OPTIMIZATION ANALYSIS OF IRRADIATED TARGETS TRANSPORT SHIELDING TO BE USED IN A ^{99}Mo PRODUCTION PLANT

Sahyun, A.; Sordi, G.M.A.A.; Biazini Filho, F.L.; Romero Filho, C.R.

Comissão Nacional de Energia Nuclear. Instituto de Pesquisas Energéticas e Nucleares.
Caixa Postal 11049 - CEP 05549 - São Paulo - SP - Brazil

INTRODUCTION

The aim of this paper is to optimize the shielding thickness to transport fission products from IPEN to a laboratory in charge of the separation of ^{99}Mo, which is placed at Great São Paulo city (ICRP Publication 55, 1989). The cooling plus the transport time is 12 hours, according to ^{99}Mo activity of 300 Ci desired after separation.

In order to calculate the shielding thickness and doses with different options, codes described elsewhere have been used (ORIGENII:Isotope generation and depletion code-Matrix exponential method, 1982; ISOSHLD:Kernel integration code purpose isotope shielding analysis, 1979).

BASIC DATA

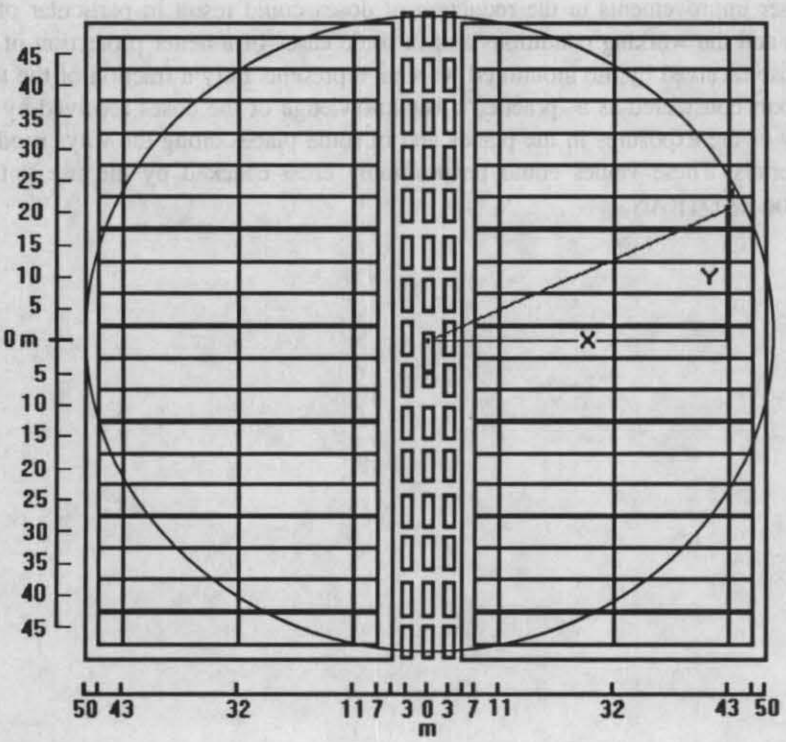


FIGURE 1 - Street and dwelling sketch used in the data

One weekly transport. 50 weeks per year. Time to transport: from 1 to 6 hours. Time of cooling, before transport, range from 11 to 6 hours, so that total hours (transport + cooling) = 12. Street dimension: 10 meter's width, three roadways, 2 meters of sidewalks; site and houses dimension: setback 5 x 25 meters, house 4 meters (Brazilian law), next house opposite to the first one.

Number of people: 5 per house (Brazilian families' average), 2 per vehicle. Vehicle dimension: 2 x 5 meters, transportation truck 2 x 8 meters.

Distance of vehicles: 1 meter in each direction, truck on the second roadway with the source centralized. The houses' people on the axes are 11 and 43 meters from the truck and the other distances are calculated through the X axes. A data sheet including the coordinated axes for the vehicles and houses' people distances for calculus are shown at figure 1.

The shielding from the own vehicles and houses' walls was disregarded on the doses' calculation.

The shielding is a cylinder with an inside empty of 3 cm. diameter and 11 cm. high where there would be placed the fission products to be processed (figure 2).

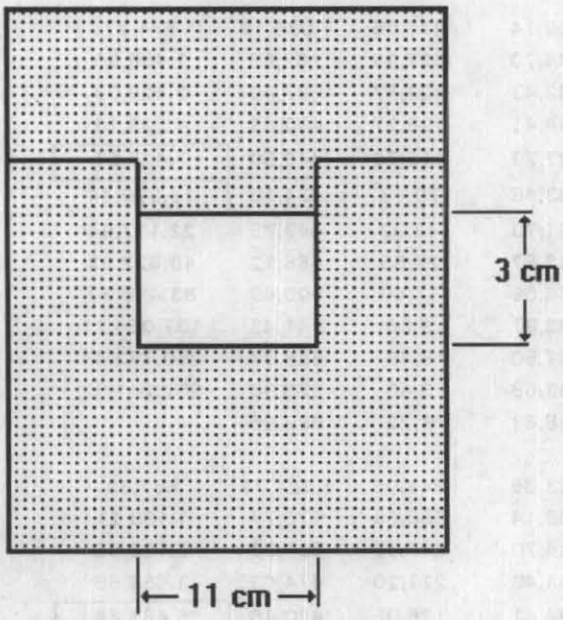


FIGURE 2 - Shielding sketch

As Safety Series 89 (IAEA Safety Series number 89, 1989) suggests for the calculus doses lower than 10 mSv/year have not been considered. The circumference on figure 2 shows the distance from the source shield to the points of 10 mSv/year.

Doses per hour on critical group and truncated dose for each transport:
6 hours: $3,33 \times 10^{-6}$ Sv/h, $3,33 \times 10^{-8}$ Sv/h;
5 hours: $4,00 \times 10^{-6}$ Sv/h, $4,00 \times 10^{-8}$ Sv/h;
4 hours: $5,00 \times 10^{-6}$ Sv/h, $5,00 \times 10^{-8}$ Sv/h;
3 hours: $6,67 \times 10^{-6}$ Sv/h, $6,67 \times 10^{-8}$ Sv/h;
2 hours: $1,00 \times 10^{-5}$ Sv/h, $1,00 \times 10^{-7}$ Sv/h;
1 hours: $2,00 \times 10^{-5}$ Sv/h, $2,00 \times 10^{-7}$ Sv/h.

1st Option: Shielding thickness, which provides the annual limit of the critical group or lower to give a round number in cm. Other options have higher shielding thickness than the 1st option, in numerical succession until a value for which the optimum option can be visualized without doubt.

Alpha detriment costs (National official value), US$10,000 person-Sv/year; shielding price based on US$ 1,5 a kg of lead; the useful time of the shielding 30 years.

Both, the detriment and protection are annualized cost estimates and the annual discount rate is 12%.

RESULTS AND CONCLUSION

Tables 1 and 2 and figure 3 show the results. The analytical solutions are underlined, both for the Cost Benefit and Cost Effectiveness Analysis.

The critical group dose was not considered to select the optimum thickness, because it is too small. The selection took into account only the two optimization techniques' results. The preference was selected from the tendencies. Example: For 11 hours decay the analytical solution is 23 cm. for cost-benefit analysis, near to 24 cm. far from 22 cm. (Table 2). On the other hand, for the cost effectiveness technique, the analytical is 23 cm. but very close to 24 cm. considering the alpha of US$ 10000 person-Sv/year (CNEN-NE 3.01, 1988). Therefore the choice considered was 23 cm. This kind of argumentation was also used for the other cases and the results are shown at figure 4.

From tables 1 and 2, we derive as main conclusions:

a) Any collective dose reaches the value of 1 person-Sv/year;

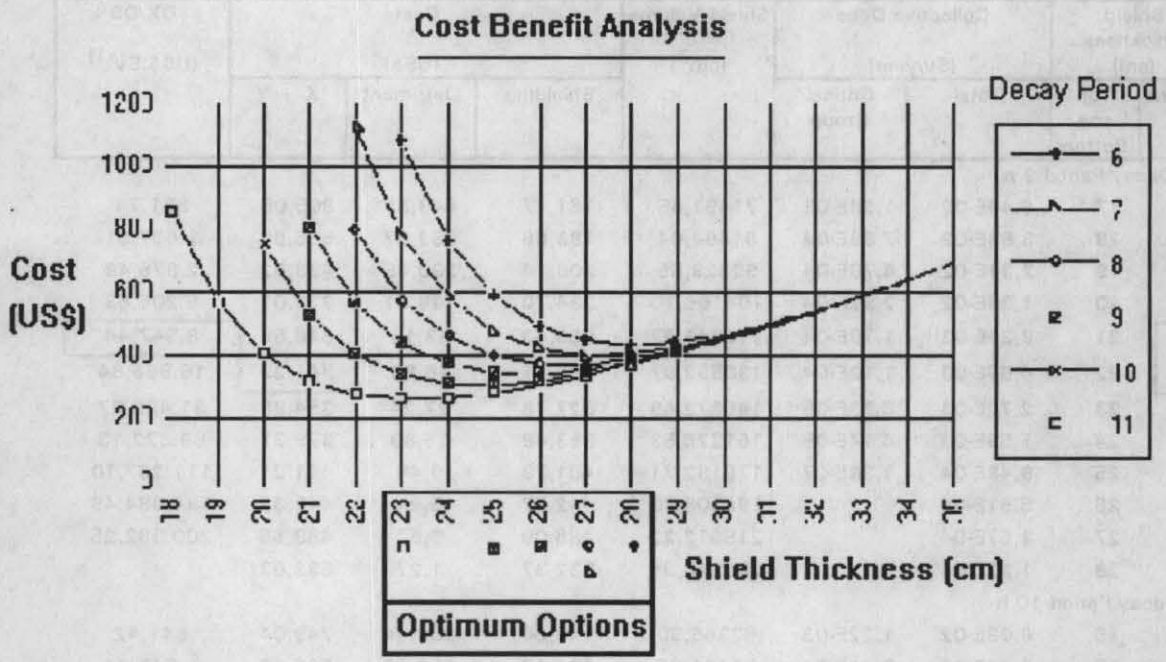
b) The doses at the analytical solution are under 100 mSv/year of the critical group. In this case the regulation exempts the application of the optimization principle; that is what we have gotten.

Shield Thickness (cm)		Collective Dose (Sv/year)		Shield Volume (cm^3)	Costs (US$)			DX/DS (US$.Sv^{-1})
Lateral	Top and Botton	Total	Critical Group		Shielding	Detriment	X + Y	
Decay Period 6 h								
23	19	8,71E-02	1,74E-03	92323,55	208,14	871,05	1.079,19	774,27
24	20	5,28E-02	1,08E-03	104106,10	234,70	527,98	762,68	1.408,30
25	21	3,24E-02	6,68E-04	116849,97	263,43	323,97	587,40	2.426,09
26	22	1,96E-02	4,14E-04	130592,87	294,41	196,27	490,68	4.299,13
27	23	1,19E-02	2,57E-04	145372,49	327,73	118,76	446,50	7.425,51
28	24	7,06E-03	1,60E-04	161226,53	363,48	70,63	434,10	13.370,44
29	25	4,20E-03	9,93E-05	178192,71	401,73	42,02	443,75	22.117,94
30	26	2,36E-03	6,18E-05	196308,70	442,57	23,55	466,12	48.622,93
31	27	1,46E-03	3,85E-05	215612,22	486,09	14,60	500,69	83.499,30
32	28	9,06E-04	2,39E-05	236140,95	532,37	9,06	541,43	137.054,21
33	29	5,48E-04		257932,61	581,50	5,48	586,97	250.772,43
34	30	3,40E-04		281024,89	633,56	3,40	636,96	252.241,92
35	31	1,22E-04		305455,48	688,63	1,22	689,85	
Decay Period 7 h								
22	18	9,41E-02	1,88E-03	81464,64	183,66	941,06	1.124,72	657,33
23	19	5,69E-02	1,16E-03	92323,55	208,14	568,63	776,77	1.199,21
24	20	3,47E-02	7,14E-04	104106,10	234,70	347,13	581,83	2.113,66
25	21	2,11E-02	4,40E-04	116849,97	263,43	211,20	474,63	3.638,66
26	22	1,26E-02	2,72E-04	130592,87	294,41	126,05	420,46	6.481,89
27	23	7,46E-03	1,68E-04	145372,49	327,73	74,64	402,38	11.749,05
28	24	4,42E-03	1,04E-04	161226,53	363,48	44,22	407,70	20.900,15
29	25	2,59E-03	6,45E-05	178192,71	401,73	25,92	427,65	38.268,95
30	26	1,52E-03	4,00E-05	196308,70	442,57	15,25	457,82	74.673,83
31	27	9,42E-04	2,48E-05	215612,22	486,09	9,42	495,51	122.771,01
32	28	5,65E-04		236140,95	532,37	5,65	538,02	229.474,41
33	29	3,51E-04		257932,61	581,50	3,51	585,01	230.610,66
34	30	1,25E-04		281024,89	633,56	1,25	634,81	
Decay Period 8 h								
22	18	6,12E-02	1,24E-03	81464,64	183,66	611,78	795,44	1.012,56
23	19	3,70E-02	7,59E-04	92323,55	208,14	370,01	578,15	1.821,44
24	20	2,24E-02	4,66E-04	104106,10	234,70	224,17	458,88	3.224,58
25	21	1,35E-02	2,86E-04	116849,97	263,43	135,08	398,51	5.666,44
26	22	8,04E-03	1,76E-04	130592,87	294,41	80,40	374,81	9.753,32
27	23	4,62E-03	1,09E-04	145372,49	327,73	46,24	373,97	18.568,97
28	24	2,70E-03	6,69E-05	161226,53	363,48	26,99	390,46	34.218,92
29	25	1,58E-03	4,13E-05	178192,71	401,73	15,81	417,54	67.318,92
30	26	9,74E-04	2,70E-05	196308,70	442,57	9,74	452,31	111.314,92
31	27	5,83E-04		215612,22	486,09	5,83	491,92	140.412,21
32	28	2,54E-04		236140,95	532,37	2,54	534,91	

TABLE 1 - Costs evaluation for 6, 7 and 8 hours decay

Shield Thickness (cm)		Collective Dose (Sv/year)		Shield Volume (cm^3)	Costs (US$)			DX/DS (US$.Sv^{-1})
Lateral	Top and Botton	Total	Critical Group		Shielding	Detriment	X + Y	
Decay Period 9 h								
21	17	6,44E-02	1,28E-03	71491,65	161,17	643,88	805,05	861,74
22	18	3,83E-02	7,83E-04	81464,64	183,66	382,97	566,62	1.607,61
23	19	2,31E-02	4,78E-04	92323,55	208,14	230,69	438,82	2.875,48
24	20	1,38E-02	2,92E-04	104106,10	234,70	138,31	373,01	5.206,63
25	21	8,31E-03	1,79E-04	116849,97	263,43	83,13	346,56	8.547,44
26	22	4,69E-03	1,10E-04	130592,87	294,41	46,88	341,29	16.966,64
27	23	2,72E-03	6,73E-05	145372,49	327,73	27,24	354,98	31.499,97
28	24	1,59E-03	4,14E-05	161226,53	363,48	15,89	379,37	59.672,13
29	25	9,48E-04	1,38E-07	178192,71	401,73	9,48	411,21	111.237,10
30	26	5,81E-04		196308,70	442,57	5,81	448,38	194.084,49
31	27	3,57E-04		215612,22	486,09	3,57	489,66	200.982,25
32	28	1,27E-04		236140,95	532,37	1,27	533,63	
Decay Period 10 h								
20	16	6,08E-02	1,22E-03	62366,90	140,60	608,44	749,04	841,42
21	17	3,64E-02	7,42E-04	71491,65	161,17	363,96	525,13	1.541,04
22	18	2,18E-02	4,51E-04	81464,64	183,66	218,06	401,72	2.720,02
23	19	1,28E-02	2,74E-04	92323,55	208,14	128,06	336,20	4.981,44
24	20	7,47E-03	1,67E-04	104106,10	234,70	74,74	309,44	9.245,62
25	21	4,37E-03	1,02E-04	116849,97	263,43	43,66	307,09	15.824,76
26	22	2,41E-03	6,22E-05	130592,87	294,41	24,08	318,50	35.386,47
27	23	1,47E-03	3,81E-05	145372,49	327,73	14,67	342,40	62.497,18
28	24	8,95E-04	2,33E-05	161226,53	363,48	8,95	372,42	105.486,39
29	25	5,32E-04		178192,71	401,73	5,32	407,05	197.493,14
30	26	3,25E-04		196308,70	442,57	3,25	445,82	207.153,41
31	27	1,15E-04		215612,22	486,09	1,15	487,24	
Decay Period 11 h								
18	14	7,50E-02	1,50E-03	46511,28	104,86	749,92	854,77	560,53
19	15	4,47E-02	9,02E-04	54052,67	121,86	446,60	568,46	1.029,01
20	16	2,64E-02	5,44E-04	62366,90	140,60	264,45	405,05	1.908,61
21	17	1,57E-02	3,28E-04	71491,65	161,17	156,67	317,84	3.535,39
22	18	9,31E-03	1,99E-04	81464,64	183,66	93,07	276,73	6.271,07
23	19	5,40E-03	1,20E-04	92323,55	208,14	54,03	262,17	11.001,92
24	20	2,99E-03	7,30E-05	104106,10	234,70	29,89	264,59	22.756,76
25	21	1,73E-03	4,44E-05	116849,97	263,43	17,26	280,70	45.586,20
26	22	1,05E-03	2,70E-05	130592,87	294,41	10,47	304,88	77.908,49
27	23	6,19E-04		145372,49	327,73	6,19	333,93	

TABLE 2 - Costs evaluation for 9, 10 and 11 hours decay



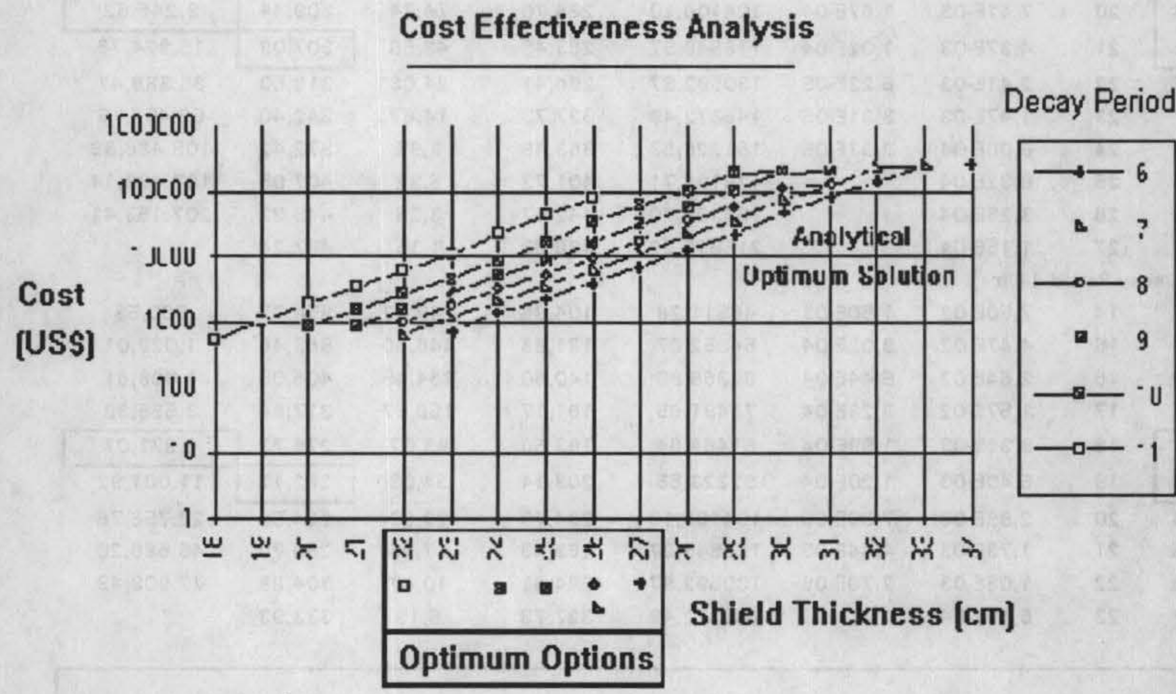


FIGURE 3 - Results from cost-benefit analysis and cost-effectiveness analysis

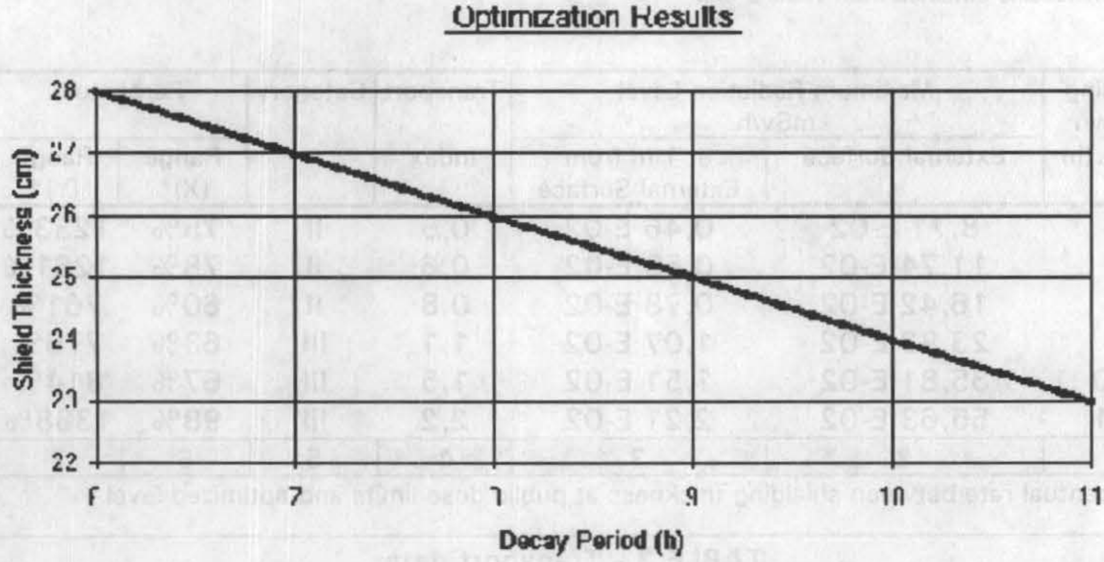


FIGURE 4 - RESULTS OF THE OPTIMIZATION SHIELDING THICKNESS

Other conclusions derived from table 1 and 2 are:

a) From column 4, the dose on critical group nearest the annual limit range from 0,87 to 0,61 mSv/year and at the optimization results from 8,95 x 10^{-2} to 6,00 x 10^{-2} mSv/year, but whether for 11 hours of cooling we consider the analytical solution as 22 cm. thickness, the range would be from 9,95 x 10^{-2} to 8,00 x 10^{-2} mSv/year.

b) From column 6, the shielding costs to obey the annual dose limits for the public have a range near 100%; while at the optimization results, has a range near 75%; and comparing the values nearest the public annual dose limit with the optimization solutions. The range is near 70%, except for 11 hours of cooling save that we considered the optimized solution as 22 and not 23 cm., to attend this average value.

c) From column 7, the costs of detriment, for annual dose limits for the public, have a percentage range near 40%, while at the optimization solution this range is 65%.

d) From column 8, the costs range of (X + Y) to obey the annual limits for the public, for the optimized solution is 65%.

e) From column 6, a shielding with 28 cm., is sufficient to include all of the optimized solution and in the bad case the increase on the protection cost near 75%, comparing with the optimized thickness for 11 hours cooling.

The conclusions obtained from Table 3 are:

Cooling Down Time (h)	Maximum Radiation Level mSv/h		Transport Index	Category	Percentual	
	External Surface	at 1 m from External Surface			Range (X)*	Range (Y)*
6	8,71 E-02	0,46 E-02	0,5	II	75%	1233%
7	11,74 E-02	0,59 E-02	0,6	II	78%	1261%
8	16,42 E-02	0,78 E-02	0,8	II	60%	761%
9	23,83 E-02	1,07 E-02	1,1	III	63%	775%
10	35,81 E-02	1,51 E-02	1,5	III	67%	814%
11	55,63 E-02	2,21 E-02	2,2	III	98%	1388%
1	2	3	4	5	6	7

* Percentual rate between shielding thickness at public dose limits and aptimized level

TABLE 3 - Transport data

a) From columns 2, 3, 4 and 5 the I.T. range from 0,5 for 6 hours to 2,2 for 11 decay hours and the category is II for 6, 7 and 8 decay hours and III for 9, 10 and 11 decay hours.

b) From column 7, the detriment cost range near 1000% from the annual limits relative to the optimized thickness while the protection cost range near 80%.

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