TREATMENT ROOM STUDY FOR WASHINGTON STATE UNIVERSITY BORON NEUTRON CAPTURE THERAPY

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August 19, 1994

Student Research Participation Program
Associated Western Universities Incorporated

Funded by
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, ID 83415

ABSTRACT

A shield wall study has been performed for shielding around an epithermal neutron beam opening at the Washington State University Reactor Facility. This beam is not currently available, but a feasibility study has been performed which indicates that the existing thermal column could be modified and a beam comparable to the epithermal neutron beam at the Brookhaven Medical Research Reactor could be achieved. Using the output from the thermal column calculations, and further calculations again using the two-dimensional DORT discrete-ordinates computer code, a shield design has been developed which would both restrict access and minimize radiation dose to occupied areas around the thermal column. This shield wall would enclose a proposed treatment room into which the beam would be directed. In addition, consideration was given to minimizing the radiation levels inside the proposed treatment room for the benefit of the patient.

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TREATMENT ROOM STUDY FOR WASHINGTON STATE UNIVERSITY BORON NEUTRON CAPTURE THERAPY (BNCT)

1. INTRODUCTION

Several pharmaceutical drugs are currently available which seek out and attach themselves to rapidly reproducing cells, i.e. cancer cells. Boron can be added to these drugs during fabrication and then the Boron could also be attached to the cancer cells. Once the Boron has been attached to the cancer cells they can be irradiated with neutrons which will then destroy the cancer cells while leaving the healthy tissue around the cancer unharmed. This is accomplished through neutron capture of the boron yielding a destructive, but short lived, alpha particle.

This procedure is currently being performed in the United States on animal patients and there are many interested parties who would like to see this type of treatment become available to human patients. This treatment is presently being performed on human patients in Japan for a minimum cost of $60,000.00. Japan is the only country performing this procedure at this time and they have been the only one for about 20 years[1].

Problem: Design a workable plan to set up a cancer treatment facility at the Washington State University nuclear radiation center. To safely provide a directed epithermal neutron beam that will be effective in destroying the cancer cells and at the same time not increase unduly the radiation risk to other personnel.

I. The filter design to provide the epithermal neutron beam is being worked on by Floyd Wheeler and David Nigg of INEL (EG&G). This involves the use of an AlF3/Al material developed in Helsinki Finland. The achievable beam would be comparable to the epithermal neutron beam at the Brookhaven Medical Research Reactor (presently the best epithermal beam in the world)[2].

II. I have been working on shield designs for the treatment room itself. I have used as an input the output beam calculations from Floyd Wheeler's filter design. The computer calculations I have used employ the two-dimensional DORT code.

Design Criteria: The shielding must reduce the neutron and gamma flux to below the maximum local levels and below .5 mrem/hr. Cost of materials should be considered as well as availability of materials.

1.The Spokesman Review, Wed. May 4, 1994, "DOE bolsters cancer studies"

2. Reference 9

2. ANALYSIS

The following information is based upon a shield wall study performed using the two dimensional DORT discreet-ordinates computer code. The input for these calculations was the output from earlier DORT calculations done for the filter design. These used reactor model 34 BNCT (see figure 1) and exterior beam filter design E4 with 65 cm AlF3/Al and Al2O3 outer perimeter (see figure 2). The calculated neutron spectrum for this combination is shown in figure 3. The comparison of the neutron beams for different facilities is given in table 1.

2.1 Materials Considered

The materials considered for the shield design are commonly used for various shielding applications and are readily available through companies such as Reactor Experiments or local contractors. These included Borated Polyethylene, Lithiated Polyethylene, heavy concrete, and lead. The costs for these materials, which were used to determine model costs, are given in table 2.

2.2 Beam Insert

The greatest change in radiation levels outside the shield took place, not with varying the shielding materials, but with the variation of the beam intensity entering the room. A combination of smaller beam opening size and a simulated head reduced the inside room neutron radiation by a factor of over six (compare models 4 and 17 of table 3). By completely covering the beam opening with water, the inside room neutron radiation was, again, reduced by a factor of over five (compare models 23 and 24 of table 3). The complete covering of the beam opening with water was done to simulate a beam insert effect. At Brookhaven, beam inserts are currently available which fit the shape of patients' heads. This has the dual effect of reducing the body radiation to the patient, himself, and reducing the radiation to those outside the shielding. Actual neutron dose inside the room dropped from 130.9 Rem/hour to 3.29 Rem/hour because of these modifications. Figures 4 and 5 show a theoretical beam insert by itself and inserted into the thermal column.

2.3 Use of Heavy Concrete

Heavy concrete was chosen as the main shield material because of its low cost and structural support. It interacts with and reduces both the neutron flux and the gamma flux. Various thicknesses were tested. Findings proved that a back wall of two and a half feet and a side wall and ceiling of two feet would be adequate, in combination with the other shield materials, for reducing the neutron and gamma fluxes to less than one mrem/hour. The back wall needs to be thicker to account for the directional beam coming into the room.

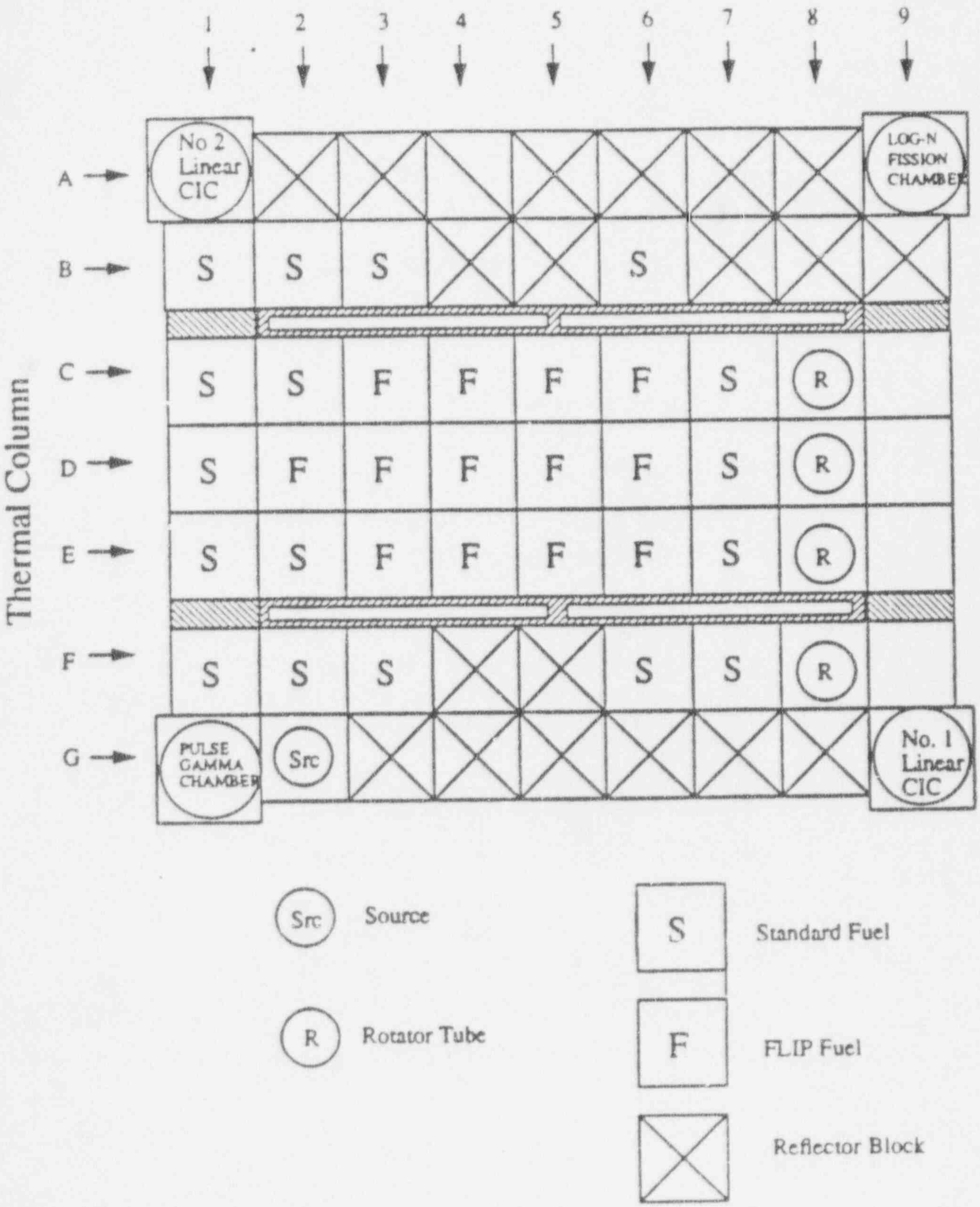
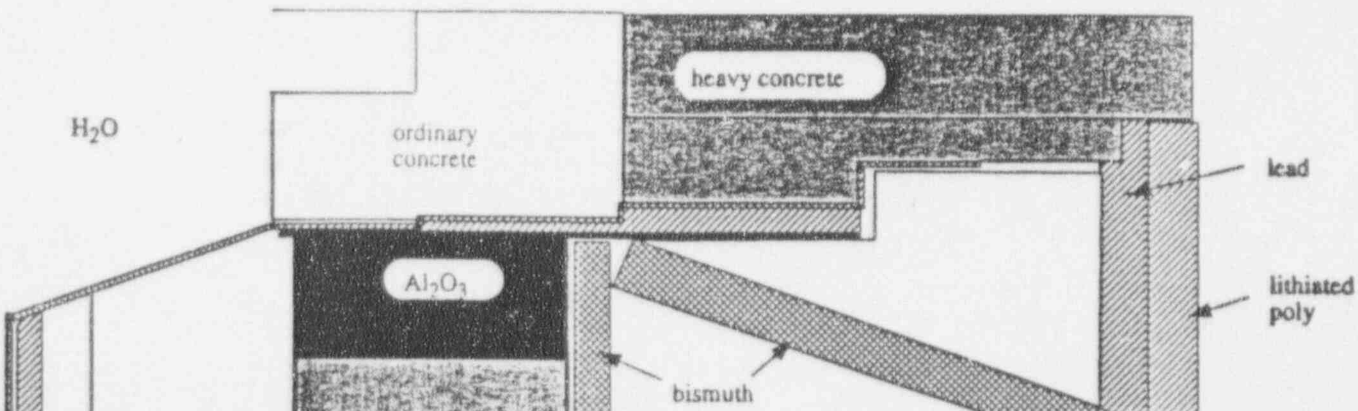


Figure 1. Reactor Model 34 BNCT



Thermal column assembly with $A1F_3/A1$ and $A1_2O_3$ filter (not to scale).

Figure 2. Filter Model E4

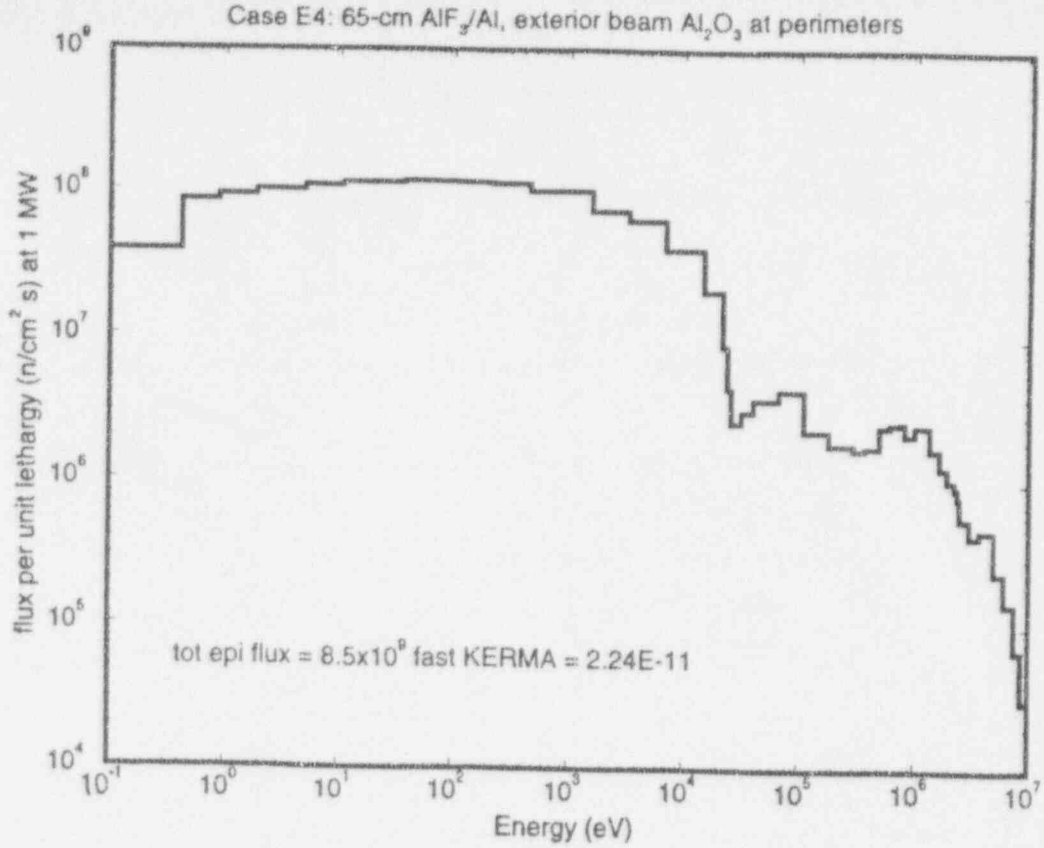


Figure 3. Calculated Neutron Spectrum for BNCT Case E4

Table 1. Beam Characteristics (from references 9 and 10)

Reactor	Epithermal Flux intensity (1.0E9 n/cm2-s)	Fast Neutron KERMA Kf (1.0E-11 cGy/n-cm2)	Gamma KERMA Kg (1.0E-11 cGy/n-cm2)
BMRR (3MW)	1.80	4.30	1.30
WSU -E4 (1MW)	0.846	2.24	1.20
HFR (45MW)	0.33	10.4	8.40
MITR-II	0.20	13.0	14.0

Table 2. Material Costs

MATERIAL	1"x48"x48"	2"x48"x_	4"x48"x36"
B-Poly (201)	$485.00	96" $2275.00	$1900.00
Li-Poly	$1480.00	48" $3085.00	$4675.00

Table 3. Radiation Levels for each Model

#	total cost in $	side wall neutron max out (mr/h)	side wall gamma max out (mr/h)	back wall neutron max out (mr/h)	back wall gamma max out (mr/h)	room neut. max (z=550) (r/h)	room gamma max (z=550) (r/h)
3	175980	0.670	1.704	19.[illegible]9	10.72	unavail	unavail
4	167108	0.598	1.704	6.104	6.310	130.9	1.642
5	163913	0.660	1.702	6.106	6.309	130.9	1.641
6	138580	0 670	1.703	17,878	399.3	130.9	1.642
7	93463	0.537	2.060	5.482	6.704	131.3	2.438
8	99704	0.102	0.492	1.547	1.937	131.3	2.533
10	26389	0.251	16.22	2.528	18.66	116.3	5.061
11	173349	0.113	0.623	1.492	1.852	107.3	1.780
12	173349	0.103	0.511	0.926	1.623	19.34	0.915
13	154839	0.103	0.512	1.921	2.036	19.34	0.915
14	118989	0.187	0.811	1.505	1.894	19.30	0.941
15	125159	0.187	0.812	1.505	1.894	19.31	0.944
16	118989	0.150	0.225	1.363	0.707	19.31	0.945
17	106483	0.392	0.168	4.619	0.487	19.28	0.910
18	112724	0.082	0.044	1.159	0.154	19.35	0.916
19	108187	0.397	0.171	1.164	0.155	19.31	0.913
20	114357	0.396	0.168	0.990	0.126	19.29	0.911
21	109298	0.400	0.168	0.307	0.053	19.27	0.929
22	95273	0.402	0.167	0.553	0.087	19.27	0.933
23	63108	0.137	0.051	0.766	0.110	19.36	0.977
24	63108	0.128	0.085	0.531	0.063	3.290	1.544
25	63108	0.128	0.085	0.645	0.372	3.290	1.544

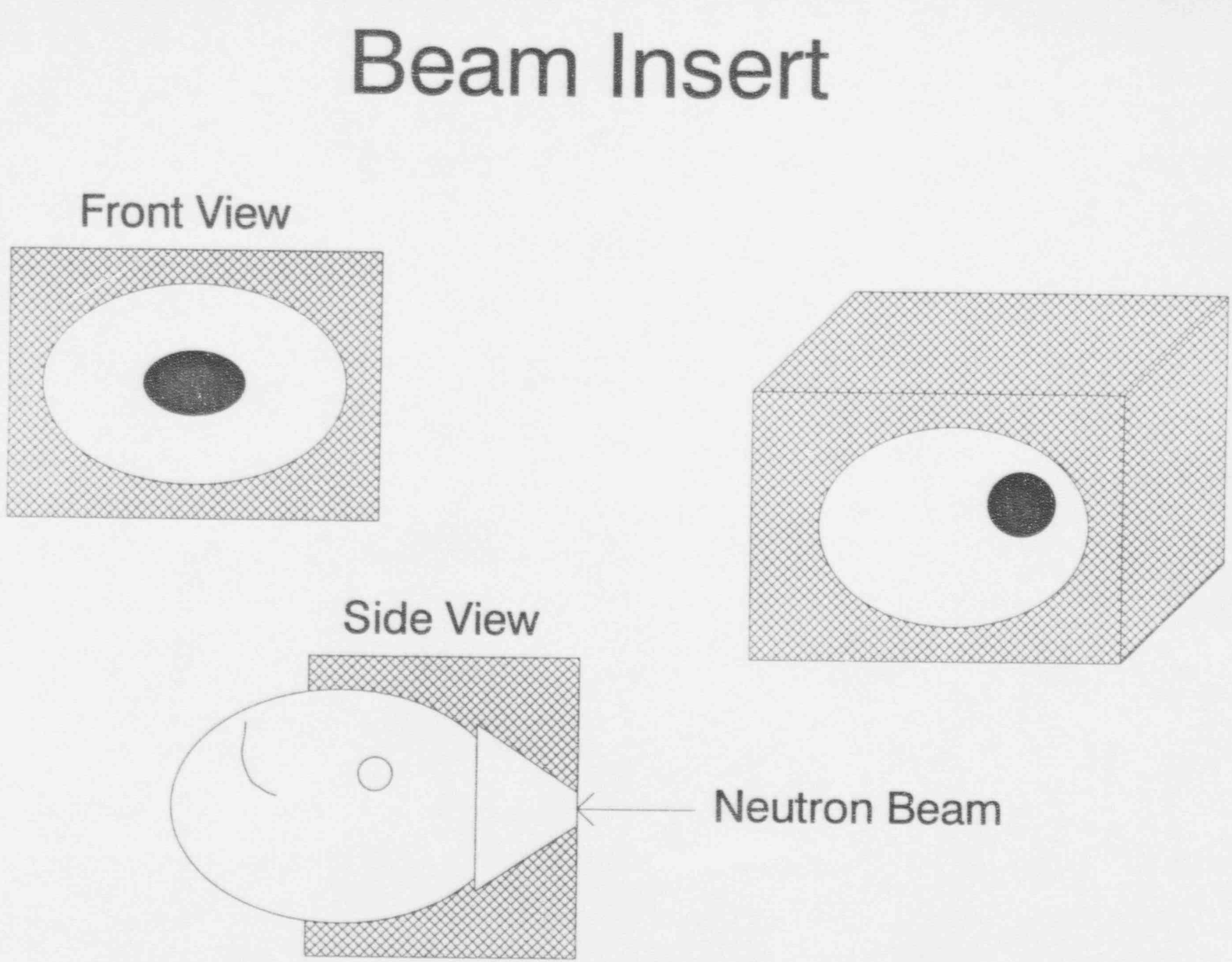
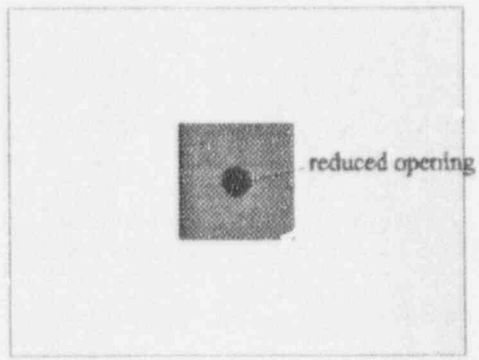
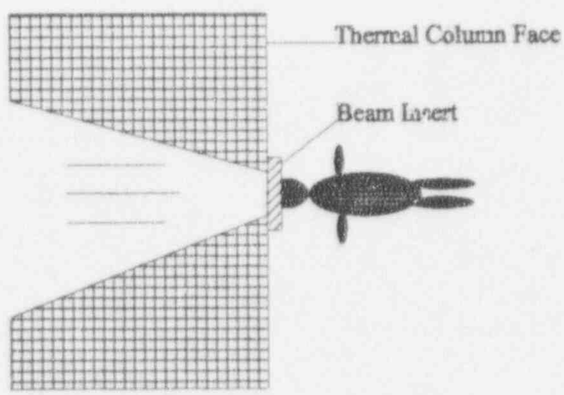


Figure 4. Beam Insert



Front view of thermal column with beam insert



Side view of thermal column with beam insert

Figure 5. Beam Insert Installed

2.4 Room Lining

Within the room, several models were considered to determine if a lining would be used for the concrete walls. There are two benefits to a lining: first, the gamma dose inside the room reduces by a factor of three if one is used (compare models 4 and 10 of table 3), and second, the concrete, itself, does not become activated from neutron interactions. Also, studies showed that the gamma dose produced by boron interaction in the Borated Poly raised the inside room gamma dose by a factor of about 1.5 over an identical model using Lithiated Poly (compare models 4 and 7 of table 3). With respect to a lining, the study showed that the thickness of the lining did not seem to greatly effect the radiation dose in the room. As long as some lining was there, the room dose went down. As a result of these findings, a one inch Lithiated Polyethylene model was selected as the most cost-effective and patient-beneficial model.

2.5 Use of Lead

Lead was considered for bordering outside the concrete to further reduce the gamma dose. Lead bricks are fairly easy to obtain and could possibly even be donated by various facilities. Additional structural support would have to be considered for the lead. However, the sharp decreases in gamma doses could well be worth the investment. The gamma dose for similar models, one with two inches of lead and one without any lead, showed a difference in radiation levels by a factor of 15 (compare models 14 and 23 of table 3). Lead sheets are available which are one half inch thick. When compared, there was a radiation factor difference of six between the two lead thicknesses with equal thicknesses of concrete (compare models 24 and 25 of table 3).

2.6 The Ideal Model

A shield model with a one inch Lithiated Polyethylene lining on the inside walls, two feet heavy concrete side walls, two and a half feet heavy concrete back wall, and two inch lead bricks around the exterior of the room would provide the optimum shield design (see figure 6). This would minimize patient radiation, minimize external radiation from the room, and minimize material cost in construction. Figures 7, 8, and 9 show the radiation plots for a model of these specifications. For a twelve by twelve foot room with this shielding the estimated material cost would be $63,000.00, assuming the lead bricks would be donated. The cost breakdown for this is given in table 4. Note that this does not include the cost for a containment type door, nor were radiation effects for a door included in this study. For a detailed description of the other models used see table 5. Using this table and the radiation levels given in table 3 one can compare how the radiation changed for each change in specific models.

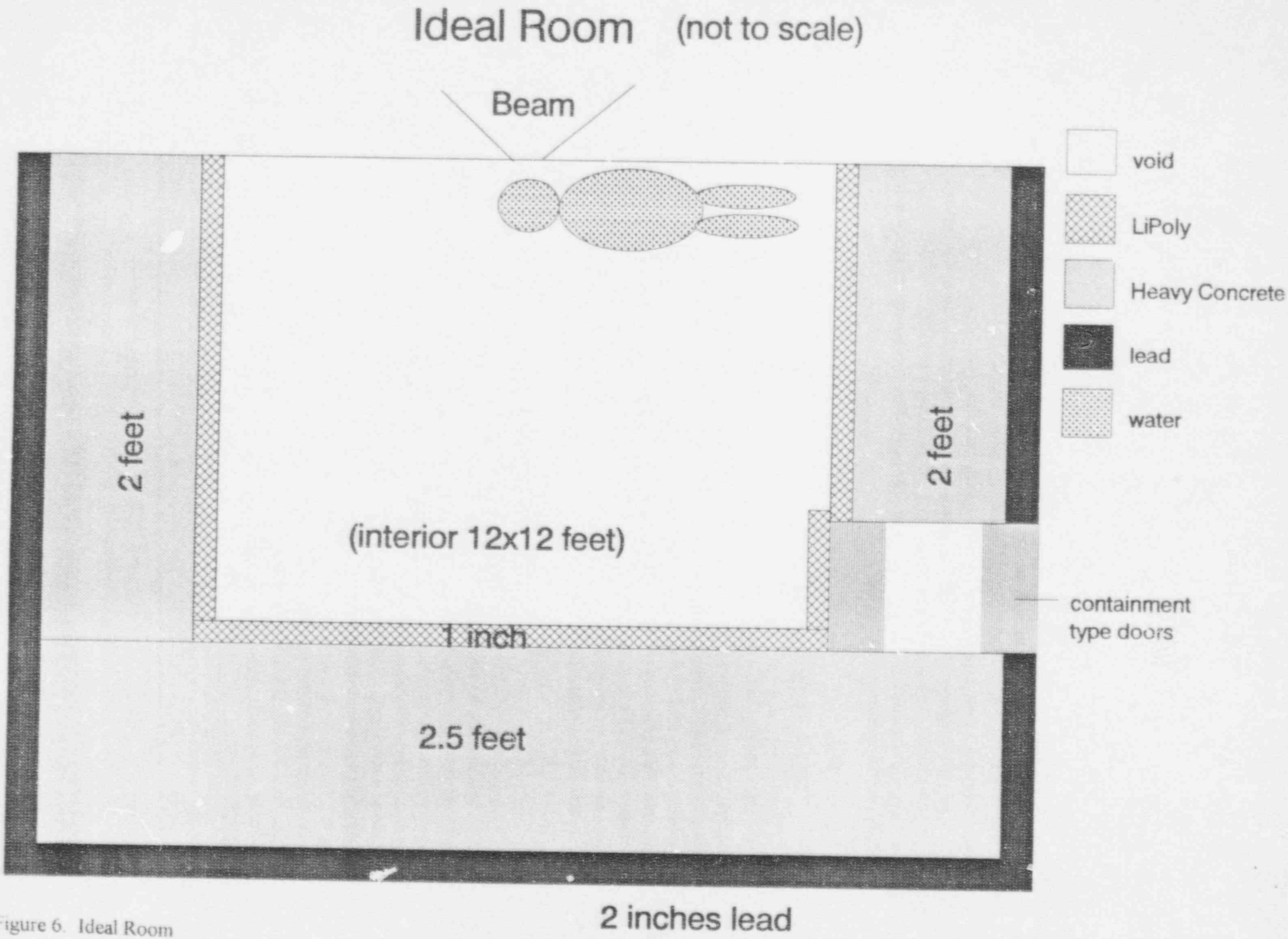


Figure 6. Ideal Room

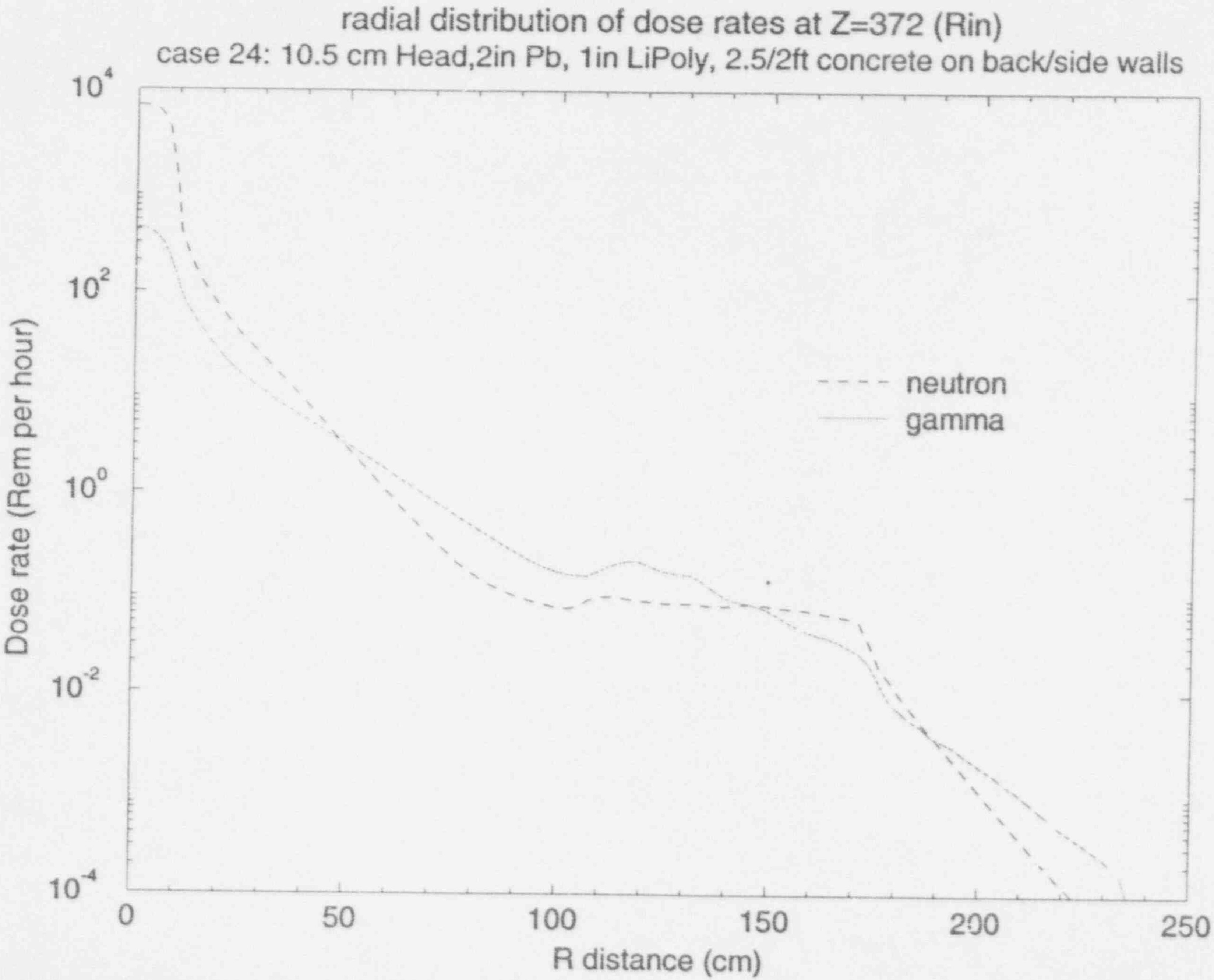


Figure 7. Plot of radiation into room (radial)

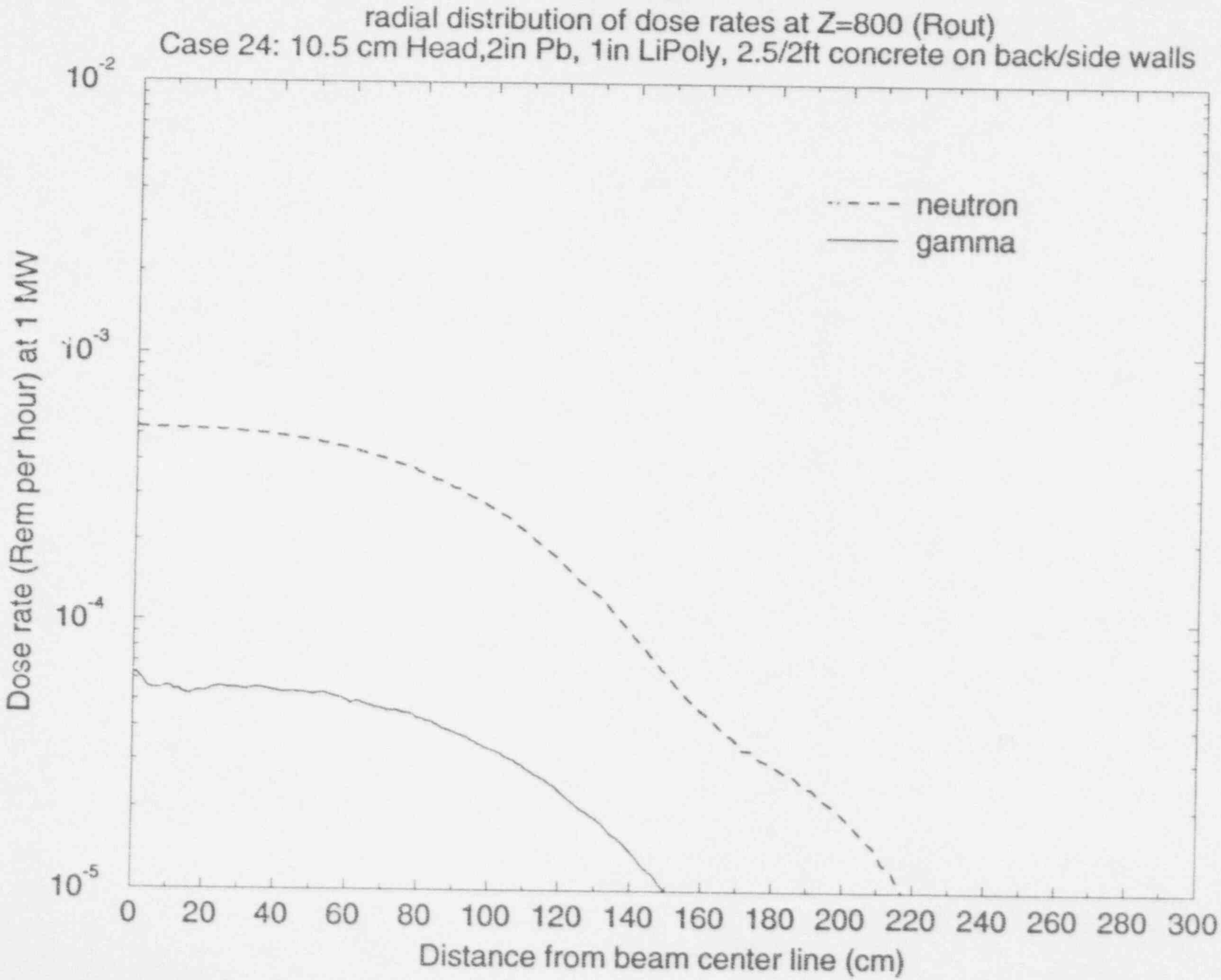


Figure 8. Plot of radiation out of room (radial)

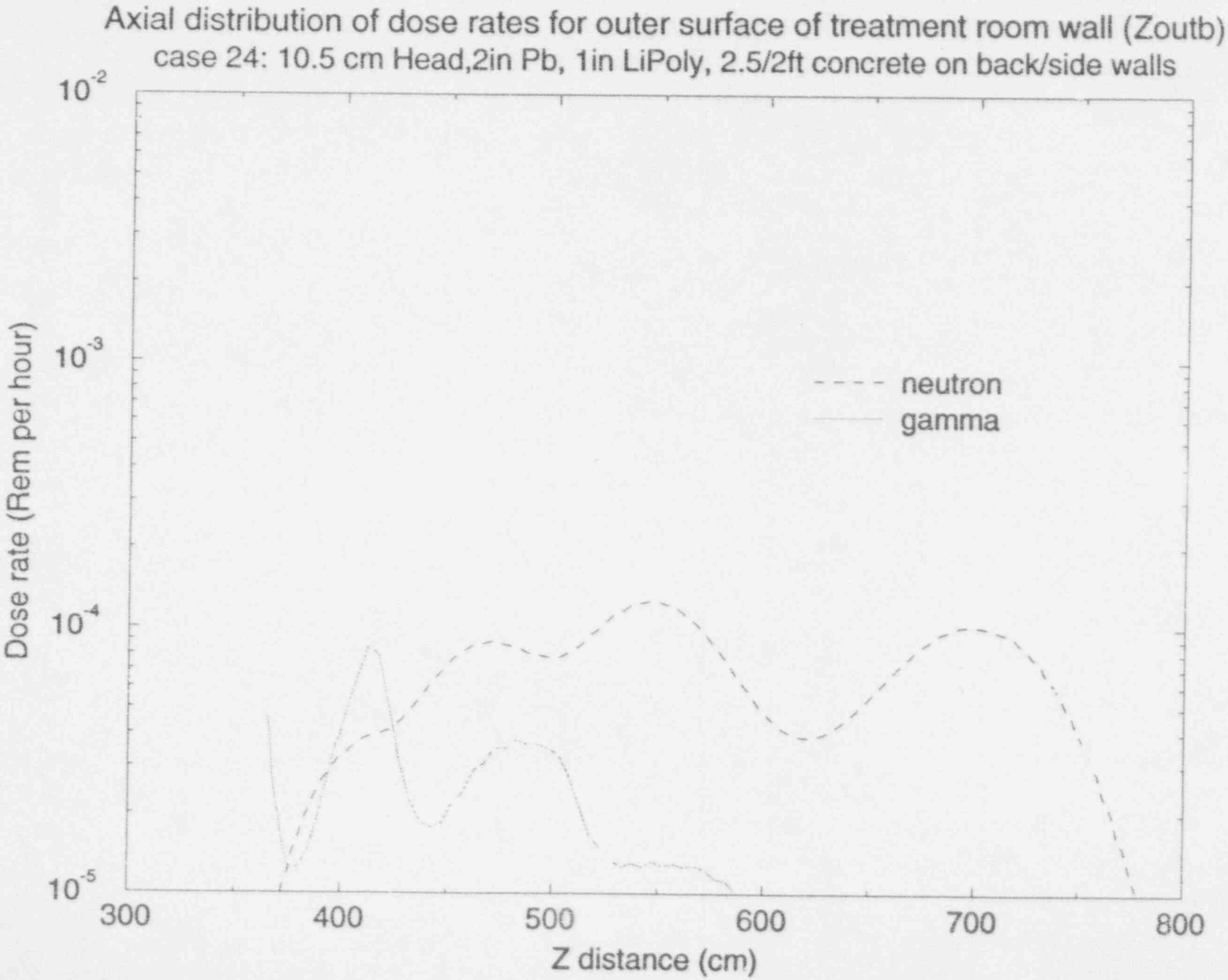


Figure 9. Plot of radiation out of room (axial)

Table 4. Ideal Model Costs

Number of one inch LiPoly sheets	Cost per sheet	total cost
27	$1480.00	$39,960.00
Cubic feet of heavy concrete	**Cost per cubic yard**	**total cost**
1250	$500.00	$23,148.00
Lead Bricks - no cost calculated		
	Total material cost	$63,108.00

Table 5. Model Descriptions

Model and poly	Beam size (cm)	back concr (cm)	side concr (cm)	back Poly (cm)	side Poly (cm)	Lead (cm)	notes
3 Li	15	44	44	6	6		
4 Li	15	44	44	15	6		
5 Li	15	44	44	15/6	6		15 to 151cm
6 Li	15	44	44	6	6		hole to 16cm
7 B	15	44	44	15	6		
8 B	15	60	59	14	6		
9	15	74	65	none	none		not used
10	15	74	65	none	none		head hereafter
11 Li	15	60	59	14	6		
12 Li	8.25	60	59	14	6		
13 Li	8.25	60	59	8	6		
14 Li	8.25	60	59	10/4	3		10 to 106cm
15 Li	8.25	60	59	10/4	3		Li on front
16 Li	8.25	60	59	10/4	3	2	
17 Li	8.25	45	45	10/5	5	5	10 to 67cm
18 Li	8.25	60	60	10/5	5	5	
19 Li	8.25	60	45	10/5	5	5	
20 Li	8.25	60	45	15/5	5	5	15 to 67cm
21 Li	8.25	75	45	10/5	5	5	10 to 67cm
22 Li	8.25	75	45	5	5	5	
23 Li	8.25	75	60	2.5	2.5	5	
24 Li	8.25	75	60	2.5	2.5	5	hole fully covered
25 Li	8.25	75	60	2.5	2.5	1.25/5	1.25 on back wall

2.7 Cost Determination

To determine the material costs for the various models the following assumptions were made:

1. The Poly sheets could be cut in length or height, but not in width, thus 1", 2", or 4" thick sheets would have to be used.

2. For a given model, even if the dimension is just over the inch thickness, the next thicker size would have to be used for the calculation to be valid.

3. Concrete could be poured in any thickness. A proportional cost to that per cubic yard was used.

4. The walls would be eight feet high.

5. The inner dimension of the room would be 12' by 12'.

6. 5 cm is about 2 inches, 10 cm is about 4 inches, etc.

7. The ceiling thicknesses and materials would be the same as the side walls

Using these assumptions tables 6 and 7 were generated, which show for each model the exact number of polyethylene sheets and feet of concrete used. Table 7 gives the cost summary for each model.

3. CONCLUSIONS

The ideal model, as shown in figure 6, and with a cost of $63,108.00, would provide the optimum in minimizing cost and radiation levels. A beam insert should be used in conjunction with this design to yield the ne calculated radiation levels. A further study, which would include radiation effects for a door, must still be performed. The costs for such a door will increase the material costs of the room as well. The actual construction costs will vary and depend on local contracting.

Table 6. Material Summary for each Model

#	4" sheets sides/back/top	2" sheets sides/back/top	1" sheets sides/back/top	feet of concrete sides/back/top
3		12/6/9	12/6/9	300/192/336
4	0/8/0	12/6/9	12/0/9	300/192/336
5	0/7/0	12/6/9	12/1/9	300/192/336
6		12/6/9	12/6/9	300/192/336
7	0/8/0	6/3/5	12/0/9	300/192/336
8	0/8/0	6/3/5	12/0/9	400/272/493
10				466/352/607
11	0/8/0	12/6/9	12/0/9	400/272/493
12	0/8/0	12/6/9	12/0/9	400/272/493
13	0/8/0	12/0/9	12/0/9	400/272/493
14	0/5/0	12/3/9		400/272/493
15	0/5/0	12/3/9 2-front		400/272/493
16	0/5/0	12/3/9		400/272/493
17	0/3/0	12/4/9		300/192/336
18	0/3/0	12/4/9		400/272/493
19	0/3/0	12/4/9		300/272/348
20	0/3/0	12/6/9		300/272/348
21	0/3/0	12/4/9		300/320/360
22		12/6/9		300/320/360
23			12/6/9	400/340/510
24			12/6/9	400/340/510
25			12/6/9	400/340/510

Table 7. Cost Summary for each Model

#	# of 4" sheets/cost	# of 2" sheets/cost	# of 1" sheets/cost	feet of concrete/cost	total cost in $
3	8/$37400	27/$83295	27/$39960	828/$15333	175980
4	8/$37400	27/$83295	21/$31080	828/$15333	167108
5	7/$32725	27/$83295	22/$32560	828/$15333	163913
6		27/$83295	27/$39960	828/$15333	138580
7	8/$15200	14/$31850	21/$31080	828/$15333	93463
8	8/$15200	14/$31850	21/$31080	1165/$21574	99704
10				1425/$26389	26389
11	8/$37400	27/$83295	21/$31080	1165/$21574	173349
12	8/$37400	27/$83295	21/$31080	1165/$21574	173349
13	8/$37400	21/$64785	21/$31080	1165/$21574	154839
14	5/$23375	24/$74040		1165/$21574	118989
15	5/$23375	26/$80210		1165/$21574	125159
16	5/$23375	24/$74040		1165/$21574	118989
17	3/$14025	25/$77125		828/$15333	106483
18	3/$14025	25/$77125		1165/$21574	112724
19	3/$14025	25/$77125		920/$17037	108187
20	3/$14025	27/$83295		920/$17037	114357
21	3/$14025	25/$77125		980/$18148	109298
22		27/$77125		980/$18148	95273
23			27/$39960	1250/$23148	63108
24			27/$39960	1250/$23148	63108
25			27/$39960	1250/$23148	63108

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