

## You've Got to be Carefully Taught<sup>☆</sup>

*In which, reflecting on the troubled, misunderstood history of nuclear power, we ask: Can we see beyond the media's favorite technological soap to enjoy the environmental gentility of Nature's most ubiquitous energy source?*

In 1999, less than three months before we entered the new millennium, “Radiating Terror” shrieked from the front-page—in red ink. The story continued with sub-headlines, “Japan nuclear blast triggers crisis” and “Hundreds of thousands at risk from radiation in worst accident since Chernobyl”. We learn that this was “the country’s worst nuclear accident” and that United States President Clinton had offered “all possible assistance to Japan’s Prime Minister Keizo Obuchi”.

I’m not quoting the *National Inquirer*. Rather I’m quoting *The Guardian Weekly*, one of the world’s most respected newspapers.<sup>1</sup> Published halfway round the world from where the accident happened in Tokaimura, *The Guardian* always carries copy from two other respected papers, *The Washington Post* and *Le Monde*. With news and opinion drawn from among the best newspapers of three great nations, the *Guardian* is normally expected to provide broad-based, balanced views. Most of the “nuclear blast” story was taken from the *Washington Post*, although I suspect the headlines were pure *Guardian*.

Citing the International Atomic Energy Agency, the story reported that of the three workers closest to the “flash”, two were almost certainly going to die and a third might survive although it was “touch and go”.<sup>2</sup> Throughout the story, “nuclear blast” language reinforced the too-frequent confusion between nuclear weaponry and nuclear power.

The emphasis journalists give their stories depends on the distance between where the story happens and where the readers live. As distance increases, interest decreases. For the Tokaimura story to reverberate round the globe the way it did, this news must have been thought very big indeed. So by the criterion of media attention, let’s compare Tokaimura’s “bigness” with other energy accident stories.

Seven months before Tokaimura, my local newspaper, Victoria’s *Times Colonist*, ran a brief story about an accident that had happened the day before—but not halfway round the world. It had happened a mere 40 crow-flying kilometers due east of Victoria in the charming Washington town of Anacortes that borders the San Juan Islands archipelago. We often sail *Starkindred* to Anacortes—about 5 h with a flood tide, up to eight hours against the ebb—for a wee bit of stateside culture and less expensive whiskey. Folks from Anacortes sail to Victoria for a flower-potted harbor of old-world gardens and grace. In short, we’re friends and neighbors.

The Anacortes accident happened in an oil refinery. But unlike Tokaimura, three people were not expected to die. Eight people had been killed.<sup>3</sup>

Because Anacortes folks are neighbors, I was surprised the accident was not bigger news in the *Times Colonist*. I looked in Canada’s national newspaper, *The Globe and Mail*. Nothing there. The *Washington Post* carried a brief piece on an inside page, but I found nothing in the *New York Times*. Nothing appeared in *The Guardian Weekly*.

The message was clear. Once you get out of the immediate neighborhood where lives are snuffed, families broken and wives widowed, eight people killed in an oil refinery explosion is not news. But can you *imagine* the media frenzy if these fellows had been killed in a nuclear power plant?

You might respond, “Well it’s just a fluke that a local oil refinery accident happened seven months before the Tokaimura accident”. Of course it’s a fluke. That’s what accidents are, flukes. Still there are many more “flukes” that injure and kill people

<sup>☆</sup> Song title from the Rogers and Hammerstein musical *South Pacific*.

<sup>1</sup> 1999 October 7–13 issue.

<sup>2</sup> Sadly, the worker who received the largest radiation dose died just before Christmas. The second worker survived to see the 21st century, but died shortly thereafter. The third lived.

<sup>3</sup> The accident occurred in late November 1998. Initial reports claimed five had died. Later it was learned “six union members and two supervisors” had been killed.

in the fossil energy industry than in the nuclear energy industry. But we're used to people being killed in fossil energy accidents. It's not news.<sup>4</sup>

In fact, during the six months *between* the Anacortes and Tokaimura accidents, a second fatal fossil-energy accident struck northwestern Washington. This time it happened on June 10, 1999, near Bellingham. A pipeline carrying gasoline leaked and an explosion resulted. The accident killed two young boys playing along the banks of the Whatcom creek and a teenager who was fly-fishing. The explosion made no international news, little national news, and triggered only a brief piece in the *Times Colonist*.

It was clear that I didn't need to look round the world to find fossil fuel accidents that far outweighed the Tokaimura accident. I only needed to look next door, to the northwest corner of Washington State, where a total of 11 people had died in fossil energy accidents within less than 12 months before the Tokaimura accident.

These last few paragraphs compared the safety of nuclear and fossil energy sources. We should also consider the safety record of renewable sources.

In 2000—the year following the Anacortes and Tokaimura accidents—my wife and I travelled to New Zealand and China. On New Zealand's south island we visited the Manapouri power project, an impressive hydraulic installation where four generators were built *inside* a mountain. On the gallery from which visitors could look down upon the generators, a plaque was mounted in memory of the sixteen workers who had been killed during construction. The total output from the Manapouri installation is 585 MW, less than the typical output from a single reactor in a nuclear powerplant. Then, traveling on to China we visited the Three Gorges project on the Yangtze River where, the day before we arrived at the construction site, several workers had been killed. The loss-of-life had been mounting steadily since the project began.

The Tokaimura nuclear accident where two people had been killed—bookended by earlier the Washington state fatalities and my later visits to Manapouri and Three Gorges—got me smelling land. I knew Japan generates some 30% of its electricity from nuclear power. So if Tokaimura was Japan's worst nuclear power accident, could it mean that, compared to others, nuclear might be one of the world's safest energy sources—perhaps the safest?

I looked up the numbers.

Prior to the September 1999 accident, Japan's nuclear electricity production had totaled 480 GW y<sup>5</sup> and, so far as I know, Tokaimura was the only fatalities. Therefore, the ratio of Japanese fatalities to electricity delivered comes out to be 0.004 persons killed per GW y.<sup>6</sup> For comparison, the worldwide *nuclear* safety record is 0.0084 killed per GW y of electricity produced, which means that Japan's nuclear record is more than twice as good as the world average for nuclear power. Even more stunning is the fact that the world safety record for nuclear power is more than ten times better than for natural gas, *the best of all other* technologies, and more than a hundred times better than coal. By the way, the world nuclear safety record I just quoted *includes* the world's worst nuclear accident in Chernobyl, the Ukraine—which involved a design that could never have been approved in any OECD country.<sup>7</sup>

So what struck me was this: If the Japanese had been using any other source to generate this much electricity, it would have cost the lives of many more than the two who died at Tokaimura, "Japan's worst nuclear power accident".

But this was not the message from the world's media. In October 1999, when three workers violated well-established procedures, the media had a splendid opportunity to exploit one of their staple, sure-to-get-attention fears. I'm afraid, "If it bleeds it leads" drove out thoughtful analysis or context. Story after story echoed round the world spewing hyperbole. Watching the frenzy of hyperventilating overstatement, I recalled James Lovelock's seminal book *The Ages of Gaia* in which he wrote: "they (the media) have in the nuclear industry a permanent soap opera . . ." and later in the same book, "Nuclear power from its inception has rarely been described publicly except in hyperbole" [1].

<sup>4</sup> As if to punctuate this sentence, the very morning I was completing this article (February 15, 2005) Canada's national newspaper, *The Globe and Mail*, ran a short story on page 13, headlined "Blast kills hundreds in Chinese coal mine". The story reported more than 203 miners killed in Fuxin, Liaoning province. More are still trapped and many injured. As you read this article several months or years later, will you recall learning of this coal mining accident? The story reported that at least 5000 people have been killed in mining accidents throughout *the year*. For context, remember that a little less than 3000 were killed in the 2001/9/11 terrorist attacks on the USA.

<sup>5</sup> According to the OECD publications.

<sup>6</sup> Some readers may stumble over energy measured in GW y. So let's first review the difference between power and energy. The *rate* energy is delivered is "power", commonly measured in Watts. If we multiply the *rate* of energy delivery by the *time* it's delivered, we get the total energy delivered—commonly in Watt-hours, or Wh. But a Wh is a tiny unit when we're talking about national energy use. So units of GW y are commonly used. A GW y is the energy used if 1,000,000,000 Watts were continuous delivered for one year—which is the energy that would be used by 10 million, one-hundred-watt light bulbs if they were left burning for one year.

<sup>7</sup> These numbers were drawn from *Electricity Generation Systems and Sustainability—Interdisciplinary Evaluation* a study prepared by Switzerland's prestigious Paul Scherrer Institute. Most of this report discusses risk in terms of loss-of-life expectancy (LLE) for the *full* energy system chain—including both operation and construction accidents as well as emissions and decommissioning. In my view, LLE is usually a better way to judge the comparative safety/risk of various energy options. But since this article began with the media's response to the Tokaimura accident, I decided to stay with *accident* records.

The experience pulled me back to childhood memories: lying on the living room floor, listening to the music from *South Pacific*, enveloped in “Some Enchanted Evening” and “Bali Ha’i”. But now my head is filled with “You’ve Got to be Carefully Taught”. With his precocious lyrics, Oscar Hammerstein II wrote of how we can be carefully taught to hate some types of people. The media’s selective response to energy accidents reminded me that we can be carefully taught to hate some technologies—and topping that list is nuclear power.

Can’t resist. Here is the libretto:

*You’ve got to be taught to hate and fear,  
You’ve got to be taught from year to year,  
It’s got to be drummed in your dear little ear,  
You’ve got to be carefully taught.*

*You’ve got to be taught to be afraid,  
Of people whose eyes are oddly made,  
And people who’s skin is a different shade  
You’ve got to be carefully taught.*

*You’ve got to be taught before it’s too late,  
Before you are six, or seven or eight,  
To hate all the people your relatives hate,  
You’ve got to be carefully taught,  
You’ve got to be carefully taught.*

The musical *South Pacific* was one of the few good things to emerge from the 1940s war in the Pacific. A different legacy was nuclear bombs. So when I chose “You’ve Got to be Carefully Taught” as the title for this article, the war-setting reminded me that many people don’t distinguish very well between nuclear power and nuclear weapons. And the media—I expect more in ignorance and laziness than purposeful dishonesty—reinforce the association.

So I suggest a test: When you next read a newspaper headline that speaks of something “bad” about nuclear, see if you can tell—from the headline itself—if the article is about nuclear weapons or nuclear power. I’ve been applying this test for years and, most often, I can’t tell—until I’ve read deeper into the piece. In contrast, when reading a headline about oil, I don’t expect the article to be about napalm. Yet the fuel of nuclear power is much, much more different from the ingredients of a nuclear bomb than is gasoline different from napalm.

All this suggests that we should “know nukes”. Perhaps the first step to knowing should be to examine the bases of our mistrust of nuclear power. There seem to be three legs to this mistrust:

1. The risk of accidents at nuclear generating stations that might kill many people.
2. The uncertainty of how to deal with the waste products (spent fuel).
3. The possibility that bad guys acquire spent fuel and use it to make bombs.

Binding together all three is the fear of radiation. So let’s first talk about radiation: what it is, where it comes from and what it does. Then we’ll return to these three legs.

### **The underlying concern: *Nuclear radiation:***

The adjective, nuclear, means radiation that originates from the *nucleus* of an atom, rather than from elsewhere—like decelerating electrons falling into lower energy levels, which are the energy source of X-rays, northern lights or illumination from a fluorescent lightbulb. Yet if we want to speak about the health effects of radiation, the adjective “ionizing” is more relevant than “nuclear”. That’s because ionizing radiation has enough energy to ionize molecules within material.

When ionizing radiation strikes living biological material it can stimulate positive biological responses, have little effect or—when there is too much ionization—cause biological damage, like cancer.

The statement “. . . can stimulate positive biological responses . . .” may astonish. Certainly I was astonished when I first learned of this reality. Astonished because we’ve *all* been carefully taught that no good can come from ionizing radiation—that the smallest dab, however slight, will increase the likelihood of cancer. But for those who have gathered and examined the extensive epidemiological data, it’s become evident that low doses of radiation can bring measurable biological benefits.

To most people—including me—the acronym ABS means “antilock braking system”. But for researchers studying the after-effects of Hiroshima and Nagasaki, it means “atomic bomb survivors”. One finding from these epidemiological studies (of some 30,000 survivors monitored for more than half a century) has been that—if people weren’t directly killed by the explosion or died

shortly thereafter from extremely high radiation doses—the mean life-span of the ABS cohort was *longer* than the life-spans in the general Japanese population. This healthier, longer-living ABS cohort received between twice and twenty times the radiation dose received by Japanese living far from Hiroshima and Nagasaki.

By now, many studies have confirmed a beneficial relationship between low-dose ionizing radiation and health—often called the “hormesis” relationship. These studies show that if you enjoy exposure levels up to about 20 times normal background radiation levels you’re likely to live a longer, healthier life than do “normal exposure” folks. The University of Pittsburgh’s Dr. Bernard Cohen analyzed lung cancer rates vs. average radon<sup>8</sup> concentration for over 1600 American counties (representing more than 90% of the US population). His results provide some of most persuasive data in support of hormesis response to ionizing radiation [2]. Many other studies confirm the phenomenon.

This forces a surprising conclusion—at least if we have the courage to consider “substitution” [3] as a means of acquiring knowledge. If a nuclear powerplant accident released so much radioactive material that public exposure reached as much 20 times normal (but not greater) the exposed population would probably live longer and be healthier. Except for Chernobyl, there has never been a nuclear powerplant accident that exposed the public to anywhere near this level of radiation.

The other famous accident occurred at Three Mile Island (TMI) in the United States. TMI *might* have exposed the public to ionizing radiation but, if so, at levels a minuscule fraction above normal background radiation—not by multiples of the background radiation. (As frequently pointed out, reporters, coming from around the United States to cover the TMI accident received more ionizing radiation during their high altitude flights than they received at the TMI site.) I suppose we could claim the accident bequeathed neighborhood folks a *very* small health benefit—but, because the increased dose was so minuscule, both any excess radiation and any hormesis affects, were far too small to measure. (Early reports of public radiation exposure were erroneous.) On the other hand, the TMI-hyping media increased the anxiety-induced health problems in some residents—in some cases, seriously.

Of course, excessive radiation *is* dangerous. So what is excessive? The effective average annual dose received by an American is 3.6 mSv [4]. Epidemiological studies show that the hormesis domain that brings health benefits lies from this normal background level to somewhere about 30–40 mSv. Increased cancers are likely at doses above 400 mSv and a person receiving a quick dose of about 4000 mSv has a 50% chance of dying.

If I quickly ate 10,000 aspirins, I’d be in trouble. Yet we know small, regular doses of aspirin can be good for you. I swallow one with my orange juice during breakfast. A single glass of wine is also reputed to help—but if you try to swill a vat-full at one sitting you’re a damn fool. It seems we can expect the same kind of effect from ionizing radiation—a little more than normal is probably good for you, but a thousand times more could do you in. This got me thinking that an annual, full-body low-dose ionizing radiation zap might be good preventative medicine. I’m ready to sign up. My physician chuckles at the idea but doesn’t seem interested—perhaps mindful of legal complications. And I’m confident my health care insurance wouldn’t cover it.

The two Tokaimura workers probably took the equivalent of more than 10,000 aspirins. People a few blocks away likely gained very modest health benefits. So much for *The Guardian Weekly* claim “hundreds of thousands at risk”.

Now that we understand something about ionizing radiation, let’s turn to the three issues that seem to lie at the root of public concern about nuclear power.

### **First concern: an accident that causes a nuclear plant to explode**

It’s absolutely, physically impossible for a nuclear power plant to explode like a nuclear bomb. This is not just because nuclear powerplants have been designed to be probably the safest of 20th century technologies—although they have.<sup>9</sup> Rather, it’s because the “fuel” for a power plant is entirely different than the “fuel” for a bomb. Powerplant fuel won’t work for a bomb.

Of course, it *is* possible for nuclear powerplant accident to lead to fires, steam explosions and even to the release of radioactive materials. To date, the Chernobyl accident is the only occasion when a nuclear powerplant accident exposed the surrounding population to radioactivity *in concentrations capable of health damage*. The release was possible because Chernobyl “style” reactors have no containment vessels. Such designs could never have been licensed in any western country—or, after Chernobyl, *anywhere* in the world. Aggravating Chernobyl—but not causing it—the reactor employed a graphite moderator that caught

<sup>8</sup> Radon is a gas that results from the atomic decay of radium. It is everywhere—because trace radium is everywhere, like building materials and rocks. (One of the highest concentrations is in the stone used to build Manhattan’s Grand Central Station.) Most of the “radiation” from radon decay consists of alpha particles, which have the highest “weighting factor” for biological intrusion of all ionizing radiation. So the worldwide ubiquity of radon, plus the fact that its background level can be easily determined, makes radon tracking ideal for determining the biological effects of ionizing radiation.

<sup>9</sup> Modern commercial aircrafts have also been designed with exceptional concern for safety—although they can’t be made nearly as safe as a nuclear powerplant. Towards the lower end of public safety we might find domestic water supply—especially in smaller towns and rural communities and *especially* in developing nations.

fire helping to spread radioactive materials via the fire's plume. (Almost all western reactors use either ordinary or heavy water moderators.<sup>10</sup> Water can't catch fire.<sup>11</sup> )

So although we know it's impossible for a nuclear powerplant to explode like a nuclear bomb, both history and analysis also show that, even including Chernobyl, nuclear power plants have a very low probability of fatal accidents. Moreover, analysis and experience also demonstrate that the *worst possible* nuclear power accidents would be less catastrophic than accidents that too-often occur in non-nuclear industries. Think of the repeated coal mining accidents, especially in places like China where the economy is heavily based on coal. Or think of Bhopal!<sup>12</sup>

Finally, after the infamy of 2001 September 11, it is reasonable to ask: what would happen if a jumbo jet made a direct hit on a nuclear power plant? Answer: All the people in the aircraft would die. Some workers in the power plant could be killed. But, for any western power plant, structural analysis has shown it would be impossible for the impact to break through the more than a meter-thick, reinforced-concrete containment vessel, to so severely damage the reactor core that either a core meltdown or a release of radioactive material results. A wide-body jet, aimed with pinpoint accuracy to strike the most vulnerable part of a western nuclear power plant, would be unlikely to result in a single death in the surrounding population. Terrorists have many easier and more "profitable" targets—as we are often reminded.

### Second concern: *What to do with the spent fuel?*

The short answer is: bury it! This we *can* do *very* safely, using well-understood and proven technologies. An even better answer is to first reprocess the spent fuel and use it to generate 10 to 20 times more electricity while reducing by an equivalent amount the spent fuel we need to bury.

Before we go on to discuss these answers, we should clarify a few things about spent fuel. When a neutron collides with and splits apart a fissionable atom, like uranium <sup>235</sup>U or plutonium <sup>239</sup>Pu, the total mass of the resulting bits and pieces is a little less than the mass of the original atom. This lost mass becomes energy, according to the famous Einstein equation,  $E = mc^2$ . Here  $m$  is the mass exchanged for energy and  $c$  is the speed of light. The energy released is what we've named "nuclear energy".

Spent fuel from a nuclear reactor contains four things. First, it contains some unused fuel, like original fissionable <sup>235</sup>U fuel and some fissionable <sup>239</sup>Pu that has been "bred" within the reactor. Second, it contains a lot of <sup>238</sup>U which, although not fissionable itself, can be changed to <sup>239</sup>Pu that *is* fissionable. Third, it contains fission fragments—the "bigger" bits and pieces that flew off when the nuclei of <sup>235</sup>U or <sup>239</sup>Pu were split (fissioned). Common fission fragments include elements like xenon and strontium. Fourth it can contain longer-lived transuranics that have atomic weights greater than uranium—but because they are long-lived they contribute little to spent fuel radioactivity. Spent fuel *does not* contain the "smaller" bits, like alpha and beta particles, neutrons and so on—they are long gone. It's the left-behind fission fragments in the spent fuel—like strontium—that are among the most radioactively toxic.

With this short primer, we can encapsulate some realities about fission fragments:

- Fission fragments exhibit half-lives of from less than a minute to over 10,000 years, so we might ask: aren't these long half-lives dangerous? For perspective, we should remember that the half-life of many conventional industrial wastes—mercury and lead for instance—are infinite. They hang around forever.
- If a fission fragment is highly radioactive, it's using up its "kick" quickly. Therefore it has a short half-life. High radioactivity means the "stuff will go away quickly". Low radioactivity means the "stuff will stay around much longer". So those who would claim the horrors of spent fuel cannot claim it will both stay round for hundreds of thousands of years and all-the-while emit high radiation. Can't have it both ways.

We've been speaking about spent fuel, not about the total nuclear "waste" which, in nations like the United States and Russia, overwhelmingly originates from weaponry. So once again we must remember to discriminate among nuclear weaponry,<sup>13</sup>

<sup>10</sup> The world's first reactor, CP-1, that was built beneath the Chicago stadium in 1941 used a graphite moderator. I'm honored to have a small piece of that graphite sitting on the coffee table in my living room.

<sup>11</sup> The role of the moderator was briefly introduced in "Fissile Sources, Running Out will not be a problem" the 38 in this series of articles.

<sup>12</sup> The accident during the night of December 3, 1985 at the Union Carbide chemical plant in Bhopal resulted in more than 10,000 deaths.

<sup>13</sup> War is an obscenity. And so anything that can shorten a war, once started, is a blessing. Although it's difficult to write "what if" histories, this probably means the even nuclear weaponry has, on balance and so far, been a net blessing. It surely ended the War in the Pacific abruptly and faster than would have otherwise occurred—thereby saving many lives, preventing much human suffering and leading to Japan's surrender before Stalin joined the battle to claim a USSR share of the resulting "occupation". And it seems to have been a major factor in keeping cold war conflicts from becoming hot. What happens next is, of course, a big question. If the WWII allies feel guilty about bombing civilians, that guilt should be about the horrific firebombing of Tokyo and especially Dresden, which had almost no impact in shortening the war.

nuclear power, nuclear medicine and the myriad of other civilian nuclear uses that have been an unequivocal blessing. The rather straightforward technologies for the long-term and extraordinarily safe storage of spent fuel are proven and ready to deploy. It's the politics that has twisted our knickers. Politics, underpinned by persistent, disingenuous claims that we have no way to deal with nuclear waste products. These claims come from folks not overburdened with either knowledge or honesty.

Now let's return to my earlier suggestion that we could substantially reduce the amount of spent fuel we need to bury. Today's "once through" nuclear power strategy means the spent fuel typically still contains more than 90% of its original energy. Indeed, in principle, it's possible to recycle spent fuel to generate the 10 to 20 times more power I spoke of earlier. The amount of energy recoverable from spent fuel depends upon the type of reactor. But a reasonable rule-of-thumb is that it's *feasible* to recover up to 20 times more energy than is delivered by the today's once-through reactor cycles.

If we were to follow a policy of reprocessing and reusing spent fuel—recycling at its best—we'd gain many collateral benefits. The one most relevant to the question "what will we do with spent fuel?" is this: We would reduce, by an equivalent amount—that is to *at least* one-tenth—the spent fuel we must ultimately bury.

*Today*, one drawback to this recycling strategy is that the price of reprocessed fuel is somewhat higher than virgin fuel. Yet this is ameliorated because, first, fuel cost is a comparatively small fraction of the cost of nuclear-derived electricity and, second, we'd then have less spent fuel to bury. So, although reprocessed fuel would initially cost a little more than virgin fuel, the reduced disposal costs might reduce *total* life-cycle costs. In the United States, the Carter Administration forbade re-processing—presumably because it might give "bad guys" a chance to steal the fuel. No subsequent US Administration has removed this restriction.

In contrast, the French, British and Japanese regularly reprocess their spent fuel. Moreover, I found it interesting that *The New York Times* of October 5, 2004, carried an article on the US shipping weapons grade plutonium to France for reprocessing into nuclear powerplant fuel.<sup>14</sup>

Yet getting more energy and less waste from nuclear energy can get even better. In the previous discussion I've been speaking of what we can do, today, with conventional reactors. If we move beyond today's reactors to breeder reactors, and use not only "spent fuel" but also the depleted uranium (now sometimes used for bullets) we could, in principle, get up to 100 times more energy for each shovelful of uranium taken from the ground—and, correspondingly, have about one-hundredth the waste product to bury.

There is another point. Despite what we've been carefully taught, dangerous radioactivity from spent fuel *does not* last for tens of thousands of years. Rather, in 400 and 600 years the toxicity returns to about what it was when the uranium was in the ground. So spent fuel toxicity is about a half-millennium issue.<sup>15</sup> This is still a long time. Yet for context, because the residence time of CO<sub>2</sub> in the upper atmosphere is about 300–400 years and over 1000 years in the deep oceans, fossil energy waste disposal is also at least a half-millennium issue. So the times required for fossil and nuclear waste products to return to their respective background level toxicities are the same order-of-magnitude.

Although the hang-about times for fossil and nuclear wastes are similar, there are several important differences. The most important may be the shear magnitude of waste material.

Let's compare—for equal power output—the mass of spent fuel from nuclear powerplants to the mass of CO<sub>2</sub> from, say, coal-fired powerplants. The comparison requires assumptions including: the kind of nuclear reactor, the kind of coal and the thermal efficiencies of the different powerplants. The ratios come out like this: For the electricity production that would leave behind one *kilogram* of spent fuel from a conventional nuclear powerplant, a coal-fired plant would pump between 70 and 326 metric *tonnes* (77–360 US tons) of CO<sub>2</sub> into the atmosphere. If, in the future, we adopt breeder reactors the ratio of waste products jumps to almost 70,000 metric tons of CO<sub>2</sub> for each kilogram of spent nuclear fuel.

Because the mass of nuclear waste is so small, it can be carefully and safely stored for astonishingly long timeframes. In contrast, the massive volume of fossil waste means that, practically, it can only be pitched, unconstrained, into the very efficient mixing bowl of our atmospheric and oceanic global commons.<sup>16</sup> So it's not so much the difference in volumes that is telling. Rather it's the *certainty* that continued dumping of our fossil waste into the atmosphere will bring global catastrophe.

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<sup>14</sup> During the same week, President Bush proudly proclaimed that the US would never listen to France when determining US foreign policy. I reflected: if the US had listened rather than disparaged, it might have avoided two tragic quagmires in a row, first Vietnam and then Iraq.

<sup>15</sup> In this timeframe, fission fragments decay to radioactivity levels "equivalent" to those of uranium in the ground. Spent fuel from a once-through cycles contains transuranics that have longer decay times—although their bio-risk is also lower. If the once-through spent fuel is later recycled (and "consumed" in "fast neutron" reactors), only a small fraction of the actinides remains.

<sup>16</sup> Some claim that we can sequester CO<sub>2</sub> emissions underground, say, in depleted natural gas fields. Analysis shows that this might work in limited circumstances, like when natural gas is used to produce hydrogen in stationary settings *and* when there is nearby underground storage *and* if there isn't too much CO<sub>2</sub> to store. So while the concept may serve old technologies fighting back, it doesn't really serve the environment.

### Third: What about bad guys stealing material to make bombs?

This time I can't make declarative statements like, "a nuclear power plant can't blow up like a nuclear bomb" or "the technology for safe spent-fuel disposal is well known and proven". Because I suppose it's conceivable that, somehow, bad guys might steal material from a nuclear power plant and use it as feedstock to manufacture a crude bomb. The question is: Why would they try? The ratios of both  $^{239}\text{Pu}$  and  $^{235}\text{U}$  to the "other stuff" in a nuclear power reactor (or its spent fuel) is far, far different than the ratios needed for a bomb. And aside from the difficulty of performing the theft, if they successfully nicked the stuff, it would be extremely difficult and risky to handle—and require unusually sophisticated, expensive technologies for separation and enrichment to approach bomb-grade material for even a crude, unpredictable bomb.<sup>17</sup>

Why do I say this? One reason is because it would be much more straightforward for terrorists or rogue nations to use a simple reactor to breed plutonium from un-enriched uranium. Such a dedicated, plutonium-producing reactor is easier to design and build than the sophisticated reactors needed to generate electricity or hydrogen. Why use a Mercedes when a Lada will do the job?<sup>18</sup>

Then, even if they get enough  $^{239}\text{Pu}$ , these bad guys would still need to make the bomb—a non-trivial task. Contrary to something else we're often told, it would probably be easier to build a Boeing 747 in a (rather large) back yard than a nuclear bomb—and a lot safer. There are many easier ways to kill lots of people.

The danger of terrorist-deployed nuclear weapons cannot be dismissed. But it's foolish to think that the peaceful use of nuclear powerplants significantly increases terrorist opportunities. Moreover, like it or not, we cannot put the nuclear bomb genie back in its bottle. Just like our forefathers couldn't stuff crossbow or gunpowder genies back in their bottles.

So it turns out that nuclear powerplants are the safest and most environmentally non-intrusive of energy sources. They can be used to manufacture electricity today and both hydrogen and electricity tomorrow. Nuclear is the *only* energy source that could feasibly be deployed fast enough, delivering *enough* energy, to roll back CO<sub>2</sub> emissions while simultaneously providing all the services civilization requires. Moreover, nuclear delivers its energy reliably and requires the smallest land "footprint" among energy sources—an important environmental benefit as we continue to have growing other demands that encroach upon our remaining wilderness.

Of course, as with any technology, precautions must be taken. But I fear thoughtful precaution has been trumped by hyperbole. Because this is the non-fossil source that *must* be deployed if we have any hope of deflecting climate disruption.

So we really must re-examine what we've been carefully taught.

In "Chasing Locomotives" [5] we spoke of how people seem to be inherently suspicious of technologies designed inside—even though, most often, these technologies are big improvements over earlier inside-out technologies. Nuclear energy is a masterpiece of inside-in technologies. In this chapter we never really looked inside this inside-in technology. So my observations might smack of superficiality or, worse, can only be accepted with a dose of faith. A gram of understanding is superior to a kilogram of faith. So for those who would like to better "know nukes" I recommend *Bluebells and Nuclear Energy* [4].

I probably spent more time gathering, checking and comparing information in preparing when writing this article than for any of the earlier thirty-nine articles in this series. Still some of the ideas, like the hormesis response to modest excess radiation, will be resisted by those especially pained by the "substitution" approach to acquiring new knowledge [3].

So let's leave set aside those things some folks can't yet accept. What if we don't believe the hormesis theories that small doses of radiation can be good for us, or don't believe that the technologies of burying spent fuel safely are proven and well known, or don't believe that we could massively reduce the amount of spent fuel by reprocessing *and* reduce it still more by using breeder reactors, or even—in spite of the straightforward facts to the contrary—still want to believe that a nuclear power reactor could blow up like a nuclear bomb?

We would still need to ask: Is nuclear power better for our planet, our grandchildren and us, than the prospect of continuing to burn natural gas, oil and, worst of all, coal?

The answer is clear. To continue burning fossil fuels would be to impose an unequivocal death sentence upon our civilization *and* the things we hold dear about our moist blue planet. Indeed, even if we "stop smoking" today, it might be too late. In contrast, there is no dismissing the fact that nuclear power is the *only* energy source that can be quickly and massively deployed to give us a fighting chance to escape the climate juggernaut now hovering over Earth's future.

<sup>17</sup> I've chosen the phrase "bomb-grade" rather than "weapon-grade". Weapon grade terminology is more common in the industry. My choice is based upon the fact that the fuel for a nuclear powered aircraft carrier or submarine is *far* from bomb-grade, but it can still push military vessels along quite nicely.

<sup>18</sup> A plutonium ( $^{239}\text{Pu}$ ) bomb, called "Fat Boy", was exploded over Nagasaki. A uranium (metallic  $^{235}\text{U}$ ) bomb exploded over Hiroshima.

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- [2] Cohen BL. Test of the linear-no threshold, theory of radiation carcinogenesis of inhaled radon decay products. *Health Phys* 1995;68(2).
- [3] Scott DS. The great enemy of truth. . . *Int J Hydrogen Energy* 2004;29:1569–70.
- [4] Albert B. Reynolds, *Bluebells and Nuclear Energy*, Cognito, 1996. There are many sources for this kind of data. Reynolds' book is one of easiest to read and understand. Data on background radiation levels is given in Table 2.4.
- [5] Scott DS. Chasing locomotives. *Int J Hydrogen Energy* 2003;28:1302–6.