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Natural Radioactivity and Radiation

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The measured levels of artificial radioactivity and radiation from weapons tests or the operation of nuclear facilities are often compared with the levels of natural background radioactivity. While many of these comparisons are not relevant it was felt to be worth while to have available a compilation of natural radioactivity and radiation levels. This compilation can then be used to provide general figures for cases where such comparisons are valid.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has treated natural radioactivity in its 1958, 1962 and 1966 reports and other summaries of data are also available. The present compilation makes use of these previous collections and references rather than returning to the original papers on the subject. This was done both to avoid the labor of preparing new mean values and also to take advantage of the judgment of previous compilers.

The data are presented as a series of tables indicating concentrations of radioactivity in various parts of the environment plus measurements and calculations of the amounts in diet and man as well as the calculated resultant internal radiation doses. The external radiation dose is discussed separately.

In addition to presenting an estimate of the mean value, the expected ranges are shown where the data are available. There has also been an attempt to stress measurements for the United States although these values should not be significantly different than worldwide values for the specific purposes of this compilation.

The individual contributors to exposure cannot be readily summed except in the form of radiation dose. This has not been done in the present case but the summary from the 1966 report of UNSCEAR is included here as table 16.

General Notes

The numerical values have been rounded off sometimes even beyond the rounding done in the original compilation. Since the values are intended to represent the average over large areas there is little meaning to using more than one significant figure. In many cases it has been necessary to convert the units from those of the original compilation and in a few cases it has been necessary to calculate values from basic handbook information. Those calculations relating to man are all on the basis of a 70 kg standard man with 2800 grams of skeletal ash.

Tritium (Table 1)

Natural tritium is produced in the atmosphere by cosmic ray bombardment at the rate of 0.5 to 0.6 atoms/sec per cm^2. This corresponds to an annual production rate of about 2500 pCi/m^2 of the earth's surface. The equilibrium inventory has been estimated at 70 to 85 megacuries. The complete assessment of the environment had not been finished at the start of thermonuclear weapons testing and the data are not completely firm.

Since tritium is produced in the stratosphere, the highest natural concentrations are in atmospheric hydrogen, water vapor and in precipitation. Older waters such as those from the deep oceans and deep wells have extremely low concentrations while surface waters from the continents and the ocean are intermediate. The specific activity of natural tritium in man is generally lower than surface waters.

Natural Carbon-14 (Table 2)

Natural carbon-14 is also produced by cosmic ray bombardment in the atmosphere. The production rate is about 2 atoms/sec per cm^2, which is equivalent to an annual production of 50 pCi/m^2. The worldwide inventory has been estimated as 270 megacuries which is distributed with 1.5% in the atmosphere, 3.5% in biological material and 95% in the oceans. Most of the latter is in the deep oceans with only 2% above the thermocline.

Living organic matter is generally fairly close to equilibrium with the natural C-14 in the atmosphere. This results in a specific activity of 6.5 pCi/g of carbon.

Potassium (Table 3)
Rubidium (Table 4)
Uranium Series (Tables 5-10)

At least six members of the uranium series are sufficiently important to require measurement in man and his environment. The actual uranium isotopes are not of great dosimetric significance and most attention has been paid to radium-226 and later members of the chain. Radium-226 has a gaseous daughter, radon-222, some of which escapes from soil at an annual rate of about 10^7 pCi/m^2 and decays to solid descendants which are important contributors to radioactivity in the environment. The daughters formed from the radon which does escape attach themselves to aerosols which have an average life in the troposphere of about one month or less before being deposited on the ground. The deposited material along with daughters formed from the radon which does not escape are significant contributors to the external terrestrial gamma dose rate. The airborne material contributes to the internal lung dose and to the external dose from the air.

The short-lived daughters are of greater significance indoors than out, with their concentrations being a function of the building material. For the purpose of making conservative dose estimates they may be considered to be in radioactive equilibrium with radon-222.

The long-lived daughters of radon-222 have separate existences in the environment with polonium-210 being much less than the lead-210 activity which in turn is a small fraction of the radon-222 activity. The levels of lead and polonium in man, however, are usually close to equilibrium.

Thorium Series (Tables 11-14)

The thorium series decays through a chain which is very similar to that of uranium. The short lives of Ra-228 and Rn-222 modify the behaviour considerably and exposures from airborne daughter products of thoron are relatively small. The major contribution of the thorium series to human exposure is in external gamma radiation.

External Radiation

The external radiation exposure of man comes from three sources, cosmic radiation, terrestrial gamma, and gamma radiation from airborne radionuclides. The latter is calculated as an exposure of about 5 mrad/y, but it is always included when measuring the terrestrial gamma dose rates.

Cosmic ray dose estimates have been summarized by UNSCEAR[3]. The ionizing component amounts to 28 mrad/y at sea level in the middle latitudes and is about 10% less near the equator. This dose rate is approximately doubled for each 2000 meter increase in altitude for the first few kilometers. The cosmic ray neutron dose rate is of the order of 1 mrad/y.

Measurements of gamma dose rates with scintillation spectrometers in many populated areas of the United States indicate total natural terrestrial radiation fields that fall within rather narrow limits at most locations. Nearly 90% of the several hundred available readings can be represented by an approximately normal distribution with a mean of 55 mrad/y and a standard deviation of $\pm$ 20 mrad/y[12]. The contributions of the three sources, K-40 and the decay daughters of U-238 and Th-232 have been measured spectrometrically. The results are indicated in table 15, along with their inferred soil contents that would produce these radiation levels. In general, readings in populated areas outside the range of 5 to 50 mrad/y for any of these sources, and 25 to 100 mrad/y for the total radiation, would be considered somewhat anomalous. Higher readings are readily observed near rock outcrops, but these occur relatively rarely in populated areas. This fact and a number of other factors related to urban living tend to reduce the influence of bedrock geology on the observed radiation levels, and to somewhat homogenize the distribution of radiation sources that influence population exposure. This phenomenon has been clearly observed in perhaps the most detailed study of population exposure in regions of the United States, that in northern New England[13].

1. United Nations Scientific Committee on the Effects of Atomic Radiation
XIIIth Session, Supplement 17 (A/3838) - 1958

2. United Nations Scientific Committee on the Effects of Atomic Radiation
XVIIth Session, Supplement 16 (A/5216) - 1962

3. United Nations Scientific Committee on the Effects of Atomic Radiation
XXIst Session, Supplement 14 (A/6314) - 1966

4. J. D. Burton
Radioactive Nuclides in Sea Water, Marine Sediments, and Marine Organisms
Chapter 22 in Chemical Oceanography
Academic Press, New York (1965)

5. K. S. Heier
Radioactive Elements in the Continental Crust
Nature 208, 479-80 (1965)

6. Health and Safety Laboratory
Fallout Program, Quarterly Summary Report, page I-2
USAEC Report HASL-224 (April 1970)

7. G. A. Welford and Ruth Baird
Uranium Levels in Human Diet and Biological Material
Health Physics 13, 1321-24 (1967)

8. R. S. Morse and G. A. Welford
Dietary Intake of Pb-210
Health Physics - in Press

9. T. C. Tso, N. A. Hallden and L. T. Alexander
Ra-226 and Po-220 in Leaf Tobacco and Tobacco Soil
Science 146, 1043-45 (1964)

10. B. Glöbel, H. Muth and E. Oberhausen
Auf nahme und Ausscheidung der natürliche Radionuclide Pb-210 and Po-210
durch den Menschen
Strahlen therapie 131, 218-26 (1966)

11. H. Craig and D. Lal
The Production Rate of Natural Tritium
Tellus 13, 85-105 (1961)

12. H. L. Beck
Environmental Gamma Radiation from Deposited Fission Products, 1960-64
Health Physics 12, 313-22 (1966)

13. W. M. Lowder and W. J. Condon
Measurement of the Exposure of Human Populations to Environmental Radiation
Nature 206, 658-62 (1965)

1 Tritium Unit = [illegible]
Specific Activity
10[illegible] pCi/g H-3
0.01 pCi/g H

Table 1

Natural Levels of H-3

	Estimated Mean	Range	Area	Reference
Fresh Water				
Precipitation	20 pCi/l			11
Lakes and Rivers		0.6 - 2 pCi/l		2
Drinking		" "		2
Ocean Water	3 pCi/l			4
Body Content				
Total	10 pCi			Calc.
Internal Dose - Total Body	0.002 mrad/y			2

Specific Activity
6.5 pCi/g C

Table 2

Natural Levels of C-14

	Estimated Mean	Range	Area	Reference
Ocean Water	0.1 pCi/l			calc.
Body Content				
Total	0.1 mCi			1
Internal Dose - Total Body	1 mrad/y			2

Specific Activity
800 pCi/g K

Table 3

Natural Levels of K-40

	Estimated Mean	Range	Area	Reference
Earth's Crust	20 pCi/g			5
Rocks				
Sedimentary	3 pCi/g			2
Igneous	25 pCi/g	8 - 3 pCi/g		2
Soil		1 - 30 pCi/g		2
Ocean Water	320 pCi/l			4
Human Diet	2300 pCi/d			Calc.
Body Content				
Total	10,000 pCi	7000-13,000 pCi		2
Internal Dose - Gonads	20 mrad/y			2

Specific Activity
0.08 pCi/μg Rb-87
0.02 pCi/μg Rb

Table 4

Natural Levels of Rb-87

	Estimated Mean	Range	Area	Reference
Earth's Crust	6 pCi/g			Calc.
Ocean Water	3 pCi/l			4
Internal Dose - Gonads	0.3 mrad/y			3

Specific Activity
0.33 pCi/μg U

Table 5

Natural Levels of U-238

	Estimated Mean	Range	Area	Reference
Earth's Crust	1 pCi/g			3
Rocks				
Sedimentary	0.5 pCi/g			2
Igneous	2 pCi/g	0.5 - 3		2
Fresh Water				
Lakes and Rivers		up to 1 pCi/l		Calc.
Drinking	0.01 pCi/l		New York City	7
Ocean Water	1 pCi/l			4
		0.2 - 9 pCi/l		2
Ocean Sediments	1 pCi/g			4
Human Diet	0.5 pCi/d		USA, Tri-City	7
Air	10^{-4} pCi/m^3		New York City	7
Body Content				
Skeleton	180 pCi			7

Specific Activity
20,000 pCi/μg Th

Table 6

Natural Levels of Th-230

	Estimated Mean	Range	Area	Reference
Ocean Water	0.01 pCi/l			4
Ocean Sediments		2 - 60 pCi/g		4

Specific Activity
10^6 pCi/μg Ra-226

Table 7

	Estimated Mean	Range	Area	Reference
Rocks				
Sedimentary	0.5 pCi/g			2
Igneous	2 pCi/g	0.5 - 4 pCi/g		2
Soil	1 pCi/g			2
Fresh Water				
Lakes and Rivers	0.07 pCi/l			1
Drinking	0.04 pCi/l			1
Ocean Water	0.07 pCi/l*			4
		0.02 - 0.3 pCi/l		2
Ocean Sediments	10 pCi/g			4
Human Diet	2 pCi/d		New York City	6
Body Content				
Total	40 pCi			3
Skeleton	30 pCi			3
Internal Dose - Osteocytes	1.4 mrad/y			3
Haversian Canals	0.6 mrad/y			3

* Surface water, deep water is higher.

Table 8

Natural Levels of Rn-222

	Estimated Mean	Range	Area	Reference
Fresh Water				
Precipitation		10^3 - 10^5 pCi/l		3
Lakes and Rivers	10 pCi/l			3
Ocean Water	"Close to equilibrium with Ra-226"			4
Air - Indoors	500 pCi/m^3			2
Outdoors	200 pCi/m^3	30 - 500		2
Over Oceans		0.5 - 10		3
Internal Dose - Lung	"Several hundred mrad/y"			3

Table 9

Natural Levels of Pb-210

	Estimated Mean	Range	Area	Reference
Soil - Upper layer	60 mCi/km^2			3
Fresh Water				
Precipitation		0.5 - 3 pCi/l		3
Lakes and Rivers		0.05 - 2 pCi/l		3
Drinking	0.04 pCi/l			8
Ocean Water	0.05 pCi/l			4
Human Diet	1.2 pCi/d		New York City	8
	5 pCi/d		Germany	10
Air	0.01 pCi/m^3		USA	2
		0.002 - 0.016		3
Body Content				
Skeleton	270 pCi	100 - 400 pCi		3
Internal Dose - Osteocytes	0.7 mrad/y			2
Deposition	2 mCi/km^2/y			3

Table 10

Natural Levels of Po-210

	Estimated Mean	Range	Area	Reference
Soil		0.3 - 1 pCi/g	SE - US	9
Fresh Water				
Precipitation	0.5 pCi/l			3
Human Diet	5 pCi/d		Germany	10
Air	"Small fraction of Pb-210"			3
Body Content				
Skeleton	200 pCi	100 - 400 pCi*		3
Internal Dose - Total Body	0.3 mrad/y			3
Osteocytes	4 mrad/y			3

* Po-210/Pb-210 = 0.9 (3)

Specific Activity
0.11 pCi/μg Th

Table 11

Natural Levels of Th-232

	Estimated Mean	Range	Area	Reference
Earth's Crust	1.2 pCi/g			3
Rocks				
Sedimentary	0.2 pCi/g			2
Igneous	3 pCi/g	1 - 15 pCi/g		2
Ocean Water	< 0.002 pCi/l			4
		0.0001 - 0.001		2
Ocean Sediments	1 pCi/g			4

Table 12

Natural Levels of Ra-228

	Estimated Mean	Range	Area	Reference
Body Content				
Total	50 pCi			2
Skeleton	40 pCi			2
Internal Dose - Osteocytes	1.6 mrad/y			2

Table 13

Natural Levels of Rn-220

	Estimated Mean	Range	Area	Reference
Air - Indoors	20 pCi/m^3			2
Outdoors	4 pCi/m^3			2
Internal Dose - Lung	"Small fraction of that from Rn-222"			3

Table 14

Natural Levels of Pb-212

	Estimated Mean	Range	Area	Reference
Air		0.5 - 10 pCi/m^3		

Table 15

Terrestrial Gamma Dose Rates in the United States
with Inferred Soil Contents

	K	U	Th	Total
Dose Rate Range (mrad/y)				
1. Populated areas-range (90%)	5 - 35	10 - 20	15 - 40	30 - 95
2. " " typical mean	17	13	25	55
3. All areas-range (90%)	1 - 50	0 - 45	5 - 70	15 - 130
Inferred Soil Content				
1. Range (90%)	$(0-4) \times 10^4$ ppm	0.5-9 ppm	1.5-30 ppm	
2. Typical mean	1.5×10^4 ppm	2.5 ppm	9 ppm	
	12 pCi/g	0.8 pCi/g	1 pCi/g	

Table 16

Dose Rates Due to External and Internal Irradiation from Natural Sources in "Normal" Areas (from the 1966 UNSCEAR Report)

Source of Irradiation	Dose Rates (mrad/y) Gonads	Haversian Canal	Bone Marrow
External irradiation			
Cosmic rays			
Ionizing component	28	28	28
Neutrons	0.7	0.7	0.7
Terrestrial radiation (including air)	50	50	50
Internal irradiation			
K^{40}	20	15	15
Rb^{87}	0.3	< 0.3	< 0.3
C^{14}	0.7	1.6	1.6
Ra^{226}	-	0.6	0.03
Ra^{228}	-	0.7	0.03
Po^{210}	0.3	2.1	0.3
Rn^{222} (dissolved in tissues)	0.3	0.3	0.3
Rounded Total	100	99	96

Table ____

Natural Levels of ________

	Estimated Mean	Range	Area	Reference
Rocks				
Sedimentary				
Igneous				
Soil				
Fresh Water				
Lakes & Rivers				
Drinking				
Ocean Water				
Ocean Sediments				
Human Diet				
Body Content				
Total				
Skeleton				
Radiation Dose				

Miller

HASL SURFACE AIR SAMPLING PROGRAM

Gamma Activity Measurements for March 1970

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