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AAEC/E. 11.

SOME DESIGN DATA FOR GAMMA SHIELDING
IN N.S.W.

by

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SUMMARY

It is indicated that the use of pits and ponds is the cheapest method of containing active materials but that many things can make these methods impracticable. Concrete is thought to be the most generally useful material for above-ground shields and high density shields can be made comparably cheaply by using steel punchings, ilmenite sand, iron ore or a combination of these. Lead and cast iron are among the most expensive shielding materials but they can often be justified because of their compactness. Costs are included wherever possible.

A quick method of calculating shielding thicknesses is included in the appendices.

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1. INTRODUCTION

When radioactive materials begin to emerge from HIFAR it will be necessary to protect personnel from gamma radiation of high intensity. The construction of several storage blocks and handling flasks has already commenced, and it is proposed that remote handling cells are to be erected in the reactor active area for the purpose of examining highly active metallurgical samples. In addition, the Chemistry Department has a number of projects envisaged which will require shielding.

Briefly, it appears that the need for cheap and effective methods of shielding will become more urgent as the site expands.

It is already obvious that earth and water are the cheapest bulk materials available. These are not always the most suitable materials, however, and can only be justified for use as pits and ponds. From a compactness and structural viewpoint lead and cast iron seem to be the best, but both are expensive; lead particularly so.

The most useful and flexible material seems to be ordinary concrete. Its main disadvantage lies in its bulk due to the low specific gravity of most aggregates. Some effort has been made to find ways to obtain high density concrete and the information has been included in the following report.

One of the topics in this investigation is the viewing of active materials. The method used in looking at the sample can frequently dictate the type of bulk shield to be used, and it is considered that in any shield design this should be the primary consideration. Viewing is therefore considered first.

2. REMOTE VIEWING

(a) Windows:

Large-area viewing windows are particularly desirable when used in conjunction with rapid manipulators such as Argonne-8 types. In this application the operator is not confined to a fixed eyepiece nor does he have to make any focusing adjustments as is usually necessary with periscopes. The use of dense rather than light transparent materials shortens the actual distance between observer and object. This effect is accentuated by the higher refractive index of the material.

Also, one or more observers can see through windows at the same time and the operator can detect difficulties occurring at any point in the cell. Other methods of viewing usually restrict vision to one person and concentrate only on one portion of the cell at a time.

Transparent shielding windows can be divided into two classes.

(i) The solid type and

(ii) The liquid filled tank.

(i) Solid Type.

Early research involved investigation into phosphate and lead glasses, but the field seems to have now narrowed to lead glasses only. These can be obtained from Chance Bros., in U.K, Corning in U.S.A. and Jaener in Germany. in a density range from 3.27 to 6.2 with the most popular and largest sizes at 4.3. The most troublesome aspect of glasses is the discolouration due to irradiation. Cerium stabilized glasses have been produced by the above firms at density 3.27 – 3.70 which will withstand approximately 10^8 roentgens with a permanent loss in light transmission of only a few percent or less. (Ref. 1,2 and 3).

If ordinary concrete is used in the shield construction it is advisable to use a glass of comparable density. Ordinary glasses can be used and these are referred to as commercial lime (2.52), water white lime (2.52) and protected silicate (2.68) (Ref. 4).

The cost (ex U.K.) of these glasses with two surfaces ground ranges from £360/ft^3 for small sizes up to about £480/ft^3 for the largest sizes.

(ii) Liquid Filled.

The main reasons for liquid filling appear to be the increase in light transmission due to the elimination or reflecting surfaces in the laminated glass boxes, initial cheapness and the ease of recovery after radiation exposure by retreatment.

Water is the cheapest available filling, but this is often not convenient due to its low specific gravity. Some effort was made overseas to find a high density liquid to match the heavy concretes. Some success was experienced with lead acetate, acetylene tetrabromide, zinc chloride, methylene bromide, cadmium borotungstate, thallium formate-mallonate and others, but these were not finally chosen for various reasons.

The final choice was a zinc bromide solution of S.G. = 2.5 and this seems to be the best choice in Australia. At high radiation intensities decomposition will take place unless hydroxylamine hydrochloride stabilizer is added. This is completely effective and operates as below :-

$$\rightsquigarrow + 2H\,Br \longrightarrow H_2 + Br_2$$

$$2Br_2 + 2H_2\,NOH = H_2O + N_2O + 4\,HBr$$

4 ozs/100 gallons seems to protect thin layers of solution from incident doses up to 10^7 roentgens and prevents vision being obscured by gas bubble formation for dose rates below 5×10^4 r/hr at the incident face.

A more effective stabilizer has been found to be Hydrazine Hydrobromide L which does not release Hydrochloric acid during breakdown.

This is not well known yet but it avoids many of the corrosion problems present with Zn Br and only half the quantity need be added for similar quantities of radiation absorbed.

The Chemistry Department at Lucas Heights has made an extensive survey of the available chemicals and concluded that zinc bromide is the best solution to use as a shielding medium.

This can be obtained from U.K. at approximately A£6/gallon for optical work and may be obtained locally for about A£8/gallon if the optical properties are not paramount.

The best type of containing tank seems to be a glass-fibre construction. (Ref. 6). These can be obtained from Mendip Chemical Engineering Ltd., in U.K., and possibly from Commonwealth Engineering Co., or De Havillands in Sydney, if designs are available.

(b) Closed-Circuit T.V.

Some advances have been made recently along the lines of stereoscopic vision. Television has, to date, been generally unsatisfactory, but owing to the high cost of full-viewing windows it seems likely that a stereoscopic viewer with miniature cameras could probably compete successfully in many applications. One such arrangement is being developed by the Pye-Marconi combination.

(c) Periscopes and Mirrors.

These are used mainly in specialized applications, but for general work their cheapness is outweighed by other disadvantages. Microscopic examination of samples, however, is usually by means of periscopes for optical reasons.

(d) Lighting.

To prevent chromatic aberrations, it is usual to use a mono-chromatic light. For reasons of transmissibility, intensity required and radiation discoloration it has been found best to employ sodium lights.

Sometimes, colour discrimination is necessary and white light must be used. Either fluorescent and incandescent lighting is used in these instances, but this is not recommended with very thick windows since it does not provide useful colour discrimination.

The biggest problem with lighting is the intensity necessary with high activity cells. For High Activity applications laminated lead glass windows may have a transmission of only about 5%. Zn Br windows on the other hand exhibit quite good light transmission properties, upwards of 40%, although their thickness may become excessive above 10^5 MeV. Curies.

These factors may be very important in the overall design of a cell. (Ref. 1).

(e) General.

One approach to the design of a radioactive handling system is to first of all decide on what type of viewing is necessary. The cheapest method is to look through the water in a pond but many things can make this impracticable.

Having decided on what viewing is necessary one can then choose the shielding to match. This may determine the type of manipulators to be used and the design proceeds from there in a logical fashion.

To indicate the relative importance of the various components, an abbreviated list of estimated costs for the Lucas Heights active handling cells is appended.

Concrete Structure + Steelwork	=	£30,000
External & Internal Shielding Doors	=	£30,000
General Purpose Manipulators	=	£40,000
Viewing Windows	=	£60,000
Ancilliary Buildings	=	£15,000
Ventilation & Air Filtration	=	£19,000
Internal Equipment	=	£10,000
Ancilliary Equipment + Interlocks and Monitors	=	£30,000

As can be seen, the viewing windows and the manipulators are the most expensive items. (Ref. 6).

3. CONCRETE.

For neutron attenuation the main virtue of concrete as a shielding material lies in the fact that there is a large quantity of light nuclei for slowing down purposes which can be combined with heavy nuclei for gamma absorption purposes, e.g. H_2O and Ba in Barytes concrete.

For gamma absorption we are interested in the heavy nuclei only, and in general the more massive the concrete the better. Massiveness is achieved by using a heavy aggregate.

(a) Naturally Occurring Aggregates:-

Natural ores only become markedly heavier than common aluminates and silicates if they have a heavy element in combination. Unfortunately, the heavy metals are mined because of their value and the ores are therefore usually rather expensive.

A list of some of the more readily available Australian heavy ores follows with their approximate S.G.:-

	Oxides	Sulphides	Carbonates	Others	Remarks
W	7.5				Wolframite
Bi	4.4	6.5	7.2		
Pb	6.5	7.5	6.5	Sulphate = 6.3 Phosphate = 7 Wulfenite = 6.7 Sulphate = 4.5	
Ba					Barytes
Sb	5.25	4.6			
As		6.1			Arsenopyrites
Zn	5.6	4	4.35		
Cu	6	5.7			
Ni		5.6			
Co					CoAs$_2$ = 6.2
Fe	5	5		Titinate = 4.7 (Ilmenite)	
Mn	4.8	4	3.5		
Cr				Chromite = 4.3	

Silicates are common but are too light and phosphates and arsenates are heavy but rare. In many cases the ore is mixed with large quantities of silica and clay and is thus made lighter. The cost of separation is usually too high to consider. The most likely aggregates in N.S.W. have been investigated and approximate costs obtained for delivery to the site. Tables of cost comparisons are listed below.

Ore	Estimated Concrete Density lbs/ft.^{3}	Aggregate Cost/$_{ton}$.
Wolframite	300 – 310	£300 – 400
Galena (PbS)	270 – 280	£60 – 100
Hematite	220 – 240	£5 – 7
Magnetite	220 – 240	£15 – 20
Zircon – Ilmenite Beach Sand	200 – 220	£8 – 15
Barytes	200 – 230	£33 – 35
Limonite	180 – 190	£10 – 15
Cerrusite (Lead Ore)	170 – 180	£18 – 20
Manganese Ore	170 – 180	£23 – 27

N.B.

(a) These costs obtained at the time of writing but wide fluctuations can occur. This applies to most costs given.

(b) Surface hydration of hematite to limonite causes a fine powder to be formed on some ores. This turns to clay when wet and makes it difficult to produce a workable mix. Some doubt existed to whether hematite is stable in concrete and checks were carried out by the University of Sydney. No instability was detected. (Ref. 10).

(b) Artificially Occurring Aggregates:-

(i) Manufactured Products:-

A table of costs and densities follows.

Material	Concrete Density lbs/ft^3	Aggregate Cost/ton
Steel Shot	340 - 350	£60
Sheared Bars or Punchings	350 - 360	£70
Ferro-phosphorus	300	£70 - 80
Brick	140	£5

(ii) Manufacture. By-products.

These are usually waste products and are therefore cheaper.

Material	Concrete Density lbs/ft^3	Aggregate Cost/ton
Punchings Scrap	320 - 360	£7 - 12
Copper Refinery slag	220 - 240	Transport Only from Kembla (£4 - 5).
Ilmenite	195 - 205	£6 - 8
Blast Furnace Slag	170 - 180	£4 - 5

NOTE:- Some copper refinery slags and sulphur bearing ores cause a deleterious chemical action to occur within the concrete. These materials should be rigourously checked before use.

(c) Design Considerations:-

(i) Shielding Effectiveness:-

No data is available giving exact information on attenuation as heavy concrete is usually a heterogeneous mixture of materials. However, one can usually obtain gamma mass absorption coefficients for the main aggregate and use a correction factor based on the overall density of the concrete to give a fairly accurate estimate.

(ii) Density:-

The decision on what density to use may be influenced by the type of operation to be performed, available building space, complexity of the shield and the viewing facilities required. The final analysis, however, will be basically a compromise between the ease of operation of the facility and the total cost, so that the decision on what density to use would be best left until the design is almost complete. As the design usually depends on this decision at the outset the only effective approach is to proceed by successive approximations. Concrete lends itself to this type of vacillation.

(iii) Structural Strength:-

Many of the heavy aggregates have superior properties and compressive strengths can be achieved between 2000 - 6000 p.s.i. As exact information can only be obtained by individual tests it would be a safe rule to assume 28 day strength of 2,500 p.s.i until the tests are completed. This has proved to be a good working rule with the aggregates so far tested and is usually adequate to satisfy structural requirements in the usual thick-walled cell.

(iv) Stability:-

No marked deterioration has yet been noted in concrete undergoing gamma irradiation and this would be much more severe inside reactors than in isotope shielding facilities. The temperature rise due to irradiation is the most likely cause of deterioration and with HIFAR experiment activities this is not a hazard.

(v) Placement:-

The only thing dictating against normal methods is the liability of segregation of the heavier aggregate. This can be overcome by prepacking the aggregate and pumping in an intrusion mortar or by choosing the mix proportions so that settling cannot occur. Prepacking is expensive and since careful mixing and placement can usually avoid segregation and voidage, it is only recommended where uniformity of the shielding is vital. The density, in the case of a normally mixed concrete, is fixed by the shape and density of the aggregate because any attempt to reduce density will result in segregation and weak layers between lifts.

As the mixes are heavier than normal, it is usual to reduce the batch volumes. This results in handling charges which can be compared to ordinary concrete charges but on a weight rather than a volume basis.

Formwork is a little more expensive owing to the higher density but should be a small factor in the overall cost.

(vi) Processing the Aggregate.

Many of the Australian ores have clay and other foreign materials present as supplied. It would be therefore necessary to process them to obtain the density and strength desired. This is best done on site so as to assist in quality control but will add considerably to the cost.

(d) Analysis:-

Tests have been done by the Australian Atomic Energy Commission and Mr. Campbell-Allen of University of Sydney, on the cheaper aggregates mentioned. Different combinations were tried in order to discover the best way to control the density. Some of the results are on the following page.

Coarse Aggregate	Fine Aggregate	Bulk Dens. of Coarse Agg.	Density Final Conc.	28 Day Strength	Mix Proportions lb/Cu yd.			W/C	Remarks
					Coarse	Fine	Cement		
Punchings A*	Ilmenite	300	352	2500	6960	1730	530	0.55	
Punching B + Punching D	Ilmenite & Barytes	290	340	3800	6000	2100	750	0.55	
Punchings B	Nepean Sand & Rock Dust	300	330	2000	5950	1850	745	0.55	
Punchings C*	Ilmenite	277	319		5840	1860	600	0.55	
Punchings C	Nepean Sand	277	277		5360	1260	582	0.55	
Punchings A	Ilmenite	226	282	2320	4360	1720	530	0.55	
Punchings C + Basalt	Ilmenite	221	272		4230	1860	600	0.55	
Punchings D*	Ilmenite	260	310	~3500	4920	1910	690	400	
Barytes	Barytes Dust		224		2700	2195	540	0.6	
Ilmenite Fine	Ilmenite Fine		196	2680		Sand/Cement -	3.12	0.55	
Hematite	Hematite Dust		220		4190	1050	430	290	With carefully washed Hematite
Hematite†	Ilmenite Barytes Sand		225	3500	4170	1050 524	500	0.5	

* Punchings A = ¾" – 1" Ø x 3/8" – ½" Thick M.S. cylinders

Punchings B = ¾" – 1" Ø x ¾" – 1" (90%) Thick M.S. Cylinders + 1½" x 1" x 1" butterfly shaped pieces (10%) (Nut punchings from McPherson's).

Punchings C = ¼" – 1¼" Ø x 1/16" – ¼" thick M.S. discs

Punchings D = Elliptical 1/16" thick x 3/8" wide x 2" – 3/8" long mixture of punchings from "Dexion" angle

† Barytes sand was added to increase workability of mix. With low heat cement and better graded coarse aggregate it is expected that a density of 250 lbs/ft^3 is possible.

No suitable magnetite was obtainable so no tests were carried out and manganiferous hematite from Port Kembla was tried instead.

Some doubt exists regarding the stability of hematite in concrete and the authorities on this are in some disagreement. Tests were therefore conducted to determine the stability but no instability was discovered.

Fig. 1 gives a rough guide to the relationship of coarse aggregate density to final concrete density. (Ref. 7).

(e) Sources of Information:-

The following are lists of (a) various people who have been able to supply information on aggregates and ores, and (b) firms who can supply ilmenite sand.

Name	Firm	Subject
Mr. G. Watson	Stephenson and Turner	General
Mr. Abeshouse	Dept. of Mines	"
Mr. Whitworth	Mining Museum	"
Prof. Marshall	Geol. Dept. Univ. of Sydney	"
Mr. Harding	N.S.W. Mining Co. 252 Castlereagh Street, BM.6353	Magnetite
Mr. Warren	British Metal Corpn. BW.6549	Lead-Zinc Ores
Mr. Bowen	Francis Hambridge P/L 22 Bridge Street, BU.2428	"
Mr. Ireland	Captains Flat, N.S.W. Captains Flat 5	Iron Pyrities Lead Ore
Mr. Thompson	Technical Manager, Australian Iron and Steel, Port Kembla	Hematite Magnetite Scrap Steel Copper Slag
Mr. Taylor	Divn. Building Research C.S.I.R.O. Graham Rd. Highett S.21	Concrete and cement properties

NEW SOUTH WALES MINERAL SANDS INDUSTRY

FIRMS OPERATING SEPARATION PLANTS

ILMENITE - 1957

1. Beach Mining Australia Pty. Ltd. (Subsidiary of No. 7)
206 Falcon Street,
NORTH SYDNEY

2. Bellingen Titanium Pty. Ltd.,
COFFS HARBOUR

3. Cudgen R.Z., (J.A.Foyster.)
KINGSCLIFF, via
MURWILLUMBAH. N.S.W.

4. Heavy Minterals Pty. Ltd.,
Care Charles J. Berg and Associates,
195 Pitt Street,
SYDNEY

5. Laurieton Rutile Co.,
20 Loftus Street,
SYDNEY

6. Lennox Head Company,
Box 281 D,
BRISBANE QLD.

7. Metal Recoveries Pty. Ltd.,
MOOBALL North Coast N.S.W.

8. National Minerals Limited,
Greenway Street,
WICKHAM N.S.W.

9. N.S.W. Rutile Mining Co. Ltd.,
James Murphy Esq.,
Box 125 P.O.,
SOUTH BRISBANE QLD.

10. Rusan Minerals Pty. Ltd.,
WOODBURN N.S.W.

11. Rye Park Scheelite N.L.,
LAURIETON N.S.W.

12. Silver Valley Uranium Mine N.L.,
Care Charles J. Berg and Associates,
195 Pitt Street,
SYDNEY

13. Titanium Alloy Manufacturing Co. Pty. Ltd.,
Box 71 P.O.,
TWEED HEADS

14. Titanium Minerals Ltd.,
Care K.M. Horler and Co.,
56 Hunter Street,
SYDNEY

15. Zircon Rutile Limited,
374 Little Collins Street,
MELBOURNE VIC.

16. Associated Minerals Consolidated Ltd., (Crude Concentrates only produced in N.S.W.)
SOUTHPORT QLD.

(f) Cost

It is difficult to state exact costs on concrete which has not been actually made before. However, as a guide, the following approximate costing can be applied, at the date of writing this report, to pouring thick shields.

Cost of Steelwork Erected = £150 - 200/ton

Cost of Formwork, Pouring and Finishing = £15 - 20/ton

Cost of Materials = (As specified in tables)

Approx. Cost/Ton of Useful Aggregates

Aggregate	1955 U.K. (ref. 9) £(Aust.)	1957 Australia £(Aust.)
Ordinary Granite or Bluestone		2
Limonite	13	10-15
Hematite	22	5
Ilmenite	15	6-9
Galena	75	60
Barytes	23	30
Copper Refinery Slag	12	-
Steel - Punchings	14	7-12
Iron - Shot	30	60
Common Brick	12	5

Note: It can be shown that, if building costs are included, for high activities it is sometimes cheaper to use a dense shield even if the cost of the shield is high. The saving results from a decrease in cost of the building.

4. SHELL + FILLING

(a) Steel Shell

Some shields have been constructed overseas from steel and then filled with barytes sand or ordinary sand.

Advantages:-

(i) A structure with a complete steel skin can have things easily attached.

(ii) It can be modified although this is very costly.

(iii) The effective shielding can be altered at will by changing the filling.

(iv) A wider choice of filling is possible.

Disadvantages:-

(i) It is usually much more expensive than concrete.

(b) Brick Wall Shell

This is much cheaper than a steel shell and has been used fairly extensively for blank walls.

Advantages:-

(i) It is fairly cheap

(ii) It can be incorporated easily in normal building construction.

Disadvantages:-

(i) It is bulky.

(ii) It is not easily dismantled.

(iii) It is difficult to penetrate the wall with manipulators and doorways.

(c) Water Filling

Advantages:-

(i) It is cheap.

(ii) Easily removed.

Disadvantages:-

(i) It is bulky.

(ii) It involves an expensive holding tank of steel or concrete.

5. PITS AND PONDS

(a) Pits

The principal advantage of pits is the comparative cheapness of construction for activities of over about 100 curies of cobalt. This fact is highlighted in figure 2 which shows how only large cells with thin walls can compete with pits. The above ground cells are justified only where hard rock is unavoidable, the activity to be handled is high, the cells are relatively large or where the handling techniques necessitate adequate access from the sides for viewing or manipulating.

Fig. 2 is based on a letter received from Stephenson and Turner of 8th July 1957, which gave excavation costs and on the building costs obtaining at that time. The results can therefore, only be regarded as approximate.

Although there may be many reasons why above-ground cells are required it is worthwhile considering under-ground cells for medium and high activity handling because of cost. It may be pointed out, however, that the total cost of the shield in a Remote Handling facility may not amount to more than 10% of the total cost and other factors may have a much larger bearing on the final cost, e.g. (Costs on Handling Cells. Page 4.)

(b) Ponds

One of the major costs in a handling facility can be the viewing equipment. If the activity to be handled is low and the depth of water therefore not excessive, it may be well worthwhile to handle the equipment under water. Remote handling is simplified and the problem imposed by self-heating of the radioactive material is usually rendered negligible.

The biggest disadvantages are the fact that the material to be handled must be not affected by water and that handling from above becomes mandatory. Another disadvantage is that the larger distance between the work and the operator makes viewing more difficult, but as can be seen by the cost analyses above, this would be probably the cheapest form of facility.

Also, an important consideration in cost is the amount of water clarifying and treatment plant required. This could amount to £400/1000 gals. as a capital cost in a small pond.

6. LEAD AND CAST IRON

(a) Lead

Although lead is expensive, the choice of shielding materials is governed by a variety of factors, only one of which is cost. If the gamma energies are predominantly in the region of 1 – 3 M.e.V., the shield attenuation is governed mainly by mass/unit area. But a secondary effect which becomes predominant at high and low energies increases the attenuation in materials of high atomic number. Thus a plane lead shield can be thinner than a concrete shield by a factor greater than the ratio of densities.

Two major advantages can be claimed for lead.

(i) For containers, the thinness of the shield results in a saving in overall weight.

(ii) For shields, the thinness of the shield greatly facilitates the use of simple type manipulators such as ball-tongs.

These two advantages could in some cases, result in a lower overall cost of a facility. For instance, if freight charges were balanced against overall cost for a transport container, the more expensive container might be justified. Also, the cost of manipulators can amount to a very large proportion of the cost of a shielding facility and the overall cost may thus be reduced.

(b) Cast Iron

Although not as heavy as lead, cast iron can be used quite effectively. Its only two advantages over lead, however, are:–

(i) Cheaper cost/unit mass

(ii) Structural strength

In many circumstances these two features are important and where access holes and ducts occur in concrete walls, cast iron seems to be the best material for reinforcing the shielding. It seems to have particular advantages, when used in conjunction with lead, as a construction material for transport containers.

(c) Cost Comparisons

Lead Ingots – £120–80/ton

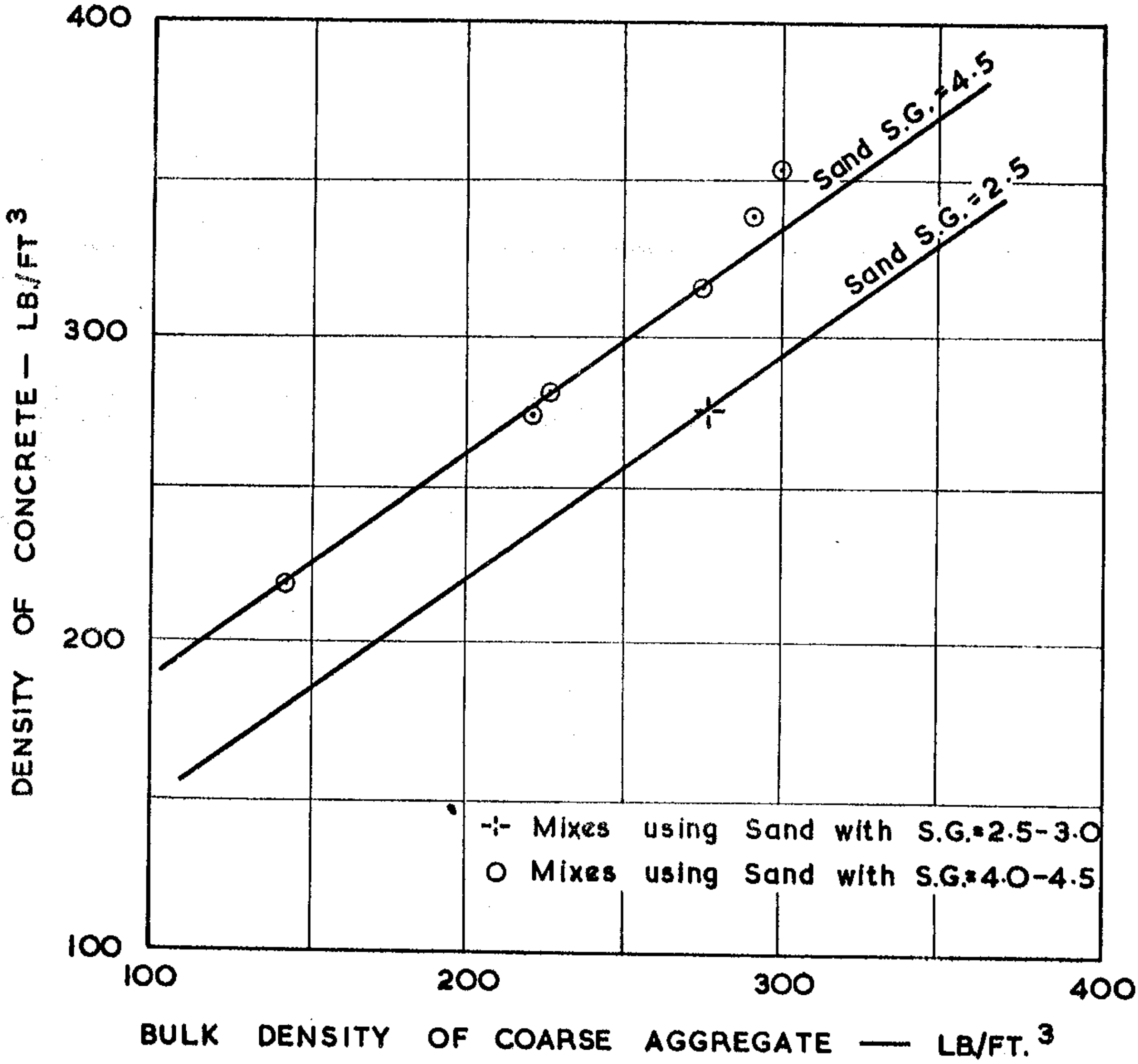
Cast Iron – £90–100/ton unmachined
(as simple castings
large sections.)

The cost in using lead comes primarily from the fact that for transport containers it must usually be contained in a strong M.S. fabricated structure. In this case the cost of lead would be 1½–2 times the cost of the Cast Iron. In the case of a simple wall where the C.I. blocks can be used in the un–machined condition, the cost of using lead would be less than 1½ times the cost of the C.I. and if many standard remote handling fittings were used there would be possibly some cost advantage in using lead.

REFERENCES

1. T.T.D. 5280 – Supplement 1
   Symposium on Hot Labs. Jan. 56.
2. Design and Construction of Shielding Windows
   – K.R.Ferguson – Nucleonics – Nov. 52.
3. A Manual of Remote Viewing – A.N.L. 4903.
4. The Performance of Shielding Windows at High Radiation Intensity –
   B.N.L. 302, 74 (1954) by K.R.Ferguson and W.B.Doe.
5. Zn Br Solution for Use in Shielding Windows – William Doe.
6. Viewing Facilities for α, β, λ Cells – F.S. Bloxham, G.B.S/39.
7. High Density Concrete for Lucas Heights Project.
   – D. Campbell Allen (Univ. of Sydney.)
8. High Density Concrete Shield – Nucleonics – June 1955 Harold S. Davis.
9. Radiation Shielding – Price, Horton and Spinney.
10. Private Communications from W.H.Taylor – P.T.O –
    Division of Building Research – C.S.I.R.O – Graham Rd., Highett, Vic.
    on 14th May and 29th April 1957.

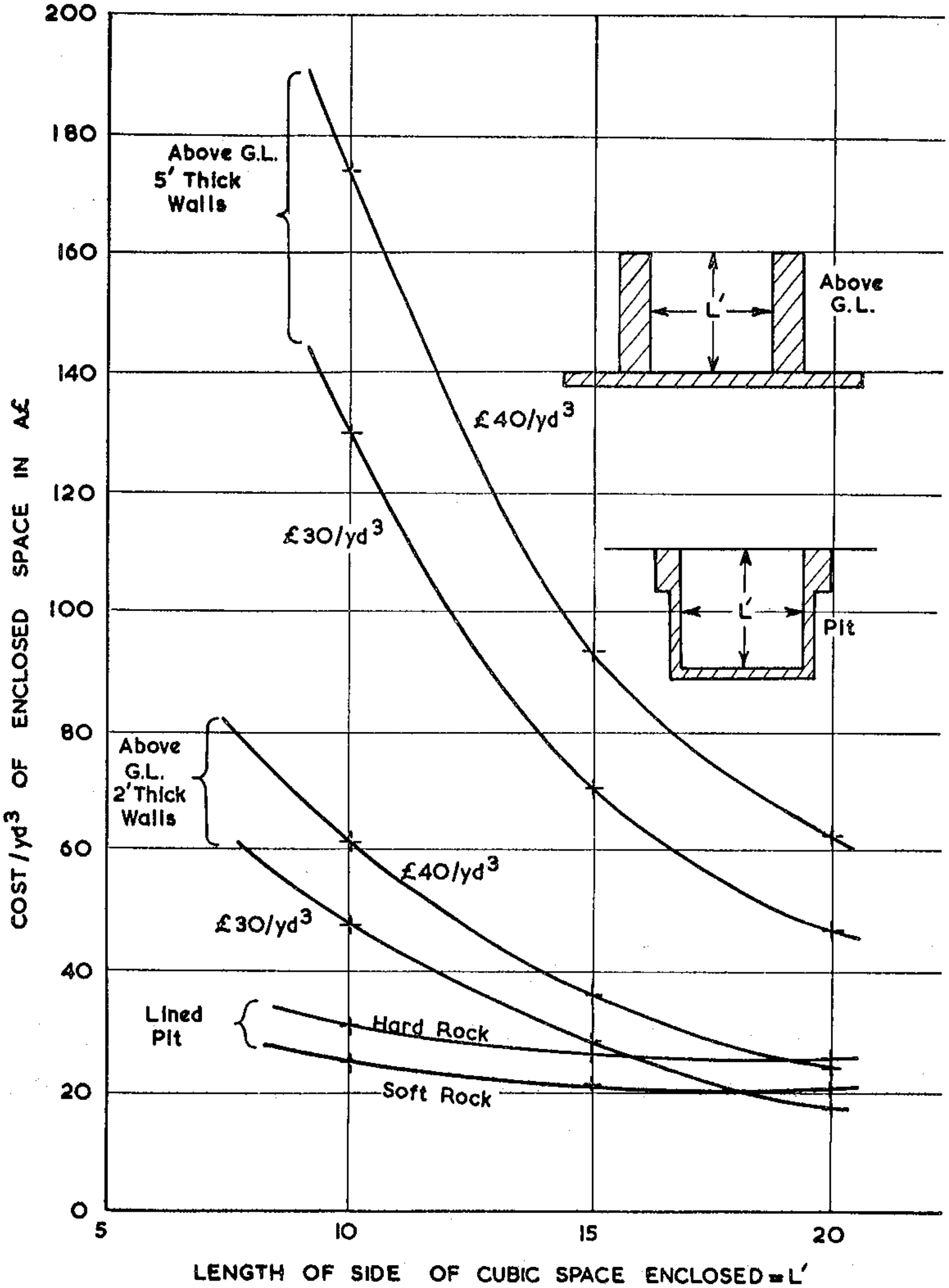
Fig. 1.



DESIGN CURVES FOR CONCRETE MAXIMUM AGGREGATE 1 IN.
W/C=0·55 BY WT.

APPROXIMATE RELATION BETWEEN BULK DENSITY OF COARSE AGGREGATE, BULK DENSITY OF SAND & FINAL DENSITY OF CONCRETE

Fig. 2



COMPARATIVE COSTS OF CONSTRUCTING PITS & ABOVE GROUND CAVES FROM ORDINARY CONCRETE — WITHOUT ROOFS OR BUILDINGS

APPENDIX 1.

NUCLEONICS DATA SHEET No. 5

Shielding Constants

Tenth-Value Thicknesses for Gamma-Ray Absorption

By JOHN MOTEFF
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FIGURES 1–3 on this page provide data useful in gamma-ray shielding calculations (*1*). Included are graphs of: tenth-value thicknesses, energy at which narrow-beam absorption coefficients are a minimum, and flux equivalent to 1 r/hr.

Tenth-value thicknesses (Fig. 1) were calculated from total absorption coefficients tabulated in G. R. White's tables (*2*) using $L_{1/10} = 0.004/\mu$. (NOTE: Pb tenth-values are wrong in Fig. 4, Stanford Res. Inst. report, "Industrial uses . . . fission products" and Fig. 4, p. 57, NU, June '54.)

Energy range is that of principal interest to reactor and isotope work. For lead and tungsten the curves can be straight-line extrapolated to get values from 0.1 to 0.2 Mev, but the 0.116-Mev *K* absorption edge in uranium makes extrapolation difficult.

The thickness to attenuate by a factor other than ten can be gotten by multiplying the tenth-value thickness by the common logarithm of the desired factor; thus, half-value thicknesses are $\log_{10} 2 = 0.3010$ times tenth-value thicknesses.

The use of tenth-value layers assumes "good," narrow-beam absorption geometry; that is, that attenuation is exponential with equal attenuation in equal thicknesses. For broad-beam poor-geometry absorption, build-up of scattered radiation has to be considered (*1*, *3*). However, good-geometry values are a guide and give a lower limit for transmitted intensity.

Figure 2 is based on Table 6 of ref. (*3*). Figure 3, flux equivalent to 1 r/hr, is based on the absorption coefficient of air (given in ref. (*3*), Table 10) and assumes that 1 r = 6.77×10^4 Mev/cm^3 of std. air, based on 32.5 ev/ion pair.

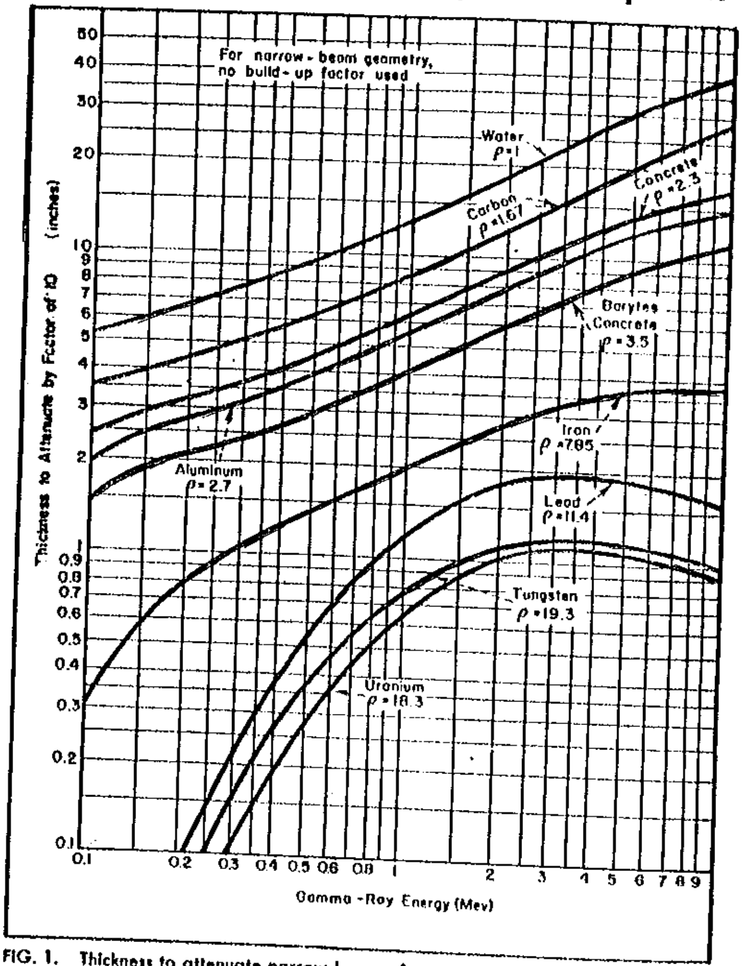


FIG. 1. Thickness to attenuate narrow beam of gamma rays by a factor of 10

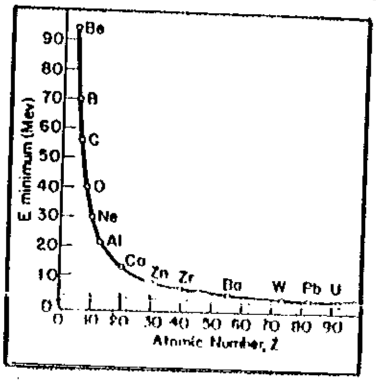


FIG. 2. Energy at which narrow—beam absorption coefficients are a minimum

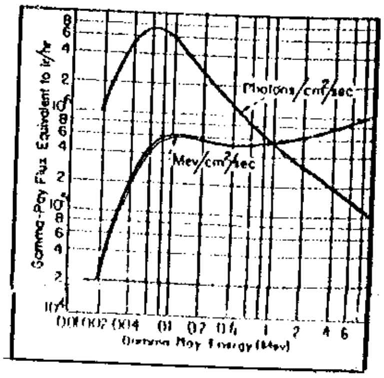


FIG. 3. Gamma—ray flux equivalent to 1 r/hr as a function of gamma—ray energy

BIBLIOGRAPHY

1. J.Moteff. Miscellaneous data for shielding calculations, APEX 176 (1954)
2. Gladys R. White. X—ray attenuation coefficients from 10 kev to 100 Mev. NBS 1003 (1952)
3. U.Fano, Nucleonics 11, No.8, 8 and 9,55 (1953)

APPENDIX 2.

The attached curves give the dose attenuation of γ rays from a point isotopic source of various energies and various thicknesses of lead, iron and concrete. It is recommended that these curves be used rather than the 1/10th value layers given in Appendix 1.

The usual expression for dose through a shield is given as ϕ

$$\frac{S\ Be^{-ut}}{4\pi d^2}$$ for point isotopic source

where S = source strength

B = build-up factor

d = distance between source and observer

U = γ linear absorption coefficient

t = thickness of shield

The curves give Be^{-ut} so that the formula can be used as ϕ

$$\frac{S}{4\pi d^2}\ \text{(Attenuation)}$$

If in the practical case a point source is not a sufficiently valid approximation, a correction can be readily applied according to the following tables. (Refer – Reactor Shielding Design Manual – Rockwell P 409.)

1. Line Source (at right angle to line joining observer and centre of source)

S = total activity

θ = 1/2 angle subtended by line source measured at observer

$$\phi = \frac{S\ \text{(Attenuation)}}{K\ 4\pi d^2}$$

			K		
θ	ut = 0	ut = 1	ut = 5	ut = 11	ut = 25
1°	1.001	1.001	1.001	1.001	1.002
5°	1.003	1.004	1.009	1.016	1.036
10°	1.010	1.016	1.036	1.067	1.142
30°	1.103	1.157	1.376	1.698	2.372

2. Disc Source (in a plane normal to line joining centre of source and observer)

S = total activity

θ = 1/2 vertex angle of cone subtended by source

K

θ	ut = O	1	5	11	25
1°	1.00	1.00	1.00	1.00	1.00
5°	1.01	1.01	1.01	1.04	1.06
10°	1.02	1.02	1.05	1.12	1.20
30°	1.22	1.30	1.65	2.34	4.36

3. Truncated Right Circular Cone Source

$$\phi = \frac{S_V \pi Ro^2}{U_s} \quad \frac{(\text{Attenuation})}{K\, 4\, \pi a^2}$$

where S_V = activity/cm ^{3} of source

Ro = radius truncated cone at end nearest observer

Us = linear absorption coefficient of the source material

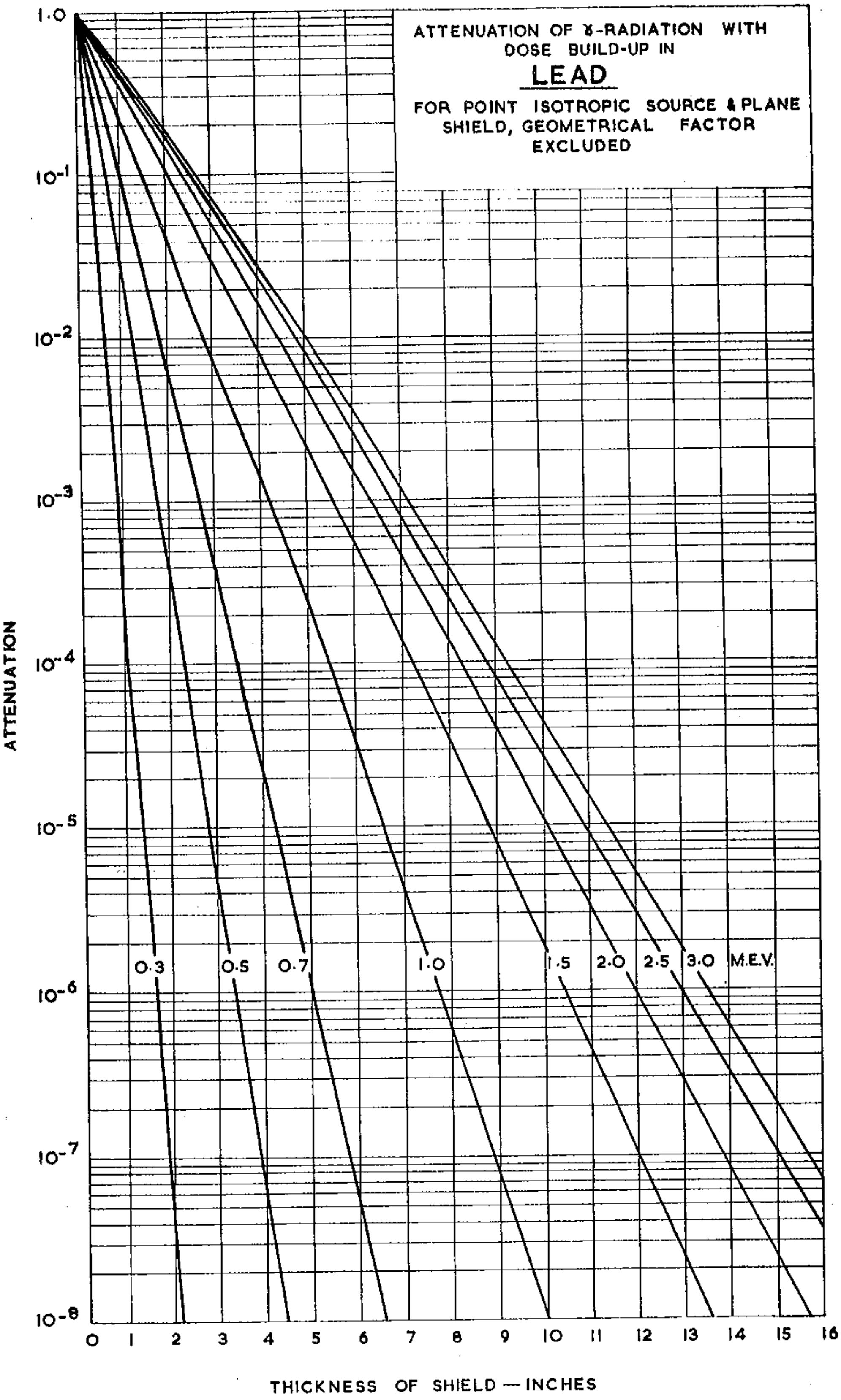
θ = ½ vertex angle of cone

K

θ	ut = O	ut = 1	5	11	25
1	1.02	1.02	1.02	1.02	1.02
5	1.02	1.02	1.02	1.03	1.06
10	1.02	1.03	1.08	1.12	1.23
30	1.08	1.34	1.75	2.49	4.56

Dose rates can be determined from Fig. 3, Appendix 1, and hence the gamma levels can be worked out in M.P.L's.

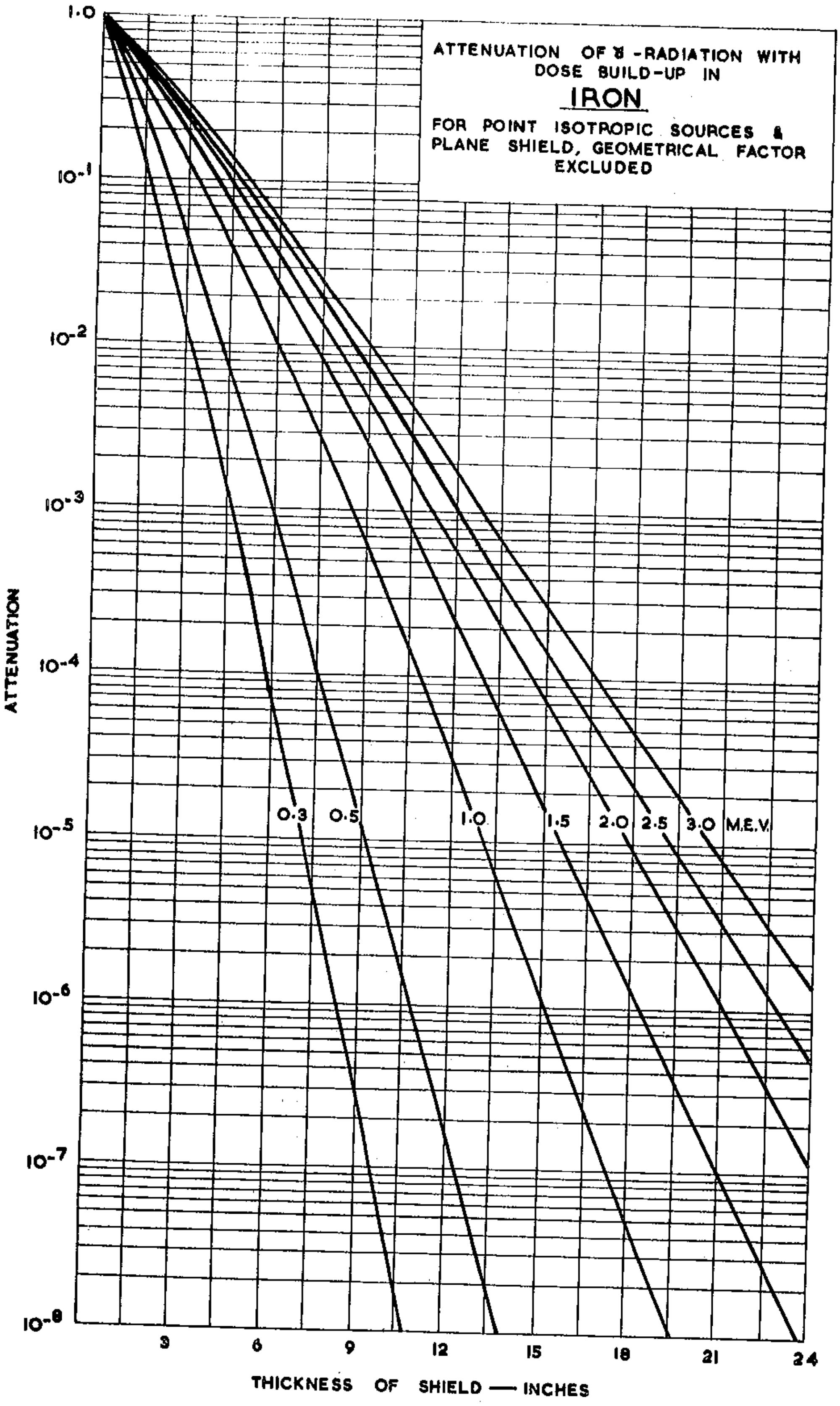
N.B. These graphs and tables should only be used as a "ready reckoner" to make quick estimates of the shielding necessary to protect personnel from γ radiation. For accurate estimation more exact information is usually available.



ATTENUATION OF γ-RADIATION WITH DOSE BUILD-UP IN

LEAD

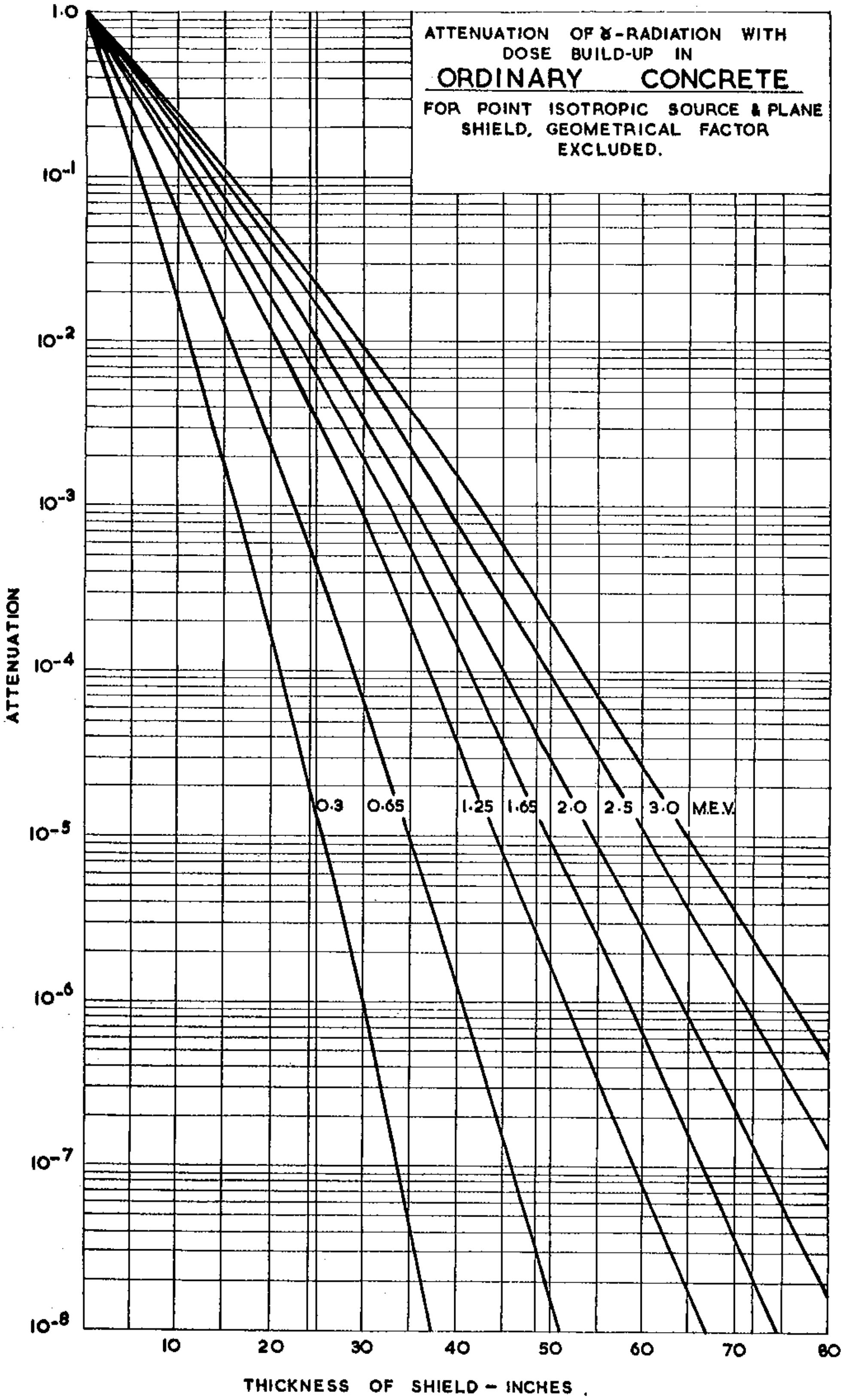
FOR POINT ISOTROPIC SOURCE & PLANE SHIELD, GEOMETRICAL FACTOR EXCLUDED



ATTENUATION OF γ -RADIATION WITH DOSE BUILD-UP IN

IRON

FOR POINT ISOTROPIC SOURCES & PLANE SHIELD, GEOMETRICAL FACTOR EXCLUDED


ATTENUATION OF γ-RADIATION WITH DOSE BUILD-UP IN
ORDINARY CONCRETE
FOR POINT ISOTROPIC SOURCE & PLANE SHIELD, GEOMETRICAL FACTOR EXCLUDED.
ATTENUATION
1.0
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
0.3
0.65
1.25
1.65
2.0
2.5
3.0
M.E.V.
10
20
30
40
50
60
70
80
THICKNESS OF SHIELD – INCHES.

ACKNOWLEDGMENTS

The author wishes to thank Mr. D. Campbell–Allen of University of Sydney for his continued help with the testing of concrete, and Mr. W.H.Taylor of C.S.I.R.O., Division of Building Research, Highett, Vic., for his advice on concrete aggregates.

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