1760
MASTER

EML-378

EXPOSURE RATE CONVERSION FACTORS FOR RADIONUCLIDES
DEPOSITED ON THE GROUND

By
H. L. Beck

July 1980

Environmental Measurements Laboratory
Department of Energy
New York, New York

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

"This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$5.00
Microfiche \$3.50

EXPOSURE RATE CONVERSION FACTORS FOR RADIONUCLIDES DEPOSITED
ON THE GROUND

Harold L. Beck

Environmental Measurements Laboratory
U. S. Department of Energy
New York, New York 10014

July 1980

This document is
PUBLICLY RELEASABLE
Larry E. Williams
Authorizing Official
Date: *04/12/2007*

ABSTRACT

Activity to exposure rate conversion factors are given for particulate gamma-emitting fission products and for a number of particulate activation products and residual nuclear materials which might be deposited on the ground as a result of weapons tests or other nuclear activities.

Activity to exposure rate conversion factors are given for particulate gamma-emitting fission products and for a number of particulate activation products and residual nuclear materials which might be deposited on the ground as a result of weapons tests or other nuclear activities. The source is assumed to be distributed uniformly over an essentially infinite area and exponentially with depth in the soil. Calculations were made for five different relaxation lengths ($\equiv$ depth in g/cm^2 at which the activity is reduced by e^{-1} from the surface activity) ranging from 0 (plane surface source) to 16 g/cm^2 .

The calculations of the basic exposure rates for monoenergetic sources were carried out a number of years ago and have been described and discussed in detail in references 1-3. These references also describe the assumed soil composition and discuss the errors which may result due to deviations from the assumed soil composition/soil moisture content and half-space geometry. The tabulated conversion factors given in this report were obtained by interpolating to obtain the appropriate factor for each actual photon energy emitted from the given source, weighting by the appropriate photon branching ratio, and then summing over all the gamma emissions for that source. Photon emission and branching ratio data were obtained from references 4 and 5.

Tables 1 and 2 give the calculated exposure rates in air at one meter above the ground for unit inventory of the given radionuclide present in the soil. Nuclides with half-lives less than five minutes, except for those having a longer-lived precursor, were not considered. Also, nuclides with negligible or no gamma

emission(plane source exposure rate less than 10^{-4} $\mu\text{R/h}$ per mCi/km^2) have not been listed in the tables.

Based on the accuracy of the original transport calculations ($\leq \pm 5\%$)^(1,2) and the interpolation scheme used ($< \pm 1\%$) and our past experience in comparing the results of similar calculations with actual field measurements⁽³⁾, we estimate that the majority of the conversion factors given in Tables 1 and 2 are accurate to $\pm 5\text{-}10\%$ for locations meeting the criteria of uniform deposition over an approximately 10 meter radius from the point of measurement for reasonably flat soil surfaces. The estimate assumes a fairly small error in the photon branching ratios given in references 4 and 5. The decay schemes for a few of the shorter-lived less common radionuclides are less well known⁽⁵⁾ and the corresponding exposure rate conversion factors can thus be expected to have somewhat larger uncertainties.

REFERENCES

1. Bennett, B. G. and Beck, H. L.
Legendre, Tschebyscheff, and Half-Range Legendre Polynomial Solutions of the
Gamma-Ray Transport Equation in Infinite Homogeneous and Two Media Plume
Geometry
USAEC Report HASL-185, August (1967)
2. Beck, H. L. and de Planque, G.
The Radiation Field in Air Due to Distributed Gamma-Ray Sources in the Ground
USAEC Report HASL-195, May (1968)
3. Beck, H. L., DeCampo, J. and Gogolak, C.
In Situ Ge(Li) and NaI(Tl) Gamma-Ray Spectrometry
USAEC Report HASL-258, September (1972)
4. Kocher, D. C.
Nuclear Decay Data for Radionuclides Occurring in Routine Releases from
Nuclear Fuel Cycle Facilities
Oak Ridge National Laboratory Report ORNL/NUREG/TM-102, August (1977)
5. Lederer, C. M. and Shirley, V. S., Editors
Table of Isotopes - Seventh Edition
John Wiley & Sons, New York (1978)

TABLE 1

EXPOSURE RATES FOR FISSION PRODUCTS ($\mu\text{R}\cdot\text{h}^{-1}$)/($\text{mCi}\cdot\text{km}^{-2}$)

Nuclide	Plane	Relaxation Length ($\text{g}\cdot\text{cm}^{-2}$)			
		0.16	1.6	4.8	16
GE-77	2.08E-2	1.81E-2	1.22E-2	8.41E-3	4.54E-3
AS-77	1.82E-4	1.58E-4	1.08E-4	7.40E-5	4.00E-5
GE-78	5.00E-3	4.32E-3	2.99E-3	1.98E-3	1.05E-3
AS-78	2.10E-2	1.82E-2	1.23E-2	8.66E-3	4.75E-3
SE-83	4.36E-2	3.78E-2	2.56E-2	1.79E-2	9.83E-3
BR-83	1.42E-4	1.26E-4	8.40E-5	5.80E-5	3.10E-5
SE-84	7.93E-3	6.85E-3	4.60E-3	3.10E-3	1.66E-3
BR-84	2.88E-2	2.44E-2	1.69E-2	1.21E-2	6.85E-3
RB-88	1.07E-2	9.04E-3	6.27E-3	4.48E-3	2.53E-3
RB-89	3.51E-2	3.03E-2	2.06E-2	1.47E-2	8.20E-3
SR-91	1.27E-2	1.10E-2	7.33E-3	5.18E-3	2.81E-3
Y-91M	1.00E-2	8.84E-3	5.91E-3	4.06E-3	2.18E-3
SR-92	2.28E-2	1.98E-2	1.34E-2	9.44E-3	5.29E-3
Y-92	4.50E-3	3.91E-3	2.61E-3	1.84E-3	1.01E-3
SR-93	4.04E-2	3.50E-2	2.36E-2	1.67E-2	9.17E-3
Y-93M	1.41E-2	1.24E-2	8.32E-3	5.73E-3	3.03E-3
Y-93	1.53E-3	1.31E-3	8.96E-4	6.28E-4	3.48E-4
Y-94	1.38E-2	1.20E-2	7.98E-3	5.66E-3	3.10E-3
Y-95	2.07E-2	1.76E-2	1.22E-2	8.72E-3	4.94E-3
ZR-95	1.39E-2	1.20E-2	7.94E-3	5.63E-3	3.02E-3
NB-95	1.44E-2	1.24E-2	8.20E-3	5.82E-3	3.13E-3
ZR-97	3.19E-3	2.77E-3	1.87E-3	1.30E-3	7.14E-4
NB-97M	1.37E-2	1.19E-2	7.83E-3	5.55E-3	2.98E-3
NB-97	1.24E-2	1.08E-2	7.15E-3	5.03E-3	2.69E-3
MO-99	2.98E-3	2.59E-3	1.72E-3	1.21E-3	6.44E-4
TC-99M	2.12E-3	1.92E-3	1.29E-3	8.78E-4	4.31E-4
MO-101	2.74E-2	2.37E-2	1.60E-2	1.13E-2	6.18E-3
TC-101	6.33E-3	5.49E-3	3.84E-3	2.52E-3	1.34E-3
MO-102	7.42E-3	6.59E-3	4.46E-3	3.01E-3	1.54E-3
TC-102	1.02E-2	8.93E-3	5.96E-3	4.12E-3	2.22E-3
RU-103	8.91E-3	7.85E-3	5.25E-3	3.58E-3	1.92E-3
TC-104	3.37E-2	2.90E-2	1.99E-2	1.38E-2	7.68E-3
TC-105	8.46E-3	7.36E-3	4.96E-3	3.45E-3	1.86E-3
RU-105	1.45E-2	1.26E-2	8.36E-3	5.83E-3	3.12E-3
RH-105M	4.43E-4	4.05E-4	2.73E-4	1.86E-4	9.10E-5
RH-105	1.48E-3	1.28E-3	9.05E-4	5.85E-4	3.11E-4
RH-106	3.83E-3	3.37E-3	2.25E-3	1.56E-3	8.37E-4
RH-107	5.96E-3	5.15E-3	3.59E-3	2.36E-3	1.25E-3
PD-111	4.60E-4	4.02E-4	2.69E-4	1.86E-4	1.00E-4
PD-111M	6.51E-3	5.68E-3	3.79E-3	2.64E-3	1.41E-3
AG-111	4.49E-4	3.88E-4	2.71E-4	1.77E-4	9.40E-5
AG-112	1.17E-2	1.01E-2	6.84E-3	4.81E-3	2.65E-3
AG-113	1.30E-3	1.13E-3	7.70E-4	5.20E-4	2.78E-4
AG-115	1.17E-2	1.01E-2	6.87E-3	4.82E-3	2.65E-3
CD-115M	3.95E-4	3.43E-4	2.29E-4	1.62E-4	8.90E-5
CD-115	4.37E-3	3.87E-3	2.59E-3	1.77E-3	9.50E-4
IN-115M	3.02E-3	2.61E-3	1.83E-3	1.19E-3	6.32E-4
CD-117	1.87E-2	1.62E-2	1.10E-2	7.66E-3	4.23E-3
CD-117M	3.39E-2	2.91E-2	1.99E-2	1.42E-2	7.92E-3
IN-117	1.28E-2	1.13E-2	7.60E-3	5.20E-3	2.75E-3
IN-117M	1.40E-3	1.22E-3	8.55E-4	5.59E-4	2.91E-4
SN-117M	2.44E-3	2.18E-3	1.47E-3	9.96E-4	4.93E-4

TABLE 1 (Cont'd)

IN-118	4.56E-3	3.99E-3	2.69E-3	1.88E-3	1.04E-3
SN-123	1.23E-4	1.08E-4	7.20E-5	5.10E-5	2.80E-5
SN-123M	2.39E-3	2.13E-3	1.44E-3	9.75E-4	4.84E-4
SN-125M	6.48E-3	5.59E-3	3.93E-3	2.56E-3	1.36E-3
SN-125	5.45E-3	4.73E-3	3.18E-3	2.25E-3	1.23E-3
SB-125	7.91E-3	6.91E-3	4.61E-3	3.17E-3	1.69E-3
SN-127	3.32E-2	2.88E-2	1.93E-2	1.36E-2	7.46E-3
SB-127	1.30E-2	1.13E-2	7.51E-3	5.23E-3	2.80E-3
SN-128	1.20E-2	1.06E-2	7.07E-3	4.86E-3	2.58E-3
SB-128M	3.60E-2	3.12E-2	2.08E-2	1.45E-2	7.81E-3
SB-128	5.84E-2	5.08E-2	3.38E-2	2.36E-2	1.27E-2
SB-129	2.48E-2	2.16E-2	1.44E-2	1.01E-2	5.51E-3
TE-129M	5.61E-4	4.87E-4	3.22E-4	2.27E-4	1.22E-4
TE-129	1.04E-3	9.12E-4	6.11E-4	4.18E-4	2.24E-4
SB-130(6.5M)	4.84E-2	4.20E-2	2.78E-2	1.97E-2	1.07E-2
SB-130(40M)	6.00E-2	5.20E-2	3.47E-2	2.43E-2	1.32E-2
SB-131	3.39E-2	2.93E-2	1.97E-2	1.40E-2	7.70E-3
TE-131M	2.60E-2	2.25E-2	1.52E-2	1.06E-2	5.75E-3
TE-131	7.51E-3	6.59E-3	4.41E-3	3.05E-3	1.61E-3
I-131	7.30E-3	6.32E-3	4.34E-3	2.89E-3	1.54E-3
TE-132	3.84E-3	3.38E-3	2.29E-3	1.54E-3	8.09E-4
I-132	4.21E-2	3.66E-2	2.43E-2	1.71E-2	9.26E-3
TE-133M	4.16E-2	3.60E-2	2.40E-2	1.69E-2	9.25E-3
TE-133	1.68E-2	1.46E-2	9.92E-3	6.82E-3	3.71E-3
I-133M	2.90E-2	2.52E-2	1.67E-2	1.18E-2	6.36E-3
I-133	1.14E-2	1.00E-2	6.72E-3	4.62E-3	2.49E-3
TE-134	1.60E-2	1.39E-2	9.29E-3	6.44E-3	3.44E-3
I-134	4.76E-2	4.13E-2	2.74E-2	1.94E-2	1.06E-2
I-135	2.70E-2	2.33E-2	1.58E-2	1.12E-2	6.20E-3
CS-137	1.07E-2	9.28E-3	6.15E-3	4.32E-3	2.31E-3
CS-138	3.94E-2	3.39E-2	2.32E-2	1.64E-2	9.23E-3
CS-139	4.99E-3	4.28E-3	2.94E-3	2.09E-3	1.18E-3
BA-139	6.42E-4	5.71E-4	3.86E-4	2.63E-4	1.34E-4
BA-140	2.73E-3	2.41E-3	1.62E-3	1.10E-3	5.88E-4
LA-140	3.88E-2	3.33E-2	2.28E-2	1.60E-2	8.96E-3
BA-141	1.51E-2	1.32E-2	8.93E-3	6.14E-3	3.32E-3
LA-141	7.15E-4	6.19E-4	4.21E-4	2.97E-4	1.67E-4
CE-141	1.22E-3	1.09E-3	7.25E-4	4.92E-4	2.42E-4
BA-142	1.86E-2	1.63E-2	1.09E-2	7.63E-3	4.15E-3
LA-142	4.21E-2	3.54E-2	2.47E-2	1.79E-2	1.01E-2
CE-143	4.88E-3	4.23E-3	2.89E-3	1.95E-3	1.04E-3
CE-144	2.77E-4	2.53E-4	1.70E-4	1.16E-4	5.70E-5
PR-144	5.27E-4	4.51E-4	3.10E-4	2.21E-4	1.24E-4
PR-145	2.37E-4	2.06E-4	1.37E-4	9.70E-5	5.20E-5
CE-146	5.79E-3	5.05E-3	3.51E-3	2.31E-3	1.22E-3
PR-146	2.00E-2	1.72E-2	1.17E-2	8.20E-3	4.55E-3
PR-147	1.30E-2	1.14E-2	7.69E-3	5.30E-3	2.86E-3
ND-147	2.50E-3	2.22E-3	1.50E-3	1.02E-3	5.41E-4
ND-149	6.88E-3	6.04E-3	4.08E-3	2.77E-3	1.46E-3
PM-149	2.17E-4	1.88E-4	1.30E-4	8.70E-5	4.60E-5
PM-150	2.81E-2	2.44E-2	1.66E-2	1.15E-2	6.34E-3
ND-151	1.04E-2	9.13E-3	6.11E-3	4.27E-3	2.28E-3
PM-151	5.89E-3	5.13E-3	3.49E-3	2.36E-3	1.25E-3
ND-152	2.90E-3	2.51E-3	1.73E-3	1.15E-3	6.10E-4
PM-152	5.44E-3	4.74E-3	3.15E-3	2.23E-3	1.21E-3
PM-153	6.68E-4	6.10E-4	4.11E-4	2.79E-4	1.39E-4
SM-153	9.39E-4	8.48E-4	5.77E-4	3.96E-4	2.01E-4
SM-155	1.71E-3	1.56E-3	1.05E-3	7.18E-4	3.65E-4

TABLE 1 (Cont'd)

EU-155	9.38E-4	8.60E-4	5.81E-4	3.97E-4	2.03E-4
SM-156	1.98E-3	1.76E-3	1.20E-3	8.06E-4	4.17E-4
EU-156	2.28E-2	1.97E-2	1.34E-2	9.53E-3	5.29E-3
EU-157	4.46E-3	3.88E-3	2.62E-3	1.77E-3	9.45E-4
EU-158	2.45E-2	2.13E-2	1.42E-2	1.01E-2	5.53E-3
EU-159	5.13E-3	4.49E-3	2.97E-3	2.09E-3	1.12E-3
GD-159	7.60E-4	6.57E-4	4.54E-4	2.99E-4	1.59E-4
TB-161	1.34E-4	1.24E-4	8.30E-5	5.60E-5	2.90E-5

TABLE 2

EXPOSURE RATES FOR ACTIVATION PRODUCTS AND MISC. ($\mu\text{R}\cdot\text{h}^{-1}$)/(mCi $\cdot\text{km}^{-2}$)

Nuclide	Plane	Relaxation Length (g $\cdot\text{cm}^{-2}$)			
		0.16	1.6	4.8	16
BE-7	9.51E-4	8.34E-4	5.58E-4	3.80E-4	2.04E-4
NA-24	6.26E-2	5.22E-2	3.68E-2	2.68E-2	1.54E-2
SC-46	3.61E-2	3.15E-2	2.09E-2	1.48E-2	8.07E-3
CR-51	6.00E-4	5.18E-4	3.67E-4	2.37E-4	1.26E-4
MN-54	1.55E-2	1.34E-2	8.82E-3	6.28E-3	3.40E-3
MN-56	2.89E-2	2.47E-2	1.67E-2	1.19E-2	6.64E-3
CO-57	1.99E-3	1.83E-3	1.23E-3	8.38E-4	4.13E-4
CO-58	1.82E-2	1.58E-2	1.04E-2	7.36E-3	3.98E-3
FE-59	2.07E-2	1.81E-2	1.22E-2	8.59E-3	4.71E-3
CO-60	4.32E-2	3.77E-2	2.54E-2	1.79E-2	9.92E-3
CU-64	3.57E-3	3.16E-3	2.12E-3	1.45E-3	7.77E-4
NI-65	9.36E-3	8.11E-3	5.51E-3	3.88E-3	2.16E-3
ZN-65	1.03E-2	9.00E-3	6.03E-3	4.25E-3	2.31E-3
CU-67	1.95E-3	1.75E-3	1.18E-3	7.99E-4	4.08E-4
ZN-69M	8.05E-3	6.99E-3	4.68E-3	3.17E-3	1.70E-3
BR-82	4.83E-2	4.21E-2	2.80E-2	1.97E-2	1.07E-2
RH-101	5.17E-3	4.65E-3	3.16E-3	2.12E-3	1.08E-3
RH-102	3.97E-2	3.47E-2	2.31E-2	1.61E-2	8.68E-3
RH-102M	6.73E-3	5.90E-3	3.95E-3	2.72E-3	1.46E-3
AG-110M	5.03E-2	4.36E-2	2.90E-2	2.05E-2	1.12E-2
SB-124	3.23E-2	2.78E-2	1.89E-2	1.33E-2	7.37E-3
I-130	4.02E-2	3.51E-2	2.33E-2	1.63E-2	8.74E-3
CS-134	2.91E-2	2.54E-2	1.68E-2	1.18E-2	6.36E-3
CS-134M	2.73E-4	2.50E-4	1.68E-4	1.15E-4	5.60E-5
CS-136	3.92E-2	3.42E-2	2.28E-2	1.60E-2	8.67E-3
EU-152	1.99E-2	1.74E-2	1.17E-2	8.17E-3	4.46E-3
EU-152M1	5.34E-3	4.65E-3	3.08E-3	2.18E-3	1.18E-3
EU-152M2	1.04E-3	9.59E-4	8.93E-4	6.09E-4	3.14E-4
EU-154	2.18E-2	1.90E-2	1.27E-2	8.96E-3	4.88E-3
TB-160	2.02E-2	1.76E-2	1.18E-2	8.26E-3	4.49E-3
HO-166	4.64E-4	4.07E-4	2.76E-4	1.93E-4	1.06E-4
HO-166M	3.25E-2	2.83E-2	1.88E-2	1.31E-2	7.04E-3
LU-174	1.86E-3	1.62E-3	1.09E-3	7.67E-4	4.16E-4
W-181	5.98E-4	5.28E-4	3.51E-4	2.42E-4	1.27E-4
W-187	8.90E-3	7.79E-3	5.18E-3	3.60E-3	1.92E-3
AU-195	1.15E-3	1.05E-3	7.01E-4	4.81E-4	2.50E-4
AU-196	8.07E-3	6.97E-3	4.84E-3	3.18E-3	1.69E-3
AU-198	7.83E-3	6.77E-3	4.54E-3	3.07E-3	1.64E-3
AU-199	1.51E-3	1.35E-3	9.11E-4	6.17E-4	3.10E-4
HG-203	4.28E-3	3.70E-3	2.56E-3	1.69E-3	9.00E-4
PB-203	4.57E-3	3.95E-3	2.73E-3	1.81E-3	9.61E-4
BI-207	2.69E-2	2.32E-2	1.56E-2	1.09E-2	5.95E-3
PB-214	4.56E-3	3.96E-3	2.74E-3	1.81E-3	9.62E-4
BI-214	2.52E-2	2.17E-2	1.48E-2	1.05E-2	5.80E-3
U-235	2.60E-3	2.34E-3	1.58E-3	1.06E-3	5.41E-4
U-237	2.31E-3	2.08E-3	1.40E-3	9.49E-4	4.88E-4
NP-237	3.72E-4	3.43E-4	2.30E-4	1.57E-4	8.00E-5
U-239	8.02E-4	7.38E-4	4.93E-4	3.37E-4	1.76E-4
NP-239	2.87E-3	2.56E-3	1.75E-3	1.17E-3	6.07E-4
NP-240M	6.07E-3	5.32E-3	3.56E-3	2.47E-3	1.34E-3
AM-241	3.35E-4	2.96E-4	1.97E-4	1.36E-4	7.10E-5