Nuclear proliferation through coal burning

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Health costs of energy sources to miners

Injury costs to individuals per year

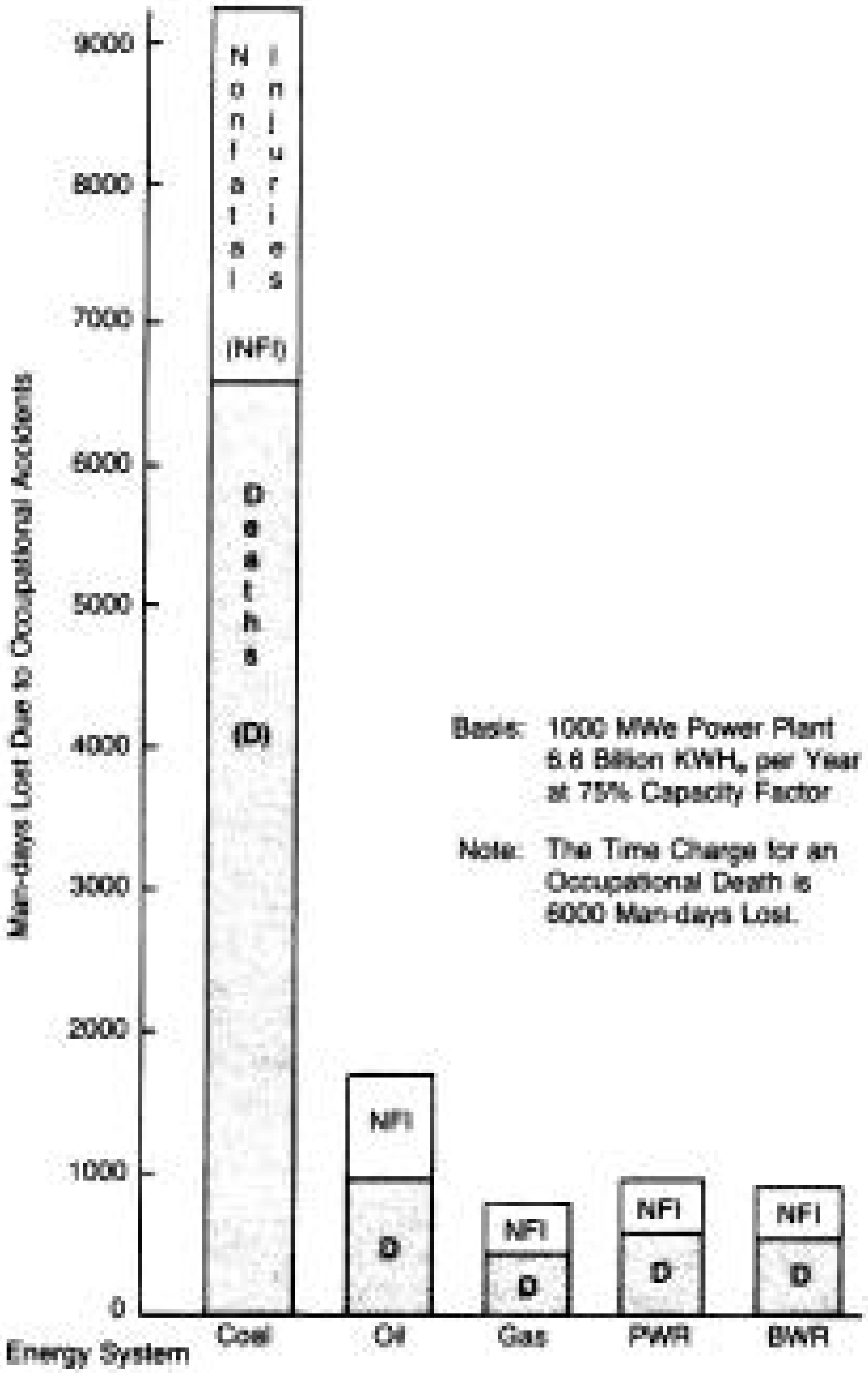
Activity	Persons Involved (number)	Injury Cost ($)	Annual Cost per Person ($)
Uranium mining, milling	620	463,200	747.09
Manufacturing	33,724	1,519,300	45.00
Reactor operations	1290	81,800	63.00
Reprocessing	800	91,720	115.00
Public near reactor	33,841,000	19,410	0.0004
Total U. S.	200,000,000	2,175,520	0.10

Risks to individual workers per GWyr of nuclear energy

Activity	Accidents (not radiation related)	Radiation related (cancers and genetic)	Total	Injuries (days off)
Uranium mining, milling	0.173	0.001	0.174	330.5
Fuel processing, reprocessing	0.048	0.040	0.088	5.6
Design, manufacture of reactors, instruments, etc.	0.040		0.040	24.4
Reactor operation, maintenance	0.037	0.107	0.144	158
Waste disposal		0.0003	0.0003	
Transport of nuclear fuel	0.036	0.010	0.046	
Totals	0.334	0.158	0.492	518

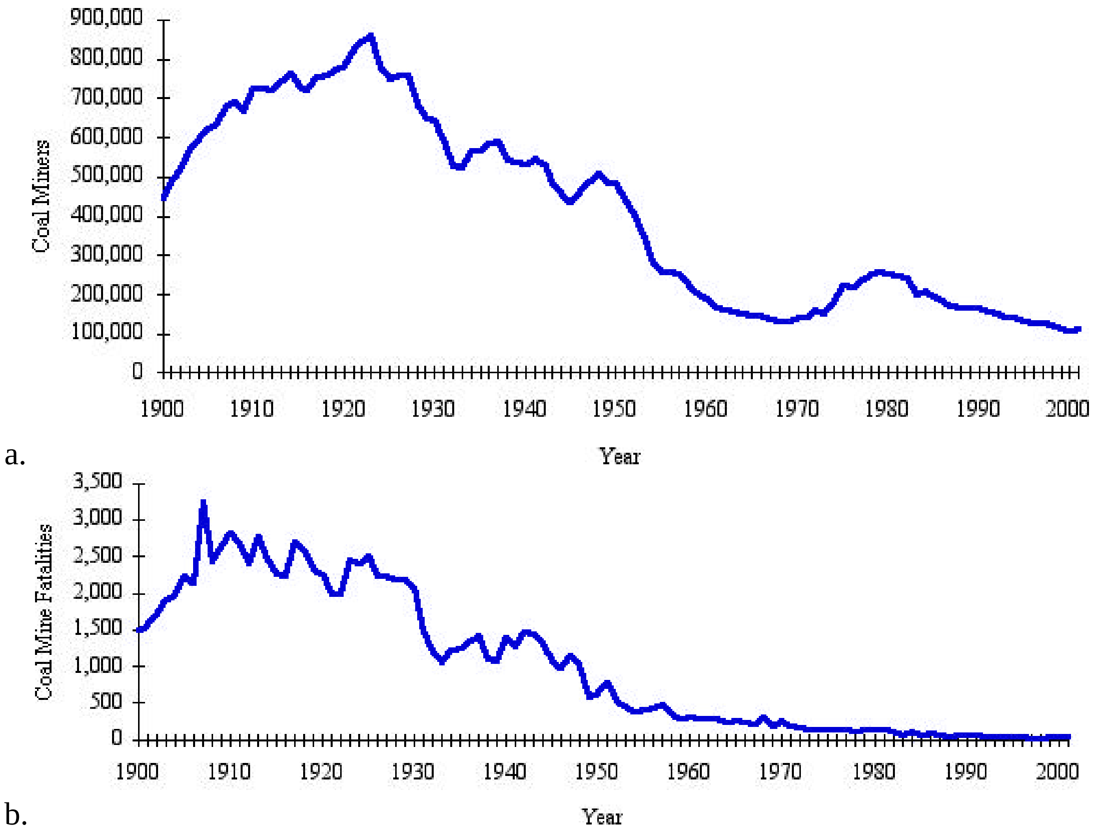
Summary of nuclear health risks per GWyr of nuclear energy

Source	Fatalities	Days lost
Sagan	0.390	1022
Rose	0.492	513
Hub et al.	0.952	373
AEC	0.161-0.364	

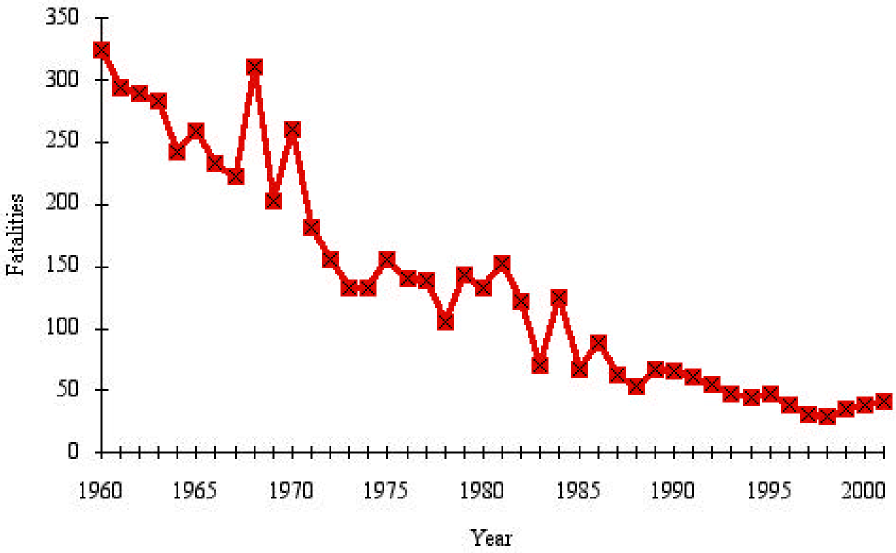


Person-days lost per MWyr over the lifetime of various energy generating system. Source: U.S. Atomic Energy Commission

For coal miners from 1900 to 2001, the death rate from coal mining is 4×10^{-4} per miner per year (67 deaths per year averaged from 1980 to 2001 out of the average number of miners, 166,000).



a. Annual number of coal miners, 1900-2001.
b. Coal miner annual fatalities, 1900-2001.
Source: U.S. Department of Labor, Mine Safety and Health Administration



Larger-scale annual coal miner fatalities, 1960-2001, enlarged from above.
Source: U.S. Department of Labor, Mine Safety and Health Administration

Coal mining claimed 0.33 deaths per Mt and coal processing 0.019 deaths per Mt; the number of disabling injuries is 25 per Mt in mining and 1.2 per Mt in processing.

Health costs to bystanders from coal and nuclear electricity

Burning coal produces huge volumes of waste gases, some part of which, still a huge volume, power plants then emit. Included among these gases is carbon dioxide, which we learned appears to be changing our climate. Climate change will have effects on health, but these are more subtle than the effects on buildings and people from particulates and sulfur and nitrogen oxides. I hope you went to my talk on global warming last evening.

Nuclear plants under normal operation emit very small quantities of a few gases. None of the gases pose a direct threat to health or property of the sort that is attributable to coal-fired plants. Of course, nuclear plant gases may contain small amounts of radioactivity. How does this differ from coal plants?

Several analyses show that coal-fired plants can release substantial radioactivity. J. P. McBride, R. E. Moore, J. P. Witherspoon, and R. E. Blanco, "Radiological impact of airborne effluents of coal and nuclear plants," ***Science*** **202**, 1045 (1978).

How can that be? All fossil fuel contains radioisotopes. Radiation comes with all deep-Earth minerals, and the radioactive decay chains exist in secular equilibrium in the rock—including coal. The amount of uranium and thorium isotopes in coal is greatly variable, but an analysis of suggests that 1 μmol/mol (1 ppm) and μmol/mol (2 ppm), respectively, for these is representative. Since the coal fired plant (operating at 80% capacity) produces electricity from 674,000 tonnes of coal, we find 2.32 million kg/MWyr, and calculate that 2.32 kg/MWyr of uranium and 4.64 kg/MWyr of thorium will be released, even assuming only 1% coal ash in the smoke (10% was more typical at the time of the study). The conclusion was that Americans living near coal-fired power plants are exposed to higher radiation doses, particularly bone doses, than those living near nuclear power plants that meet government regulations.

The EPA found slightly higher average coal concentrations than used by McBride et al. of 1.3 ppm and 3.2 ppm, respectively. Gabbard (A. Gabbard, “Coal combustion: nuclear resource or danger?,” *ORNL Review* **26**, http://www.ornl.gov/ORNLReview/rev26-34/text/colmain.html.) finds that American releases from each typical 1 GW_e coal plant in 1982 were 4.7 tonnes of uranium and 11.6 tonnes of thorium, for a total national release of 727 tonnes of uranium and 1788 tonnes of thorium. The total release of radioactivity from coal-fired fossil fuel was 97.3 TBq (9.73×10^{13} Bq) that year. This compares to the total release of 0.63 TBq (6.3×10^{11} Bq) from the notorious TMI accident, 155 times smaller.

The National Council on Radiation Protection and Measurements (NCRP) similarly found that population exposure from operation of comparable (1 GW_e) nuclear and coal-fired power plants was 4.9 person-Sv/yr for coal plants and 4.8×10^{-2} person-Sv/yr for nuclear plants, a factor of ~100 greater for the coal-fired plants.

A single 1 GW_e coal-fired plant causes 25 fatalities, 60,000 cases of respiratory disease, and $12 million in property damage, as well as emitting an amount of NO_x equivalent to 20,000 cars per year. It also produces ashes and sludge.

One physicist, Bernard Cohen, went further in analyzing probabilistically the risks of coal-fired and nuclear plants. Examples of non-radioactive carcinogens include beryllium (as an example, EPA death risk estimate ~ 5.3×10^{-6}/kg ingested), arsenic, cadmium, chromium, and nickel.

Cohen calculates the effect of their release by following the chain that leads to deaths: transfer from ground to stomach,

$$\sim 1000 \text{ kg/yr} = 1.2 \times 10^{-5} \text{ g/d} \times 365 \text{ d/yr} \times 2.6 \times 10^{8} \text{ people;}$$

transfer from ground to oceans,

$$\sim 1.9 \times 10^{6} \text{ kg/yr}$$
$$= 1 \times 10^{12} \text{ soil kg/yr} \times 1.9 \times 10^{-6} \text{ kg of Be per kg of soil.}$$

This takes place over a period of about 100,000 yr, assuming the soil is the top 5 meters and it takes about 22,000 yr to erode a meter of soil. Now, the probability that a beryllium atom in the ground enters the stomach before reaching the oceans is just 1000 kg/yr/(1.9×10^{6} kg/yr) = 5.4×10^{-4}. Therefore, the number of deaths per tonne of beryllium released that get into the top 5 meters of soil is

$$\text{Deaths} = (5.3 \times 10^{-6}/\text{kg}) \times (1000 \text{ kg/t}) \times (5.4 \times 10^{-4}) = 2.9 \text{ deaths/t Be.}$$

So, given that there is a release of 4.5 tonnes of Be/GWyr, Cohen finds

Deaths from beryllium
= (2.9 deaths/t Be) (4.5 t Be/GWyr) = 13 /GWyr.

Similarly, he is able calculate the risks for each of the carcinogens, finding

Deaths from arsenic = 10 /GWyr,
Deaths from cadmium = 20 /GWyr,
Deaths from chromium = 7 /GWyr,
Deaths from nickel = 1.4 /GWyr.

Overall, then, Cohen identified roughly 50 deaths per GWyr from non-radioactive carcinogens in the effluent of coal-fired plants.

The release of low-level wastes from nuclear reactors leads, by a similar chain of reasoning, to 0.0004 deaths per GWyr. Of course, there are about one hundred GW nuclear reactors generating electricity, so the overall risk of nuclear energy is about 0.04 deaths.

How much would it cost to reduce the risk further?

Nuclear proliferation from coal burning

Given that so much crud is coming from coal stacks, it must be no surprise that there is activity in other coal effluent as well.

Gabbard (see above) also points out that the fly ash collected at coal-fired plants is low-level waste that would be strictly regulated at a nuclear reactor. An unsettling thing is that waste fly ash from coal-fired electricity is often turned into building material such as cinder block, which can then be used in homes. The major exposure pathway for activity is building materials made out of wastes from coal burning: the estimate is a maximum individual dose at 120 μSv/yr. The average yearly dose is 3.6 mSv, so 120 μSv/yr is relatively small, but if the linear no-threshold dose relation is correct, it still causes additional health consequences.

If a nuclear reactor released the same quantity of radioactive waste in fly ash that a coal-fired plant does, there would likely be national protests.

This waste stream contains so much activity that “[i]n a few year’s time, the recovery of the uranium-235 released by coal combustion from a typical utility anywhere in the world could provide the equivalent of several World War II-type uranium-fueled weapons.” The popular press has also noticed this point: “A coal plant releases about 74 pounds of uranium-235 each year, enough for two or more nuclear bombs.” (D. R. Francis, “Energy study gives black marks to coal, boost to nukes,” *The Christian Science Monitor*, 29 May 2001.)

Gabbard also mentions that neutrons in air can breed plutonium-239 and thorium-233 from uranium-238 and thorium-232. This is worrisome both because extremely small amounts of plutonium-239 and plutonium-240 are extremely toxic and because it offers the opportunity for rogue nations to mine the wastes for fissionable uranium, plutonium, and thorium that could then be turned into bombs.

And, because coal fly ash is so ubiquitous, no one would know it was happening until too late. It wouldn’t have to be an obvious case like North Korea!

Draft Environmental Impact Statement for the JEA Circulating Fluidized Bed Combustor Project

Fossil fuels and limestone contain trace quantities of naturally occurring radionuclides, primarily uranium-238, thorium-232, and their decay products. During the burning of fossil fuels, inert material either falls to the bottom of the combustor as bottom ash or becomes entrained in the gaseous combustion products as fly ash. This ash contains radionuclides originally present in the fuel and/or limestone. Fly ash not captured by pollution control equipment is emitted into the atmosphere as particulate matter. In addition, two radioactive noble gases, radon-220 and radon-222, are emitted from the combustor as gases. The quantities of naturally occurring radionuclides vary according to fuel type and its geographical location; coal typically contains the greatest total quantity per unit mass.

For a proposed facility very similar to the proposed project, detailed dose pathway analyses were performed for radionuclides in coal and limestone using two different approaches: measurement of radioactive species at an operating plant (Weston 1995) and calculations based on coal analysis coupled with emission factors (DOE 1995). The estimated radionuclide emission rates for the similar facility were approximately 10 times greater than the estimated radionuclide emission rates of 6 mCi/year for the proposed project. Not including radon gas, a lifetime cancer risk to the maximum exposed person in a range of 2 in 10 million (2×10^{-7}) to 2 in 1 million (2×10^{-6}) was obtained using the two approaches. Given that emissions from the proposed project would be about 10 times lower and that typical risks would be proportionally lower, the lifetime cancer risk for the maximum exposed person would be in the range of 2 in 100 million (2×10^{-8}) to 2 in 10 million (2×10^{-7}).

Because radon is a noble gas that is not captured in particulate filters, it is often treated separately. Using an upper limit for radon of approximately 175 mCi/yr (DOE 1995) and an estimated dilution at the location of maximum exposure of about 6×10^{-9} s/m^3 (the ratio of the maximum annual ground level concentration in the ambient air calculated by the ISCST3 air dispersion model to the air emission rate), the dose is estimated to be approximately 3×10^{-4} μrem per year, which is a lifetime risk of 1 in 100 billion (1×10^{-11}) (ICRP 1991).

“Trace quantities of uranium in coal range from less than 1 part per million (ppm) in some samples to around 10 ppm in others. Generally, the amount of thorium contained in coal is about 2.5 times greater than the amount of uranium. For a large number of coal samples, according to Environmental Protection Agency figures released in 1984, average values of uranium and thorium content have been determined to be 1.3 ppm and 3.2 ppm, respectively.”

Releases:

0.00427 mCi/ton
= 158 Bq/tonne

“according to NCRP Reports No. 92 and No. 95, population exposure from operation of 1000-MWe nuclear and coal-fired power plants amounts to 490 person-rem/yr for coal plants and 4.8 person-rem/yr for nuclear plants.”

For the year 1982, assuming coal contains uranium and thorium concentrations of 1.3 ppm and 3.2 ppm, respectively, each typical plant released 5.2 tons of uranium (containing 74 pounds of uranium-235) and 12.8 tons of thorium that year. Total U.S. releases in 1982 (from 154 typical plants) amounted to 801 tons of uranium (containing 11,371 pounds of uranium-235) and 1971 tons of thorium. These figures account for only 74% of releases from combustion of coal from all sources. Releases in 1982 from worldwide combustion of 2800 million tons of coal totaled 3640 tons of uranium (containing 51,700 pounds of uranium-235) and 8960 tons of thorium.

Based on the predicted combustion of 2516 million tons of coal in the United States and 12,580 million tons worldwide during the year 2040, cumulative releases for the 100 years of coal combustion following 1937 are predicted to be:

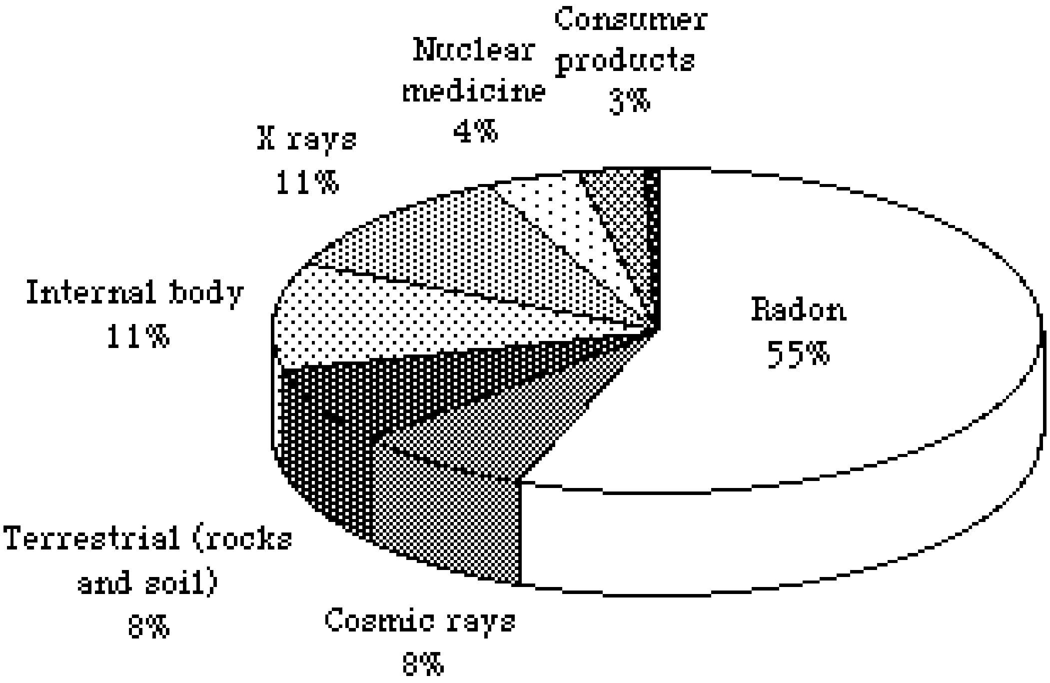
U.S. release (from combustion of 111,716 million tons):

Uranium: 145,230 tons (containing 1031 tons of uranium-235)
Thorium: 357,491 tons

Worldwide release (from combustion of 637,409 million tons):

Uranium: 828,632 tons (containing 5883 tons of uranium-235)
Thorium: 2,039,709 tons

Exposure of the U.S. population to ionizing radiation.



	Radiation doses U.S. Average Personal Dose (mSv)	Total Dose (10^3 person Sv/yr)
Radon	2.00	500
Cosmic rays	0.27	68
Terrestrial (rocks and soil)	0.28	70
Internal body	0.40	100
X rays	0.39	97
Nuclear medicine	0.14	35
Consumer products	0.10	25
Occupational	<0.01	
Fallout	<0.01 (0.04 [1963])	10-16
Nuclear fuel cycle	<0.01	0.56
Weapons development	<0.01	1.65×10^{-3}

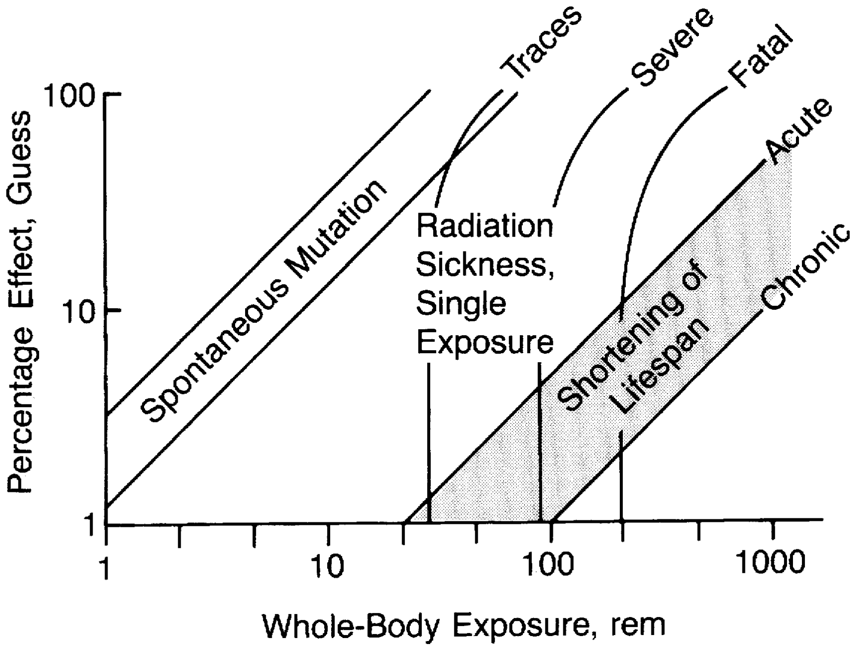
Total ~ 3.5 mSv ~ 18 DARI

Health Effects of Radiation

	Maximum Chance of Early Death/mSv/ million People	Average Shortening of Life (days/mSv/ million people)
leukemia	230	2
lung	250	6.4
stomach	120	0.65
alimentary canal	40	0.073
pancreas	40	0.073
breast	290	0.62
bone	50	0.29
thyroid	100	0.062
other	200	1.1

Source: Adapted with permission from R. L. Gotchy, "Estimation of life shortening resulting from radiogenic cancer per rem of absorbed dose," *Health Physics* **35**, 563 (1978). Copyright 1978 by Pergamon Journals, Ltd.

Effect of whole-body exposure to ionizing radiation.
Source: U.S. Atomic Energy Commission



1 rem = 10 mSv = 20 DARI

Several types of radioactive waste:

1. *Spent fuel* (high level).

A total of about 100 tonnes of offloaded fuel is generated every year, all kept in pools at nuclear plants or in dry casks that are on site. The production of this waste is 30 tonnes/GW_e/yr ≈ 20 m^3/GW_e/yr.(92)

2. *High-level wastes* (high level).

About 3000 tonnes of commercial waste is stored at a former reprocessing facility in West Valley, New York. About 120,000 tonnes of defense wastes is stored at Hanford Reservation, Richland, Washington.(92)

3. *Low-level wastes* (not spent fuel, high level wastes, or uranium mill tailings).

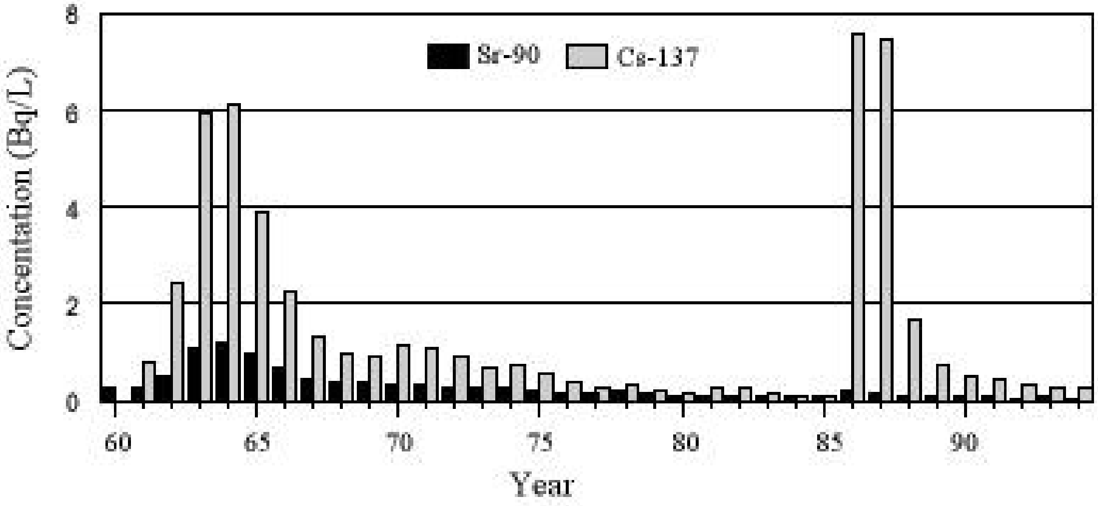
About 4×10^4 m^3 of commercial wastes were produced in 1988. Of this, 2.3×10^4 m^3, or 57%, were produced by utilities. These wastes are transferred for shallow burial in Richland, Washington; Beatty, Nevada; or Barnwell, South Carolina. The defense low-level wastes are buried at national labs.(92)

4. *Transuranic wastes* (> 37 Bq/g activity, Z > 92).

The defense industry produced 7000 m^3, which is supposed to go to the Waste Isolation Pilot Project.(92)

5. *Uranium mill tailings* (low concentrations, lots of ^{230}Th).

A lot of tailings are produced each year by the uranium mining industry, about 75 Mt, with an activity of 18.5 PBq.(92)



Activity in milk in Germany. Increases due to fallout from weapons testing and Chernobyl are apparent. Natural levels may be assumed to be the same as between 1980 and 1985.
Source: Umweltbundesamt, *Daten zur Umwelt* (Erich Schmidt Verlag, 1998), Fig. 11.21

“[From the] estimated total [release] in the year 2040 (2516 million tons), the total expected U.S. radioactivity release to the environment by 2040 can be determined. That total comes from the expected combustion of 111,716 million tons of coal with the release of 477,027,320 millicuries [7/5 x 10^{10} Bq] in the United States. Global releases of radioactivity from the predicted combustion of 637,409 million tons of coal would be 2,721,736,430 millicuries [4.3 x 10^{11} Bq].”

Quotes are from A. Gabbard, “Coal combustion: Nuclear resource or danger?,” ORNL Report, *ORNL Review* **26**, 1 (1987).

http://www.ornl.gov/ORNLReview/rev26-34/text/colmain.html.