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NOTE ON THE CHOICE OF SHIELDING MATERIAL IN EXPERIMENTAL AREAS

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The relative usefulness of different kinds of shielding materials depends upon the nature of the shielding requirements as well as the unit cost of the shielding, and consequently for different requirements one may delect different materials. This note is intended to assist in the evaluation of the merits of the more important shielding materials for any particular purpose. In it we arrive at a figure of merit based both on cost and proposed application.

The true cost of shielding material in loco, ready to use, depends not only on initial material costs, but also most strongly on transportation and fabrication costs. Since it is frequently impossible to know such costs in advance with great accuracy, the data have been presented in the form of curves showing figures of merit vs. unit cost, so that the relative merit of materials as a function of cost may be evaluated. Table I shows the relevant input data on a variety of shielding materials. Cost has been calculated in two ways: per unit mass and per unit collision length, the latter being the relevant factor for hadron shielding calculations and the former for muons (there is an accidental coincidence for all materials, of the rate of energy loss per unit mass for muons in the 50 GeV region). Some sample cost values under various conditions are given, and then a figure of merit is calculated under various assumptions. The assumptions are as follows:

1. Hadron shielding: For a point source the figure of merit is taken as density squared/cost per collision length. This applied to shielding near a

proton target. For a line source,- an approximation to losses along a beam line,- the FM is proportional to density-cost per collision length.

2. Muon shielding: The undispersed muon beam origination from a target is so narrow (if we consider the long-range muons, above say 25 GeV) that it can be roughly approximated by a one-dimensional shield, in which case total mass is the only criterion. This case is not realistic; nonetheless, it is plotted in Fig. 2. More realistically, suppose that the muons are dispersed in one dimension, (usually the horizontal plane) either by magnetic dispersion at the target, or by escaping from beam transport lines designed for particles of some other momentum. Figs. 1 and 2 show figures of merit for hadron and muon shielding.

It is obvious that under all circumstances earth is the cheapest by far of all materials. Since earth is very inconvenient except as bulk shielding, we need materials suitable for modular use. For shielding a point hadron source, iron is by far the best material, even when its cost runs as high as 9 cents per pound. Autos in concrete are next best, at prices up to 5 cents per pound, at which point it just matches poured heavy concrete. A figure for poured concrete loaded with compressed autos would be useful as giving the highest figure of merit for bulk dense material. Uranium is nearly competitive at about .25 per pound. Lead is not competitive at prices above .13 per pound.

For shielding a line hadron source, concrete becomes relatively better, and there is no clear-out choice among the concretes and iron; the very heavy materials are not competitive. Earth is still the best; thus a concrete-lined earth-covered tunnel provides the best shielding for an intense beam line.

For shielding an undispersed muon beam, the sole criterion, in the one-dimensional approximation, is cost per pound. For the shielding downstream from a target, with a relatively diffuse source that requires shielding in one plane (the usual case, since we normally disperse muons onlu in the horizontal plane), the situation is similar to that for a hadron line source; except that the heavy elements are not as disfavored.

TABLE I

SHIELDING AND COST DATA FOR VARIOUS MATERIALS

MATERIAL	DENSITY g/cm^3 D	COLLISION LENGTH, X, g/cm^2 Ref. (1)	COST PER 100 lbs. Y Ref. (2)	COST PER X lbs., Z	COST BASIS	FIGURE OF MERIT, FM — HADRON SHIELDING: POINT SOURCE FM=D^2/Z	HADRON SHIELDING: LINE SOURCE FM=D/Z	MUON SHIELDING FM=10./Y	MUON SHIELDING space lim. FM=10D/Y
Earth	1.8	98	\$.047	\$.048	No trucking needed.	69.8	37.5	203.	364
			.098	.096	Trucking needed.	34.9	18.75	102	182
Concrete	2.2	98	\$1.60	1.56	Poured in place.	3.10	1.41	6.25	13.7
			3.30	3.24	In blocks.	1.54	0.68	3.12	6.85
Heavy Concrete	3.5	110	3.30	3.63	Poured in place.	3.72	0.96	3.12	10.9
			6.60	7.26	In blocks.	1.86	0.48	1.56	5.46
Compressed Autos in Concrete	4.6	116	(4.00)[3]	4.56	Estimated cost, autos cast in concrete blocks.	4.64	1.01	2.50	12.3
Iron	7.8	134	4.00	5.36	Cheapest form, unmachined castings	11.33	1.46	2.50	19.5
			6.00	8.04	Plates or equiv.	7.56	0.97	1.67	13.0
Lead	11.37	202	15.00[3]	30.30		3.36	0.34	0.67	7.55
Uranium	18.7	210	25.00[3]	52.50		3.72	0.28	0.40	7.50

References:

1. Yellow Book II (Exper. Uses 200 Bev Accel) pp. 311., D. Keefe.
2. Mostly from R. B. Menser, VCRL Eng. Note M3516 A, Mar. 16, 1965
3. Private Communications, various sources