Irradiated Nuclear Fuel: Scale of Danger to Drinking Water

Nuclear waste poses a real danger to safe drinking water. Most nuclear power plants are located near bodies of water (rivers, lakes, and oceans) because they require large supplies of water for coolant. The most intensely radioactive waste that nuclear power plants produce is the waste fuel rods: irradiated nuclear fuel (often misleadingly called “spent fuel”). Irradiated fuel remains extremely hot and lethally radioactive for hundreds of years, and the radioisotopes within it remain dangerous in the environment for over one million years. It must be stored at the reactor sites until there is a federal repository that could limit it leaking into water as much as possible.

Most of the radionuclides in irradiated fuel are soluble in water--meaning that once they have leaked into a water source, they could easily be ingested by humans, animals, and other aquatic lif. Given the huge quantities of radiation in this waste, and the potential for it to contaminate water sources it is near, the crisis of continued generation and management of nuclear waste is a threat to our access to clean, safe drinking water for generations and millennia to come.

In fact, the amount of radiation in the existing stockpile of irradiated fuel is enough to make every drop of drinking water on Earth too dangerous to drink, many times over.

Liquid Units of Measure

- 1 cubic mile = 1.101 trillion gallons
- 332.5 million cubic miles of water[1] = 366.1 quintillion (10^{18}) gallons of water = 3.661×10^{20} gallons
- 1 gallon = 3.78541 liters
- $3.661\ 10^{20}$ gallons = 1.386×10^{21} liters

Global Quantities of Water

- Freshwater = 2.5% of global water = 3.465×10^{19} gallons
- Drinking water (fresh groundwater + fresh surface water (lakes, rivers, atmosphere)) = 0.76% of global water = 2,551,434 cubic miles = 2.809×10^{18} gallons = 1.063×10^{19} liters

[1] https://www.usgs.gov/special-topic/water-science-school/science/where-earths-water?qt-science_center_objects=0#qt-science_center_objects

Radioisotopes and Drinking Water Standards

- Cs-137 inventory in commercial irradiated fuel (2011)[2] = 4.5 billion (10^9) Ci = 4.5 x 10^{21} pCi
- US EPA Maximum Concentration Limit (MCL) = 200 picoCuries per liter (pCi/l)[3]

Major Beta and Gamma Emitters

Cs-137 4.5 billion Ci (30.17y) = 423.2 pCi/l @ MCL = 200 pCi/l ===> 211% of MCL (2.11 x)
Pu-241 3.2 billion Ci (14y) = 301 pCi/l @ MCL = 300 pCi/l ===> 100% of MCL (1 x)
Sr-90 3.0 billion Ci (28.8y) = 282.2 pCi/l @ MCL = 8 pCi/l ===> 3528% of MCL (35.3 x)

Major Alpha Emitters

Am-241 220 million Ci (430y) = 20.70 pCi/l @ MCL = 15 pCi/l ===> 138% of MCL (1.4 x)
Pu-238 240 million Ci (88y) = 22.58 pCi/l @ MCL = 15 pCi/l ===> 151% of MCL (1.5 x)
Pu-239 24 million Ci (24ky) = 2.26 pCi/l @ MCL = 15pCi/l ===> 15.1% of MCL (0.15 x)
Pu-240 36 million Ci (6500y) = 3.39 pCi/l @ MCL = 15 pCi/l ===> 22.6% of MCL (0.23 x)

TOTAL: 4272.3% of combined MCL for alpha-, beta-, and gamma-emitting radioisotopes.

Increase in commercial irradiated fuel inventory (2010-2020) = ~132%

[2] Alvarez, Robert. *Spent Nuclear Fuel Pools in the U.S.: Reducing the Deadly Risks of Storage.* Institute for Policy Studies. May 2011. Washington, DC.
[3] U.S. Environmental Protection Agency. “Radionuclides in Drinking Water: A Small Entity Compliance Guide.” February 2002. https://www.epa.gov/reg-flex/radionuclides-drinking-water-small-entity-compliance-guide-february-2002

Radionuclides in U.S. Commercial Irradiated Fuel (2010)

Radionuclide	Half-Life (years)	Curies (Ci)	Decay Mode	MCL (pCi/l)	Concentration (pCi/l)	% of MCL	Half-Lives @ 500yrs	% MCL @ 500yrs	Half-Lives @ 1,000 yrs	% MCL @ 1,000yrs
Actinium-227	2.2	1	beta		9.40734E-08		227.2727		454.5454545	
Americium-241	430	220,000,000	alpha	15	20.69614299	138.0%	1.162791	61.6%	2.325581395	27.5%
Americium-242/242m	140	1,600,000	alpha	15	0.150517404	1.0%	3.571429	0.1%	7.142857143	0.0%
Americium-243	7,400	1,900,000	alpha	15	0.178739417	1.2%	0.067568	1.1%	0.135135135	1.1%
Antimony-125	2.8	3,600,000	beta	300	0.338664158	0.1%	178.5714	0.0%	357.1428571	0.0%
Cadmium-133m	14	1,500,000			0.141110066		35.71429		71.42857143	
Carbon-14	5,700	95,000	beta	2,000	0.008936971	0.0%	0.087719	0.0%	0.175438596	0.0%
Cesium-134	2.1	5,800,000	beta	80	0.545625588	0.7%	238.0952	0.0%	476.1904762	0.0%
Cesium-135	2,300,000	36,000	beta	900	0.003386642	0.0%	0.000217	0.0%	0.000434783	0.0%
Cesium-137	30	4,500,000,000	beta	200	423.3301976	211.7%	16.66667	0.0%	33.33333333	0.0%
Chlorine-36	30,000	750	beta	700	7.0555E-05	0.0%	0.016667	0.0%	0.033333333	0.0%
Colbalt-60	5.3	27,000,000	beta	100	2.539981185	2.5%	94.33962	0.0%	188.6792453	0.0%
Curium-242	0.5	1,300,000	alpha	15	0.12229539	0.8%	1000	0.0%	2000	0.0%
Curium-243	29	1,300,000	alpha	15	0.12229539	0.8%	17.24138	0.0%	34.48275862	0.0%
Curium-244	18	120,000,000	alpha	15	11.28880527	75.3%	27.77778	0.0%	55.55555556	0.0%
Curium-245	8,500	29,000	alpha	15	0.002728128	0.0%	0.058824	0.0%	0.117647059	0.0%
Curium-246	4,800	6,300	alpha	15	0.000592662	0.0%	0.104167	0.0%	0.208333333	0.0%
Europium-154	8.6	120,000,000		60	11.28880527	18.8%	58.13953	0.0%	116.2790698	0.0%
Europium-155	4.8	22,000,000		600	2.069614299	0.3%	104.1667	0.0%	208.3333333	0.0%
Hydrogen-3	12.3	10,200,000		20000	0.959548448	0.0%	40.65041	0.0%	81.30081301	0.0%
Iodine-129	17,000,000	2,400		1	0.000225776	0.0%	2.94E-05	0.0%	5.88235E-05	0.0%
Iron-55	2.7	420,000		2,000	0.039510818	0.0%	185.1852	0.0%	370.3703704	0.0%
Krypton-85	10.7	150,000,000	beta		14.11100659		46.72897		93.45794393	
Neptunium-237	2,100,000	30,000	alpha	15	0.002822201	0.0%	0.000238	0.0%	0.00047619	0.0%
Nickel-59	76,000	160,000	beta	300	0.01505174	0.0%	0.006579	0.0%	0.013157895	0.0%
Nickel-63	100	22,000,000	beta	50	2.069614299	4.1%	5	0.1%	10	0.0%
Niobium-93m	16	110,000	beta	1,000	0.010348071	0.0%	31.25	0.0%	62.5	0.0%
Niobium-94	24,000	56,000	gamma		0.005268109		0.020833		0.041666667	
Palladium-107	6,500,000	8,800	beta		0.000827846		7.69E-05		0.000153846	
Plutonium-238	88	240,000,000	alpha	15	22.57761054	150.5%	5.681818	2.9%	11.36363636	0.1%
Plutonium-239	24,000	24,000,000	alpha	15	2.257761054	15.1%	0.020833	14.8%	0.041666667	14.6%

Radionuclide	Half-Life (years)	Curies (Ci)	Decay Mode	MCL (pCi/l)	Concentration (pCi/l)	% of MCL	Half-Lives @ 500yrs	% MCL @ 500yrs	Half-Lives @ 1,000 yrs	% MCL @ 1,000yrs
Plutonium-240	6,500	36,000,000	alpha	15	3.38664158	22.6%	0.076923	21.4%	0.153846154	20.3%
Plutonium-241	14	3,200,000,000	beta	300	301.0348071	100.3%	35.71429	0.0%	71.42857143	0.0%
Plutonium-242	380,000	140,000	alpha	15	0.013170273	0.1%	0.001316	0.1%	0.002631579	0.1%
Promethium-147	2.6	18,000,000		600	1.69332079	0.3%	192.3077	0.0%	384.6153846	0.0%
Protactinium-231	33,000	2	alpha	15	1.88147E-07	0.0%	0.015152	0.0%	0.03030303	0.0%
Rutherium-106	1	4,700	beta	30	0.000442145	0.0%	500	0.0%	1000	0.0%
Samarium-151	90	25,000,000	beta	1,000	2.351834431	0.2%	5.555556	0.0%	11.11111111	0.0%
Selenium-79	64,000	30,000	beta		0.002822201		0.007813		0.015625	
Strontium-90	29	3,000,000,000	beta	8	282.2201317	3527.8%	17.24138	0.0%	34.48275862	0.0%
Technetium-99	210,000	950,000	beta	900	0.089369708	0.0%	0.002381	0.0%	0.004761905	0.0%
Thorium-230	75,000	18	alpha	15	1.69332E-06	0.0%	0.006667	0.0%	0.013333333	0.0%
Tin-126	1,000,000	59,000	gamma		0.005550329		0.0005		0.001	
Uranium-232	69	2,600	alpha	660,000,000	0.000244591	0.0%	7.246377	0.0%	14.49275362	0.0%
Uranium-233	69	4	alpha	294,000	3.76294E-07	0.0%	7.246377	0.0%	14.49275362	0.0%
Uranium-234	250,000	84,000	alpha	189,000	0.007902164	0.0%	0.002	0.0%	0.004	0.0%
Uranium-235	720,000,000	1,000	alpha	66	9.40734E-05	0.0%	6.94E-07	0.0%	1.38889E-06	0.0%
Uranium-236	23,000,000	18,000	alpha	1950	0.001693321	0.0%	2.17E-05	0.0%	4.34783E-05	0.0%
Uranium-238	4,500,000,000	20,000	alpha	10.2	0.001881468	0.0%	1.11E-07	0.0%	2.22222E-07	0.0%
Zirconium-93	1,500,000	160,000	beta	2,000	0.01505174	0.0%	0.000333	0.0%	0.000666667	0.0%
TOTAL (2010)		**11,753,623,575**				**4272.3%**		**102.4%**		**63.8%**
TOTAL (2020, Est. @ +31.7%)		15,484,932,646				5628.6%		134.9%		84.0%