Radionuclides in Groundwater Fact Sheet

Environmental Defense Institute

This fact sheet presents some basic uranium and thorium decay series information that can be helpful for determining whether uranium or thorium fuel cycle contamination is involved in monitored groundwater contamination. The waste disposal of uranium and thorium materials was long thought by the Department of Energy to be acceptable because the basic materials are natural before being mined, milled and concentration. The US Department of Energy and the US Geological Survey have been avoiding the truth about contamination dumped into the aquifer. In addition, transuranics are discussed and a compilation of radiological and non-radiological contaminants prevalent in the aquifer from historical waste disposal practices at the Idaho National Laboratory is presented.

Uranium and Thorium

Environmental monitoring of air, soil and groundwater near the Idaho National Laboratory includes various radionuclides. A basic overview of the radioactive decay series for uranium-238, thorium-232 and uranium-235 is helpful for understanding the detection of various decay chain isotopes. The decay series for U-238, Th-232 and U-235 are shown is figures 1 through 3 below.

Ionizing radiation decays by alpha particle, beta particles and gamma rays. External radiation risks are primarily from gamma ray. Internal inhalation or ingestion risk occurs from alpha and beta decay as well as gamma ray. The health risks associated with ionizing radiation depend on the specific radioisotope involved and the energy imparted by its decay and how the body utilizes the radioisotope. For example, cesium-137 mimics potassium, plutonium mimics iron, and strontium mimics calcium. The human body builds tissue from the radioactive isotope which then decays, damaging cells and DNA. The targeted body tissue is not random once the radioisotope is being used as a building block in the body — a fact that the radiation health physics folks cannot seem to comprehend. To them, the energy given off decay of an isotope is always randomly distributed even when it has been assimilated by the body. The radiation health physics community likes their pretend models and they actively ignore strong epidemiological evidence that the harm of ionizing radiation is greater than their models predict.

The decay series show alpha and beta particle decay. Alpha particle decay reduces the atomic mass number by 4 (and the number of protons by two). Beta decay transforms a neutron into a proton, increasing the Atomic number (the number of protons) keeping the atomic mass constant. In addition to alpha and beta decay, often a gamma ray is emitted.

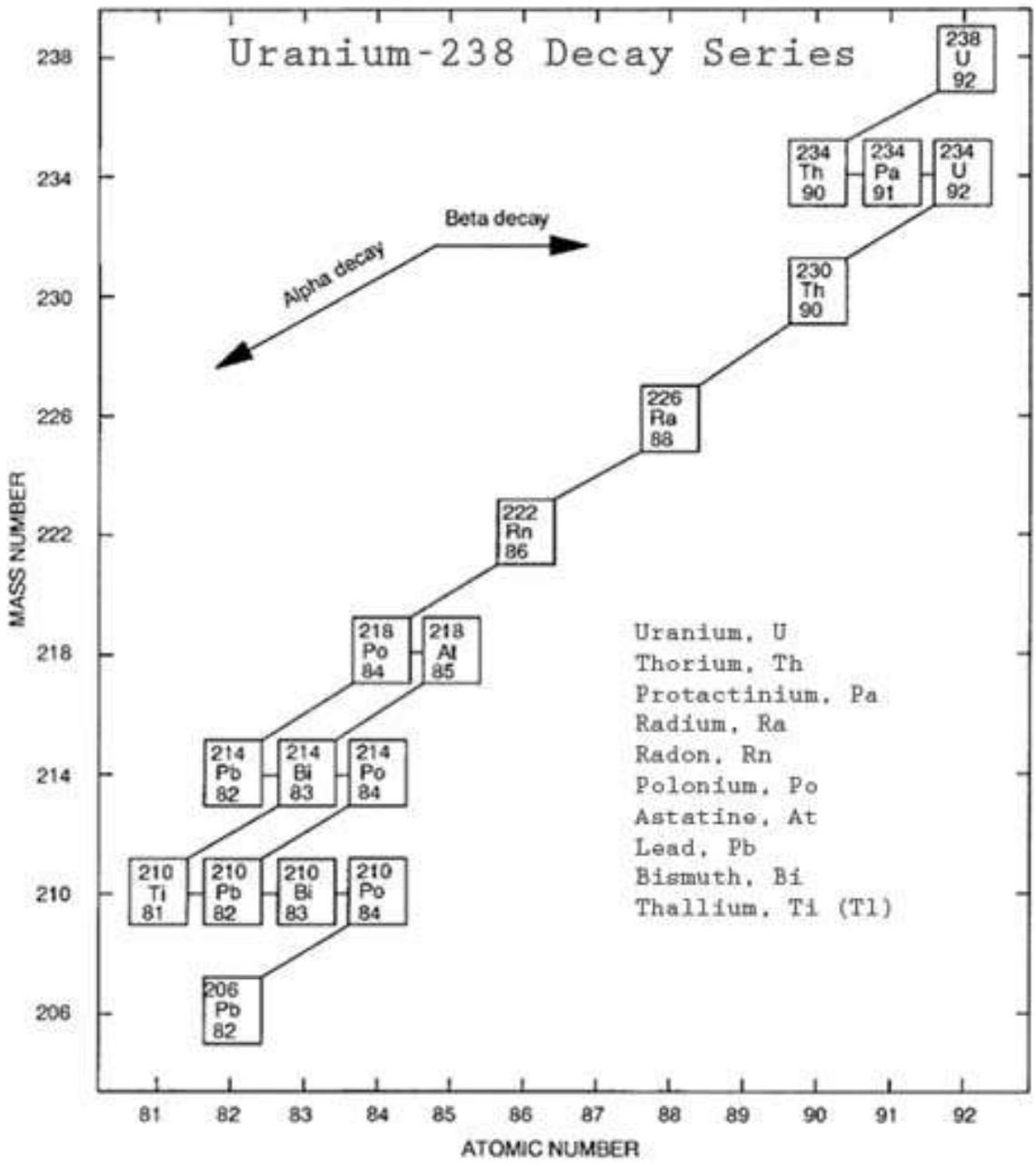

Figure 1. Uranium-238 Decay Series.

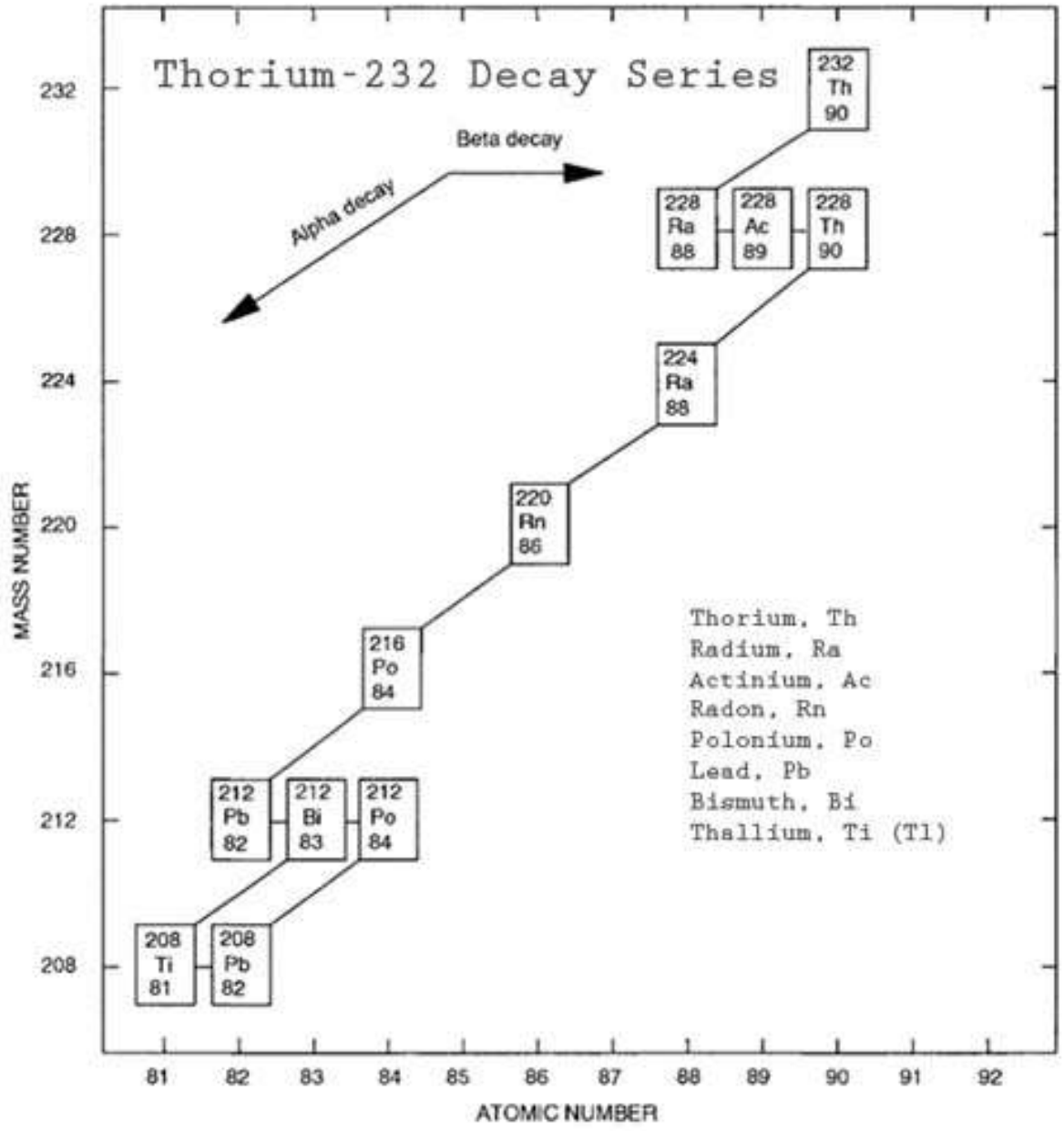

Figure 2. Thorium-232 Decay Series.

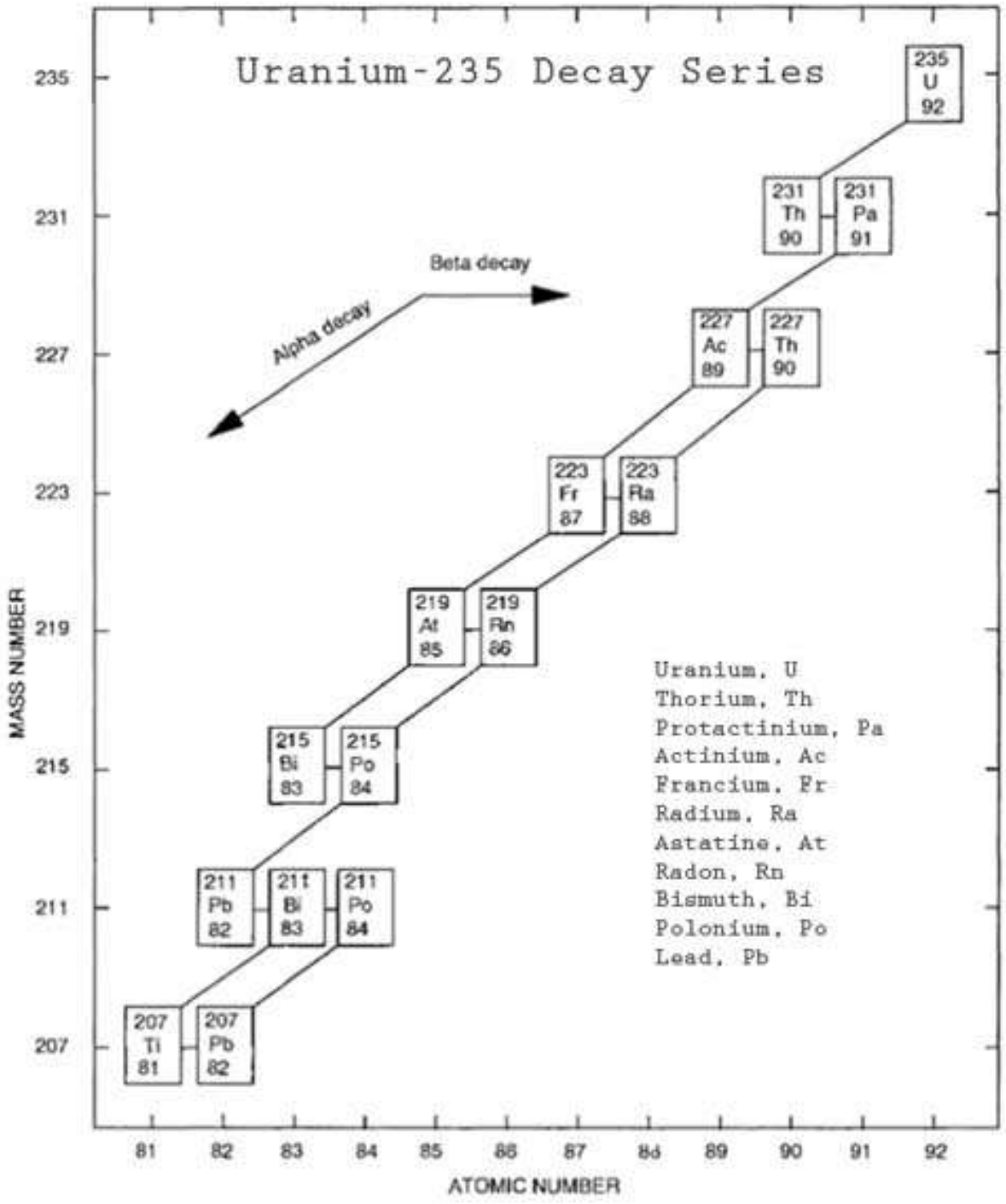

Figure 3. Uranium-235 Decay Series.

Uranium

Natural uranium consists primarily of uranium-238 by mass. But half of the radioactivity is actually from uranium-234. Note that depleted uranium which is lower in U-235 is still roughly two thirds the specific activity of natural uranium but whether enriched or depleted in uranium, waste disposal of uranium involves much more highly concentrated material and is not bound to rock as it was in its natural state. Weapons material plutonium-239 is produced in nuclear reactors from neutron capture of U-238. Uranium-235 is also a fissile weapons material as well as being used in nuclear fuel. Commercial power light water reactors use 3 to 5 percent U-235 enrichment, the rest being U-238. High enrichment fuels, as high as about 93 percent, are used in the nuclear navy fleet and in research reactors.

Table 1. Natural uranium and depleted uranium mass contribution and radioactivity.

Composition	By mass (%)			By activity (%)			Specific activity of mixture
	U-234	U-235	U-238	U-234	U-235	U-238	Bq/mg
Natural Uranium	0.5E-3	0.72	99.3	48.9	2.2	48.9	25.2
Depleted Uranium	1.0E-3	2.0E-1	99.8	15.5	1.1	83.4	14.8

Bq = Becquerel (disintegrations/second), mg = milligram.

Table 2. Radioactive Properties of Key Uranium Isotopes and Associated Radionuclides

Isotope	Half-Life	Natural Abundance	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
					Alpha	Beta	Gamma
U-234	240,000 yr	0.0055	0.0063	Alpha	4.8	0.013	0.0017
U-235	700 million yr	0.72	0.0000022	Alpha	4.4	0049	0.16
U-238	4.5 billion yr	>99	0.00000034	Alpha	4.2	0.010	0.0014
Tl-231	26 hr		540,000	Beta	-	0.17	0.026
Th-234	23 days		23,000	Beta	-	0.060	00093
Pa-234m	1.2 min		690 million	Beta	-	0.82	0012
Produced in man-made nuclear reactors [a]							
U-232	72 yr	0	22	Alpha	5.3	0.017	0.0022
U-233	160,000 yr	0	0.0098	Alpha	4.8	0.0061	0.0013
U-236	23 million yr	0	0.000065	Alpha	4.5	0.011	0.0016

Ci = curie, g = gram, MeV = million electron volts.

Notes: a.U-236 is made in a nuclear reactor by neutron capture of U-235 — highly enriched fuel, high in U-235 produces more U-236. Plutonium-240 also alpha decays to U-236. U-232 is a side product of the thorium cycle which uses thorium-232 to make U-233, a fissile weapons material analogous to plutonium-239. U-233 is also produced in the neptunium-237 decay series.

Thorium

Weapons material U-233 is produced in thorium cycle reactors from neutron capture of Th-232. Uranium-233 is analogous to plutonium-239. Thorium fuel cycles for weapons material uranium-233 is a waste problem at Department of Energy sites in addition to uranium fuel cycles for weapons material plutonium-239.

Uranium-238 decay product radium-226 and thorium-232 decay product radium-228 each have half-lives greater than one year and are of concern for Department of Energy contamination sites. Radium-226 is the precursor of radon-222. Both Ra-226 and Ra-228 give rise to many additional short-lived radionuclides, resulting in a wide spectrum of alpha, beta and gamma radiations.

Table 3. Radioactive Properties of Key Thorium Isotopes.

Isotope	Half-Life	Natural Abundance	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
					Alpha	Beta	Gamma
Th-232	14 billion yr	>99	0.00000011	Alpha	4.0	0.012	0.0013
Th-230	77,000 yr	<<1	0.020	Alpha	4.7	0.015	0.0016
Th-229	7,300 yr	<<1	0.22	Alpha	4.9	0.12	0.096

Ci = curie, g = gram, MeV = million electron volts.

Table 4. Radioactive Properties of Key Radium Isotopes and Associated Radionuclides.

Isotope	Half-Life	Natural Abundance	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
					Alpha	Beta	Gamma
Uranium-238 decay series from radium-226							
Ra-226	1,600 yr	>99	1.0	Alpha	4.8	0.0036	0.0067
Rn-222	3.8 days		160,000	Alpha	5.5	<	<
Po-218	3.1 min		290 million	Alpha	6.0	<	<
Pb-214	27 min		33 million	Beta	-	0.29	0.25
Bi-214	20 min		45 million	Beta	-	0.66	1.5
Po-214	< sec		330 trillion	Alpha	7.7	<	<,
Pb-210	22 yr		77	Beta	-	0.038	0.0048
Bi-210	5 days		130,000	Beta	-	0.038	0.0048
Po-210	140 days		4,500	Alpha	5.3	<	<
Thorium-232 decay series from radium-228							
Ra-228	5.8 yr	<<1	280	Beta	-	0.017	<
Ac-228	6.1 hr		2.3 million	Beta	-	0.48	0.97
Th-228	1.9 yr		830	Alpha	5.4	0.021	0.0033
Ra-224	3.7 days		160,000	Alpha	5.7	0.0022	0.010
Rn-220	56 sec		930 million	Alpha	6.3	<	<
Po-216	0.15 sec		350 billion	Alpha	6.8	<	<
Pb-212	11 hr		1.4 million	Beta	-	0.18	0.15
Bi-212	61 min		15 million	Alpha, Beta	2.2	0.47	0.19
Po-212 (64 %)	<< 1 sec		180,000 trillion	Alpha	8.8	-	-

Tl-208 (36%)	3.1 min		300 million	Beta	-	0.60	3.4

Ci = curie, g = gram, MeV = million electron volts, < means the radiation energy is less than 0.001 MeV, and a dash means the entry is not applicable.

Transuranics

Along with plutonium-239 production in a nuclear reactor by neutron capture of uranium-238, plutonium-241 is also produced in nuclear reactors. Plutonium-241 decays to americium-241. But Am-241 decays to unstable neptunium-237, so its decay half-life of 430 yrs is misleading. Table 5 presents the half-life and decay mode and energy of a few transuranics, beyond uranium in the chart of the nuclides.

Table 5. Radioactive Properties of Selected Transuranic Radionuclides.

Isotope	Half-Life	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha	Beta	Gamma
Am-241[a]	430 yr	3.5	Alpha	5.5	0.052	0.033
Am-243	7,400 yr	0.20	Alpha	5.3	0.022	0.056
Np-239	2.4 day	230,000	Beta	-	0.26	0.17
Np-237	2.1 million yr	0.00071	Alpha	4.8	0.070	0.035
Pa-233	27 days	21,000	Beta	-	0.20	0.20
Pu-238	88 yr	17	Alpha	5.5	0.011	0.0018
Pu-239	24,000 yr	0.063	Alpha	5.1	0.0067	<0.001
Pu-240	6,500 yr	0.23	Alpha	5.2	0.011	0.0017
Pu-241	14 yr	100	Beta	<0.001	0.0052	<0.001

Ci = curie, g = gram, MeV = million electron volts, a dash means the entry is not applicable, IT = isomeric transition, EC = electron capture.
Note: a. Americium-241 decays to neptunium-237.
For a more complete listing and the transuranic decay series, see https://www.remm.nlm.gov/ANL-ContaminationFactSheets-All-070418.pdf

Drinking Water Maximum Contaminant Levels

A table of federal drinking water maximum contamination levels (MCLs) is given in Table 6, with emphasis more on long-lived radionuclides. For a listing of beta emitter limits in pCi/L to equal 4 mrem/yr for an individual radionuclide, see this table: http://www.iem-inc.com/information/tools/maximum-contaminant-levels-for-water . Tritium, although a beta emitter, is considered separately with MCL 20,000 pCi/L. Gross alpha is limited to 15 pCi/L, excluding uranium, Uranium is limited to 30 micrograms/L, and combined Radium-226/-228 is limited to 5 pCi/L. Non-radiological contaminants are also included in the table.

Table 6. Typical aquifer contaminants of concern at the Idaho National Laboratory.

Constituent	Regulatory maximum contaminant level[1]	Natural background level	Location of Primary Interest[2]
Radionuclide (half-life, main decay mode)			
Tritium (12.3 year, beta)	20,000 pCi/L	0 to 150 pCi/L	INTEC, ATRC, RWMC, TAN, NRF, other areas
Carbon-14 (5730 year, beta)	2,000 pCi/L	0	RWMC
Chlorine-36 (301,000 year, beta)	700 pCi/L	0	RWMC, INTEC
Iodine-129 [3] (17,000,000 year, beta and gamma)	1 pCi/L	0 to 0.0000054 pCi/L (DOE/ID-22225, 2013)	RWMC, INTEC
Technetium-99 (213,000 year, beta)	900 pCi/L	0	RWMC, INTEC 2,200 pCi/L and increasing trend.
Neptunium-237 (2,144,000 year, alpha)	15 pCi/L	0	RWMC
Cesium-137 (30.2 year, beta)	200 pCi/L (previously 160 pCi/L)	0	RWMC, INTEC, ATRC, TAN, MFC
Strontium-90 (29.1 year, beta)	8 pCi/L	0	RWMC, INTEC, ATRC, TAN
Uranium-238 (4,470,000,000 year, mixed, alpha)	10 pCi/L	0	RWMC, TAN, INTEC
Total uranium	(30 ug/L)	<3 pCi/L or < 2 ug/L [7]	RWMC, TAN, INTEC, TRA, NRF
Uranium-234, pCi/L	(Note: 8)	1.36 pCi/L [7]	see total uranium
Uranium-235, pCi/L	(Note: 8)	0.025 pCi/L [7]	see total uranium
Uranium-238, pCi/L	(Note: 8)	0.541 pCi/L [7]	see total uranium
Uranium-233, pCi/L	(Note: 8) from thorium cycle	0	see total uranium
Uranium-236, pCi/L	(Note: 8) from neutron capture in a nuclear reactor	0	see total uranium
Gross alpha [4]	15 pCi/L		
Gross beta/gamma [5]	4 mrem/yr (8 pCi/L derived from 4 mrem/yr based on Sr-90)	7 pCi/L (DOE/ID-11492, 2013)	
Organic Compounds			
Carbon tetrachloride (CCl_4)	5 ug/L	0	RWMC, INTEC
Methylene chloride	5 ug/L	0	RWMC
Tetrachloroethylene (PCE)	5 ug/L	0	RWMC, TAN

Trichloroethylene (TCE)	5 ug/L	0	RWMC, TAN 1350 ug/L
Inorganic Analytes			
Nitrate	10 mg/L	0.655 mg/L from USGS 2016 [9]	INTEC, RWMC, MFC
Chromium	100 ug/L	<1.9 ug/L [10] Hexavalent chromium should be 0	Primarily TRA now ATRC. Also RWMC, TAN, INTEC, PBF, NRF
Sodium	(an indicator of nuclear process waste)	8.3 ug/L from USGS 2016 [9]	1.5 million lb/yr discharged by INL during 1989-1991 at INTEC, ATRC, NRF, CFA, MFC

Units: pCi/L = picocurie/liter; mg/L = milligram/liter; ug/L = microgram/liter; mrem/yr = millirem/yr; lb= pound.

Table Source: Department of Energy, *Operable Unit 7-13/14 Five-Year Monitoring Report for Fiscal Years 2010-2014*, DOE/ID-11507, August 2014, and Idaho Cleanup Project, *Five-Year Review of CERCLA Response Actions at the Idaho National Laboratory*, DOE/NE-ID-11201, Revision 3, February 2007.

Table Notes:

1. Maximum contaminant level from US Environmental Protection Agency for drinking water, 10 CRF 141.
2. Some monitored locations indicated here may apply to perched water rather than the aquifer. RWMC soil sampling is also included.
3. "I-129 is monitored for indirectly by analyzing for Tc-99" at the RWMC superfund site; USGS tends to report I-129 but not Tc-99. USGS monitoring of Tc-99 reported in journal articles rather than accessible USGS reports.
4. Gross alpha includes radium-226 but excludes radon and uranium. The activity of uranium having a natural composition can be estimated from mass in microgram/Liter by multiplying by 0.67 pCi/microgram.
5. Gross beta excludes naturally occurring potassium-40.Gross beta given here is based on strontium-90.
6. Facilities are Advanced Test Reactor Complex (ATRC) formerly the Test Reactor Area and Reactor Technology Complex; Central Facilities Area (CFA); Idaho Nuclear Technology and Engineering Center (INTEC), formerly the Idaho Chemical Processing Plant; Materials and Fuels Complex (MFC) formerly Argonne National Laboratory – West; Naval Reactors Facility (NRF); Power Burst Facility (PBF);Radioactive Waste Management Complex (RWMC); Test Area North (TAN).
7. Uranium background level estimated from USGS report 2016-5056 (DOE/ID-22237) Table 1 values for western tributary, median values for U-234, U-235, and U-238 in picocuries/liter, converted to micrograms/liter by dividing by 0.67 pCi/ug.
8. The uranium limit is for total uranium, the sum of each uranium isotope after converting reported activity (pCi/L) to mass uits (ug/L).
9. Chromium was sampled in the Birch creek area in USGS 2003-4272, off INL site levels below 1.9 ug/L.
10. Nitrate and sodium background level from USGS report 2016-5056 (DOE/ID-22237) Table 1 values for western tributary, median values for U-234, U-235, and U-238 in picocuries/liter, converted to micrograms/liter by dividing by 0.67 pCi/ug.