Science Fact

Taming the Genie: How Fear of the Atom Threatens Our Future

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On March 11, 2011, a magnitude 9 earthquake heaved up the seafloor 70 kilometers east of the Tōhoku region of Japan. Within an hour, tsunami waves rolled ashore, reaching up to 40 meters high and 10 kilometers inland. Carpets of black brine scoured away idyllic Japanese villages. Untended fires inked infernal skies over urban and industrial ruins. The world responded with sympathy and compassion, but also, somewhat irrationally, with fear.

All throughout Japan, nuclear plants had shut down safely, but at Fukushima Daiichi, mid-way between Tōhoku and Tokyo, a 15-meter tidal surge had disabled cooling to four 1970s-era reactors. Operators were forced to pump in seawater in an attempt to prevent a meltdown. Hydrogen gas explosions wracked the plant. The spent fuel storage facility sprang a leak, raising fears that spent fuel might overheat and catch fire. Self-styled journalists took to the Internet with pronouncements of doom from Japan to the South Pacific to even the US West Coast. Alarmist memes went viral. Even Europe's energy commissioner chimed in,[1] calling the situation "an apocalypse." Soon, Japanese leaders were contemplating a step back from nuclear power and with it, their sixty-year drive toward reduced foreign energy dependency. This, though not one of the eighteen thousand people killed by the Tōhoku earthquake and its aftermath had succumbed to radiation.

Fifty years after daring to walk on another world, how have we become so skittish? Whatever happened to the nuclear genie in the old Disney film[2] who with one hand promised clean, abundant energy and with the other, a new era of peace and progress? How could he let us down?

Well, he hasn't—far from it. Despite Three Mile Island, Chernobyl, and Fukushima, more people die every year on American construction sites[3] than in all the world's nuclear accidents to date. Compare this to the twenty-one thousand Americans killed by exposure to natrually occurring radon each year, the thirty-six thousand killed in traffic accidents,[5] or the two hundred thousand or so prematurely killed by air pollution.[6]

Life is full of risks, and modern life brings technical dangers that lurk like hidden bogey men. But real risks must be evaluated in context of the real world. Three Mile Island released 43,000 curies of radiation into the environment[7], but that same year, American coal power released 150 times that much[8]. The Fukushima cleanup will take decades, but not as many as restoration of the Upper Clark Fork Basin in Montana, still poisoned by heavy metals from open pit smelting over a century ago. Pripyat, near Chernobyl, is a ghost town, but so is Centralia, Pennsylvania, afflicted by an underground coal seam fire, examples of which can burn for *millennia*.

Meanwhile, experts calculate that clean nuclear power has prevented 1.8 million air pollution-related deaths and will save another 7 million over the next half century.[9] That's to say nothing of all the millions saved by nuclear medicine and research, or reductions to greenhouse gas emissions. The genie's got our back.

At Fukushima and Chernobyl, mistakes were made that should never have been permitted and ought never be repeated, but it's not as if these plants were misbegotten toys. Energy isn't just an expensive luxury that fowls the air to keep SUVs and air conditioners humming. Almost a third of US energy[10] goes to the chemical industry—everything from nylon to Portland cement, aspirin to life saving streptokinase. A tenth is used—even today—to make paper (including toilet paper). Another tenth is used in refining metals. Over six percent is used directly in food production. Without mountains of fertilizer, without today's pesticides, defoliants, and our energy-hungry distribution systems, we simply could not feed the over seven billion people now on the planet.[11]

Energy is the lifeblood of civilization. It's the heart of industry, the spirit of innovation, the currency that buys our standard of living and pays for "the general welfare." It buys more than that, too. Niven and Pernoulle tell us "a civilization has the ethics it can afford,"[12] and they're absolutely right. It was coal and industrialization, lest we forget, that ended the slave trade, not some newfound human nobility. Energy pays the price of freedom. It buys peace, too. Before we start chanting "remember Fukushima," we might do well to remember Pearl Harbor.

To the Japanese, WWII was a battle for energy. When Japan occupied French Indochina in July of 1941, the US, Britain, and the Netherlands responded with an oil embargo, forcing the Japanese to fall back on reserves. Japan hoped a decisive strike would cripple the US fleet and free them to seize Singapore and the rich oil fields of the Dutch East Indies and Borneo. It worked too, but once we recovered enough to deprive them of their prize, the war, in strategic terms, was over. By the end, the Japanese were distilling fuel from pine sap.

Then came the great post-war Japanese economic miracle. Japan grew into a manufacturing and technical powerhouse out of all proportion to its size and resources. Nuclear power was a big part of that, providing stable base generation and buffering the economy from fickle world markets and political instability. That freed the business community to invest in Japan's future with a measure of protection from the dozen odd energy-related crises and shocks that have struck since 1970[13] of which the 1973 Arab oil embargo is just one example.

Energy is everything, and base generation from stable, reliable, industrial-scale sources is like bedrock to our economic foundations. That's not going to change in the foreseeable future. Today we have a broad pallet of proven and emerging energy sources, but every single one of them has its issues.

Geothermal is clean and economical, but only in the handful of places where the Earth cooperates. Hydroelectric power is clean, but can have drastic ecological consequences and, anyway, is already fully exploited in most of the developed world. Wave and tide power show promise—but are limited in application, will suffer corrosion and wear, and may have unanticipated consequences. Biofuels also show promise, but are limited by climate and land availability and can compete with food crops with nasty results. When the Bush administration tried to cut US foreign oil dependency by stretching domestic gasoline supplies with ethanol, it triggered riots in some parts of the world as diversion from food production, combined with similar effects from biofuel production in Europe, fueled record spikes in the price of staple grains.[14]

Wind is one of the fastest growing power technologies, but it's fickle, often remote nature means it will remain a niche player unless transmission loss and industrial-scale power storage can be effectively addressed. The same is true of photovoltaics and local solar heat collection. Heliostats do better, concentrating sunlight from giant mirror arrays and storing its heat underground—but they only make economic sense in arid climates and have been known to vaporize passing birds. Orbital solar collection might be even better, but it would suffer from even greater transmission losses and, let's face it, anything capable of beaming industrial quantities of power down from space is, by definition, a death ray.

Fusion is twenty years away for the fiftieth year in a row and is unlikely to be as clean or economical as many hope.

Nothing in life is perfect. No technology is perfectly safe or clean. We all know fossil fuels emit greenhouse gases and contribute to chemical and particulate pollution. Less well known are the "Technically Enhanced Naturally Occurring Radioactive Materials" or TENORM, released with the smog.

Radioactivity is the natural result of the stellar crucibles that forged all matter in the Universe. It persists in Earth today, deep underground where it contributes to maintaining the Earth's protective magnetosphere, but also up here with us. You and I are weakly radioactive (traces of potassium-40 in our bones, carbon-14 from the air, and a dozen other radionuclides from our food and water). My kitchen is too (traces of uranium in granite countertops). If you have smoke detectors in your home (and you should) there's a good chance they are radioactive (americium—harmless unless you ingest it).

This low-level background radiation is utterly harmless—after all, we evolved with it. It's often said there is no safe dose of radiation, but in fact that isn't true. We know from studies of real populations in Brazil, Iran, and India for example that even 10 times the normal background radiation doesn't necessarily raise cancer risks by a detectable amount.

TENORM, however, are byproducts of industry that expose or concentrate radioactive elements found in nature. These include radon emitted through smoke stacks, thorium and uranium in coal fly ash, and from oil exploration, uranium, thorium, radium, polonium, and strontium to name but a few. Worried about nuclear waste? Concentrated TENORM of this kind can be more radioactive than most low level wastes from the nuclear industry, yet it's usually just dumped, buried, or—increasingly—turned into building materials.

Frightened yet? Well you *shouldn't* be. Contrary to popular belief, radiation isn't magic death cooties. To better illustrate this, let's look at Japan's other historic nuclear disaster, the bombings of Hiroshima and Nagasaki. If you expected those cities to be uninhabitable for the next thousand years, you're in for pleasant disappointment. Both are prosperous, modern cities full of healthy people with the correct number of heads, and not a lizard monster in sight.

To understand why, we first need a quick refresher on radiation. When it comes to health, what counts is ionizing radiation—that which can break chemical bonds like those in our cells and genes. It can take the form of alpha, beta, and neutron radiation, or x-rays and gamma rays. All of these can be released from unstable atoms as they shed excess energy, mass, or both in the process of decaying into smaller, more stable atoms.

Alpha particles (basically helium nuclei) are heavy and reactive, but are stopped by a few centimeters of air or even our outer layer of dead skin cells. Beta particles are high speed electrons or positrons. They penetrate farther, but not much. Keep either of these at arm's length and they can't hurt you. X-rays and gamma rays are high energy photons and penetrate easily. These, you hide from behind mass shielding. Still, even gamma rays lose half their punch with every 150 m (500 ft) of air, which is why people can watch nuclear weapons tests from a few miles away with no ill effects.

Lastly, energetic neutrons can travel thousands of meters in air but are absorbed by hydrogen-rich materials like concrete, plastic, or water. Lacking any charge, they don't damage chemical bonds directly but can be absorbed by atomic nuclei, making them unstable. This makes them the only form of radiation that can induce radioactivity in other materials.

With this in mind, what happens when the genie throws a tantrum? The Little Boy bomb dropped on Hiroshima contained 64 kg (141 lb) of highly-enriched uranium, but that wasn't the dangerous part. Uranium 238, the most abundant kind in nature, has a half life of 4.5 billion years. Its radiation is spread out over far too long to cause much harm. Bomb-grade uranium is enriched with U-235, a less stable variety with a half life six times shorter. This makes it so radioactive . . . that you can hold it in your hands with no danger at all. High cancer rates among uranium miners result from exposure to radon leaching into mines from the surrounding geology. Uranium itself might actually be more dangerous as a chemical toxin than for its weak radiation. Just don't inhale its dust; it's an alpha emitter.

So, if uranium is barely radioactive, what gives the genie his superpowers? Fission. When you put enough U-235 together, its normal trickle of liberated neutrons can start a chain reaction. As those neutrons crack nuclei to release ever more neutrons, the element's natural radioactive decay speeds up and all that pent up atomic energy comes rushing out all of a sudden. Depending on exactly how this is done, it can give you a lethal radiation dose in a few seconds, boil water to run a turbine, or go boom.

Of the uranium in the Little Boy bomb, only about 1.5% actually fissioned. The remaining 63 kg (139 lb) went up in the mushroom cloud and spread across the Pacific—which was not the nightmare you might imagine. The ocean was already full of uranium. This is Earth, after all, a rocky, radioactive planet, and the ocean catches all the runoff from our weathering mountains and the soup from hydrothermal vents. Every 20 cubic kilometers of unadulterated seawater already contains as much uranium as the Hiroshima bomb. The whole ocean contains about 1.3 billion cubic kilometers of water, so it holds 66 million times the uranium spilled over Hiroshima. Put another way, the bomb had no long-term impact on the global environment. Zilch. Zero. Nada.

But what about that other 1.5%? That's your nightmare poison, right? Well, yes. Fission transmutes uranium into a cocktail of highly radioactive nastiness. However, highly radioactive isotopes don't hang around very long. Japanese bomb radiation victims were almost all those exposed directly to the detonation[15] or to fallout immediately thereafter. The vast majority of casualties suffered from burns and physical trauma, not radiation. War is a ceaseless stream of human horror, no matter the weapons.

The most dangerous products of fission are dangerous specifically because they have half lives of milliseconds, hours, or days. After that, isotopes with longer half lives and less activity predominate. The most important of these are iodine-131, which lingers for weeks and can be taken up by the thyroid gland, and strontium-90 which lasts for decades and can affect our bones. These, you want to avoid, but then, you also want to avoid carcinogens and toxins from a host of natural and industrial sources. At least radionuclides decay over time, and the longer they take to do so, the less harmful they are in the first place.

And what are we avoiding, exactly? Well, not a race of mutants, if that's what you've been thinking. With the bombings 70 years behind us, we now know that the only real long-term health impact of the radiation itself, even for those who survived the worst radiation sickness, was an overall 44% increase in the risk of cancer.[16] That's bad, even tragic, but hardly an apocalypse.

The harm done by Fukushima is small potatoes in comparison, but we can do much better. Fukushima, Chernobyl, and most of the hundreds of other commercial nuclear plants operating today use second-generation reactor designs developed in the 1960s. They may have fancier computers and upgraded controls, but these are still the Ford Model-As of the technology, still limping along without radial tires, air bags, or anti-lock brakes. Chernobyl No. 4 was built without any real containment vessel around the reactor because . . . seriously, WTF guys? Fukushima disregarded the reasonably foreseeable risk a large tsunami might pose to the automatic systems required to keep it safe. And that's the problem. All second-generation reactors require constant, effective management and cooling to prevent catastrophic failure, even for a time after shut down.

We should definitely welcome the retirement of these older units, but what do we replace them with? Renewables, even in theory and allowing for maturation of collection and storage technologies, cannot do the job, alone.[17] In most cases, the only feasible answers are coal, natural gas, or oil, but if you think any of those is safer than what we have now, think again.

Radiation is the shark attack of the industrial world—an invisible, lurking terror—but largely undeserving of so fearsome a reputation. Or for a more apt metaphor, a plane crash is a terrifying way to die, but the world's roadways are 4,000 times more likely to actually kill you.[18] (Cars are 750 times more dangerous per passenger mile[19], but roads also kill people out walking the dog.)

The public fears nuclear energy for its Cold War associations and for the mostly inflated specter of radiation, but in terms of deaths per unit of energy generation, it's actually between a thousand and a *hundred thousand* times safer than coal,[20] depending on how well both are regulated.

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Even compared to natural gas, long the poster child for clean, safe energy, the atom reigns supreme, and it has far further yet to go, technologically speaking.

Fail-safe reactors using passive safety systems have been used by schools and naval vessels since the 1950s. Current or planned third-generation reactor designs enhance safety through waste reduction, improved resistance to accident or attack, and features like highly redundant cooling with gravity-fed backup, and a sacrificial catch basin beneath the core, just in case. Neither the Chernobyl nor Fukushima releases could have happened with such a design, and there's more yet to come.

Forth generation reactors will see heavy use of passively safe features like self-throttling pebble bed and prismatic block core designs. Non-water based cooling will eliminate the risk of steam explosion and steam-mediated core damage, and the chance of subsequent hydrogen explosion and fire. Some designs will be small enough and safe enough for co-generation on manufacturing sites. Some will only need natural convection for cooling. Others will suspend fuel in molten salts that must be actively held inside the reactor to stop gravity and heat from forcing an immediate, safe shutdown. Traveling wave reactors won't need enriched uranium or plutonium at all, except for startup, and *can actually consume existing spent fuel waste* along with natural and depleted uranium left over from weapon and fuel production. In return, they'll produce wastes that remain radioactive for hundreds of years, rather than thousands.

That last point is key, because after slumping natural gas prices made possible by recent development of previously unreachable shale plays, public risk aversion has emerged as a significant force slowing the switch from older plants to their newer, safer replacements.[21] One of the principle concerns is waste storage, a problem often portrayed by activists as insoluble and looming.

Energy Source	Mortality Rate (deaths/trillion kWh)	Utilization (% of global generation)
Coal – global average	100,000	41%
Coal – U.S.	10,000	(32% U.S.)
Oil	36,000	8% (33% of all energy)
Biofuel/Biomass	24,000	21%
Natural Gas	4,000	22%
Solar	440	<1%
Wind	150	2%
Hydro – global average	1,400	16%
Hydro – U.S.	5	(6% U.S.)
Nuclear – global average	90	11%
Nuclear – U.S.	0.1	(19% U.S.)

Illustration 1: Deaths per trillion kilowatt hours for major sources of electricity.

Such fears are understandable but poorly founded. Yes, spent fuel is highly radioactive. Yes, it will remain dangerous for thousands of years—if it isn't consumed as fuel first. However, the danger is mostly because fuel assemblies are so large. Even the infamous Chernobyl "elephant's foot" has been visited by workers as early as a decade after the meltdown. Because it's so large, it could definitely kill you, but it's not exactly going to sneak up on you. Leaks, even from such as this, are just a drop in the ocean of background radiation as long as they are detected and responsibly managed. The danger is even lower for properly stored wastes from normal operations.

This isn't 1950, when the 55 gallon drum was the go-to storage for all things toxic. After its dip in the pool, spent nuclear fuel is packed in neutron absorbing aluminum racks, bathed in nonreactive helium, and sealed inside a shielded, stainless steel cask. Then it's locked inside a bigger cask made of more steel and concrete—one hundred tons worth. Dry storage and transport casks have been subjected to mishandling, missile strikes, train wrecks, plane crashes, and infernos. They just don't break open, at least not for anything short of a point blank nuclear or meteor strike. But maybe we should put them underground to be on the safe side?

Well of course we should. Around the world, 17 deep geologic storage sites are in operation or planning, but in the US, the facility at Yucca Mountain, "the most studied piece of real estate in the world," is languishing in political purgatory. That's unfortunate, because this ideal site could be bringing jobs and federal dollars to Nevada for the foreseeable future, but it's being blocked over radiation fears that, even if realized, would do less harm than the state's dental x-ray machines. Of course, no one asked Nevadans before nuking their deserts a few hundred times, and people have long memories about that sort of thing.

Regardless, nuclear energy is not going away. Within a century or so, our fossil fuels will be gone, greenhouse gases be damned. We're going to need every trick in the toolbox to replace them, and despite the hyperbole from a certain charismatic tech entrepreneur, we're a long, long way from bridging the gap between solar or wind generation and demand. Buildings full of batteries are already being used to shave peaks, but one shudders to contemplate the mountains of batteries required to meet base load on a cloudy day. Building them will release ozone destroying CFCs. Deploying them on that scale will inevitably lead to toxic fires and to cobalt and nickel leaching into the water supply, just like cadmium and lead before them, but on a vastly greater scale.

No technology is perfect, and no one energy source is a panacea. But for now, that nuclear genie is our safest energy source, our best hedge against greenhouse gas emissions, and our only way of "burning up" our present stockpiles of high level nuclear waste—waste that otherwise will still be in storage long after the last gram of fossil fuel has burned.

It's also our ticket to the stars, if we're going. Whatever our vision, substantive exploration of space is just not going to happen until the costs come down. Atomic rockets and nuclear pulse propulsion weren't the most sensible ideas for reaching orbit, but electric or magnetic rail launchers might be, at least for raw materials and consumables that can endure the G-forces. To work, though, they'll need the sort of cheap, dense, safe energy that fourth generation modular reactors promise. So will the plasma rockets needed to economically carry manned exploration beyond lunar camping trips to future colonies and deep space research stations wherever we decide to go next. Solar power isn't really viable much beyond the asteroid belt anyway, and colonists won't want to stake their lives on batteries and sunlight when timely resupply isn't a given. Without life cranking out unreacted oxygen, other worlds will offer few other options to power more than extended visits.

Back on Earth, whether we're ready or not, global energy demand will double or triple by 2100, and hydrocarbon reserves will be depleted not long after. Renewables alone are unlikely to fill the gap, no matter how much we might like them too. If energy insecurity is piled atop food, water, and territorial shortages fueled by population increase and sea level rise, the results are unlikely to be pleasant. Our approach to energy over the coming century, therefore, will define our civilization for the next millennium—whether it grows into a true global community or slides back into the petty struggles that have already brought us, several times, to the brink of destruction.

Blind fear will not make us safer. Blind faith will not make the world less complex. Fukushima awoke us to the need to reevaluate and shore up safety at today's nuclear plants. Let it also be the impetus, not to recoil from an imperfect but still valuable tool, but to sharpen it and find its proper place within our energy toolbox. We're going to need all the tricks we can muster.

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