5.79m
Minimum Occupancy Limit
Unlimited Occupancy Limit
EOC
EOC
EOC
#402
#316
#228
#635
#100
Max. Radiation Dose(rem/p)
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
0
5
10
15
20
Distn. betn. the EOC and pt. of Highest Radiation (meter)

Fig. 7c

MI 24in PIPE CULVERTS : A UNIVERSAL CURVE

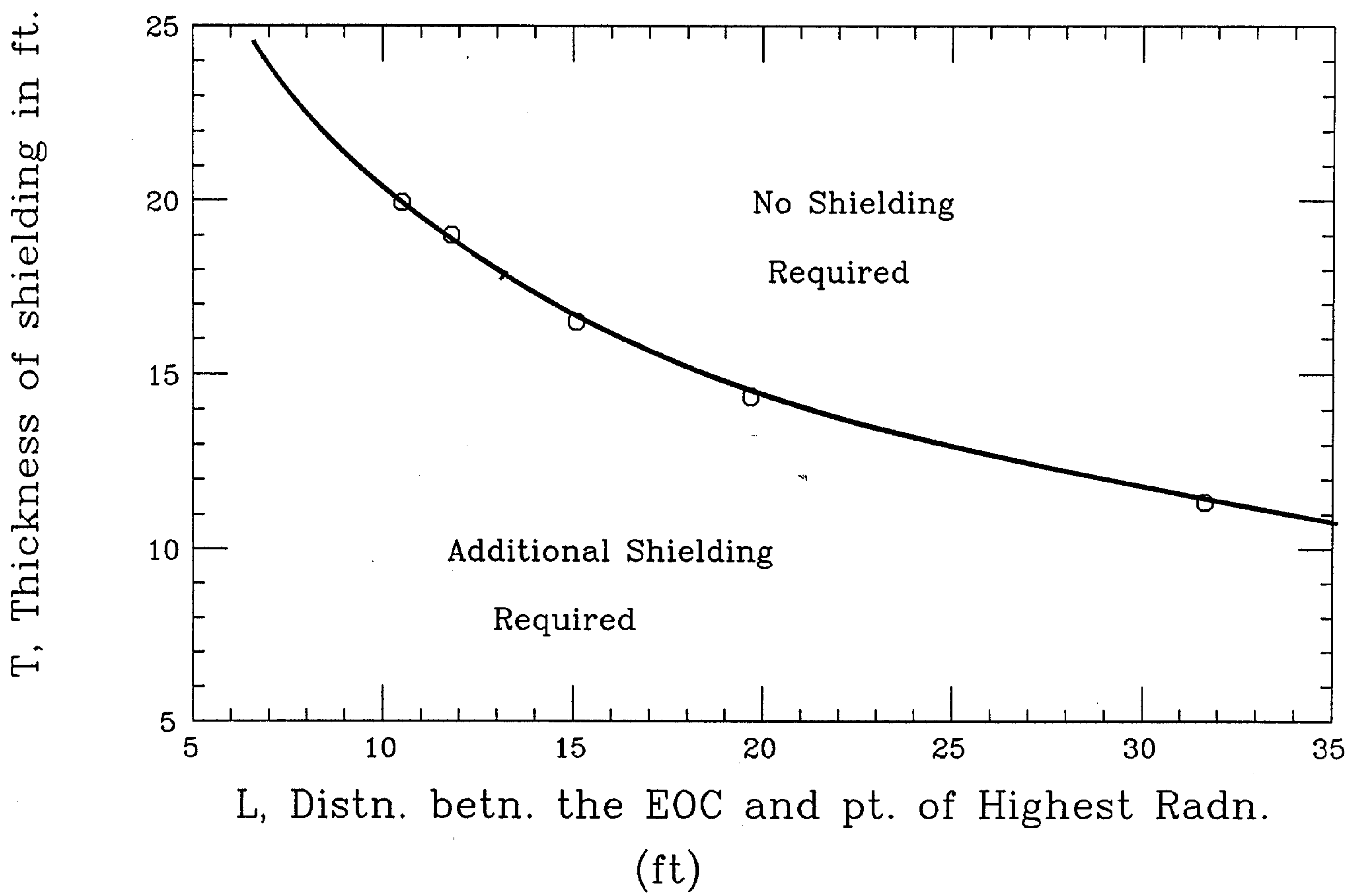


Fig. 8