Proliferation of nuclear weapons through use of coal-fired electricity?

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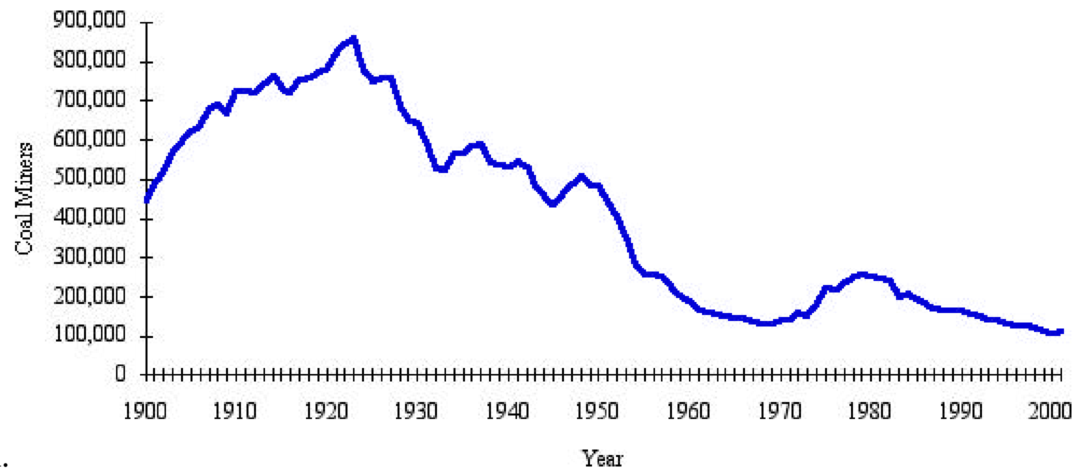
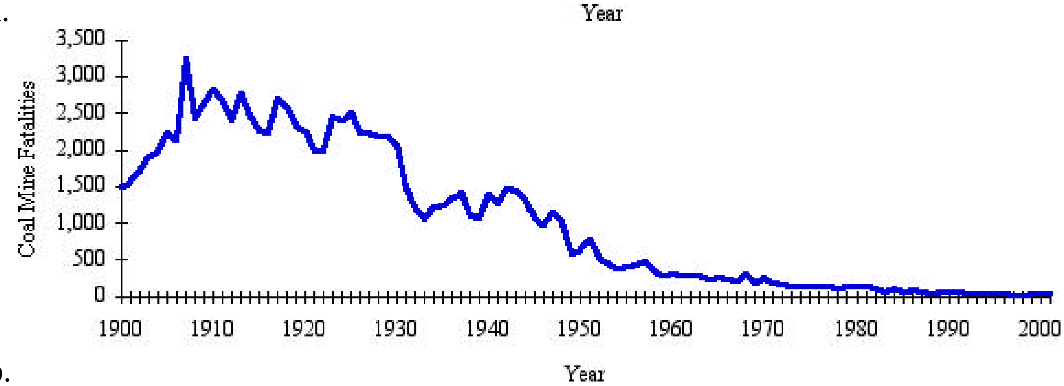
It is not universally known that coal-fired electricity generation leads to emissions of activity that would be banned in a nuclear generator. Even less well known is the amount of activity that can be amassed from the fly ash that remains after burning the coal. We relate here some of these lesser-known consequences of reliance on coal for generation of electrical energy.

Coal mining is dangerous to miners

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.



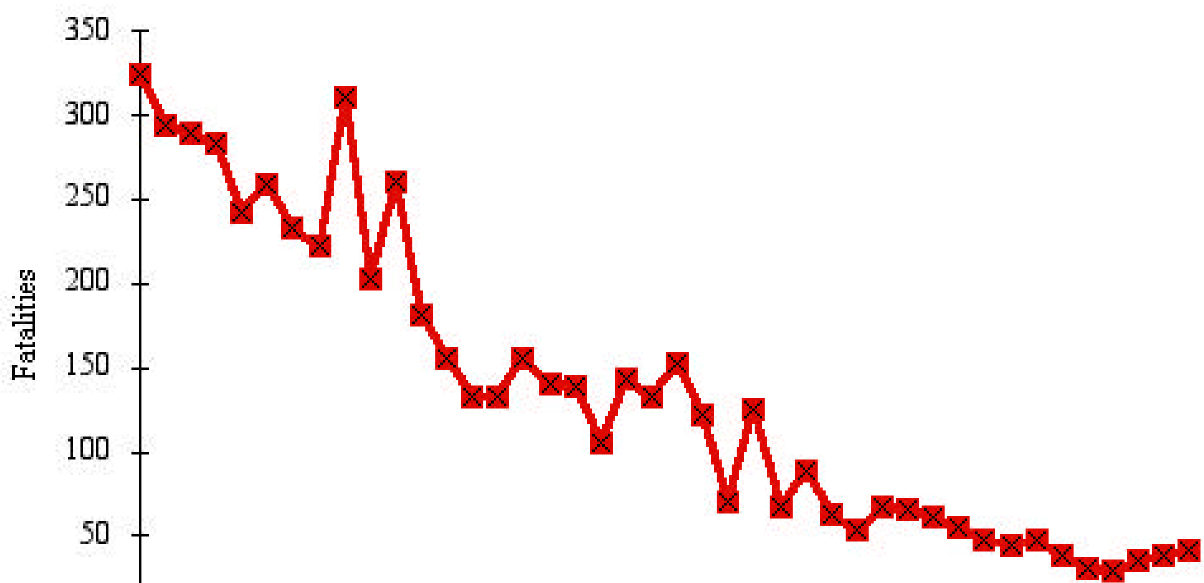
a.



b.

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



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 to the atmosphere: NO_x, SO_2, Hg, etc. Included among these gases is carbon dioxide, which we have learned appears to be changing our climate. Climate change will have effects on health, but these are indirect, more subtle than the effects on buildings and people from particulates and sulfur and nitrogen oxides.

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.

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 sedimentary 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 2 μmol/mol (2 ppm), respectively, for these is representative. Since a 1 GW coal fired plant (operating at 80% capacity) produces electricity from burning 674,000 tonnes of coal per year, 2.32 million kg of gases /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.

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).

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.

Since about two orders of magnitude of activity more than nuclear plants is released by coal-fired plants, the release of radioactivity from coal would lead to about 0.05 deaths per gigawattyear, four orders of magnitude lower than the risk from chemical carcinogens.

How much would it cost to reduce the risk further?

You can see that the danger to health of nuclear emissions from coal-fired electricity generation is *trivial* compared to the danger to health from the other emissions of a coal-fired plant!

The point is not that the American population is so endangered from radioactivity released from coal-fired plants—our health is not greatly endangered compared to the problems caused by other health hazards ... among them SO_2, NO_x, and particulates smaller than 2.5 μm in diameter.

The point is that *even for the release of radioactivity*, *coal-fired energy is more hazardous by far (two orders of magnitude) than nuclear electricity*.

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 (reference above) also points out that the fly ash collected at coal-fired plants is low-level waste that would be strictly regulated if it came from a nuclear reactor. One unsettling fact is that waste fly ash from coal-fired electricity is often turned into building material such as cinder block, which can then be used to build 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 that a coal-fired plant does in fly ash, there would likely be national protests.

“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.” (Gabbard, op. cit.)

Releases:

4.27 μCi/ton

= 158 becquerel per 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 from coal combustion between 1937-2037 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

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 in the fly ash. 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.

Because coal fly ash is such a ubiquitous byproduct, no one might know it was happening until too late. It wouldn't have to be an obvious case like North Korea!