GAMMA RAY REFLECTION FACTORS FROM CONCRETE

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This brief note is a supplement to the summary which appears in the ANS Trans. 6, No. 1, p. 200. It is a further progress report on research in progress, and does not necessarily present final conclusive results.

Using the differential dose albedo formula devised by Chilton and Huddleston, it is possible to map the field from a radioactive point source near a concrete-air interface, for those conditions in which the distances involved are larger than a mean-free-path in concrete but substantially smaller than a mean-free-path in air. Since ratios of scattered to direct dose rates are independent of geometric scale, it is possible to put a great deal of information on a single chart.

The accuracy of results will depend upon (1) the degree of approximation inherent in the Chilton-Huddleston formulation, (2) the accuracy with which the parameters in the C-H formula are obtained from Raso's Monte Carlo results (or any other results to which it might be fitted), (3) the accuracy of the Monte Carlo computation. Once the parameters for the albedo formula are selected, the subsequent computation of reflection factors can be carried out to any desired degree of accuracy. Computational errors are kept to substantially less than 5 ~~one~~ percent of the resulting output values, it is believed.

A comment on the albedo concept and nomenclature: The C-H formula is for differential dose albedo, based on parallel beam incident on a concrete plane with angle from normal θ_o, and considering the radiation emerging per unit surface area in a direction expressed by angle θ from the normal and by an azimuthal angle ϕ. Rockwell calls this differential factor R, and Raso calls it α_d. The total albedo, or simply "the albedo", is given by

$$\int_{2\pi} \alpha_d \, d\Omega$$

It describes a flow through the surface and is therefore a ratio based on currents. If one multiplies the differential albedo by the ratio of the cosines of the polar angles, one may integrate to get a ratio of dose rates from the emergent and the incident radiation based on flux:

$$\int_{2\pi} \frac{\cos \theta_o}{\cos \theta} \alpha_d \, d\Omega$$

Some workers (Raso, for example) do not consider this latter type of ratio to be within the definition of albedo; but others (such as Leimdorfer) seem to be willing to use the term flux albedo for this ratio and to use current albedo for the former. In reporting my work, I have been willing to use the terms "albedo based on current" or "albedo based on flux" for these two integral concepts. The term "reflection factor", which I use most often, is a ratio of reflected dose to incident dose. The incident dose may come from a point source, a broad parallel beam source, or any other source which must be designated in each case.

DISCLAIMER

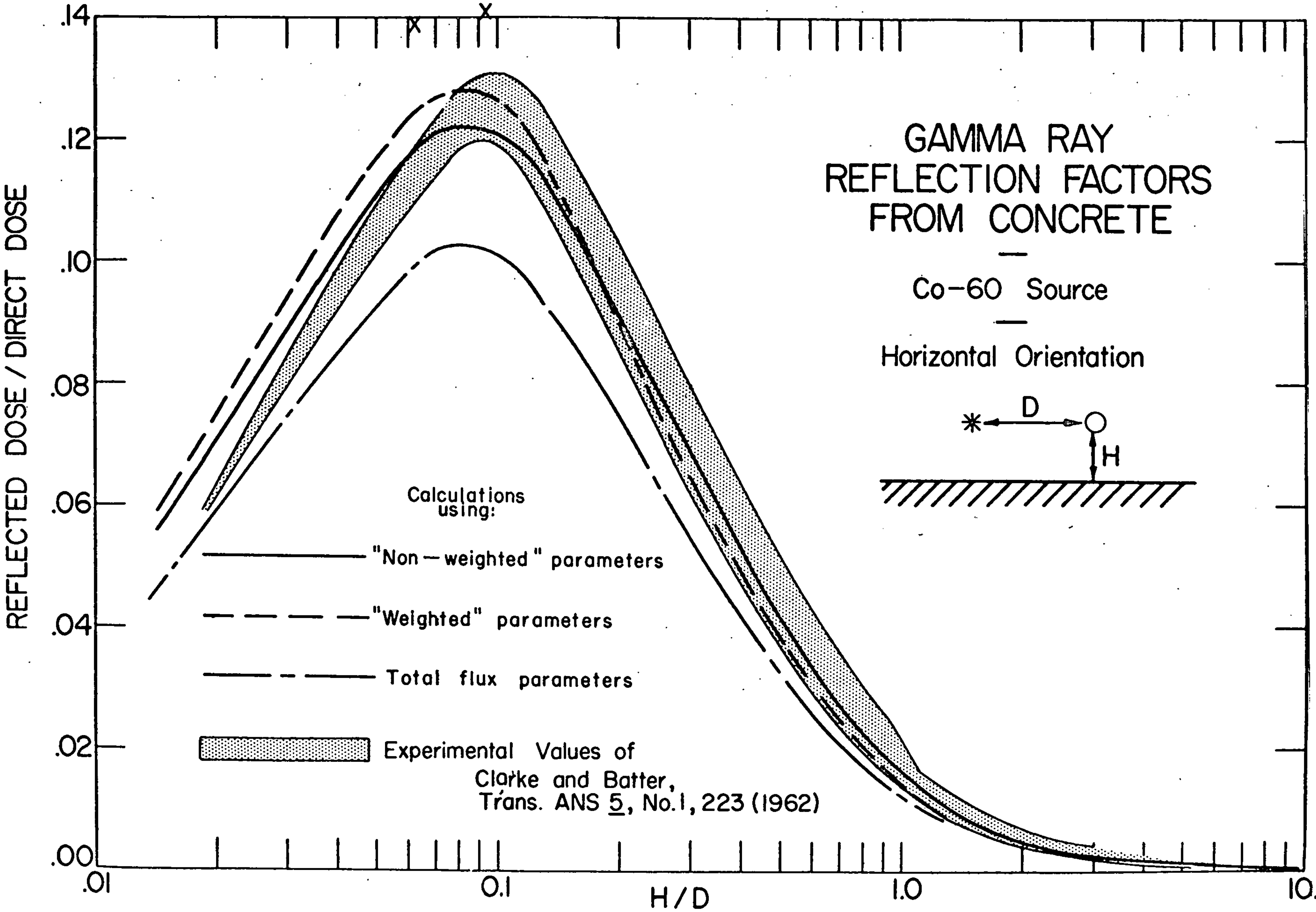
For the broad parallel beam case, the terms "dose reflection factor" and "dose albedo based on flux" are completely equivalent.

Results obtained thus far are contained in the attached illustrations. The first one indicates results obtained for the horizontal orientation of source-to-detector line, as compared with experimental work of Clarke and Batter. The two upper curves used C-H formula parameters fitted to individual Monte Carlo values for differential albedo obtained by Raso. The terms "weighted" and "non-weighted" refer to the variation in least-squares technique for obtaining the values of parameters (see Chilton and Huddleston article on Gamma Ray Albedo on Concrete, to be published in NS&E). The results seem well within experimental error.

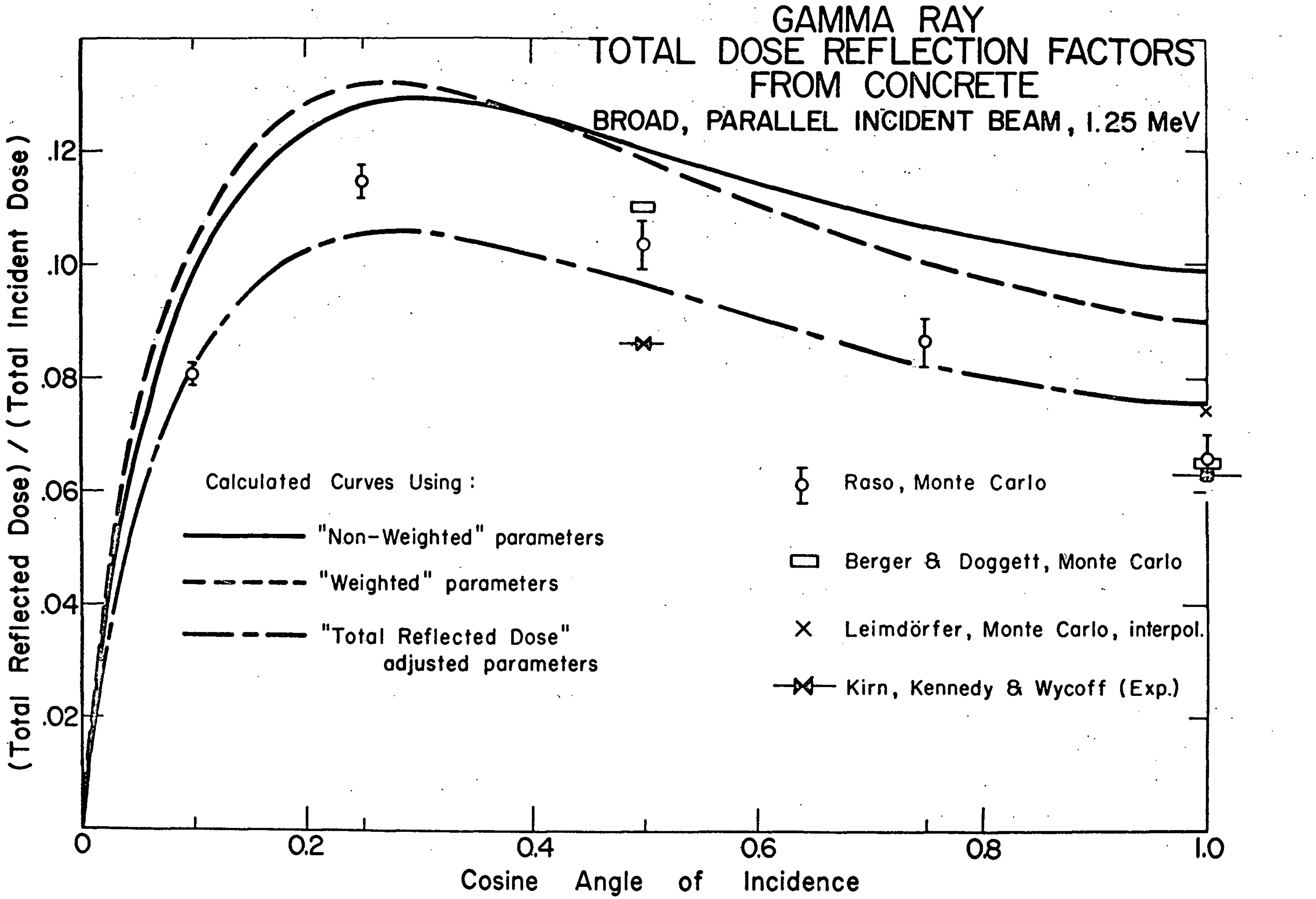
Unfortunately, calculations of total albedos using either the weighted or non-weighted set of parameters give values generally (and in some cases, substantially) greater than the Monte Carlo results for total albedo quoted or obtainable from Raso's own calculations, as well as other available information. See the second figure for demonstration of this for the energy 1.25 MeV. An additional set of parameters was therefore obtained by getting a "best fit" to total flux albedo rather than differential data. Unfortunately, as shown by the first figure, this doesn't fit the Clarke-Batter data quite so well, underestimating it consistently by 15-20%. Further work is needed, both experimental and theoretical, to improve this situation.

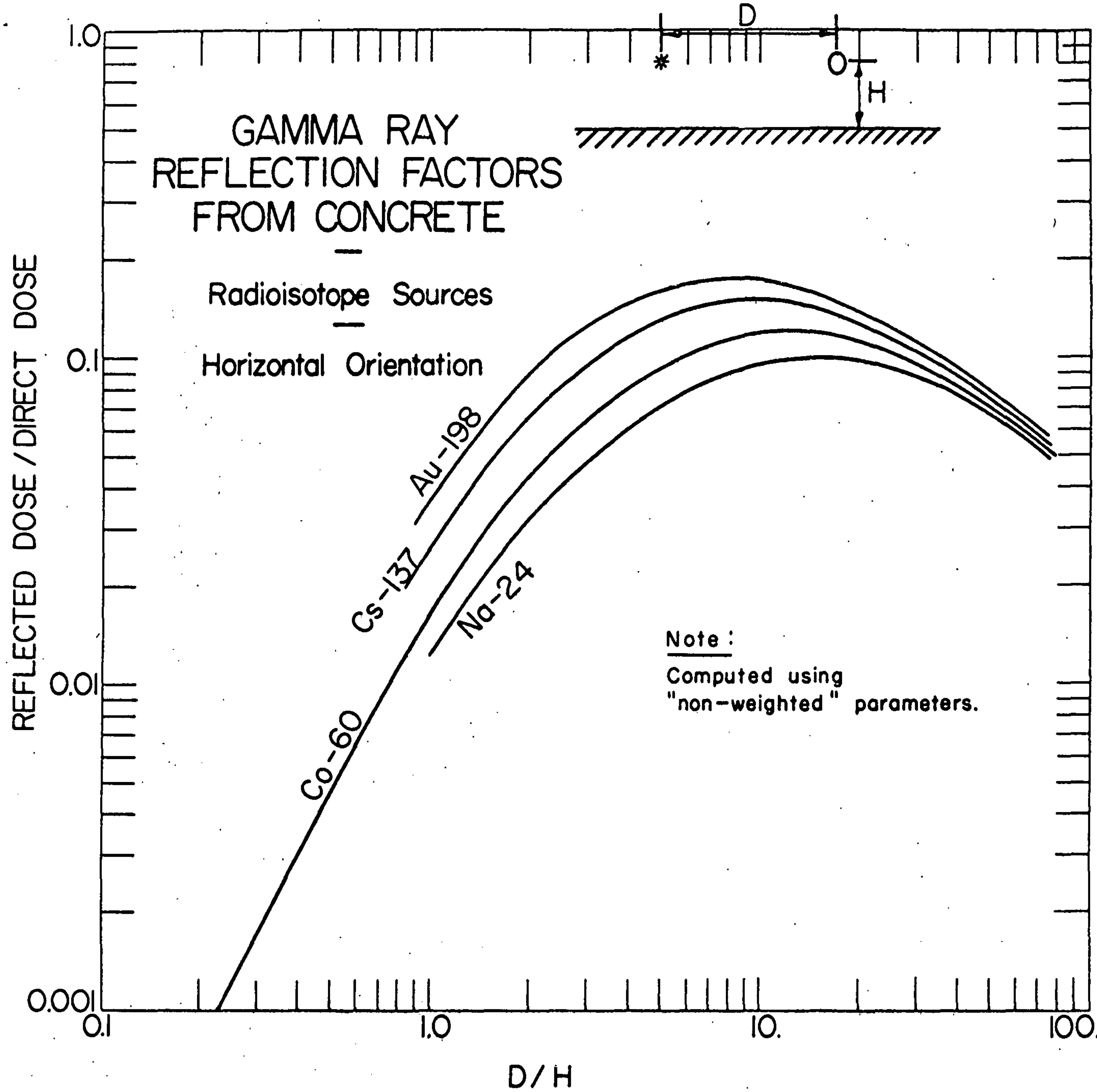
Subsequent figures are largely results obtained using the University of Illinois IBM-7090 computer ~~results~~ for the point-source-to-detector situation. The figures for the horizontal orientation case and the vertical orientation case are just special cases of the more general curves which appear as contour lines of equal reflection factor. Two sets of graphs are provided: one using the "non-weighted" factors based on original fit to differential albedo; and the other based on the fit to total dose albedo based on flux. At present, the author has no preference between the two. It is possible that one is better in certain portions of the detector field and the other is better in others. The curves at least provide some understanding of general trends and make the task of future estimating of the whole field from a limited number of measurements a little easier.

Two final comments: The last figure gives an interesting picture of the effect of a finite reflecting surface, in terms of the infinite surface value. This "finiteness" factor is essentially the same regardless of which set of formula parameters were used. Finally, it might be noted that within the framework of the C-H approximate formula for albedo, the position of source and detector may be exchanged and the same value obtained for reflection factor.

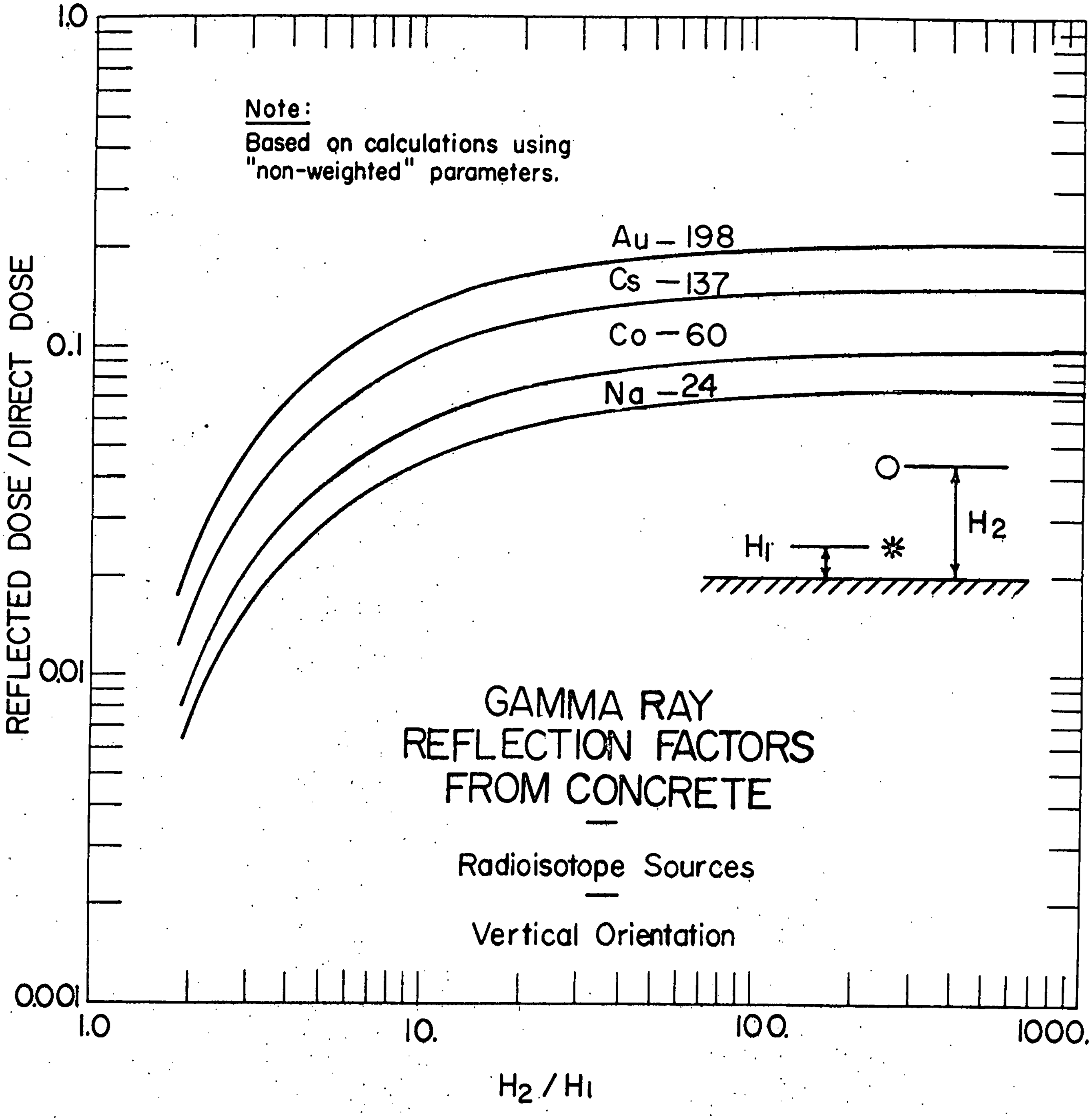


GAMMA RAY
REFLECTION FACTORS
FROM CONCRETE
Co-60 Source
Horizontal Orientation
D
H
Calculations using:
"Non-weighted" parameters
"Weighted" parameters
Total flux parameters
Experimental Values of
Clarke and Batter,
Trans. ANS 5, No.1, 223 (1962)
REFLECTED DOSE / DIRECT DOSE
H / D
.14
.12
.10
.08
.06
.04
.02
.00
.01
0.1
1.0
10.

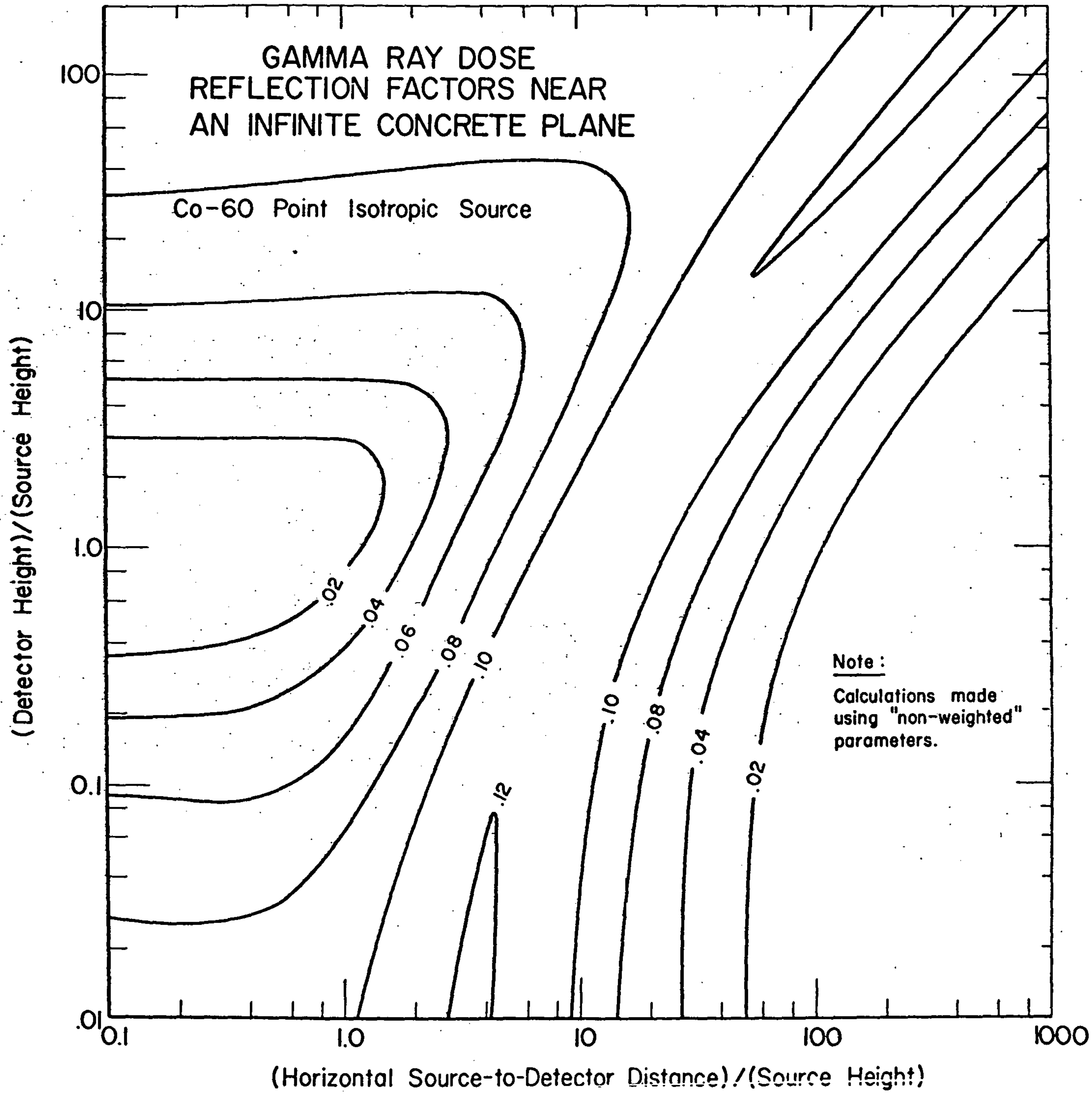

GAMMA RAY
TOTAL DOSE REFLECTION FACTORS
FROM CONCRETE
BROAD, PARALLEL INCIDENT BEAM, 1.25 MeV
(Total Reflected Dose) / (Total Incident Dose)
.12
.10
.08
.06
.04
.02
0
0.2
0.4
0.6
0.8
1.0
Cosine Angle of Incidence
Calculated Curves Using :
"Non-Weighted" parameters
"Weighted" parameters
"Total Reflected Dose" adjusted parameters
Raso, Monte Carlo
Berger & Doggett, Monte Carlo
Leimdörfer, Monte Carlo, interpol.
Kirn, Kennedy & Wycoff (Exp.)

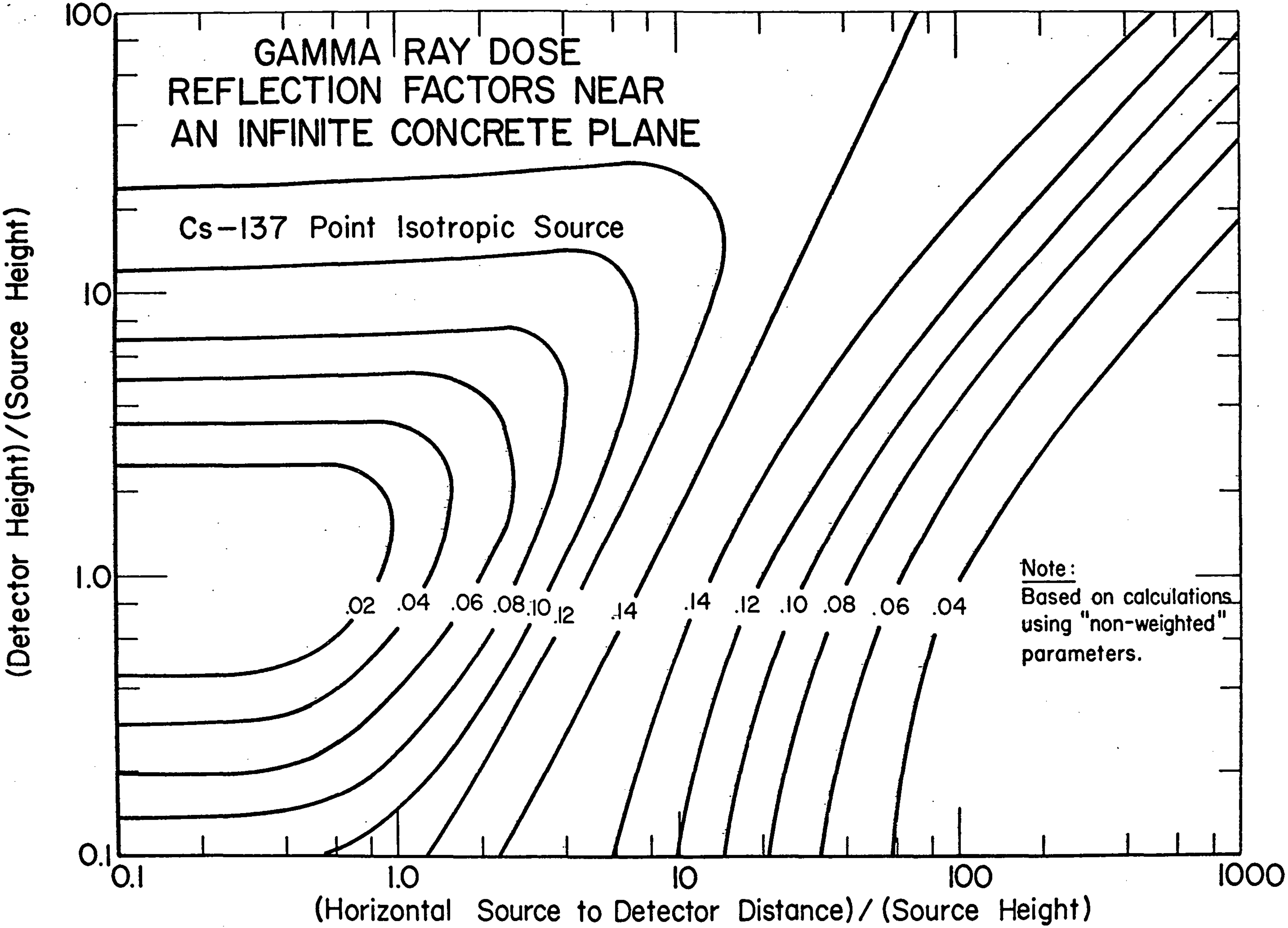


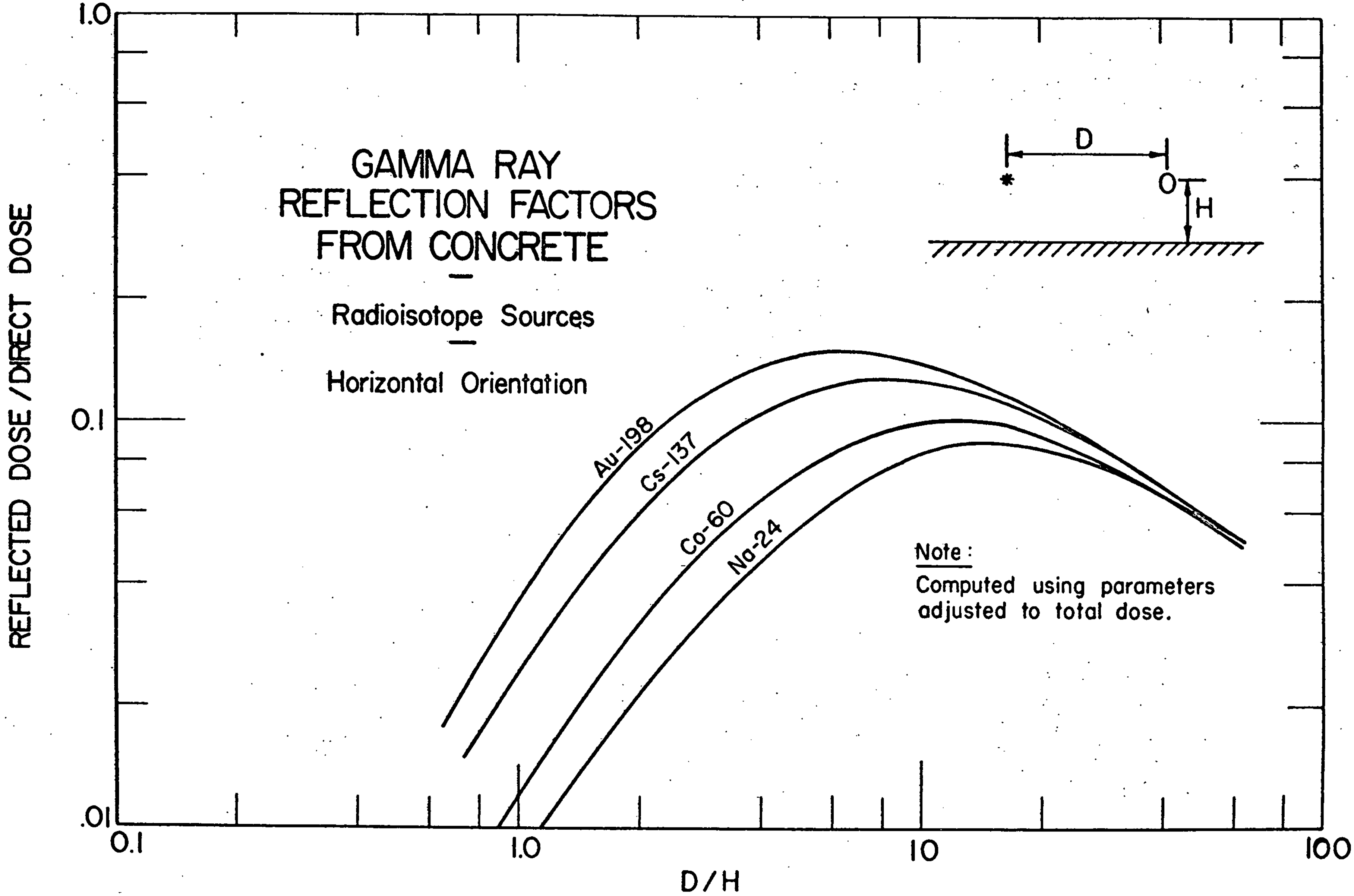
GAMMA RAY REFLECTION FACTORS FROM CONCRETE
Radioisotope Sources
Horizontal Orientation
D
H
REFLECTED DOSE / DIRECT DOSE
D/H
1.0
0.1
0.01
0.001
0.1
1.0
10.
100.
Au-198
Cs-137
Co-60
Na-24
Note:
Computed using "non-weighted" parameters.



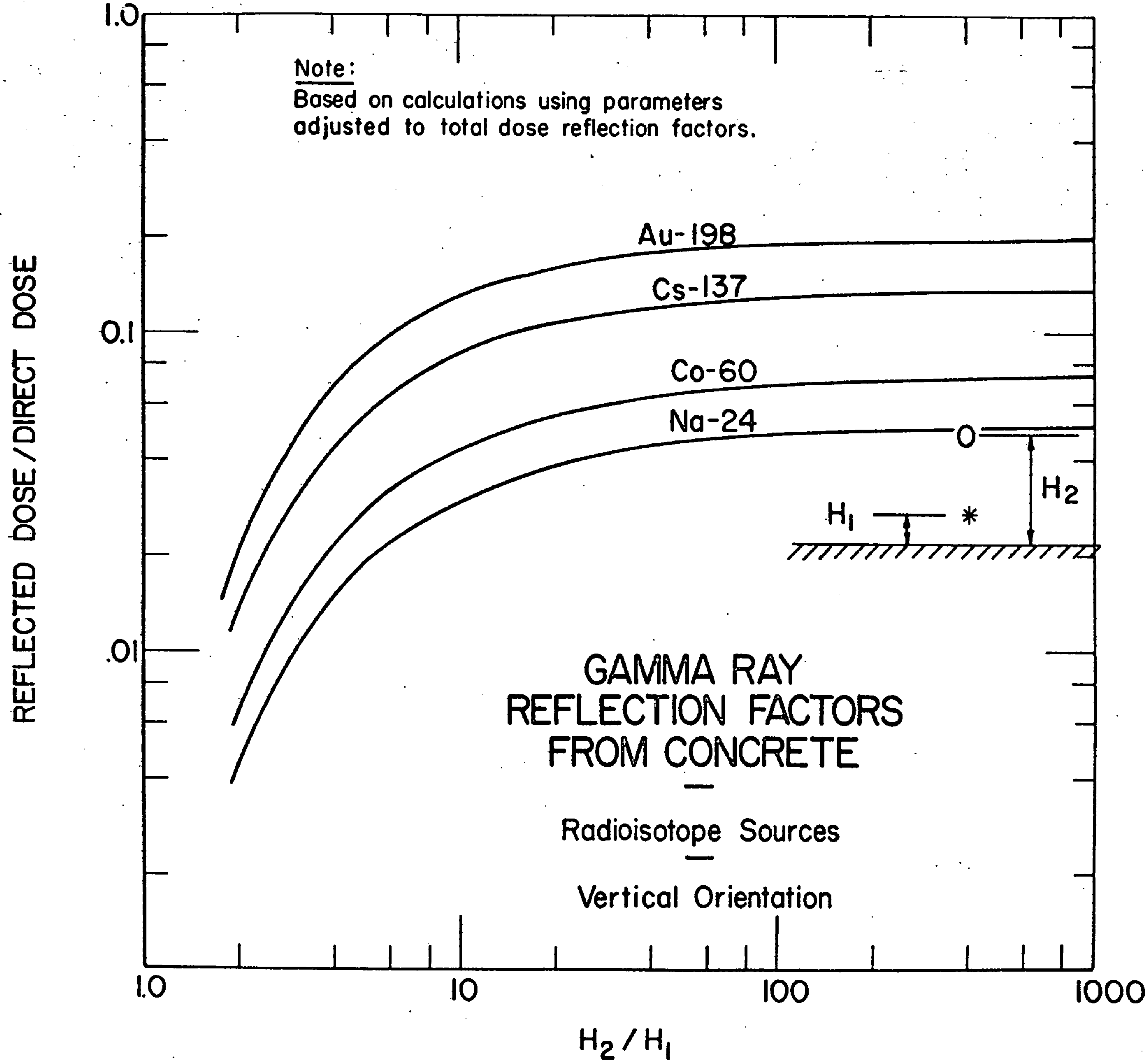
Note:
Based on calculations using "non-weighted" parameters.
Au – 198
Cs – 137
Co – 60
Na – 24
H2
H1
GAMMA RAY REFLECTION FACTORS FROM CONCRETE
Radioisotope Sources
Vertical Orientation
REFLECTED DOSE / DIRECT DOSE
1.0
0.1
0.01
0.001
1.0
10.
100.
1000.
H2 / H1


GAMMA RAY DOSE
REFLECTION FACTORS NEAR
AN INFINITE CONCRETE PLANE
Co-60 Point Isotropic Source
Note :
Calculations made
using "non-weighted"
parameters.
.02
.04
.06
.08
.10
.12
.10
.08
.04
.02
100
10
1.0
0.1
.01
0.1
1.0
10
100
1000
(Detector Height)/(Source Height)
(Horizontal Source-to-Detector Distance)/(Source Height)


GAMMA RAY DOSE
REFLECTION FACTORS NEAR
AN INFINITE CONCRETE PLANE
Cs-137 Point Isotropic Source
.02
.04
.06
.08
.10
.12
.14
.14
.12
.10
.08
.06
.04
Note:
Based on calculations using "non-weighted" parameters.
100
10
1.0
0.1
0.1
1.0
10
100
1000
(Detector Height)/(Source Height)
(Horizontal Source to Detector Distance)/(Source Height)



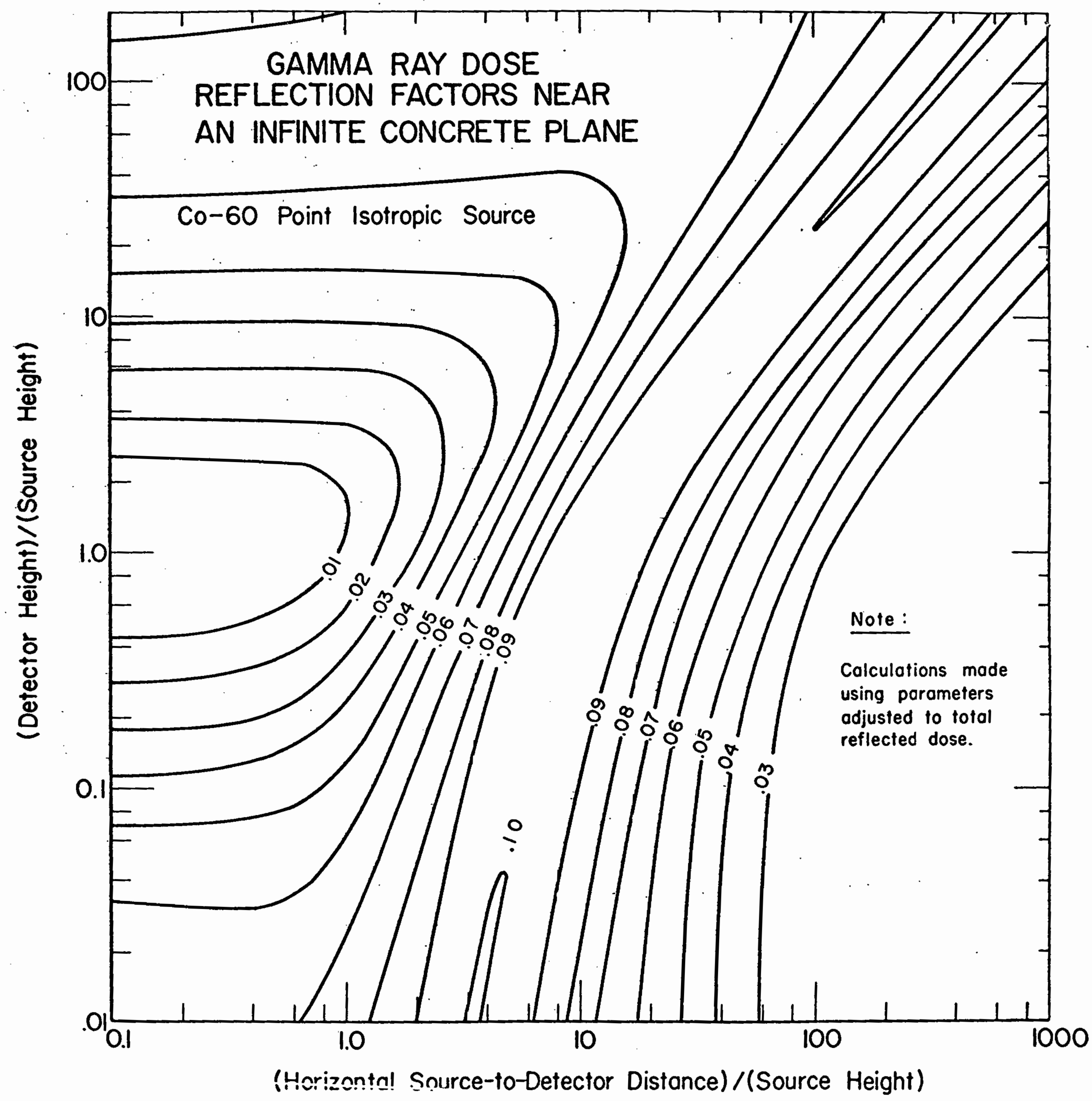
GAMMA RAY
REFLECTION FACTORS
FROM CONCRETE
Radioisotope Sources
Horizontal Orientation
D
H
Au-198
Cs-137
Co-60
Na-24
Note :
Computed using parameters adjusted to total dose.
REFLECTED DOSE / DIRECT DOSE
1.0
0.1
.01
0.1
1.0
10
100
D / H



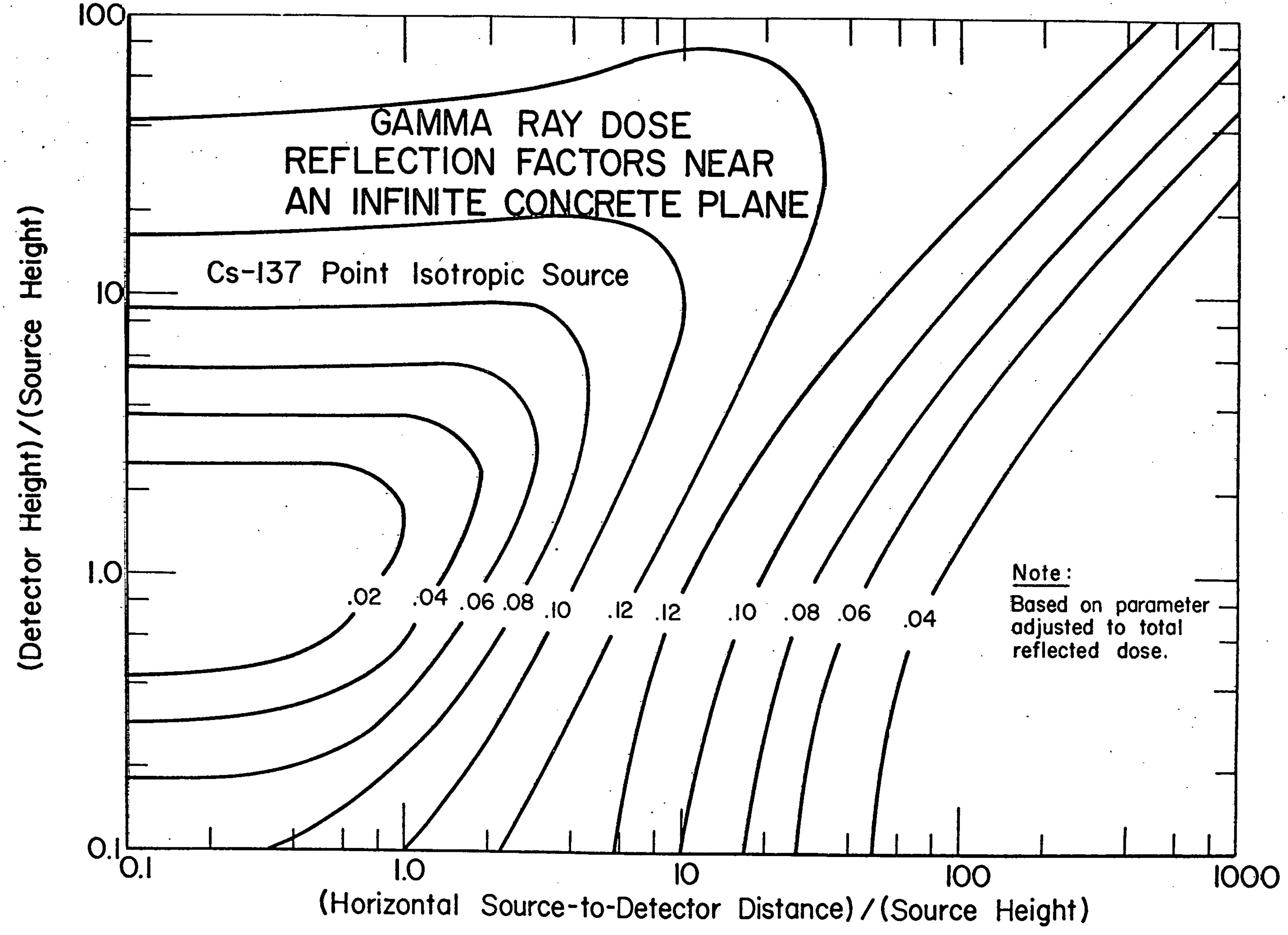
GAMMA RAY
REFLECTION FACTORS
FROM CONCRETE

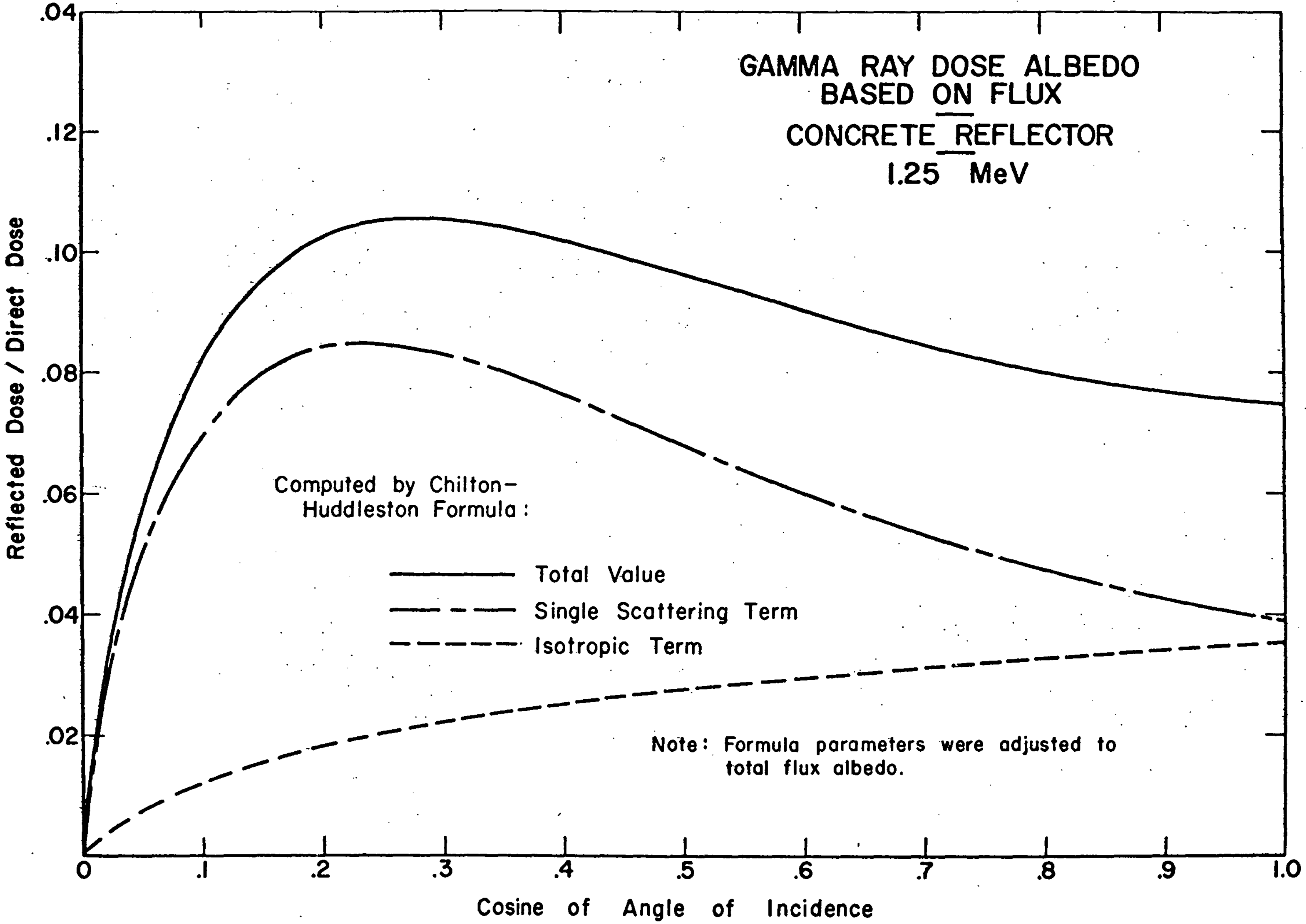
Radioisotope Sources

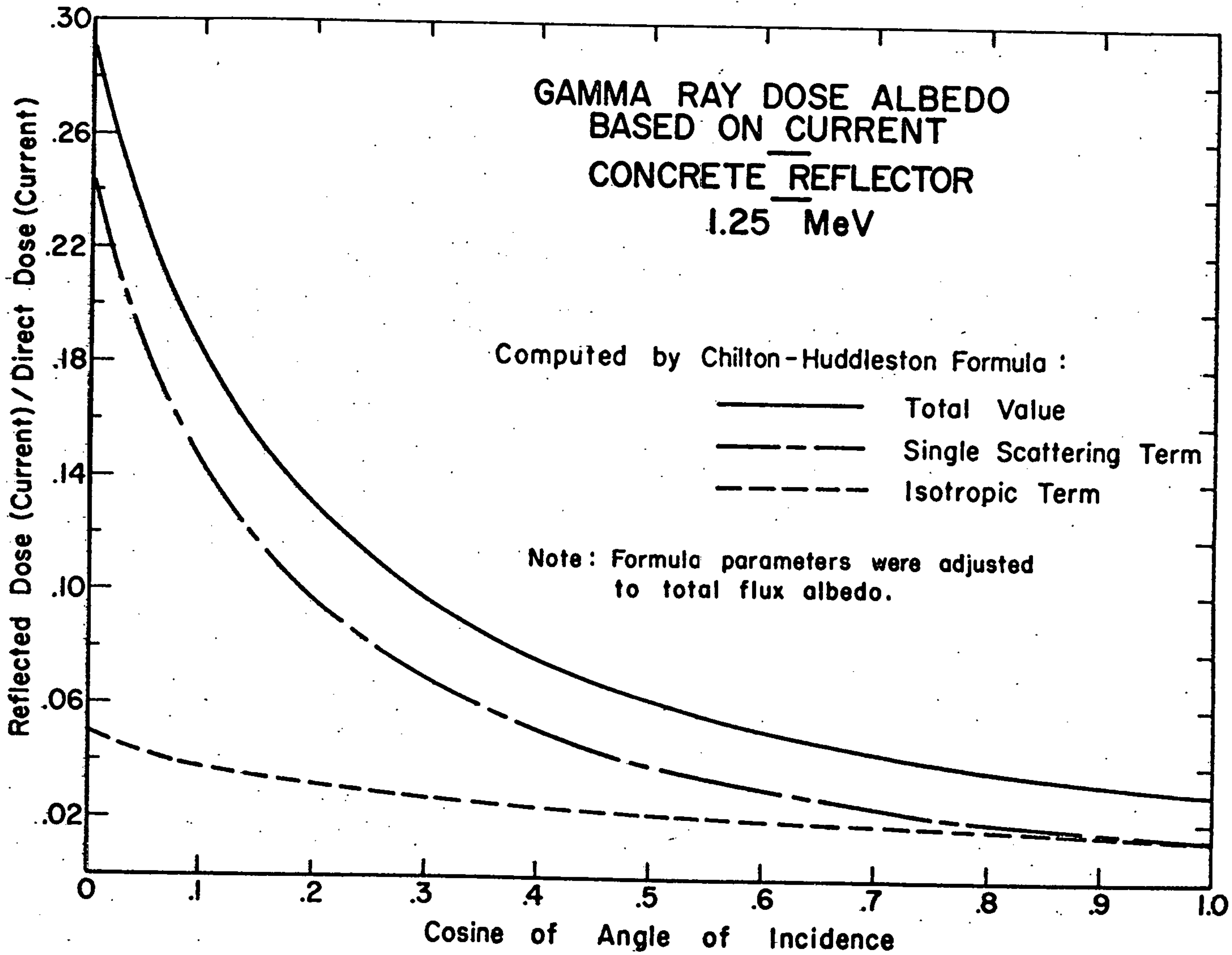
Vertical Orientation



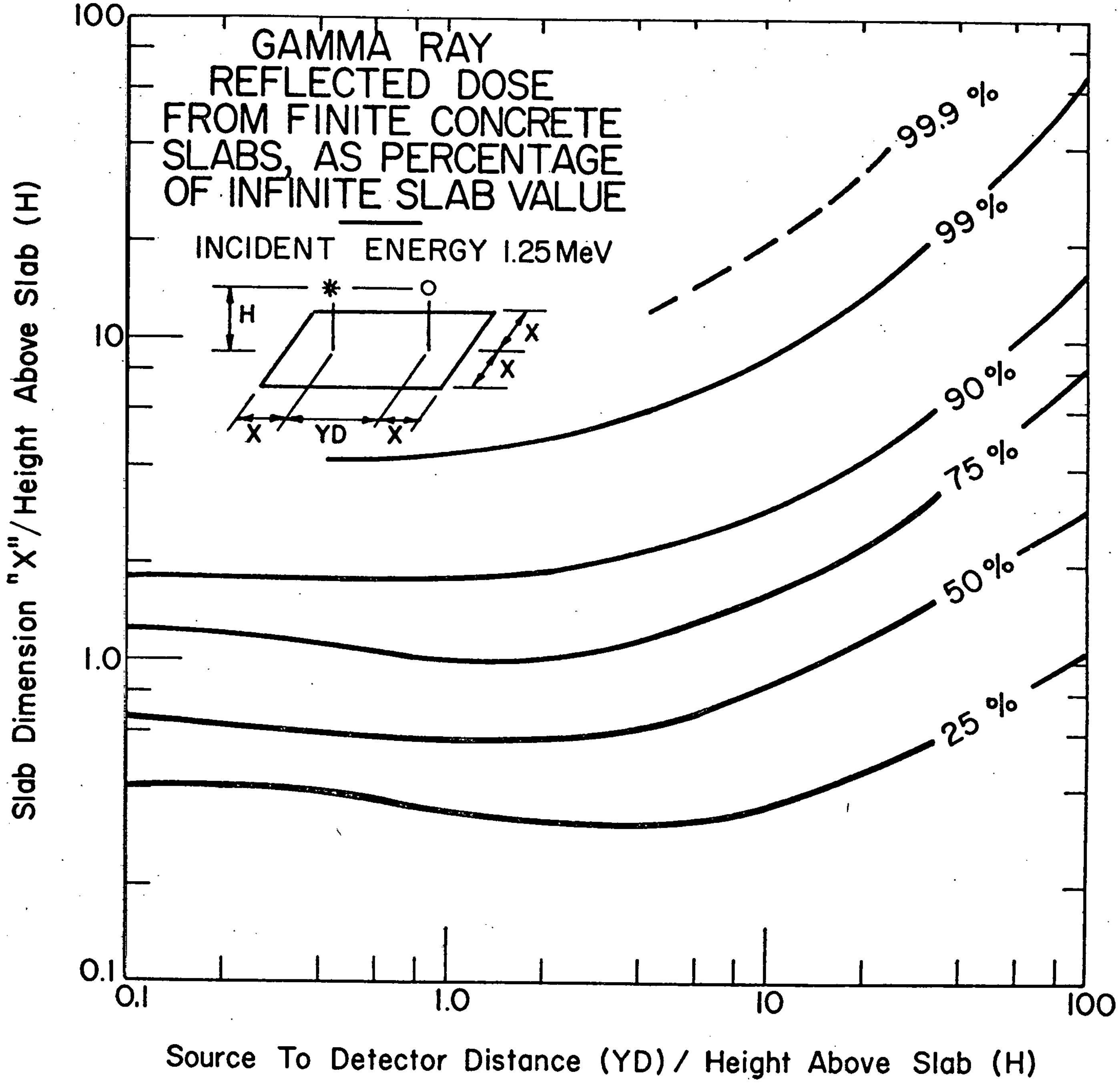
GAMMA RAY DOSE
REFLECTION FACTORS NEAR
AN INFINITE CONCRETE PLANE
Co-60 Point Isotropic Source
Note :
Calculations made using parameters adjusted to total reflected dose.
.01 .02 .03 .04 .05 .06 .07 .08 .09
.10
.09 .08 .07 .06 .05 .04 .03
(Detector Height)/(Source Height)
(Horizontal Source-to-Detector Distance)/(Source Height)
100
10
1.0
0.1
.01
0.1
1.0
10
100
1000


GAMMA RAY DOSE
REFLECTION FACTORS NEAR
AN INFINITE CONCRETE PLANE
Cs-137 Point Isotropic Source
100
10
1.0
0.1
0.1
1.0
10
100
1000
(Detector Height)/(Source Height)
(Horizontal Source-to-Detector Distance)/(Source Height)
.02
.04
.06
.08
.10
.12
.12
.10
.08
.06
.04
Note:
Based on parameter adjusted to total reflected dose.


GAMMA RAY DOSE ALBEDO
BASED ON FLUX
CONCRETE REFLECTOR
1.25 MeV
Reflected Dose / Direct Dose
.04
.12
.10
.08
.06
.04
.02
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Cosine of Angle of Incidence
Computed by Chilton-Huddleston Formula:
Total Value
Single Scattering Term
Isotropic Term
Note: Formula parameters were adjusted to total flux albedo.



GAMMA RAY DOSE ALBEDO
BASED ON CURRENT
CONCRETE REFLECTOR
1.25 MeV
Computed by Chilton-Huddleston Formula:
Total Value
Single Scattering Term
Isotropic Term
Note: Formula parameters were adjusted to total flux albedo.
Reflected Dose (Current) / Direct Dose (Current)
.30
.26
.22
.18
.14
.10
.06
.02
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Cosine of Angle of Incidence



GAMMA RAY REFLECTED DOSE FROM FINITE CONCRETE SLABS, AS PERCENTAGE OF INFINITE SLAB VALUE
INCIDENT ENERGY 1.25 MeV
H
X
X
X
YD
X
99.9 %
99 %
90 %
75 %
50 %
25 %
100
10
1.0
0.1
0.1
1.0
10
100
Slab Dimension "X"/Height Above Slab (H)
Source To Detector Distance (YD) / Height Above Slab (H)

PT. SOURCE, GAMMA-RAY SCATTERING FACTORS COMPUTED

FROM NON-WEIGHTED PARAMETERS, USING CHILTON-HUDDLESTON

ALBEDO FORMULA

$\frac{\text{Ht. of Det.}}{\text{Ht. of Source}}$ $X = \frac{\text{Hor. Dist, Source to Detector}}{(\text{Ht. of Source}) \times (\text{Ht. of Detector})}$

Ht. of Det. / Ht. of Source	0	.25	.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0
Au-198										
1	.000	.003	.011	.036	.087	.144	~~[illegible]~~ .168	.142	.099	.062
2	.021	.025	.037	.068	.120	.165	.162	.123	.082	.050
4	.069	.072	.082	.109	.150	.175	.153	.110	.071	.043
8	.117	.116	.122	.142	.171	.178	.145	.101	.065	.038
16	.153	.147	.151	.164	.183	.177	.139	.096	.061	.037
32	.176	.167	.170	.179	.190	.175	.135	.092	.059	.036
64	.190	.179	.181	.187	.193	.174	.132	.090	.057	.035
128	.197	.186	.187	.192	.195	.173	.131	.089	.057	.034
Cs-137										
1	.000	.002	.008	.026	.064	.112	.144	.130	.093	.060
2	.015	.018	.026	.049	.090	.133	.144	.114	.077	.048
4	.049	.051	.058	.080	.115	.147	.138	.103	.067	.041
8	.084	.083	.089	.105	.134	.152	.132	.094	.061	.037
16	.110	.107	.111	.123	.145	.153	.126	.089	.057	.035
32	.128	.122	.125	.135	.152	.152	.122	.086	.055	.034
64	.139	.131	.134	.142	.156	.150	.120	.084	.054	.033
128	.145	.137	.139	.146	.158	.150	.118	.082	.053	.032
Co-60										
1	.000	.001	.005	.016	.041	.077	.111	.113	.086	.057
2	.009	.011	.016	.031	.059	.095	.118	.103	.073	.046
4	.030	.031	.036	.051	.077	.110	.118	.094	.064	.040
8	.052	.052	.056	.068	.092	.118	.114	.087	.058	.036
16	.070	.067	.071	.081	.102	.121	.110	.081	.054	.033
32	.081	.078	.080	.089	.108	.121	.106	.078	.051	.032
64	.089	.084	.086	.094	.111	.121	.104	.077	.050	.031
128	.093	.088	.090	.097	.113	.120	.102	.074	.049	.030

	0	.25	.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0
				Na-24						
1	.000	.001	.004	.012	.031	.053	~~.047~~ .087	.097	.079	.054
2	.007	.008	.012	.024	.045	.072	.096	.093	.068	.044
4	.023	.024	.028	.039	.053	.085	.099	.085	.060	.038
8	.040	.040	.043	.052	.069	.093	.098	.079	.054	.034
16	.053	.052	.054	.061	.077	.096	.095	.074	.050	.032
32	.062	.060	.061	.067	.082	.097	.092	.070	.047	.030
64	.068	.064	.066	.071	.085	.097	.089	.067	.046	.029
128	.071	.067	.069	.074	.087	.097	.087	.066	.044	.028

	0	.25	.5	1.0	2.0	4.0	8.0	16.0	32.0	64.0
				Na-24						
1	.000	.001	.002	.008	.022	.044	.073	.086	.067	.049
2	.004	.006	.008	.016	.032	.057	.083	.082	.061	.040
4	.015	.016	.019	.027	.043	.070	.087	.076	.058	.034
8	.027	.027	.029	.037	.053	.078	.086	.071	.049	.031
16	.036	.035	.037	.044	.060	.081	.084	.066	.045	.029
32	.042	.044	.042	.049	.064	.082	.080	.062	.043	.027
64	.046	.044	.046	.052	.067	.082	.078	.060	.041	.026
128	.049	.046	.048	.054	.068	.082	.076	.058	.039	.025