

Recommendation for

Data on shielding from ionizing radiation —

Part 1: Shielding from gamma radiation

ICS: 13.280

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Foreword

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The main purpose of this recommendation is to provide data adequate for the calculation of shielding barriers against gamma radiation. The data presented have been chosen with the radiation shielding problems of industry in mind. Most of the material has been drawn from existing sources although a certain amount has been measured or calculated specially. It is not possible to provide a compendium to cover all possible contingencies, but data are provided to allow for calculations to be made for a wide range of materials and geometry likely to be encountered, and it is envisaged that additional data will be added from time to time.

Provision of data alone is not sufficient to permit the calculation of the required barriers and the methods of calculation which are necessary are given in the text together with examples.

Section 1 of the document deals with the calculation of barriers against primary gamma radiation and Section 2 provides the data which permit the calculation to be carried out. Appendix A gives methods and data for the calculation of primary barriers in cases where insufficient data are given in Section 2. Appendix B is concerned with the calculation of the secondary barriers which are required against leakage and scattered radiation.

Where possible, forms have been simplified to allow calculations to be made by designers who do not have specialist knowledge of radiation shielding.

This document does not attempt to define maximum permissible dose nor does it make any recommendations as to exposure rates for design purposes. Such matters are outside the scope of this recommendation as they are, in many cases, subject to legislation or various codes of practice.

Exposure rates are quoted in roentgens per hour (R/h) or milliroentgens per hour (mR/h). These units have been adopted by the International Commission on Radiological Units. Calculations may be required in millirads in air/hour. Although the millirad is a slightly larger unit than the milliroentgen, calculations giving the required answer in milliroentgens rather than millirads will be acceptable for protection purposes.

Text introduced or altered by Corrigendum No. 1 is indicated in the text by tags **[C1]** **<C1>**. Minor editorial corrections are not tagged.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 75 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. Introduction

1 General

This section of the recommendation presents simple equations defining the exposure rate from a point radioactive source of radiation. By using the methods given in this section, together with the information given in the data sheets, the thickness of various shield materials for a number of different sources commonly encountered may be calculated. The shield thickness will, of course, depend on the activity of the source and on the required exposure rate.

The equations are developed further in Appendix A to cover non-point sources and materials for which transmission data have not been tabulated.

Definitions of terms used in this recommendation are given in Appendix C.

2 Radioactive sources

The activity of a radioactive source is determined by the number of disintegrations occurring per second, and is measured in curies. One curie (Ci) corresponds to a disintegration rate of 3.7×10^{10} disintegrations per second; other terms commonly encountered are the kilocurie (kCi) equalling 10^3 curies, millicurie (mCi) equalling 10^{-3} curie, and the microcurie (μ Ci) equalling 10^{-6} curie.

The activity, and hence the radiation output of the source decays with time in an exponential manner. A convenient measure of the rate of decay is given by the half-life of a source, which represents the time taken for the source activity to fall by a factor of two. To enable rapid assessment of the activity of a source to be determined given its half-life and original activity, a graph is given (Figure 1) of the fractional reduction in source activity as a function of the number of half-lives passed since its original activity was known. Thus for example, considering ^{24}Na with a half-life of hours, if it is assumed that the original source activity was Q curies, and the activity after 84 hours is required, proceed as follows:

$$\text{Number of half-lives passed} = \frac{84}{15} = 5.6$$

From Figure 1 this corresponds to a fractional reduction of 0.02.

Hence the source activity is 0.02 Q curies.

Conversely, if the existing activity is P curies, then the activity 84 hours previously was $P/0.02$ curies.

The values of half-lives are given in the data sheets for the radionuclides considered. A knowledge of the half-life is necessary if it is desired to calculate the activity of a source for which a given shield was originally designed, having knowledge of the exposure rate at the time of calculation.

3 Calculation of exposure rate from a point source

In this section, consideration is only given to the exposure due to the primary beam. The effects of scatter are considered in Appendix B.

For a source of gamma radiation, the exposure rate at a given position depends on the following:

- i) the radionuclide concerned, and its specific gamma-ray constant;
- ii) the source activity;
- iii) the distance between the source and the position of interest (the exposure rate will be inversely proportional to the distance squared);
- iv) the type and thickness of shield material placed between the position and the source.
 - a) *Unshielded source.* For the purposes of this recommendation, the specific gamma-ray constant for a given source is taken as being equal to the gamma-ray exposure rate in roentgens per hour at a distance of 1 m from a source of activity one curie.

NOTE Other definitions exist, and care should be taken that the data in this recommendation are used in conjunction with specific gamma-ray constants in these terms.

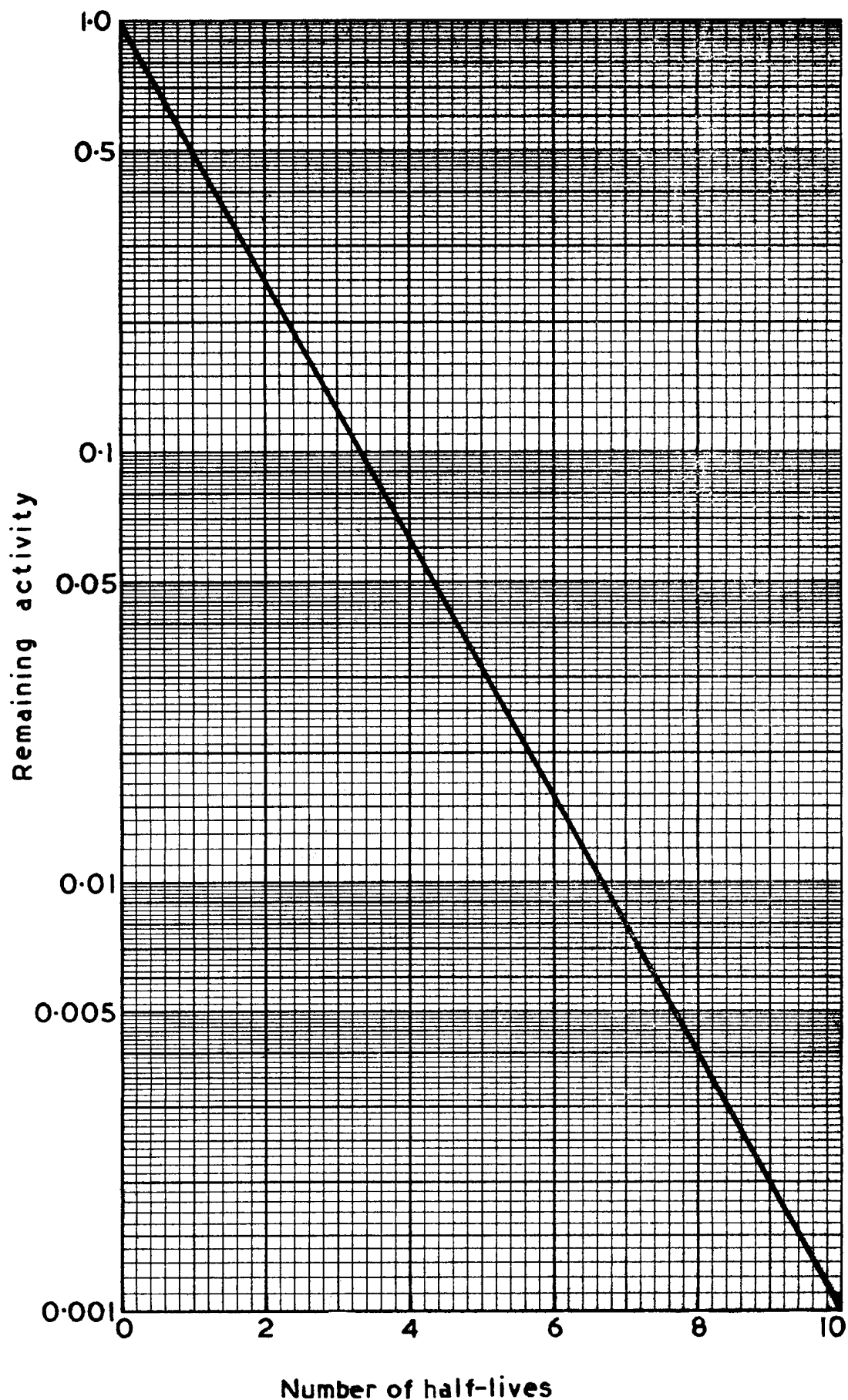


Figure 1 — The relation between remaining activity and half-lives

Thus for a source of activity Q curies, the exposure rate at d m from the source in the absence of any shielding material between the source and position of measurement may be determined as follows:

Exposure rate from one curie at one metre distance = Γ R/h

where Γ is the specific gamma ray constant for that source.

Therefore,

exposure rate from Q curies at 1 m = ΓQ R/h

and hence,

exposure rate from Q curies at d m = $\frac{\Gamma Q}{d^2}$ R/h

the $\frac{1}{d^2}$ term arising from the inverse square law.

Values of the specific gamma-ray constant Γ are given in the data sheets; Γ is plotted as a function of photon energy in Figure 8.

b) *Shielded source — transmission factor.* The presence of a shield between the source and a defined position will reduce the exposure rate below the unshielded value due to absorption in the shield.

Thus for the source considered in a) and a given shield, the exposure rate at a distance d m from the source is given by:

$$\text{Exposure rate} = \frac{\Gamma Q T}{d^2} \text{ R/h}$$

where T is the transmission factor, which depends on the material and thickness of the shield, and the type of source.

Values of the transmission factor are given in the data sheets in the form of graphs showing transmission as a function of thickness for various shielding materials. The data given refer to broad beams of radiation (see Appendix A, Subsections A.2 and A.3).

4 Data sheets

Data sheets are provided for the following sources:

^{24}Na ^{50}Co ^{85}Kr ^{124}Sb
 ^{137}Cs ^{170}Tm ^{182}Ta ^{192}Ir ^{198}Au
 ^{226}Ra + decay products ^{232}Th + decay products

The information necessary to calculate the radiation transmitted through various shielding materials is given on the data sheets for each of the sources. The information on the sheets includes:

The radionuclide and decay scheme

Radioactive half-life

Specific gamma-ray constant (Γ)

Broad beam transmission curves for various materials.

Examples

i) Suppose that the exposure rate due to a ^{192}Ir source at the point to be shielded is 2.5 R/h and that it is required to reduce this to 0.75 mR/h.

The transmission factor, T , is given by

$$0.75 \times 10^{-3} = T \times 2.5$$

$$\text{i.e. } T = \frac{0.75 \times 10^{-3}}{2.5} = 0.0003$$

From Figure 2h(i), the required thickness of shielding is 5.7 cm Pb.

ii) Consider a ^{60}Co source of 200 curies, shielded by lead, and assume that because of the layout of the laboratory in which it is being used, the nearest distance of approach of personnel is two feet. It is required to determine the shielding to reduce the exposure rate at this point to 2.5 mR/h.

From data sheet No. 2, the specific gamma-ray constant (Γ) for ^{60}Co = 1.32 R/Ci.h at 1 m.

Hence for a source of 200 curies, the exposure rate at

$$2 \text{ feet (0.61 m) from the source} = \frac{200 \times 1.32}{0.61^2} \text{ R/h}$$

$$= 7.1 \times 10^2 \text{ R/h}$$

Since the required exposure rate is 2.5×10^{-3} R/h, a transmission factor of $\frac{2.5 \times 10^{-3}}{7.1 \times 10^2} = 3.52 \times 10^{-6}$ is required.

From Figure 2b(i) the required thickness of shielding is 22.5 cm Pb.

iii) If, however, it is required to determine the shield thickness to give an exposure rate of X mR/h at the shield surface, as for a transport container, the procedure is more complicated because distance, and

hence the geometry factor $\left(\frac{1}{d^2}\right)$ and the transmission factor, are variables. It is recommended that the

following procedure be adopted:

Let X be the required exposure rate at the shield surface;

$$\text{then } X = \frac{\Gamma Q T_t \times 10^3}{d^2} \text{ mR/h,}$$

where T_t is the transmission factor for a shield of thickness t (cm) and d is the distance in metres from the source to the outer surface of the shield.

$$\text{Thus } \frac{T_t}{d^2} = \frac{X}{\Gamma Q \times 10^3}$$

Evaluate $\frac{T_t}{d^2}$ using transmission data for a series of values of d until a quotient of the required value is found; hence the necessary thickness of shielding is obtained. It should be noted that, in certain circumstances, d and t may be equal.

Section 2. Data sheets and associated broad-beam transmission graphs

NOTE Transmission graphs in this section are for the following densities of brick, concrete and barytes concrete,

Brick	1.6 g/cm ²
Concrete	2.35 g/cm ²
Barytes concrete	3.2 g/cm ²

For brick, concrete and barytes concrete of other densities, it is sufficiently accurate to apply a correction factor equal to the ratio of the densities. The effectiveness of the shield increases with increasing density of the shield material.

DATA SHEET No. 1

SODIUM-24

(²⁴Na)

Half-life: 15.0 hours.

Decay scheme:	Radiation:	Beta	Gamma
	Energy MeV:	1.39–100 %	1.37–100 %
			2.75–100 %

Specific gamma-ray constant (Γ): 1.84 R/Ci.h at 1 m.

Transmission factors: See Figure 2a.

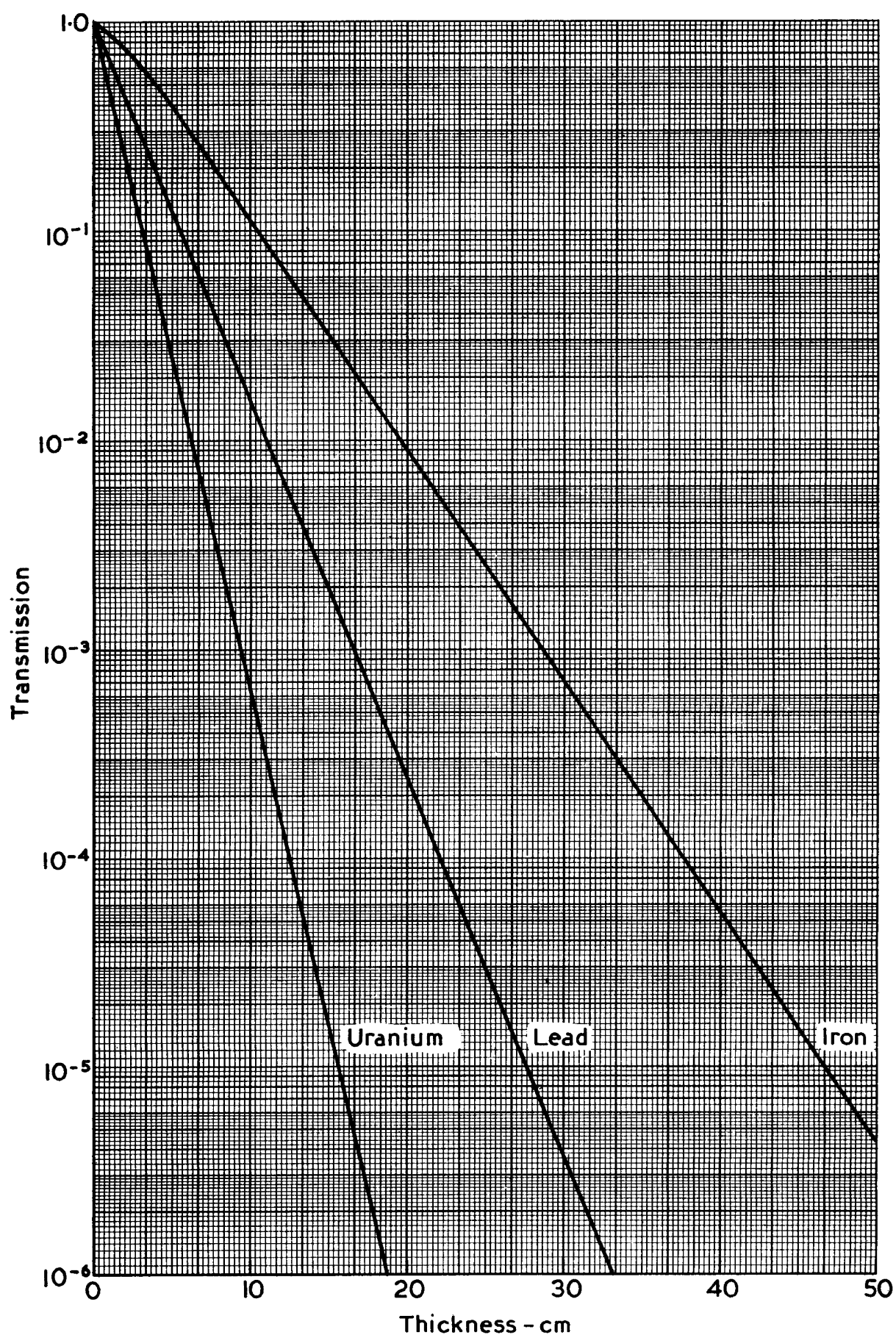
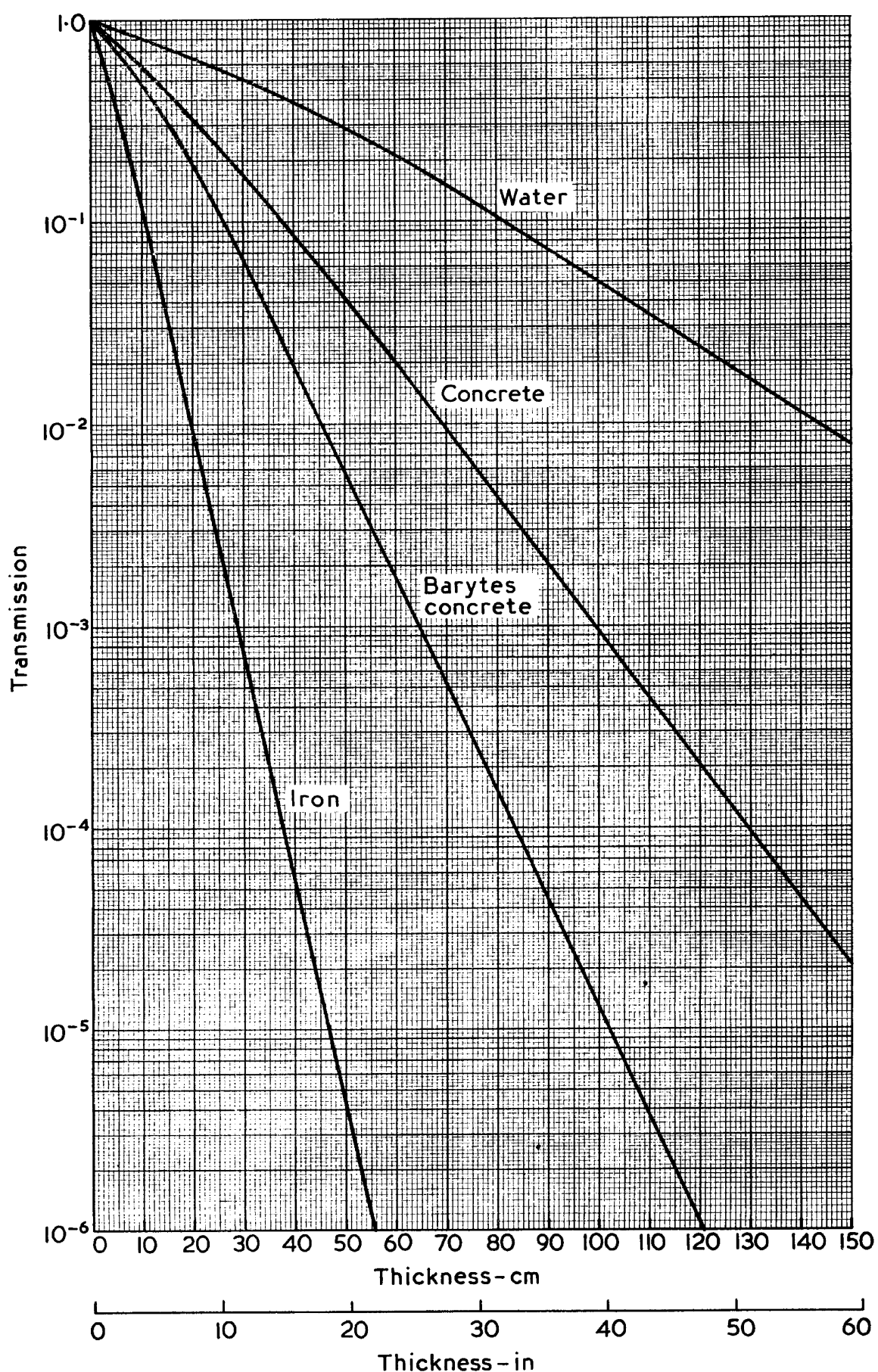


Figure 2a(i) — Transmission of gamma rays from ^{24}Na through barriers of various materials

Figure 2a(ii) — Transmission of gamma rays from ^{24}Na through barriers of various materials

DATA SHEET No. 2**COBALT-60****(⁶⁰Co)**

Half-life: 5.26 years

Decay scheme:	Radiation:	Beta	Gamma
	Energy MeV:	0.31–100 %	1.17–100 %
		1.48–approx. 0.01 %	1.33–100 %

Specific gamma-ray constant (Γ): 1.32 R/Ci.h at 1 m

Transmission factors: See Figure 2b.

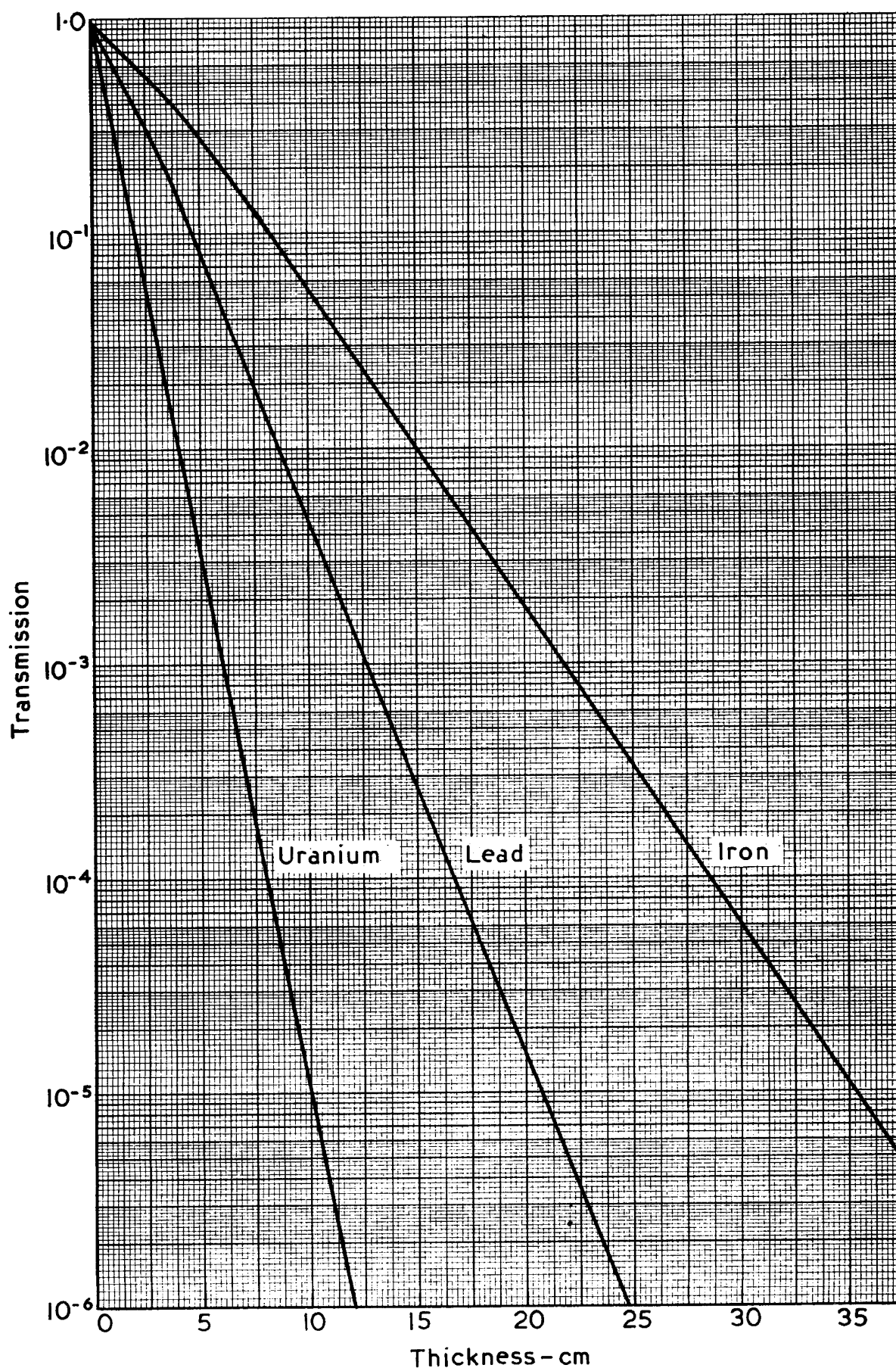


Figure 2b(i) — Transmission of gamma rays from ^{50}Co through barriers of various materials

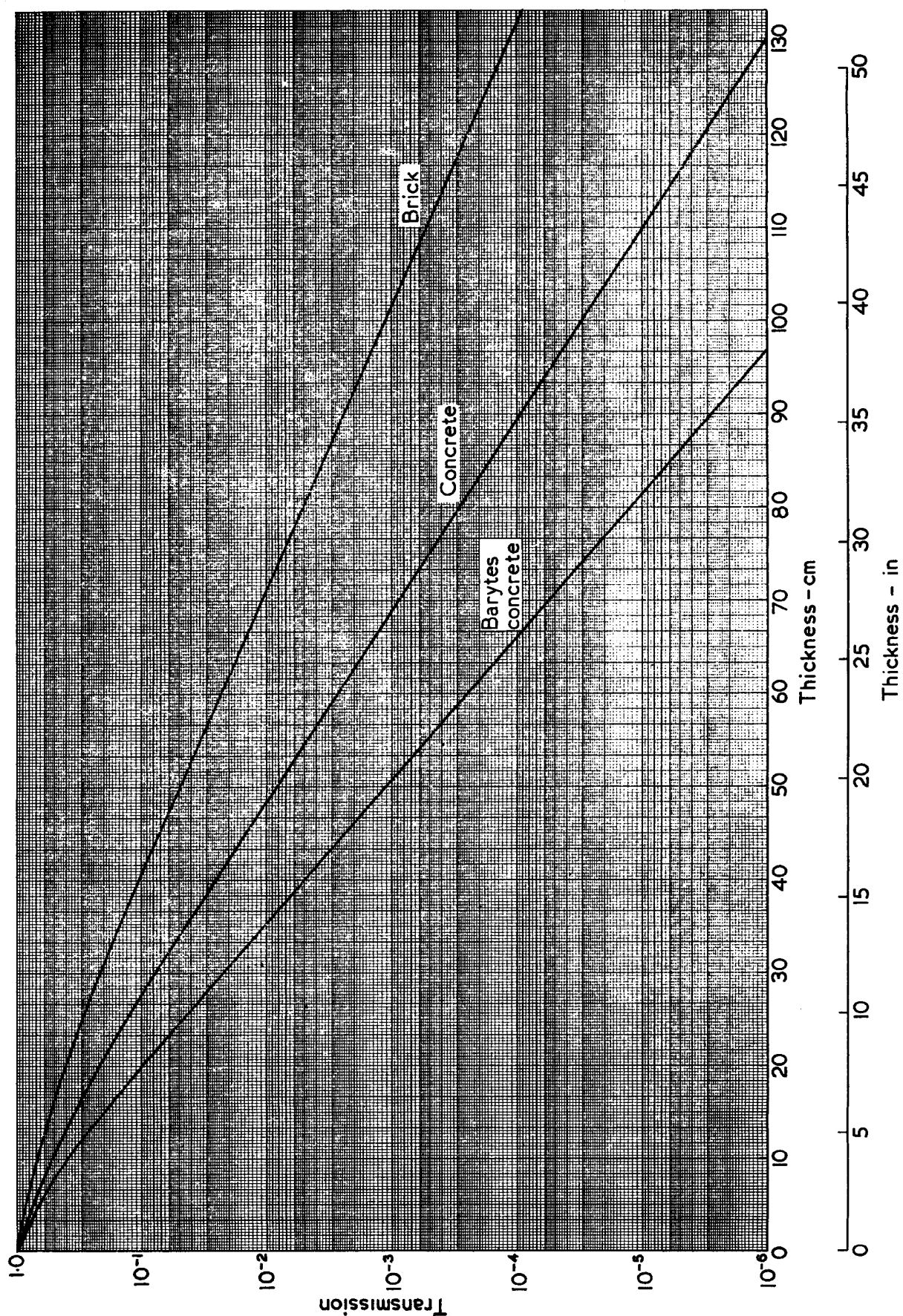


Figure 2b(ii) — Transmission of gamma rays ^{60}Co through barriers of various materials

DATA SHEET No. 3**KRYPTON-85****(⁸⁵Kr)**

Half-life: 10.6 years

Decay scheme:	Radiation:	Beta	Gamma
	Energy MeV:	0.15– 0.7 % 0.67–99.3 %	0.51–0.7 %

Specific gamma-ray constant (Γ): Theoretical (not taking bremsstrahlung into account): 0.0012 R/Ci.h at 1 metre.
⁸⁵Kr luminous signs:
0.020 R/Ci.h at 1 m.

Transmission factors: See Figure 2c.

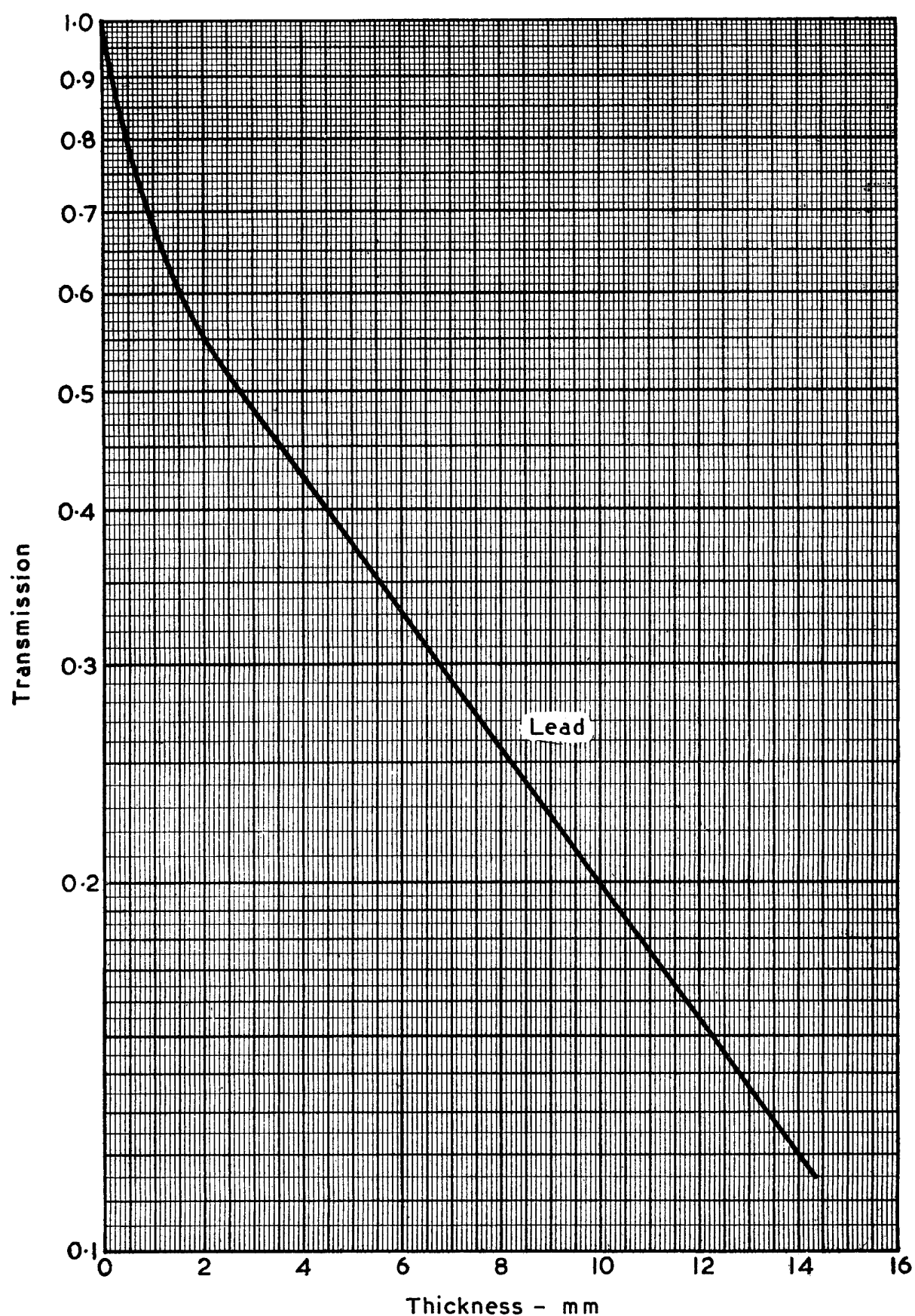


Figure 2c — Transmission of gamma rays plus bremsstrahlung from luminous signs filled with ^{85}Kr through lead barriers

DATA SHEET No. 4**ANTIMONY-124****(¹²⁴Sb)**

Half-life: 60 days

Decay scheme:	Radiation:	Beta	Gamma
	Energy MeV:	0.22–11 %	0.60–99 %
		0.61–51 %	0.65– 8 %
		0.95– 6 %	0.72–14 %
		1.59– 7 %	0.97– 3 %
		1.66– 2 %	1.05– 2 %
		2.31–23 %	1.33– 1 %
			1.37– 5 %
			1.45– 2 %
			1.70–50 %
			2.09– 6 %

Specific gamma-ray constant (Γ): 0.98 R/Ci.h at 1 m.

Transmission factors: See Figure 2d.

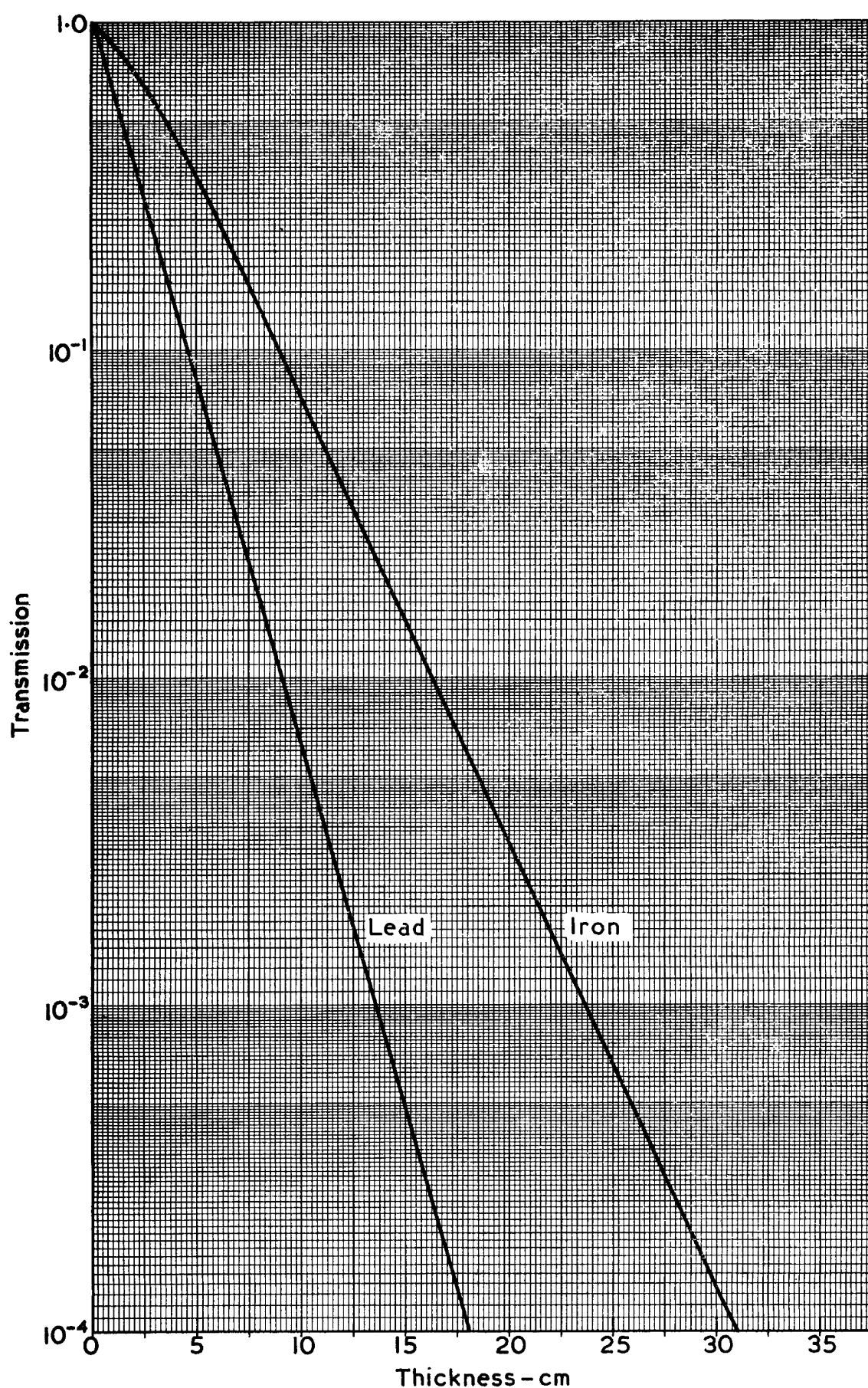


Figure 2d(i) — Transmission of gamma rays from ^{124}Sb through barriers of various materials

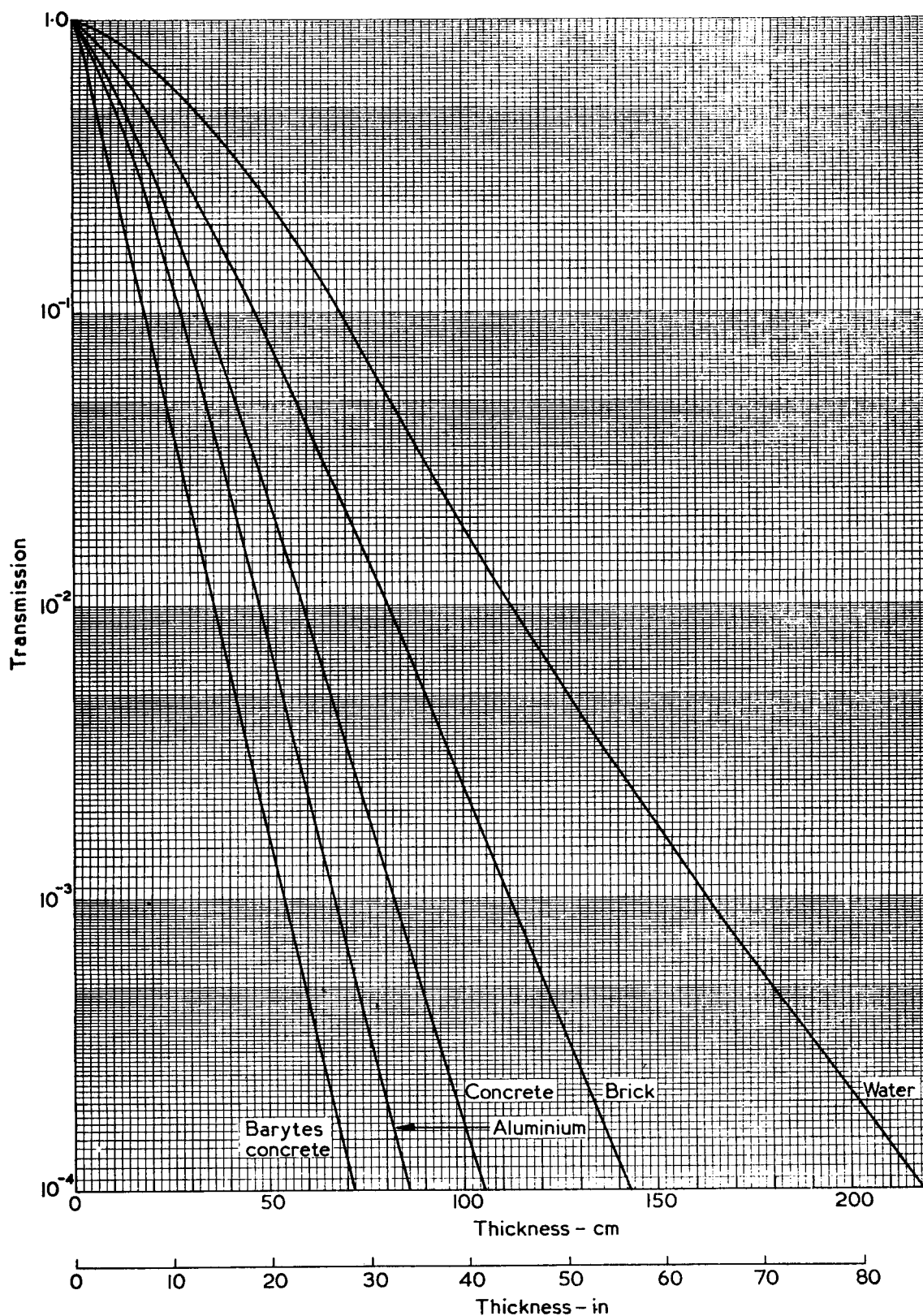


Figure 2d(ii) — Transmission of gamma rays from ^{124}Sb through barriers of various materials

DATA SHEET No. 5**CAESIUM-137****(^{137}Cs)**

Half-life: 30.0 years

Decay scheme:	Radiation:	Beta	Gamma	I.C.
	Energy MeV:	0.51–95 %	0.662–86 %	9 %
		1.17– 5 %		

Specific gamma-ray constant (Γ): $\overline{C_1}$ 0.33 $\overline{C_1}$ R/Ci.h at 1 m.

Transmission factors: See Figure 2e.

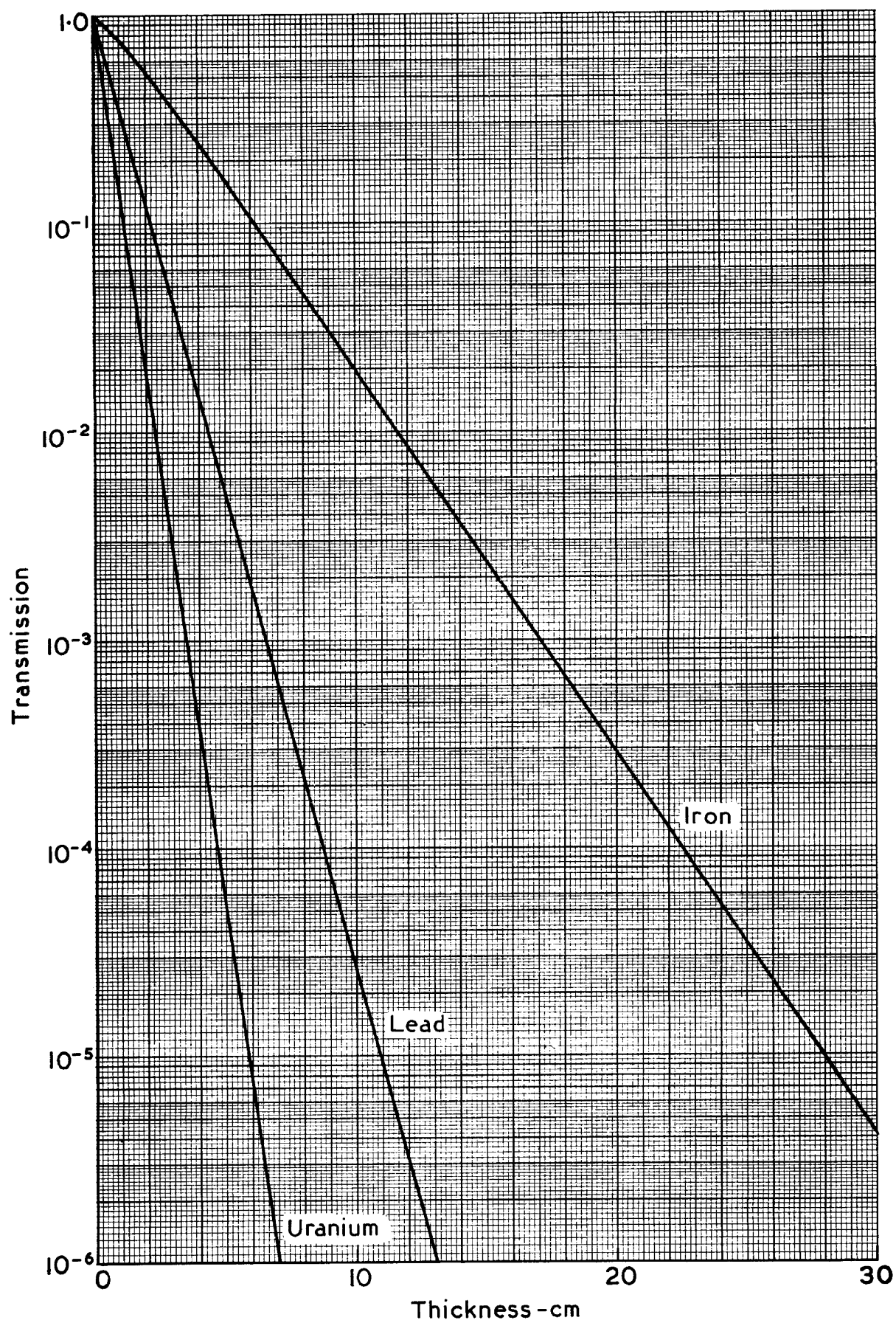


Figure 2e(i) — Transmission of gamma rays from ^{137}Cs through barriers of various materials

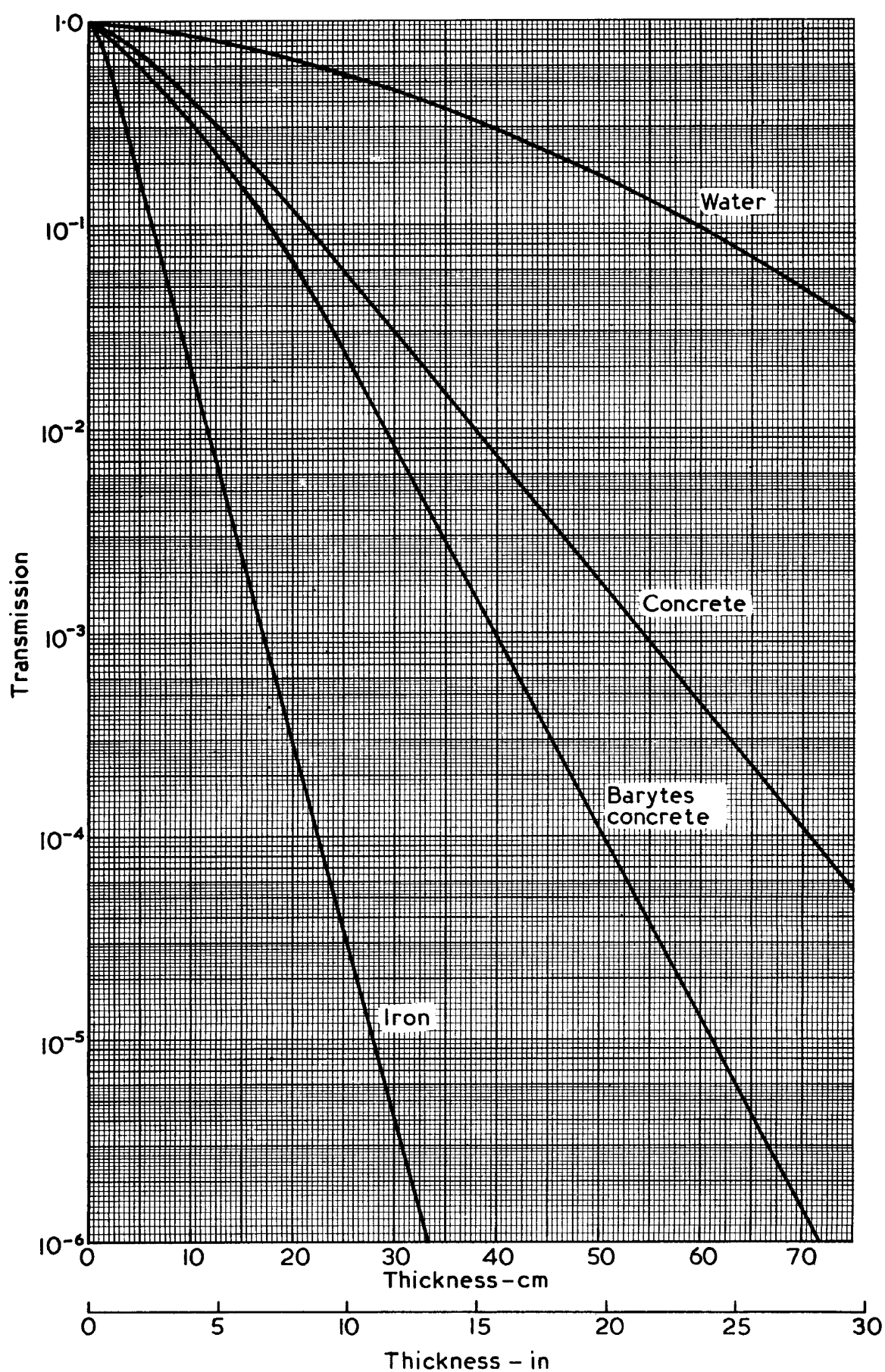


Figure 2e(ii) — Transmission of gamma rays from ^{137}Cs through barriers of various materials