

NUCLEAR ENERGY FACTS REPORT – APRIL 2010

Theodore Rockwell¹

Introduction

This is the latest edition of the Nuclear Energy Facts Report. The Report itself contains only facts on nuclear and alternative energy that manifest in the physical world; there are no opinions, conclusions, recommendations, or attempts at consensus-building. But we have found it helpful to precede the Report with some explanatory material on energy production, radiation, and safety, and to conclude the Report with comments on the historical context.

As always, we welcome input from readers. This is not intended to be a public relations document, but an interactive reference document for people who work in, or report on, energy production.

Why energy is so important and so much bigger than most people realize

Energy is one of the few words for which the popular and the scientific definitions are the same. Energy is defined as “the capability to take action, to do work, to bring about change.” *So the first responsibility of any energy program is to produce enough energy to take the actions, do the work and bring about desired changes. Even actions to reduce energy wastage, such as insulating old houses, will require that energy be spent. Access to energy is what distinguishes living organisms from non-living entities, and allows the organisms some control over their destinies.*

Of course, one should try to reduce wastage and improve efficiency of energy generation and usage. But that goal can be pursued just as effectively while increasing energy generation to meet desired goals. If energy can be generated with little deleterious impact on the earth, then *pursuing energy reduction (conservation) for its own sake need not be a priority goal.*

Our two biggest energy demands are for 1) transportation: fueling airplanes, cars, trucks, ships and trains, and 2) generating heat and electricity. These two sectors comprise over 80% of our total energy demand and are now met largely with fossil fuels: oil for cars, coal for half of our electricity. They also produce most of our pollution and contribute to the causes of warfare.

Large amounts of energy will be required to desalinate seawater—there’s no shortage of seawater. To get desalinated water to where it is needed is also just a matter of energy.

Energy discussions to date have involved mostly opinions and hypothetical concerns, and too little use of real-world data. *This report examines the facts on alternative energy sources and assesses whether these sources are, worthy competitors to nuclear. And then it discusses some of the concerns that have been expressed about the nuclear option.*

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It is often claimed that concern about climate change is persuading many Americans to favor nuclear power. This is probably true in some cases. But a March 2009 survey by Bisconti Associates found that the majority of the American public has favored nuclear power for decades, long before climate change became a public issue. While 74% of the public “agree that nuclear energy is clean air energy,” the public puts climate change last in a list of eight favorable characteristics it associates with nuclear energy, behind Reliable Electricity, Efficiency, Affordable Electricity, Energy Security, Clean Air, Energy Independence, Sustainability, and Economic Growth. For decades, a majority of Americans have favored nuclear power for those reasons. Climate change is just the latest argument that favors nuclear.

Construction of large-scale wind- and solar-energy systems constitutes an unprecedented experiment in climate control.

Hypothetical Problems Versus Reality

Nuclear Radiation

When a new technology arises, scientists try to foresee all possible problems or dangers that might arise, and they generally do a good job of it. Most of the problems usually turn out to be overstated, and the early researchers piled up a number of unnecessary precautions and protections. But occasionally real problems are not foreseen, and people get hurt while discovering them. *In the case of nuclear radiation, this process began over 100 years ago*, with discoveries by Roentgen, Becquerel, the Curies and others. In the early days, a number of scientists got skin burns or worse, and some members of the public were exposed to more radiation than necessary, through some ill-advised medical usages. But the actual injury and death-toll was much smaller than that resulting from many other new technologies, such as steam engines or aircraft.²

By 1934, national and international radiation protection committees (the NCRP and the ICRP) had been formed, standards had been established, and Lauriston S. Taylor, one of the founders of these organizations, wrote (in *Health Physics* 32: 851-874, 1980): “*No one has been identifiably injured by radiation while working within the first numerical standards set by the NCRP and the ICRP in 1934 [which were 35 times higher than current requirements]. The theories about people being injured have still not led to the demonstration of injury and, if considered as facts by some, must only be looked upon as figments of the imagination.*” Today, hundreds of millions of people, from dentists to welders, use radiation daily in their work. More than ten million medical procedures involving radiation take place in America each year.

The nuclear medicine pioneer, Rosalyn Yalow, Nobel Laureate in Medicine, asserted: “*No reproducible evidence exists of harmful effects from increases in background radiation three to ten times the usual levels. There is no increase in leukemia or other cancers among American participants in nuclear testing, no increase in leukemia or thyroid cancer among medical patients receiving I-131 for diagnosis or treatment of hyperthyroidism, and no increase in lung cancer among non-smokers exposed to increased radon in the home.*”

² In the 1930s, my older brother’s teenaged high-school buddies built an airplane on a vacant lot, and flew it in the annual Curtis-Wright competition. There was no one to license, or even inspect, airplanes or pilots, and some of the entrants were killed making their first tight turn. “Dive bombing” the spectators was not outlawed until one plane inadvertently crashed into the crowd. As regulators scrambled to put rules in place, “old time pilots” grumbled that “soon they’ll be putting stop-lights in the sky.”

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“The association of radiation with the atomic bomb and with excessive regulatory and health physics ALARA practices [As Low As Reasonably Achievable] has *created a climate of fear* about the dangers of radiation at any level. However, there is no evidence that radiation exposures at the levels equivalent to medical usage are harmful.”

“The *unjustified excessive concern with radiation* at any level, however, precludes beneficial uses of radiation and radioactivity in medicine, science and industry.” (*Mayo Clinic Proc* **69**: 436-440, 1994)

The French Academy of Medicine asserts (*Medical Irradiation, Radioactivity Releases, and Disinformation: An Opinion of the Academy of Medicine*, 4 Dec 2001): “The hypothesis of the risks of cancer induced by low doses and dose-rates is founded on the extrapolation of data of highly-exposed human groups, applying the risk as being constantly proportional to the received dose without being limited by a threshold, the linear no-threshold (LNT) assumption. This hypothesis conflicts with itself and has many scientific objections (10); and it is contradicted by experimental data (11) and epidemiology. ... [the Academy] *denounces utilization of the linear no-threshold (LNT) relation to estimate the effect of low doses...*” (http://www.radscihealth.org/rsh/Docs/academy_of_medicine_of_france.htm)

In an unprecedented move, the French Academy of Science and the National Academy of Medicine issued a unanimously-approved joint declaration that it “*denounces the utilization of the LNT relation to estimate the effect of low doses,*” explaining that “*This hypothesis conflicts with itself and has many scientific objections; and it is contradicted by experimental data and epidemiology,*” documenting the scientific evidence for each of these statements.

On 28 Oct 2009, the Director-General and the Board Chairman of the World Nuclear Association (WNA) wrote to the Director-General of the International Atomic Energy Agency (IAEA) as follows:

"It is a disservice to the public interest to set safety standards on the implicit premise that all radiation is harmful, even extremely low doses. Standards that are so designed result in distorted public policies. The reality is that doses lower than a few millisieverts per year are unlikely to change cancer risk. In this regard, we call your attention to a new study performed by Japan's Central Research Institute of the Electric Power Industry (CRIEPI). This analysis underscores that many radiation protection standards now imposed on the nuclear industry are simply not justified by any rational calculation of public health benefit. It demonstrates that the sum of measures implemented by the Japanese nuclear industry to protect the public from radiation exposures below 1 mSv/y will not alter the general background cancer risk from all causes in Japan. Just the variability of this general risk (1.7 mSv/y) is greater than 1 mSv/y. In other words, there is no actual gain in public health protection associated with such measures, despite all the effort and expense involved. As the general background cancer risk in Japan is among the world's lowest, this key finding is likely to be valid for most countries worldwide."

Most people exposed to low-dose radiation are benefited thereby, not harmed: e.g., NCRP-136 states on page 6: “It is important to note that the rates of cancer in most populations exposed to low-level radiation have not been found to be detectably increased, and that in most cases the rates have appeared to be decreased.” This phenomenon, a substance that is *toxic at high level being beneficial at low levels, is called hormesis*, and is widespread in biology. Calabrese and Baldwin report (*Nature* **421**: 691, 2003) “thousands of studies demonstrating hormesis ... we see it across the whole plant and animal kingdom ... and at essentially every endpoint ... *hormesis is not an exception to the rule, it is the rule.*”

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Marshall Brucer's canonical tome, *A Chronology of Nuclear Medicine*, states on page 423: "In August 1985, a Conference on Radiation Hormesis in Oakland CA recognized the reversal in concepts of radiation effects. Its proceedings, published in the *Health Physics Journal* in 1987, finally recognized that *low-dose radiation is not only good for you, it is essential to life.*" See also: H. Planel, et al., *Health Physics* **52**(5): 571 (1987).

There is no valid evidence of genetic damage in humans from low-dose radiation, e.g., W. Schull, et al., "Genetic Effects of the Atomic Bomb: Reappraisal," *Science* **212**: 1220-1227 (1981) or K. Sankaranarayanan, lecture presented at 46th session of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 18 June 1997. Previous concern about genetic damage arose from 1920s irradiation experiments by Hermann Muller on fruit flies, which showed they are more vulnerable than humans to radiation. Work with mice at Oak Ridge seemed to confirm this concern, until it was discovered that the mega-mice program was being incorrectly interpreted. The data from the atomic bomb victims also showed no increase in heritable birth defects.

The conclusion of all this is clear: *There is no longer any justification for treating nuclear radiation as uniquely dangerous*, or otherwise exempt from the rules that govern all other physical processes. The comparison between radiation and other assaults on the system are well understood, and permissible radiation standards, with wide safety margins, have been in effect for 75 years. There is no valid reason to further tighten these overly conservative standards.

Nuclear Power

The first half-century of nuclear power has been remarkably safe and reliable. I know of *no other enterprise of this size that has so thoroughly protected the public health*. Ironically, the public, the media and much of the technical literature have interpreted the extraordinary safety measures adopted by the industry as evidence that the dangers must also be commensurately extraordinary. The long-nurtured myths about nuclear power have created wonderful careers for generations of scientists, engineers and associated others, but it's now time to get real. Nuclear technology is not the "Faustian Bargain" claimed by some, beyond the reach of ordinary science and engineering.

The nuclear nightmares all occurred only in someone's inflamed imagination, not in the real world. Many of the horror stories were computer-aided, but that does not make them any more real. The undeniable fact remains that the *commercial nuclear power enterprise has not led to a single radiological death or injury to the public or significant ecological damage.*³ And we now know, and have documented, that the type of commercial nuclear plants we have built or planned, cannot, in fact, create a radiological disaster. In 1981, after the Three Mile Island incident, Chauncey Starr, Milton Levenson and others summarized and documented their research on the potential consequences of the worst realistic casualty for commercial nuclear power plants of the type being built in the developed world. This work was done at ORNL,

³ The Chernobyl incident in 1986 is not really relevant to the kind of commercial reactors we're discussing. The radioactivity release was driven by the enormous power surge and the reactor's graphite, which burned for several days. These factors are not physically possible in the type of plants we're building, which are neutronically stable and have no graphite. We are not claiming that *all* types of reactors are incapable of creating a radiological problem. The statements in this paper refer only to the types of large commercial reactors built and planned in America, and similar plants elsewhere. It's worth noting, however, that even at Chernobyl, the number of public deaths attributed to radiation was limited to the 10 or 12 children who underwent thyroid surgery.

ANL, INEL, Karlsruhe and other sites, sponsored by NRC, DOE, EPRI and others. An EPRI summary report of this work by Milton Levenson and Fred Rahn with 48 technical references was published in *Nuclear Technology* **53**, May 1981, with an editorial on page 97 and an article on pages 99-110. The paper was published in all the IAEA languages. The author gave invited seminars in England, France, Japan, South Korea, China, Taiwan, and about 10 places in the US. No one raised any serious challenge to the findings. They concluded that *few if any deaths would be expected off-site*. That conclusion was publicly agreed to by the then-Chairman of the Nuclear Regulatory Commission.

The research was expanded to a billion-dollar effort, by several nations, over the following decades to the present. After September 11, 2001, with another 20 years of data accumulated, I arranged for 19 nuclear-expert members of the National Academy of Engineering to publish a Policy Forum in the mainstream, peer-reviewed journal *Science* (Sep. 20, 2002, p.1997, and Jan. 10, 2003, p.201), updating the 1981 report after TMI, and reaffirming its conclusion that the worst that can be expected is few if any deaths offsite. The American Nuclear Society's White Paper on Realism, followed up with more details, additionally confirming that conclusion. (See: www.radscihealth.org/rsh/realism/WP-TableOfContents.htm.) *We can no longer claim that radiation is mysterious or uniquely dangerous*. The risks of nuclear power are now better understood than most other hazards we face in our daily life.

We've been concentrating on this problem for 37 years

In 1973, the world suddenly faced an unexpected dilemma: the OPEC oil embargo, leading to worldwide depression and a dangerous political situation. It was clear we were going to have to curb our appetite for imported oil. In addition, beginning with Earth Day 1970, the public developed a burgeoning awareness of environmental issues posed by coal, automobile emissions and other polluting fuels on which we depended.

So a massive program was undertaken, generously sponsored by governments, industry and public interest organizations, to explore every possible energy alternative: windmills, solar panels, ethanol—"even nuclear." Nuclear power, with its demonic baggage, was penalized and restrained in many ways, and wind, solar and their variants, such as ocean tides, waves, etc., were heavily subsidized and blessed with favorable legislation. Yet, in that situation, only nuclear power was able to overcome its initial problems and uncertainties and establish a large and stable market for itself. France seized the opportunity to "go nuclear" at that time, and has sold electricity profitably to the rest of Europe ever since. No other non-fossil fuel source was able to do that. Nuclear became the default solution, which any other contender must first outperform.

So, for example, when a misled U.S. Congress issued a "Sense of the Congress" resolution, proclaiming that "Since World War II federal nuclear activities have been explicitly recognized by the U.S. Government as an ultra-hazardous activity," we don't have to argue about their data or their rationale. We know from insurance statistics, based on real deaths and illnesses, that *the nuclear business is, in fact, safer than most clerical jobs*. And when critics argue that the public will never accept nuclear power, we read what the *public actually tells neutral pollsters like Gallop: they favor nuclear power by a large margin*. Some critics insist that what people tell pollsters does not necessarily reflect how they would act; that the people who really feel the terror are those living close to the plants. But pollsters find just the opposite: people closest to the plants are most favorable, and sailors who spend months at a time sealed into a closed submarine hull within feet of an operating reactor are generally most favorable of all.

Similarly, when Amory Lovins gives us a persuasive argument about how economics will not

permit a nuclear renaissance to develop, we don't have to wrestle with his logic or his data. (Students of conflict generally agree that one should avoid fighting an adversary on the battlefield of his choice.) We simply look at what's happening in the real world. We see that, of the 436 commercial nuclear power plants now operating, very few are shutting down; most are getting their operating licenses extended for years, if not decades. In addition, the latest WNA list of world commercial nuclear power plants shows 53 more plants under construction (first concrete poured), 142 more ordered (funded), and another 327 proposed (specific programs), *totaling nearly 1000 plants worldwide, already committed.* This includes just commercial, electricity-generating plants. There are a comparable number of research and other special-purpose reactors in universities, hospitals and research centers. And there are hundreds of highly reliable, safe naval reactors. The generic, abstract arguments just don't match the actual facts.

It has been argued that we cannot build new nuclear plants fast enough to meet the ecological challenge. But, let's look at the history. During the 1980s, mass production of full-scale commercial nuclear power plants was just getting underway in the U.S. In the slump after the Three Mile Island incident, many of these plants were canceled, and others were converted to gas or coal. *But 177 nuclear plants were officially issued Construction Permits by the U.S. Nuclear Regulatory Commission, and 134 of these were issued full-power Operating Licenses.* An Operating License means that a plant has reached the stage where no further regulatory questions remain. For our purposes, that plant is considered "built," whether or not it was later destroyed or converted to fossil fuel, or shut down. In addition, as many as 200 plants had spent several years ordering and obtaining the large pressure vessels, steam generators, pumps, etc. that are the limiting factors in construction. Most of these plants were canceled before entering the licensing process, but they demonstrate the construction capability that existed even then.

In addition, by 1990, 150 U.S. nuclear naval vessels were in operation, which, with land prototypes and multiple-reactor ships, comprised about 200 reactor plants, built and maintained by 11 shipyards—6 government, 5 private. The nuclear construction rate of the Soviet Navy was even larger, and there are several other nuclear navies as well.

Granted, that obstacles exist today that did not exist in the previous century: we have lost most of our capability to manufacture heavy machinery; much of our nuclear expertise resides in workers retired, or about to retire; capital is harder to raise, etc. Those facts are well known and oft repeated. But they are usually pitted against a record of 47 plants built *and still operating*, rather than those built or nearly built. A plant fully built does not become "unbuilt" because it is no longer operating.

When we hear arguments of economic viability of wind or solar systems, we search in vain for a real-world example of these systems actually leading to the shutdown of any fossil plants. *The carbon release actually increases in regions with significant numbers of windmills.*

Comparing the economic arguments with the real world, we note that numerous European countries are now finding that nuclear plants, having amortized much of the initial construction cost, are now clearing about \$2 million profit per day per plant. This profit is so large and so certain that the competitors to nuclear plants are howling "unfair!" And *nuclear plant owners are now facing "windfall profits taxes" and "unearned income" fees* of hundreds of millions of dollars each year, each plant. Not just in socialist Europe, but even the Attorney General of Connecticut has joined in the call for such a tax. This is "the bottom line" in any discussion of long-term economic viability.

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So what are the consequences of fully acknowledging the real-world status of nuclear power? First of all, it does *not* mean we should lower nuclear quality standards to match the lowest, or even the average, industrial standard. Like other highly-controlled industries—such as the “clean rooms” used to manufacture electronic parts, and some medical and biological materials—the value of extremely tight control is justified on its own merits. We don’t need a satanic bogeyman. *The levels of excellence that sustain the extraordinary record of safety and reliability can, and must, be continued.* That’s just good business.

The issue of safety

First of all, unlike temperature or pressure, **safety is not an independent variable.** We can decide to design a plant to run at a particular temperature or pressure, but we cannot do the same for safety. Safety is an emergent property, dependent on the selection and control of materials and personnel, attitude and competence of management, ability to exchange information and experience with others, etc. The statements we occasionally hear, e.g., that the AP-1000 plant “is 100 times safer than previous plants” is neither defensible nor deliverable. How can you measure it, let alone guarantee it? Since no post-TMI commercial American plant has suffered serious radiological failure, **how can you better such a record?**

Furthermore, **adding unnecessary “safety provisions” does not make a system safer.** Any additional hardware or procedure poses an additional potential casualty. Consider the “core catcher,” a provision incorporated into AREVA’s EPR plants. The only American commercial reactor to have a core-catcher was Fermi-1. The added structure vibrated loose and ended up partially blocking the coolant flow and leading to the event described in “The Day We Almost Lost Detroit” oft cited by nuclear critics. In contrast, the casualty that a core-catcher is designed to deal with is the dreaded China Syndrome. The Three Mile Island reactor inadvertently initiated that condition in 1979, when ten to twenty tons of molten fuel slumped down onto the bottom of the reactor vessel. How did the real world respond to this provocation? The thick-walled reactor vessel froze the molten fuel mass before the trip to China had progressed more than five-eighths of an inch. **There was no need for a core-catcher.**

The issue of tritium

In our nuclear-is-uniquely-hazardous context, *we may sometimes promise more than we need to*, and come to regret it. A good example is tritium. Tritium is listed by the US EPA and the US NRC as one of the least hazardous radioactive materials. Beer, bananas and salad dressing are thousands of times more radioactive. A leak or spill of oil, solvent or other industrial liquid is very likely more hazardous. Putting potassium salt fertilizer on a farmer’s field usually involves much more radioactivity than a tritium leak. The proper response to a leak should depend on, not whether it’s radioactive, but how toxic it is. But that’s not the way things are handled in the nuclear field. In 1997, a tritium leak was detected from the medical research reactor at the Brookhaven National Lab on Long Island. The underground leakage plume never left the confines of the fenced-in laboratory property, and thus never reached the public or the local drinking water. Moreover, the leakage fluid itself was within the permissible levels for drinking water! But U.S. Senator Alphonse D’Amato said, “The bastards are killing my people, and I’m not going to let them get away with it.” And he forced an emergency, permanent shutdown of the reactor and its associated research. Not content with that, he specifically forbade by law any effort to restart the facility into the indefinite future. *That’s what comes of claiming*

that any small amount of radiation is dangerous, regardless of the toxicity data specifically showing that it is not.

Here we need to clarify the idea of toxicity, as it applies here. The classical use of the term, in murder mysteries and in medieval royal court intrigues, refers to a few drops of a potion, dropped surreptitiously into the King's wine. The toxicity of the potion is measured by the number of drops it takes to do the job. We can quantitatively compare radioactive and non-radioactive material at that level of toxicity. But when we get to less dangerous material, the issue is not so simple. It may be physiologically impossible to kill someone with tritium. In the body, it generally takes the form of water, and the lethal dose calculates to be something like 100 gallons per day—not an easy diet! Moreover, like uranium, the physiochemical properties may be more harmful than its radioactivity. (Chemically, it is hydrogen, but the larger molecule behaves differently in the body with regard to diffusion, etc.) Similarly, “ordinary” materials like oil or various industrial solvents may be carcinogenic, but it's not clear how many drops constitute a hazard.

The Canadian CANDU reactors are moderated with heavy water, so they produce much more tritium than light water reactors do. Canadian regulators have therefore been especially diligent in ensuring that the tritium toxicity question is properly dealt with. In response to a recent newspaper scare story on CANDU safety, the President of the Canadian Nuclear Safety Commission stated on March 4, 2010:

“CANDU reactors are safe. They pose no risk to Canadians or to the environment. They have been operating in a safe manner—both in Canada and abroad—for over 30 years, and will continue to do so.”

The derived release limit for tritium in water from the Bruce B nuclear power plant is about 60 million curies per year; and the operators control emissions to be well below the limits. The Canadian limit for tritium in drinking water has been 7,000 Becquerel per liter (Bq/L). The actual level in the lake is less than 20 Bq/L. The Brookhaven leak never left the plant premises and never exceeded the U.S. drinking water limit (740 Bq/L or 20,000 pCi/L)

So, when some tritium leaks were discovered near nuclear power plants, a cry arose for “zero tritium leakage.” Such a demand was neither scientifically justified nor politically wise. We want to promise there will be no accidents, but no one can guarantee that. Unmet promises degrade our credibility. Instead, *we should ensure that the consequences of any foreseeable accident are tolerable*. And, of course, we should try to eliminate leaks. Non-nuclear facilities, handling much greater quantities of much more harmful materials, don't promise there will be no spills or leaks. They mop up as much as they can, but they (sensibly) don't try to create food-standard purity for the dirt or concrete in the spilled area. The ground around most ordinary “gas stations” where we refuel our cars is much more toxic than the recent tritium leak at the Vermont Yankee nuclear plant. Based on sampling wells within fifty feet of the buildings, the *total leakage was a very small fraction of one curie!* (Compare that to the annual release limit from the Canadian facility of 60 million curies.) Yet, Vermont has decided to shut down the facility, which has been reliably operating for 38 years. The plant could supply 85% of the state's electricity demand, but the state has chosen to export two-thirds of its production, so it can claim that Vermont is losing only one-third of its electricity supply when VY is shut down. (Other complaints were also cited in the shutdown decision, but the leak seems to be the factor that instigated protest marches and calls to shut down the entire nuclear industry.)

In a radioactive world, in which *cosmic rays continuously produce an estimated 4 to 8 million curies of tritium each year*, the additional production of a small fraction of one curie should not be considered a significant public health problem.

“Nuclear Waste”

The fact is, “*nuclear waste*” is a *misnomer for the valuable materials* that compose used fuel, which will be recycled in breeder reactors, to use most of the remaining fissionable uranium, and use also the fertile uranium that creates more fissionable material while generating electricity. Part of the used fuel is fission products, worth literally billions of dollars, which will be recovered. The residual material, with no further use, amounts to about two pounds for each person’s lifetime supply of electricity. The radioactivity of the used fuel decreases, until after 300 to 600 years, it approaches the level of the ore from whence it came. Nothing uniquely hazardous there.

We know more about the toxicity of radiation than about many other materials we handle routinely. We can compare quantitatively the toxicity of radioactive materials with any particular non-radioactive poison. So there is no excuse for saying, “Oh, but radiation is much worse.” Critics like to cite the fact that if all the electricity produced in the U.S. came from nuclear plants, the radioactivity produced as a by-product could kill ten billion people. You don’t have to say that very loud to terrify a lot of people. But it’s not unique or unprecedented. Here are some common non-nuclear materials that show *much bigger potential mortality rates*, that could potentially result from the *annual U.S. production of just these five chemicals* (compared with nuclear):

Number of Potential Human Deaths*

Nuclear Power	10 billion
Barium	100 billion
Hydrogen cyanide	6000 billion
Ammonia	6000 billion
Phosgene	20,000 billion
Chlorine gas	400,000 billion

* These numbers, including the nuclear power figure, are calculated by dividing the estimated lethal dose into the total quantity of material produced annually. They are purely hypothetical numbers, useful only for making comparisons. *A large public swimming pool may contain enough water to drown a million people, but we don’t consider it a potential mass killer.*

THE FACTS REPORT

What follows is the latest draft of a report that I have found useful for focusing discourse on nuclear energy. It is a list of purported facts about the use of nuclear energy for generating electricity, and purported facts about the principal, non-fossil alternatives: wind, solar and biofuels. It is not a public relations report, but is for science writers, policy makers, teachers and staffers. There are no conclusions or recommendations here, just facts; no predictions or estimates or opinions. Just facts that manifest, or could realistically manifest, in the physical world. A number of colleagues I respect have found that using the Report does in fact significantly facilitate constructive discussion.

Because the Report does not reach any conclusions, make any recommendations, or attempt to achieve a consensus, it can properly emphasize contradictions among these facts, rather than trying to gloss them over. That is the most direct way to facilitate resolution of the contradictions

One can object that particular statements of fact in the Report are outdated, misleadingly stated, or otherwise inaccurate. If we're shown better, supportable facts, they will replace the criticized ones. Or one can argue that our facts have been "cherry picked," or that certain facts have been left out that should be included. That too can be fixed. *If every fact included gets replaced by a better one, that will vindicate, not repudiate, the purpose of the document, which is to get people to consider the facts.*

If the facts can be made clear enough, not only to the arguers, but also to the by-standers, it should become easier to overcome some of the fear-generated myths, and engage in more rational discussion. I urge recipients to try it, and to make their own contributions toward making the facts as clear and accurate and up-to-date as possible. Thus, the Report can have a long life as a useful, working document.

The first part is a summary, listing key facts in a novel format: one-line, "bumper sticker" statements. You can skim these, nod at the familiar ones, and think about some of the others. These one-liners are not to convince you; they are more like titles, to alert you to the sections of the report that follows, which discuss and document the facts. You may notice that some of these facts contradict each other.

Facts are included here if some aspect of public policy or belief depends on them. If the fact has been refuted, but the policy or belief depending on it continues, we will continue to list it. Every purported fact in this report is subject to being repudiated or superceded, and thereby losing its place here. When we finally get people talking about the facts, we will have made a significant step toward rationalizing the discussion and educating both policy-makers and the public at large.

Ted Rockwell

Jerry Cuttler has played a big role
in bringing this report into being.

SUMMARY [in one-line bullets]

A. About this Report and its very limited scope

1. Intent is to compare American commercial nuclear power with alternative sources of energy.
2. Working document, not formal public or policy statement. Its usefulness trumps other considerations.
3. Scope limited to maintain focus; e.g., does not discuss making liquid fuel; nukes not now involved there.
4. Facts only, to facilitate discussion and policy-making. Conclusions, recommendations left to others.
5. Thus, can highlight, not obscure, contradictions and weak premises. Status of claimed facts negotiable.
6. Controversial facts will be documented; undisputed historical or scientific facts will not be documented.
7. Scientific/engineering considerations only. Political, policy, social considerations are left to others.
8. Distinguishes between obstacles to be overcome and inherent problems that remain.
9. Radical or long-shot options, such as zero-point energy not covered here. No judgment implied thereby.
10. I expect these facts to be challenged; good! That's the point of this report. Let's discuss the facts.

B. Key facts about the American nuclear decision-making process

1. Nuclear marked by some as uniquely dangerous, "Faustian Bargain," last resort, mysterious, unnatural.
2. Radiation treated as more harmful than other biological hazards, such as chemical or biological threats.
3. "Man-made" radiation declared more dangerous than same radiation from natural sources.
4. Price-Anderson, Yucca Mtn, Govt Employee Compensation, Sense of Congress, all unique nuclear penalties.
5. Nuclear charged up-front for decommissioning, insurance, financial viability, etc.
6. Unique multimillion-dollar licensing process continues despite 50-year, nearly flawless safety record.
7. Engineering practice with "ordinary machinery" often discounted as inadequate for nukes by definition.
8. Precautionary Principle requires emergency actions to proceed without full evaluation of alternatives.
9. Nuclear has yielded to unreasonable safety demands because it could. Now facing unanticipated costs.
10. "Reductio ad absurdum" reasoning fails when it is profitable to be unwilling to acknowledge the absurd.
11. Many nuclear spokesmen haven't accepted (nor disproved) that nuclear catastrophe is physically impossible.
12. Policy-makers often assume majority of public opposes nuclear. Not true. Large majority favors nuclear.

C. Key facts about American LWR commercial nuclear power plants

1. Nukes have up to 50 years of operation in various cultures and are now the only proven choice beyond fossils.
2. 264 PWRs and 92 BWRs worldwide have virtually unblemished reliability and safety records.
3. American commercial nukes have > 90% availability vs. 20-40% for wind or solar. No radiation deaths.
4. Virtually no effluents from plants to pollute the environment. "Waste" is contained, for future recycle.
5. Nuclear fission produces millions of times more energy from a pound of fuel than chemical combustion.
6. Nuclear power is potentially renewable. There's enough fuel and "fertile material" to last for many millennia.
7. Some European nukes are now facing large "unearned profits fees" for being so reliably profitable.
8. Peer-reviewed article in *Science* documents that American nukes cannot create a radiological catastrophe.
9. Yet NRC requires mass evacuation procedures, involving large numbers of people and organizations.
10. Government officials state: Predicting deaths from low-dose radiation is scientifically indefensible.
11. Yet radiation protection practice claims: There's no safe radiation level; that one gamma ray can kill you.
12. Presuming new safety problems, EPR nukes have 4-5 times more steel and concrete than AP-1000s.
13. Possibility of contribution to proliferation of nuclear weapons material remains, but has not materialized.

D. Key facts about wind-energy for the American electric power grid⁴

1. No mining required for fuel. No polluting effluents from operation.
2. Cannot supply power on demand. Electricity that is not dispatchable is hard to sell, and harder to store.
3. Wind-farms are shut down > 60% of the time, sometimes for long, unpredictable periods, over wide area.
4. Windmills kill huge numbers of birds and bats, some of which are on the endangered list.
5. There is growing alarm that mosquito-borne diseases will increase as bat and bird killing continues.

⁴ "<" = less than; ">" = more than; MW = megawatts = 1,000 kilowatts

6. Fossil plants backing wind-farms are showing increased degradation from unaccustomed power swings.
7. Local and federal concern that wind-farms' slowing airspeed may detrimentally change weather patterns.⁵
8. Power generation varies as cube of wind speed; doubling wind speed creates an eight-fold power surge.
9. Windmills' inherently erratic speeds must accommodate to grid's need for tight control of frequency.
10. Below minimum wind speed, and above a design maximum, a windmill cannot produce any electricity.
11. Transmission system has to handle peak load that seldom comes. Peak capacity paid for, not used.
12. Wind towers are huge structures, small output. 2000-3000 towers + spinning backup = 1 nuke.
13. The massive wind-farms in California produce only a tiny fraction of the state's electrical needs.
14. Towers require space around, with access roads, no large trees, > 300 sq mi = 1 nuke (< 1 sq mi.)
15. 2 MW windmills are 30-story structures with 500 tons of concrete base blasted 40 feet into bedrock.
16. Windmills' annoying vibrations and flickering light patterns cause traffic accidents, medical problems.
17. Several hundred politically active anti-wind organizations formed in America; more in Europe, like anti-nuke orgs
18. Federal subsidies for wind-power total \$23 per megawatt hour, vs. \$1.59 for nuclear.
19. These tax-payer subsidies could buy nuclear electricity directly at market cost, with money left over.
20. Laws force some utilities to buy from "renewable sources;" utilities can profit from just the subsidies.
21. Windmills have reportedly caused 651 accidents, 61 deaths, from blade and ice-throw, fires, etc.

E. Key facts about solar-energy for the American electric power grid

1. No mining required for fuel. No polluting effluents from operation.
2. Cannot supply power on demand. Electricity that is not dispatchable is hard to sell, and harder to store.
3. Solar systems are shut down > 60% of the time, sometimes for long, unpredictable periods.
4. Photovoltaic (PV) systems use highly toxic materials. Must be treated like radwaste, but forever.
5. PV panels on *all* US south-facing roofs could generate only few % of electrical output from one nuke.
6. Solar-thermal systems prone to fire, requiring evacuation and potential public health problems.
7. Large solar systems still very expensive and experimental. Exotic PV elements can't be synthesized.
8. Shade trees may interfere with solar. Solar systems in desert have significant transmission losses.
9. Solar panels lose up to 30%, if millions of square feet of panels are not washed every few days.
10. Transmission system has to handle peak load that seldom comes. Peak capacity paid for, but not used.
11. Federal subsidies for solar power total \$24 per megawatt hour, vs. \$1.59 for nuclear.
12. These tax-payer subsidies could buy nuclear electricity directly at market cost with money left over.
13. Laws force some utilities to buy from "renewable sources;" utilities can profit from just the subsidies.
14. 90% of world's direct solar electricity is from one facility, 355 MW peak, 77 MW average (10% of one nuke).

F. Key facts about burning biofuels for the American electric power grid

1. Burning vegetation vs. returning nutrients and fiber to the soil raises serious, unanswered agronomic questions.
2. Magnitude of harvest is challenging. Agronomists see "multiple limits to plant production on earth."
3. Replacing coal, which uses half of US freight train capacity, with less dense carbon, will strain transport system.
4. Study claims we can truck cane only 25-50 miles to process, or will have negative energy balance.
5. Biofuel source spread over non-food-growing land; no "mine mouth" or "well-head" source.
6. Productivity and harvest efficiency of such land has not yet been demonstrated.
7. All that harvesting and trucking will impact earth deleteriously.
8. Studies show many ways that net decrease of CO₂ may be thwarted by various natural processes.

G. Key considerations about the process of selecting among these energy sources

1. If we decide a particular energy source cannot play a major role, what do we get from building a few?
2. Are willing to put most of our resources into one energy form? (We now do this with cars, ships and aircraft.)

⁵ Research at Maryland, Princeton, Harvard, et al., found serious uncertainties that should be better understood. See e.g. www.livescience.com/environment/041109_wind_mills.html or WashPost Weather Blog, July 2009.

Facts about windmills to feed electricity into the American electric power grid

Wind-farms cannot produce electricity on demand. Typical availability is 20-40%, compared with 60-80% for coal and over 90% for nuclear. Such unpredictable electricity is hard to sell. In addition, note that *each windmill contributes only a tiny amount of electricity to the grid, yet it is a major structure*. Windmills kill a significant number of bats and birds, some of which are on the endangered species list. This has created concern, at both the local and the federal level, over potential increase in mosquito-borne diseases caused by bats and birds killed by wind-turbines.⁶

Since thrown blades can kill people nearly a mile away, and windmills must be spaced so as not to interfere with each other's wind, they must be surrounded by considerable land area. To generate (at peak power) as much electricity as a single 1000-megawatt nuclear plant, a wind-farm would occupy 200 to 300 square miles. (A nuclear power station might have two or more such plants and occupy only about one square mile.) Each two-megawatt wind-turbine is one-third taller than the Statue of Liberty from the ground to the torch-tip. To make these windmills: "Coal-fired cement plants would be needed to make millions of cubic yards of concrete for the bases. Rocks might have to be blasted away, or trees cut down to make room for the bases, towers, and the wind itself."⁷ Per kilowatt-hour generated, wind farms require considerably more steel and concrete than a nuclear plant.⁸ And this cost can be amortized over only the short—typically 15 years—life of wind-turbines. By comparison, nuclear power plants will run for 60 or more years.

If you'd prefer all this be done off-shore, you'll need monopole towers about nineteen feet in diameter sunk deep into the seabed. Cravens notes that "The U.S. Army Corps of Engineers is planning to test a monopole installation and has announced that four species of endangered turtles, four species of endangered whales, two species of endangered seabirds, and a threatened beach plant may be affected by such an experiment. Warning lights for aircraft and boats would light up the wind-park at night, and foghorns would bellow as needed. An underwater cable would connect the turbines to the grid." (Curiously, environmentalists don't appear to mind *that* cable—just the one across Long Island Sound.)

The above discussion is just to document the fact that the *wind-turbines used in connection with "wind power" plants are not at all like the simple, small windmills* commonly seen on farms before the electric power grid made them obsolete.

As the magnitude of the intrusion such wind-turbines would make on any neighborhood became apparent, public opposition of the NIMBY type (Not In My Back Yard), reminiscent of early anti-nuclear rallies have sprung up, and given rise to national and international anti-wind-power organizations.⁹ The bases for objection were many. The Audubon Society was horrified at the *bird- and bat-slaughtering capability of these "avian cuisinarts"* (their words). The Industrial Wind Action Group opened one of its newsletters with the words: "Building turbines in some of the best places to harvest wind in Ohio could put millions of birds and bats—some protected by state and federal law—at risk."¹⁰ Other objectors are concerned about the noise and

⁶ E.g., Paula Reed Ward, *Pittsburgh Post Gazette*, Sep 27, 2005, p.B1 et seq.

⁷ Gwyneth Cravens' *Power to Save the World*, Alfred A. Knopf (2007)

⁸ Comparison with nuclear is from Per Peterson Peterson@nuc.berkeley.edu personal correspondence

⁹ E.g., www.windenergy-the-truth.com or www.epaw.org or Google "National Wind Watch"

¹⁰ www.windaction.org/news/14848

aesthetics of “industrialized ridgelines.” The late Senator Edward Kennedy tried to kill a proposed wind-farm visible from his home in Hyannis Port, but such projects die hard. His nephew, Robert F. Kennedy Jr. is trying to kill another wind-farm in Long Island Sound.

In addition to requiring a large amount of materials, labor and money for each small increment of energy generated, the *output from wind-farms is erratic and unpredictable*. Unlike a 1000 megawatt nuclear plant, which reliably generates over 900 megawatt-years of energy each year, a 1000 megawatt wind-farm could be expected to generate no more than 200 to 300 megawatt-years, because of the variability of the wind.

The variability of wind speed imposes specific limitations on the electric output of any wind-driven generator. Below 7-10 miles per hour (mph), the wind is too slow to generate useful power. Rated speed for most machines is in the range of 25 to 35 mph. At high wind speeds, typically between 45 and 80 mph, most wind-turbines have to shut down to prevent damage.

The important fact about wind-turbines is that *electric power output varies as the cube of the wind speed*. Thus, when wind speed doubles, the power output from the wind-turbine increases eight-fold. A variation from 10 to 12.6 mph doubles the output. And conversely, dropping from the rated speed by a third (from 31 to 21 mph) decreases the power generation by more than two-thirds. This presents a serious problem for the electric power grid, because there is no place to store any significant amounts of electricity. The National Electrical Reliability Council estimates that for safe grid operation, voltage can vary no more than 5% without potential damage to electrical equipment. Information storage and handling systems are even more vulnerable—blips as brief as a sixtieth a second can be damaging.

So, an electric power grid is a continuous delicate balancing act, having to match up each new demand for more electricity by increasing generation accordingly, and matching each turned-off light switch by correspondingly decreasing output from one of its power stations. The grid accomplishes this balancing by maintaining a good-sized “spinning reserve” of some reliable energy source, such as coal or gas. Of course, this is all done automatically, under the coordinated watchful eye of various human operators. But in that situation, *having an energy source, such as a wind-farm, that on its own initiative doubles its output or cuts it in half from time to time, is seen as pure mischief*. As evidence of this, note that it usually requires 24 hours or more to restabilize the grid after a blackout. If we had never heard of unpredictable energy sources, and we observed unpredictable surges into and out of the grid, we might reasonably suspect sabotage. It is easier to harm the system by scrambling the demand than by blowing up transmission towers.

Not only is a wind-farm’s output unpredictable, but *what pattern there is, is often counter-productive*. In much of the U.S., the wind is apt to be higher speed and steadier at night, when the demand is lowest. And the gusts are strongest in the spring and fall, when neither heating nor air-conditioning demand is in full swing. But such conditions are local, and some are favorable.

Europe now has enough wind energy to pose serious grid problems. Utilities would not buy wind-power by choice, so they are required to do so by government mandate. One suggested remedy is to disperse the wind turbines over a wide area, to smooth out some of the wind bursts. But this requires that more of the energy travel over greater distances, and even at 500,000 volts (to minimize losses), *a significant part of the energy being transmitted is lost as heat on the way*. Even within a few tens of miles, as much as 9% is lost. Getting approval to place high-voltage power lines is even harder than for nuclear power plants. So, although 19% of west Denmark’s

electricity is produced by wind-turbines, 96% of the region's electricity is produced by other means. Overall, *85% of Denmark's wind-turbine electricity in 2004 had to be exported, generally at highly discounted prices.*

A recent development to *ease this problems is a bank of high-speed spinning flywheels to level off power surges,*¹¹ being developed by Beacon Power (NasDaq:BCON). These are like the surge suppressor you put on your computer. It prevents a sudden power burst from blowing out your computer. Such protection is even more important on the power grid because of the grid's need to *reduce frequency variations.* But in no sense does it replace the *need for a much larger energy back-up source.* If you have a UPS (Uninterruptible Power Supply) on your computer, it has a battery that will keep the system powered for a couple of hours or more. These flywheels are like a good surge suppressor with only a small battery.

The systems are rated in megawatts, but they don't store megawatts (power), they store megawatt-hours (energy). The systems are huge and sophisticated. The 1-MW system has been tested. It consists of a bank of 10 one-ton carbon-fiber cylinders, magnetically levitated in a vacuum chamber, spinning 16,000 rpm. It stores 250 kW-hours, which would keep a 1-MW system going for 15 minutes. Three megawatt and 5 MW units are planned for the near future, with increasing energy capacity. These systems will not be cheap, but they may be very important for voltage stabilization of the grid. But they do not overcome the problem that wind- or solar-energy may be down overnight or longer.

There is another issue we seldom hear about in connection with windmills: safety. We tend to think of windmills as green, pristine and benign. (Only nuclear has known sin, although coal is getting a reputation.) But any activity that involves *working with tons of concrete and steel in some very large pieces is going to incur some injuries and deaths.* Ed Hiserodt has pulled together some of the data on injuries and deaths from windmills.¹² The data are maintained by the Caithness Windfarm Information Forum in Great Britain¹³ in its report, "Summary of Wind Turbine Accident Data. This report¹⁴ has been reproduced below. Gary Troyer updated the data and prepared the accompanying figure.

Summary of Wind Turbine Accident Data to 31 December 2009

These accident statistics are copyright Caithness Windfarms Information Forum 2009. The data may be used or referred to by groups or individuals, provided that the source (Caithness Windfarms Information Forum) is acknowledged and our URL www.caithnesswindfarms.co.uk quoted at the same time. Caithness Windfarms Information Forum is not responsible for the accuracy of Third Party material or references.

The attached detailed table includes all documented cases of wind turbine related accidents which could be found and confirmed through press reports or official information releases up to 31 December 2009. CWIF believe that this compendium of accident information may be the most comprehensive available anywhere. Data in the detailed table attached is by no means fully comprehensive – CWIF believe that what is attached may only be the "tip of the iceberg" in terms of numbers of accidents and their frequency. However, the data gives an excellent cross-section of the types of accidents which can and do occur, and their consequences.

¹¹ <http://www.cleantech.com/news/3869/beacon-downsizes-flywheel-storage-plans>

¹² <http://thenewamerican.com/tech-mainmenu-30/energy/788?tm>

¹³ <http://www.caithnesswindfarms.co.uk/>

¹⁴ <http://www.caithnesswindfarms.co.uk/page4.htm>

The latest version of this Report will always be available at <http://learningaboutenergy.com>

The trend is as expected – as more turbines are built, the more accidents occur. Numbers of recorded accidents reflect this, with an average of 72.1 accidents found per year from 2002 to 2009 inclusive, and only an average of 16.0 accidents found per year in the previous seven years (1995-2001 inclusive). With few exceptions, before about 1997 only data on fatal accidents has been found.

There is a general trend upward in accident numbers over the past 10 years. This is predicted to escalate unless HSE make some significant changes – in particular to protect the public by declaring a minimum safe distance between new turbine developments and occupied housing and buildings (currently 2 km in Europe), and declaring “no-go” areas to the public, following the 500 m exclusion zone around operational turbines imposed in France.

Data attached is presented chronologically. It can be broken down as follows:

Number of accidents

Total number of accidents: 715

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.	1	8	17	5	9	16	8	33	29	12	63	51	52	55	55	83	112	106

Fatal accidents

Number of fatal accidents: 60

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.	1	8	8		2	4		1	3		1	3	4	3	5	4	9	4

Please note: **There are more fatalities than accidents as some accidents have caused multiple fatalities.**

Of the 66 fatalities:

- 47 were wind industry and direct support workers (maintenance/engineers, etc.), or small turbine owners/operators.
- 19 were public fatalities, including workers not directly dependent on the wind industry (e.g., transport workers).

Human injury

A further 38 accidents regarding human injury are documented.

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.			2		1		1	1	4	1	2	2	1	2	4	3	8	6

Twenty-nine accidents involved wind industry or construction/maintenance workers, and a further nine involved members of the public. Four of these injuries to members of the public were in the UK.

Blade failure

By far the biggest number of incidents found was due to blade failure. “Blade failure” can arise from a number of possible sources, and results in either whole blades or pieces of blade being thrown from the turbine. A total of 167 separate incidences were found:

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.			3	3	3	6	2	18	4	5	15	12	14	10	13	17	18	24

Pieces of blade are documented as travelling up to 1300 meters. In Germany, blade pieces have gone through the roofs and walls of nearby buildings. This is why CWIF believe that there should be a minimum distance of at least 2 km between turbines and occupied housing – in line with other European countries - in order to adequately address public safety and other issues including noise and shadow flicker.

Fire

Fire is the second most common accident cause in incidents found. Fire can arise from a number of sources – and some turbine types seem more prone to fire than others. A total of 138 fire incidents were found:

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.			1	1		1	1	2	3	1	24	17	15	14	12	20	16	10

The biggest problem with turbine fires is that, because of the turbine height, the fire brigade can do little but watch it burn itself out. While this may be acceptable in reasonably still conditions, in a storm it means burning debris being scattered over a wide area, with obvious consequences. In dry weather there is obviously a wider-area fire risk, especially for those constructed in or close to forest areas and/or close to housing. Two fire accidents have badly burned wind industry workers.

Structural failure

From the data obtained, this is the third most common accident cause, with 84 instances found. “Structural failure” is assumed to be major component failure under conditions which components should be designed to withstand. This mainly concerns storm damage to turbines and tower collapse. However, poor quality control, lack of maintenance and component failure can also be responsible.

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.			1				3	6	9	2	8	4	3	7	6	11	9	15

While structural failure is far more damaging (and more expensive) than blade failure, the accident consequences and risks to human health are most likely lower, as risks are confined to within a relatively short distance from the turbine. However, as smaller turbines are now being placed on and around buildings including schools, the accident frequency is expected to rise.

There has been a sharp rise in structural failures from the latter part of 2007 continuing through 2008 to present.

Ice throw

27 incidences of ice throw were found. These are listed here unless they have caused human injury, in which case they are included under “human injury” above.

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.					3	3		3			2	1	4	3	2		3	3

Ice throw has been reported to 140 m. Some Canadian turbine sites have warning signs posted asking people to stay at least 305 m from turbines during icy conditions.

These are indeed only a very small fraction of actual incidences – a report* published in 2003 reported 880 icing events between 1990 and 2003 in Germany alone. 33% of these were in the lowlands and on the coastline.

Transport

There have been 45 reported accidents – including a 45 m turbine section ramming through a house while being transported, a transporter knocking a utility pole through a restaurant, and a turbine section falling off in a tunnel. One man lost his leg in 2006 following a transport accident off the Scottish coast. Most involve turbine sections falling from transporters, though turbine sections have also been lost at sea, along with a £50M barge. Two turbine sections fell from main roads in Scotland.

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.										4		2	4	3	3	14	8	10

Environmental damage (including bird deaths)

Only 60 cases of environmental damage have been reported – the majority since 2007. This is perhaps due to a change in legislation or new reporting requirement. All involved damage to the site itself, or reported damage to or death of wildlife. Twenty-seven instances include deaths of protected species of bird.

By year:

Year	70s	80s	90-4	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
No.			1							1	1	7	1	5	3	8	20	13

Other (miscellaneous)

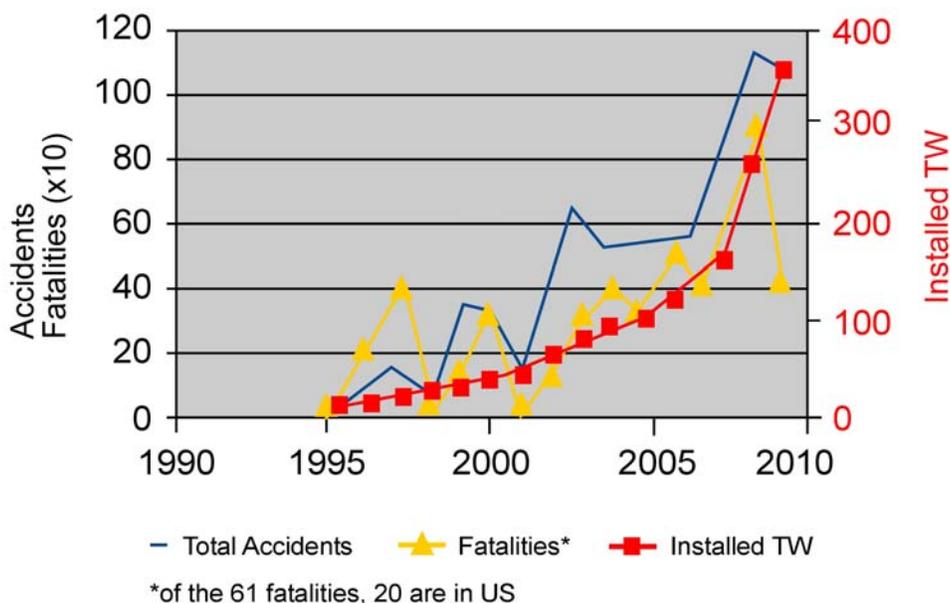
95 miscellaneous accidents are also present in the data. Component failure has been reported here if there has been no consequential structural damage. Also included are lack of maintenance, electrical failure (not led to fire or electrocution) and planning “accidents” where

* “A Statistical Evaluation of Icing Failures in Germany’s ‘250 MW Wind’ Programme – Update 2003”, M Durstwitz, BOREAS VI, 9-11 April 2003, Pyhänturi, Finland

towers have been installed closer than permitted to housing, etc. Construction accidents are also included, also lightning strikes when a strike has not resulted in blade damage or fire. A separate 1996 report** quotes 393 reports of lightning strikes from 1992 to 1995 in Germany alone, 124 of those direct to the turbine, the rest are to electrical distribution network.

 ** Data from WMEP database: taken from report "External Conditions for Wind Turbine Operation – Results from the German '250 MW Wind' Programme", M Durstewitz, et al, European Union Wind Energy Conference, Goeteborg, May 20-24, 1996

World Wind Farm Accidents



Now, of course there are similar types of accidents and deaths in building nuclear plants, too. But, as Hiserodt puts it, "It would take 2,000 30-story tall wind turbines to produce the electricity from one typical nuclear plant, assuming 90 percent and 30 percent capacity factors. *How many accidents would you expect when building 2,000 30-story turbine generators as compared to pouring concrete for a single containment building of a few thousand square feet?*" How will the accident rate change when these complex and enormous structures are being built off-shore, where the hazards of working at elevation while exposed to the weather increase?

But there is a good side to all this (for investors only, not for taxpayers). In America, some *wind-farms are now being built solely for tax credits, and to fill renewable energy portfolios.* Warren Buffet's MidAmerican Energy project calculates that it can break even after six years, *without ever producing any electricity.* And Boone Pickens is offering his investors a 25% return on a 4000 MW wind-farm *based entirely on federal tax credits.*¹⁵ Europe's experience with wind-energy is confirming the theoretical calculations: *no fossil plants are being closed down; energy use and CO₂ are up; electricity costs are up; cost per job created is high, and no compensating benefits are apparent.*

¹⁵ Much of the information in the above few paragraphs is based on sources cited in William Tucker's *Terrestrial Energy*, Bartleby Press (2008).

Facts about solar energy for electricity into the American electric power grid

The sun is a powerful energy source. It lights the day, heats the climate to a livable temperature, created the fossil fuels we now burn at such an astonishing rate, powers the production of all plant life on which our own lives depend, and charges us no money for its services. The total energy of all the sunshine hitting the earth is nearly 20,000 times our current energy needs. But that number has little practical meaning in our search for energy to drive our cars or run our factories. Numbers of comparable magnitude apply to the energy in the ocean waves or the heat of the earth a few hundred or thousand feet below the surface. Yet, as we have seen in trying harness the restless winds, *capturing such low-level energy for our own purposes is not easy*. And the burden for accomplishing it falls on the environment.

One way to visualize this problem is to picture a house on a cold winter day. Its dark roof absorbs nearly all the sun's energy that strikes it. But even at noon, that energy is not enough to heat the house to a comfortable temperature, and most of the 24 hours it gets significantly less energy. If *all* the sun's energy cannot heat the house, clearly no solar panels that convert only 10 to 20% of it to electricity can do it. And, during warm weather, providing energy for air-conditioning and for various household appliances is an additional challenge.

Amory Lovins, founder of the Rocky Mountain Institute, has made a career of showing us how one can get along on a minimum amount of energy. Rather than trying to get more heat out of the sun, his approach is to minimize the heat losses from the house, and, like a greenhouse, it may get warm enough. At 7000 feet, the clear mountain air makes both sun and wind more effective than average (but the thinner air takes away much of the wind advantage). There he built a house and office with no conventional heating system, but with a variety of special features to reduce heat losses drastically. Many of these features are commonsense measures, used by progressive architects since the days of Frank Lloyd Wright—overhanging eaves, to keep the overhead sun out but permitting the slanting rays of the winter sun to enter; double-paned windows, more effective insulation, etc.

But Lovins carried this to the limit, with such niceties as multiple-pane windows combining two or three transparent heat-reflecting films with insulating krypton or xenon gas, so that they block heat as well as 8-14 panes of glass. And a heat-recovery system to warm up the outside ventilating air and recover 95% of that heat before returning it to the outside. And a state-of-the-art data acquisition and control system, with 140 sensor points throughout the house. The building's photovoltaic system has been fitted with a "6-kilowatt array of the most efficient solar panels on the market, courtesy of *SunPower*... With new batteries sucking up the extra electricity, the house will have several days of energy stored. The building will also have two of the most efficient residential air-to-air heat exchangers ever constructed ...a new, highly efficient electric stove integrated with specially designed pots to save around 60% of the energy normally needed for cooking." The LED-dominated lighting system has just undergone its fifth retrofit. There is radiant solar floor heating. (He says he buys wind power at night from the grid, but one cannot buy wind-power from the grid. The grid sells power whether the wind is blowing or not, and the customer gets whatever mix of generators is on at the moment.) Lovins uses solar in the day, and uses the batteries only when the grid is down.¹⁶ The energy consumed by his institute's

¹⁶ Quotes and much of the data in this section are from "Remodeling Amory Lovins' Home" <http://green.yahoo.com/blog/amorylovins/70/remodeling-amory-lovins-home.html>
See also "Green House in Decatur to Go on Tour," *News-Sentinel* (June 29, 2009)

office equipment is wired directly from the utility and not included in his “zero energy consumption” tabulation.

The North American Insulation Manufacturers Association estimates that Americans have spent more than a billion dollars on insulation since 1970 and that this has reduced their heating and air conditioning costs by 20%, but 65% of our homes are still under-insulated.¹⁷ As buildings became increasingly bundled up, the U.S. Environmental Protection Agency (EPA) started to worry about the “Sick Building Syndrome.” When buildings are too tightly sealed up (to prevent heat loss), then solvents, plasticizers, paint and other noxious fumes build up and become health hazards to the occupants. So more and more ventilation and air purification systems (running on electricity) have to be installed.

All these special features cost money, so despite the use for two years of more than 100 volunteers, a dozen professional builders, and equipment supplied free or at cost, the house cost considerably more than most owners could afford. Note also that the big shade trees many home-owners might want would interfere seriously with both solar and wind-turbines. (Lovins avoids the latter problem by buying wind-energy generated elsewhere. Presumably he could also buy solar-generated electricity. But in both cases, there would have to be a commercial source near-by, and he’d have to account for the electricity lost in transit.)

It’s good to have a demonstration of how far such energy-conserving efforts can go. And if you believe, as Lovins does, that there is no way to generate energy without significantly harming the earth, then you would applaud, and presumably emulate, his efforts. But this would also involve considerable behavior modification for the occupants, as Lovins is quick to point out. He does not have most of the electrical appliances found in the average modern home. He hangs his clothes on a clothesline to dry. He seldom uses his car. He keeps the house temperature lower than usual in winter and hotter in summer. He has demonstrated that a zero-energy house can be built. But I wonder how much energy was spent in creating this demonstration? And how many people would be willing to pay the price, both in cash and in life-style modification?

Projects whose only purpose is to minimize energy use at all cost, remind me of Ernest Vincent Wright, a 67-year old MIT grad, who spent 165 days writing a 50,110-word novel without the letter *e*. An interesting experiment, but I have no interest in reading the book, and don’t know anyone who has read it. There is little difficult in getting as many *es* as one wants, or buying the modest amount of electricity that would permit normal activities in any well-insulated house. With today’s variety of households, the EIA says the average American household uses 12,000 kWh per year. This value includes nights with no loads and days when no one is at home. When getting ready for work or for supper, *the average values quadruple or more*.

We no longer have to speculate as to what energy choices people will make. *Passive solar works well for heating swimming pools to about 80°F*, and this niche now constitutes *94% of the solar thermal market*. Despite large subsidies and continued pressure to “go green,” the passive solar option for residential water heating is down to 4% and space heating to 2%.

So let’s take a look at how solar energy can be amplified to produce higher temperatures.

There are two ways to *get higher temperatures out of solar energy*:

¹⁷ Douglas Land and Laura Lind, “Green and Clean,” *Alliance to Save Energy*, April 2001

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- *Use mirrors to focus the sunlight* onto a tank of fluid, to raise its temperature, or
- *Convert the sunlight directly into electricity*, via photovoltaics, to power electric heaters.

Let's look at a couple of examples of each.

Solar-thermal systems

The U.S. Department of Energy's Sandia National Laboratory built and operated "Solar One," a *solar-thermal* generator on 126 acres of California's Mojave Desert. A large number of large mirrors focus the sunlight onto a tank at the top of a tower, like a child focusing sunlight through a magnifying glass to ignite a piece of paper. This process does not *generate* any energy; it just collects sunlight from a wider area, raising the temperature at the focal point. In this case, the tank contains a synthetic heat-transfer oil called *therminol*, which is used because it is stable at high temperature. The therminol heats up to 735°F, and transfers its heat to water, that generates steam to drive a conventional turbo-generator producing 10 megawatts (peak) of electricity. On August 31, 1986, 240,000 gallons of therminol caught fire and burned, destroying the tower and its equipment. A new tower was built, and the system ran until it shut down permanently in 1988. Solar One had no way to store either heat or electricity, so it had to shut down every time the sun went under a cloud. Literally.

In 1996, "Solar Two" started up, with the ability to ride out short cloudy periods by storing heat in molten salts. It actually sold electricity to the grid until 1999 at the same rating, 10 MW peak. This is less than 1% the size of a typical nuclear power reactor, of which there might be several at a typical nuclear power station, occupying about a square mile. Moreover, the capacity factor of Solar Two was about 16% and a typical nuclear station is over 90%, year after year. So, it would take *several hundred Solar Twos to equal the electrical output of one nuclear power reactor, and several times that many to match the output of a single nuclear power station.*

So how would you scale up the size of a solar-thermal plant like Solar Two? You'd have to put in more mirrors, further away from the tower, and then increase the height of the tower, to "see" the added mirrors. You'd have to beef up the tower, to take the larger tank and system, and to resist the wind pressure. You'd probably conclude, as did Howard Hayden¹⁸, that it's *easier to just build another system, tower, mirrors and all.*

A 355 MW (peak) solar-thermal plant in the Mojave Desert is the SEGS (Solar Electric Generating System) built by LUZ International. It consists of 100 acres of 40-foot high parabolic mirrors that rotate to follow the sun. They form long straight troughs, with a long black pipe lying on the focal line (rather than a single focal *point* like Solar Two). The therminol in the pipes is heated to 735°F. But the SEGS system has a big advantage over Solar Two: it has a natural gas heater to insure that the steam turbine continues to get the same temperature steam, regardless of the temperature of the therminol. Under the applicable solar subsidy rules, a "solar energy" system can make up to 25% of its electricity by burning natural gas, so this is its usual mode of operation, masking some of the variability of the sun.

One fact that by itself challenges the practicality of this approach to serious energy production is this: To maintain the efficiency of the process, all of the 40-foot-high mirrors—*ten million square feet of mirror surface—must be washed every five days or so*, plus a high-pressure

¹⁸ *The Solar Fraud: Why Solar Energy Won't Run the World*, Vales Lake Publishing (2001)

wash every ten-to-twenty days! As Dr. Hayden expressed it, “The good news is that the SEGS system (using a natural gas backup to maintain power) produces ... 10% as much electricity as one large nuke; the bad news is that the *SEGS system’s paltry output is 90% of the world’s direct solar-thermal electricity.*”

LUZ went bankrupt in 1991, but the project was revived under *California’s green laws that require utilities to buy from such suppliers.*

Like Solar One and Two, SEGS was vulnerable to serious fires. Quoting William Tucker¹⁹

“On January 10, 1990, a series of explosions rocked one of the cooling towers and ignited large quantities of therminol. Thirteen engine companies needed 1500 gallons of foam to quench the flames. Then on February 27, 1999, almost a million gallons of therminol caught fire, destroying considerable portion of the facility. The flames released toxic fumes, and a half-square-mile had to be evacuated. The Federal Aviation Administration also set up a no-fly zone around the facility. When it reopened in 2000, SEGS still represented 90% of the world’s solar-thermal capacity.

To get away from large quantities of hot, flammable liquids, we turn to photovoltaics.

Photovoltaic cells

Photovoltaic (PV) cells convert the sunlight that strikes them directly into electricity. It is DC (direct current) electricity, and requires an inverter to use it in connection with the AC used in most places today. Like the solar-heat process, the PV cell is limited to working with the sunlight it captures, and thus faces the same *need for hundreds of square miles of real estate to produce significant amounts of electrical power.* This is one of the reasons that the American Physical Society concluded: “It is unlikely that photovoltaics will contribute more than 1% of the US electrical energy produced near the end of the [20th] century.”²⁰ But for a wide variety of low-power applications, it has proved itself useful. This includes solar-powered lights to line suburban walkways, recharging remote batteries, and providing other applications that can get by on the *few watts maximum that PV cells of a few square feet can produce* in bright sunlight.

How about a PV-powered house? We’ve heard a lot about that. Silicon, from which most cells are made, is the second most abundant material on earth. Silicon cells are at best about 12% efficient—that is, they convert about 12% of the sunlight they receive into electricity. But we’re told that 20% efficiency has been achieved, and probably even higher efficiencies will be reached in the future. There is an element of truth in those two statements, but here’s how it plays out in real life:

The higher efficiencies have been achieved by “doping” silicon cells interstitially with *exotic materials such as germanium, gallium, antimony, indium, and cadmium.* And using gold or platinum for the conducting “wires.” And we find out why these elements are called “exotic.” The APS study just cited concluded that to produce *only 1%* of the US electricity by 2000 would require three times the world’s annual production of germanium or twenty times the world’s annual production gallium. And being elements, *these materials cannot be synthesized out of other materials.*

¹⁹ William Tucker, *Terrestrial Energy*, op. cit.

²⁰ *Solar Photovoltaic Energy Conversion: Principal Conclusions of the American Physical Society Study Group on*, H. Ehrenreich, Chairman, (APS, Jan. 1979)

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Just to produce the *structure to hold the flat-plate solar collectors would require 17% of the US annual production of Portland cement*. These mundane facts have to be dealt with, before planning any large scale use of PVs. And there's more.

PV panels can be put on the rooftops. How much electricity can we produce that way? Howard Hayden²¹ shows us the best we can hope for there. The peak solar flux at the earth's surface, at the equator, no clouds, high noon, is 95 watts per square foot. The maximum 24-hour average is 30. The US average is 20. Assume a typical American home with a 1500 square foot roof, half of which faces south and is fully covered with PV cells. And assume no shade trees. Even at 20% efficiency, this system would average 4 watts per square foot, for a total of 3000 watts electrical. That will cover the lighting, but you'll have to find another energy source if you want to have an energy-efficient dishwasher (1500 watts), coffee-maker (1000 watts), clothes dryer (2500 watts), etc. Can you live without these appliances? Certainly. Do you want to? Do you have to?

But that's not yet the whole story. If we're going to make enough electricity to light all American homes, we have to deal with the fact that apartment dwellers generally have virtually no roof of their own. We have to provide some PV space for them. You could find more roof space on factories and other buildings. But you'd also have to provide for the fact that many people heat and cook with electricity. If you have no other heat source, you will have to go to extraordinary measures to insulate adequately to virtually eliminate heat loss.

What will all this cost? Well, you'll be glad to know that your friendly tax collector is willing to give you thousands of dollars to install a solar PV system. For example, the Los Angeles Department of Water and Power will *pay half of the purported \$20,000 installation cost*. But then, you have to buy an inverter, some switchgear and a large storage battery, which *adds another \$5000 up front*. After three years of this program, only 500 units had been installed, and they were *delivering only 45% of the expected power*. Henry Martinez, DWP assistant general manager for power generation said, "We would have expected the energy we generate from these systems would be a lot more than we're getting."²²

Like the mirrors in a thermal-solar system, the advertised performance figures are based on spotlessly clean PV panels. *If panels are not periodically cleaned with soap and water, electrical output could drop by as much as 30%*.²³ Washing with soap and water every one or two weeks and rinsing every two or three days is recommended. It is also advised that washing not be done by hand, but preferably be done by a completely automatic cleaning system, to avoid risk of personal injury and damage to the panels or associated equipment.

The cleaning system described requires nozzles to be attached directly to the array of each solar panel. The nozzles are *run by a microprocessor with a programmable logic controller and a web-based software interface*. A specially formulated, biodegradable soap concentrate is mixed into the water line during wash cycles, and a second rinse follows the wash cycle. "A PV system operator can schedule or initiate a panel washing with the touch of a button."

²¹ *Op. Cit.*

²² William Tucker, *op. cit.*

²³ Information in this section from:

<http://science.howstuffworks.com/earth/greentechology/sustainable/community/solar-panel-cleaning-system.htm>

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A homeowner with a PV unit on the roof may not worry about some loss of efficiency, and be willing to let the rain do his washing. But cost calculations for the national grid, using peak sunlight in the Mojave Desert, cannot afford to give away 30% loss to dirty panels.

At Nellis Air Force Base in Nevada, America's largest PV array, covering 140 acres, produces 14.2 MW (DC) peak power, with 90% of its huge panels movable and 10% fixed. PV systems have some of the same limitations discussed in connection with solar-thermal systems. The performance capability achieved in the Nevada desert cannot be matched in other, less sunny locations, and transmitting its electricity to customers hundreds or thousands of miles away encounter drastic *loss of power through the wires*. Alternatively, building the PV arrays in cloudier, rainier, more forested locations would also heavily impact performance. If actual year-round performance drops to 20-30% of peak, it would require 300 of these 140-acre systems to equal one typical nuclear reactor, if it had the storage or backup capacity to supply electricity continuously.

But the most serious problem associated with PVs is the *highly toxic materials they're made of and the heavy metals, lethal and explosive gases, and carcinogenic and flammable solvents* used in their manufacture. If a fire were to envelop a PV panel, the resulting fumes and smoke could pose a *serious health hazard* to the community. At the end of their short life, the panels would have to be disposed of in *special toxic waste dumps*—they cannot be burned in municipal waste incinerators. *The ash must be treated as controlled landfill*. Unlike “nuclear waste,” which will be recycled during the next few decades and the residue no longer a significant risk after 100 years, the arsenic, cadmium et al., from PVs *retain full toxicity forever*, and must be *prevented forever from leaching into the soil and water-table*.

The Washington Post reported²⁴ the devastating effects of inadequately controlled wastes from the manufacture of photovoltaic panels. “It’s a green energy company, producing polysilicon destined for solar energy panels ... the by-product of polysilicon production—silicon tetrachloride—is a highly toxic substance that poses environmental hazards.” After reporting that buckets of the substance have been dumped almost daily near an inhabited village in China, the article quoted Professor Ren Bingyan of Hebei Industrial University, “The land where you dump or bury it will be infertile. No grass or trees will grow in the place ... it is poisonous, it is polluting. Human beings can never touch it.” A villager near the dumping site said, “It’s poison air. Sometimes it gets so bad, you can’t sit outside. You have to close all the doors and windows.”

The article concludes, “The situation points to the environmental trade-offs the world is making as it races to head off a dwindling supply of fossil fuels.” And to avoid nuclear power, I must add.

Facts about biofuels to feed electricity into the American electric power grid

Professor Jeff Dukes, an ecologist at Stanford University, wants us to understand how fast we’re burning up our heritage of fossil fuels. In a 2003 paper²⁵ on the subject, and recent personal discussion, he said: “Can you imagine loading 40 acres worth of wheat—stalks, roots and all—

²⁴ Arian Eunjung Cha, “Solar Energy Firms Leave Waste Behind in China,” March 9, 2008, Page O1

²⁵ JS Dukes, “Burning Buried Sunshine: Human Consumption of Ancient Solar Energy” *Climatic Change*, 61: 31-44 2003 and personal discussions with Prof. Dukes.

into the tank of your SUV every 20 miles? That’s how much ancient plant matter had to be buried millions of years ago, and converted by pressure, heat and time into oil, to produce one gallon of gas ... Every *day*, people are using the fossil fuel equivalent of all the plant matter that grows on land and in the oceans over the course of *a whole year*. Ninety-eight tons of plants to the gallon—196,000 pounds—that’s not very good gas mileage.” This huge figure is because he’s talking about replacing the ancient plants that eventually became oil with modern plants.

He sums it up: “Fossil energy—coal, oil, gas—supplies over 80% of human energy demand. Replacing this energy with energy from *modern biomass would require 22% of all the harvestable plant-life (i.e., not underground) grown each year on land or sea—all the trees, weeds, grass, algae, seaweed, most of which we have never attempted to harvest.*”

One indicator of the magnitude of the energy problem is illustrated by the *enormous quantity of material that must be gathered up, transported, processed, converted to useful form such as liquid fuel or electricity and much of it disposed of as waste*. As an example, here’s the material consumed annually in generating U.S. electricity.²⁶ (4 trillion kilowatt-hours)

<u>Energy Source</u>	<u>% of Total</u>	<u>Consumed</u>	<u>For 100%</u>
Coal	49%	~1 billion tons	2 billion tons
Natural Gas	21%	~6.5 trillion cu ft	30 trillion cu ft
Hydro	6%	Not applicable	Not applicable
Oil	2%	~20 million tons	1 billion tons
Non-hydro Renewable	2%	Not applicable	Not applicable
Nuclear	19%	550 tons	2800 tons

How much of this fossil fuel demand can biofuels replace? One of the first obstacles is that *biofuels compete for sunshine (land area), nitrogen and water* with existing demand for food, fiber and other agricultural crops. This showed up quickly when we started to create a demand for *ethanol* made from corn, as a substitute for petroleum fuels. Before much of a dent was made in the fuel market, the diversion of corn from the food supply *drove up the price of corn and soy foods worldwide*. This convinced most people that *we should not burn foods as fuel, nor infringe on agriculturally productive lands* for non-food; but I still see a notice on my gas pump: “Contains 10% ethanol.” And realistic *predictions of biofuel yields per acre should be based on demonstrated productivity of marginal lands*, not the prime cropland often pictured in biofuel literature.

The next step was to consider as fuel *agricultural and forest wastes*, such as specially-developed, fast-growing trees,²⁷ woodchips, cornstalks, switch-grass, and even chicken manure. The idea was, that left alone, these materials would decay, and create the same amount of carbon dioxide as if they’d been burned. Therefore, burning them in a furnace to make electricity would not add to the biosphere’s carbon dioxide total. But this leads to two new issues: *Can we produce fuel this way in a large-scale, reliable, affordable process? And can we sustainably deprive the soil of the fiber and nutrients it now counts on?*

²⁶ “Annual Energy Outlook 2009 with Projections to 2030,” DOE/EIA-0383 (2009)

²⁷ <http://www.emeraldplantations.com> <http://www.treefreebiomass.com> <http://www.newearth1.com>

Non-edible crops like switch-grass should be grown on soil too poor for food crops. Trucks will have to be driven to that land, and the sparse crop harvested and loaded into trucks. This low-energy crop will have to be driven to a processing plant, and from there to the user site. *The economics of this operation will be difficult to justify, in dollars or in carbon balance.*

Thomas Sinclair discusses²⁸ some of these problems, warning: “Before nations pin big hopes on biofuels, they must face some stark realities. Crop physiology research has documented multiple limits to plant production on earth.” He describes in detail some severe requirements: *sunlight*, which translates to extensive land use; need to return to the soil *nitrogen* and other nutrients lost in burning; and uncontaminated *water*; all in serious competition with food crops. The Policy Forum²⁹ of Tilman, et al., warns that society “cannot accept the undesirable impacts of biofuels done wrong ... they must be derived from feedstocks produced with much lower life-cycle greenhouse-gas emissions than traditional fossil fuels, and with little or no competition with food production... Recent research suggests that it is to the benefit of farmers to leave substantial quantities of crop residues on the land,” and not burned. There are niceties such as the fact that to be suitable, forest residues should include “branches, but not leaves and needles,” which presumably requires some separation processing.

But then the authors state more sweeping concerns:

Looming over the future of biofuels are several wrong options. Sometimes the most profitable way to get land for biofuels is to clear the land of its native ecosystem, be it rain-forest, savanna, or grassland. The resulting release of carbon dioxide from burning or decomposing biomass and oxidizing humus can *negate any greenhouse-gas benefits for decades to centuries*. Decisions regarding lands for biofuels can have *adverse consequences far beyond the land directly in question*.

For example, if fertile land now used for food crops (such as corn, soybeans, palm nuts or rape seed) is used to produce bioenergy, this could lead, elsewhere in the world, to farmers clearing wild lands to meet displaced demand for crops. In this way, *indirect land-use effects of biofuels can lead to extra greenhouse-gas emissions, biodiversity loss, and higher food prices*.

Dramatic improvement in policy and technology are needed to reconfigure agriculture and land use...Legislation that is vague could allow significant portions of the biofuels industry to develop along counterproductive pathways ... *Unless new technologies and lifestyles are adopted globally over the coming decades, the massive projected increases in global energy and food consumption will greatly elevate atmospheric greenhouse-gas levels from fossil fuel combustion, land-clearing, and livestock production, and will create immense biodiversity loss from habitat destruction and climate change. The quality of human life will be compromised.*” (Emphasis added. Seven supporting references omitted.)

P.J. Crutzen, et al.³⁰ presents arguments that “Many first-generation biofuels may under non-ideal (= practical) conditions produce same amount or more greenhouse gases (N₂O) than

²⁸ TR Sinclair, “Taking Measure of Biofuel Limits,” *American Scientist* **97**: 400-409 (Sep-Nov 2009)

²⁹ David Tilman, et al., “Beneficial Biofuels—The Food, Energy, and Environment Trilemma,” *Science* **325**: 270-271 (17 July 2009)

³⁰ P.J. Crutzen, et al., “N₂O Release from Agro Biofuel Production Negates Global Warming Reduction by Replacing Fossil Fuels,” *Atmos Chem & Physics* **8**: 389-395 (2008)

comparable fossil fuels do (CO₂). Whether or not biofuels balance GHG [greenhouse gases] better than fossil fuels is a difference of uncertain numbers.”

Another option that has been presented optimistically is **algae-produced biodiesel fuel**: huge open tanks in the desert with algae doing the work. An analysis³¹ of some of the problems and limitations facing the algae approach begins: “*Large-scale production of algae biodiesel is not a viable solution in the displacement of petroleum-based fuels ... not competitive with more advanced and emerging renewable technologies ... algae biodiesel has an approximate cost of \$33/gallon ... due in part to the energy required to circulate gases, fluids and other materials in the growth environment ... While sunlight is an inexhaustible source, the energy and additional resources used in processing, refining and transporting the biodiesel are not ... Although less land area is involved ... there remains significant surface area involved ... 20% of the land in the United States would need to be devoted to algae production in order to match petroleum fuel consumption ... there is no existing data that supports the theory that algae biofuel could be a viable solution.*”

I present all these warnings to *counter a widespread belief that the biofuel approach is familiar, simple, natural, and has few uncertainties, as contrasted with nuclear fission*, whereas the whole subject of making megatons of fuel from cellulosic plant material is an entirely new and untested field, with many uncertainties and unanswered questions. Enthusiasts have written about harvesting 500 million tons of biofuels in the U.S. each year, to replace some of the billion tons of coal now used to generate half of America’s electricity.

But apart from these challenging new issues, I was struck by one mundane problem that looks like *a show stopper*: Suppose we could find a way to harvest this huge crop, on land unsuitable for food crops, *how can we transport it to the market?* Let’s ignore for the moment the problem of fueling our cars, trains and airplanes, and just focus on replacing the coal used to generate electricity. And look just at the U.S.

Nearly half of all US freight rail capacity is devoted to carrying coal, and most of that is for the 600+ coal-fired electric power plants generating about half of U.S. electricity. A typical large coal-fired electric power plant needs one or more *daily* visits of “unit trains,” 100 cars with 100 tons of coal each. Coal is the most efficient form to transport carbon, and with coal, we’re just getting by.

Instead of 100-ton railcars transporting coal, picture huge trucks piled high with loosely packed sugar cane stalks. Sun-dried, it contains 40-50% water, so that half the energy from its combustion goes into boiling out the water. The payload of those trucks isn’t enough to fill their own fuel tanks. Paul Williams states:³² “Biomass is a bulky solid, with relatively high water content. *The range over which it can be economically transported to a manufacturing facility is 40 to 80 km [25-50 miles].*”

In addition, there is a storage issue. To protect against temporary interruptions in supply, it is considered necessary to maintain a three-day supply at the processing facility. (Some plants,

³¹ Caroline de Monasterio, “Bleak Future for Mass Production of Algae Biodiesel” <http://snremitigation.wordpress.com/2009/03/24/bleak-future-for-mass-production-of-algae-biodiesel/>

³² Paul Williams, Science Perspective, “The Biofuels Landscape Through the Lens of Industrial Chemistry” *Op. cit.*

with limited access to the fuel supply, might want more like a two-week supply, multiplying all the following quantities nearly five-fold.) Even a modest-sized processing plant (450 MW) would need a 1.6 million cubic foot fuel pile. To maintain such a straw-based direct combustion plant would require a huge truck delivery every four minutes. To impose such traffic on small rural roads would be apt to meet considerable local opposition.

Could we do better, *shipping by pipeline or by train?* An analysis³³ of this option notes that *biomass starts off with two disadvantages compared with coal or oil:* 1) Its *energy density* is one half of coal, one third of oil. 2) Its *point of origin is dispersed* across the degraded lands abandoned from agricultural use, compared with having concentrated extraction points at coal mines or oil wells. So there's *apt to be an unavoidable truck ride from the harvest point to the rail or pipe terminal or occasionally a ship dock.* After detailed analyses, particularly exploring the effects of cost of diesel fuel, the author concludes that the use of other shipping modes is not likely to be a decisive factor in favor of biofuels. For example, in *trying to ship wood chips by pipeline, a fluidizing liquid would probably be needed.* Water could work, but absorption by the chips result in 13% increase in their moisture content. *The absorbed water then requires some of the combustion energy to be diverted to boiling off the water,* which the author says is enough to rule out this usage. Alternatively, the chips could be fluidized by heavy gas oil. Surprisingly, they found that *chips absorb 50% of their weight in oil.* This oil will burn with the chips, but then two-thirds of the energy comes from the oil and *only one-third from the biomass,* which is not a very effective use of the biomass.

Is this a show stopper! Even if we could harvest, transport, process, burn and handle the waste from *500 million tons of biofuel feedstock* each year, would the earth and its people be better off to use just *few hundred tons of uranium,* for which there is little competition, to generate the same amount of electricity?

The Case for Nuclear Energy, and a Response to the Concerns

A useful exercise is to describe what one would *consider an ideal energy source.* What would its properties be? I heard someone do this, and then say, "Maybe nuclear fusion would be like that." I asked: "How is what you described any different from what we already have with nuclear fission?" And the speaker was hard pressed to answer. Starting the consideration of nuclear technology on a fundamental basis like that can be enlightening.

The Nuclear Curse

There is no shortage of perceived problems or questions regarding nuclear matters, so let's give them a hard look. In comparing nuclear with non-nuclear options (e.g. biofuels, sunshine, or the friendly breezes), we may be more comfortable with the non-nuclear. But in fact, *radiation and nuclear reactions are also natural—in fact, they predate the origin of life—and are more thoroughly researched and better understood* than trying our hand at climate control.

³³ Harry Short, "Pipes, Trains and Trucks: How to Move Biomass Cost-Effectively"
<http://snrecmitigation.wordpress.com/2009/04/24/pipes-trains-and-trucks-how-to-move-biomass-cost-effectively/>

The Nuclear Proliferation Question

Most nuclear power plants *require fuel enriched in the fissile isotope of uranium*. In addition, fissile isotopes of *plutonium are created* as a by-product of the energy-releasing process itself. This raises two questions:

*Could the uranium enrichment process be used clandestinely to produce nuclear weapons?
Could the by-product plutonium be diverted to weapons production?*

Although nearly half-a-century of operation of several hundred reactors worldwide *has yet to create bombs from a commercial power plant*, the question is still of valid concern. Much has been written about the numerous hypothetical scenarios by which this might be done. And peaceful nuclear power programs have been used as a cover-up for weapons development.

A recent credible summary of the subject is *The Atomic Bazaar*³⁴ by the well-known investigative reporter William Langewiesche, who spent years touring Russia, Georgia, Turkey, Iran and other potential smuggling venues, talking with “leaders of smuggling clans.” He emphasizes that little can be done to prevent smuggling. But after exploring scores of possible smuggling scenarios, he concludes:

“In the final analysis, *if a would-be nuclear terrorist calculated the odds, he would have to admit they were stacked against him*, simply because of all the natural circumstances that could cause his plans to fail ...”

Richard Rhodes quotes³⁵ remarkably blunt and passionate public statements by McGeorge Bundy, for the Kennedy administration, and Nikita Khrushchev, for the Soviet government, saying that *use of nuclear weapons simply cannot be part of any government’s planning*. Of course, one can argue that the new realities of terrorism render such ideas obsolete. However, it is still true that, for more than 60 years—a human lifespan, two human generations—the threat has not materialized.

It is also true that *none of the countries that have developed nuclear weapons capability have used commercial nuclear power plants to assist in that endeavor*.³⁶ They developed weapons, as the West did, by an entirely separate technology, using machinery and institutions created for, and dedicated to, that purpose. If they had been forbidden to develop nuclear power plants, it apparently would have had little or no effect on their nuclear weapons buildup.

A new international assured fuel supply is needed that would eliminate the excuse for non-nuclear weapons countries to build enrichment facilities. On a longer term basis, the same can be said for used fuel reprocessing facilities, to remove the opportunities to obtain weapons-useable plutonium for bombs from the used fuel from nuclear plants.

The importance of high energy density

An important and unique advantage of nuclear for large-scale electricity generation is energy density millions of times greater than any non-nuclear process, enabling it to generate a given amount of electricity with *grams of fuel instead of tons*. This difference is seldom

³⁴ Farrar, Straus & Giroux (May 2007)

³⁵ Richard Rhodes, *Arsenals of Folly*, Vintage Press, page 81 (Paperback, 2008)

³⁶ India used a heavy-water research reactor to extract enough plutonium for a bomb, which they exploded in 1974. See: <http://www.barc.ernet.in/webpages/reactors/cirus.html> and http://archives.cbc.ca/science_technology/energy_production/topics/104-910/

discussed because only nuclear is significantly different from its competitors. *This difference will not change with additional research*; it comes from the inherent difference in binding energies of the atomic nucleus and the molecule.

Carbon dioxide is not the only measure of potential ecological damage. The *amount of fuel material* that has to be gathered up, transported, processed, burned and then have its remains disposed of as waste is a clear measure of ecological damage. It is also important that *uranium*, unlike many of the green fuels, is *not needed for other vital human purposes*, like food, *nor does it compete with food* or other human necessities for sunshine or nitrogen. *It does not require vast land areas* needed by biofuels, solar panels or wind farms. All these factors give nuclear a *very light “footprint” on the earth*.

The complete absence of polluting effluents

In recent years, the absence of carbon dioxide generation has been used as the major argument for nuclear power. But quite independent of that point, the toxic effluents from fossil fuel combustion are a sufficient reason for replacing them. *Coal-fired plants release tons of serious poisons* such as lead, arsenic, mercury and selenium. Unlike radioactive materials, these toxicants do not get less toxic day by day, but *maintain full toxicity forever*. In addition, Alex Gabbard, a physicist at the Oak Ridge National Laboratory, reported³⁷ on the *radioactivity released* from coal-fired power plants. *People living near a coal-fired plant get more radiation exposure than people living near a nuclear plant*. The work had previously been reported in *Science*.³⁸ He documents the inconsistencies of treating nuclear or radiation issues as uniquely dangerous, while *many of the same physical situations in non-nuclear areas are accepted without concern*.

Gabbard found that a typical 1000 MWe of coal combustion releases approximately 27 tons of Thorium-232, Uranium-238, Uranium-235, Potassium-40 and other radioactive materials annually into the biosphere. Air, earth, and water pathways are unrestricted for all 40 of the radioactive materials identified. The total radioactivity released from just the 600 U.S. coal-fired power plants is about *36,000 curies each year*. All radioactivity releases from coal combustion were ruled “safe” in 1984 by the U.S. Environmental Protection Agency. Yet, many power plants that should have been nuclear were built coal-fired because of the misplaced fear of radiation.

(Prof. Howard Hayden points out that, since Gabbard’s paper was written, coal-fired plants have added bag houses, scrubbers, sulfur, mercury and arsenic removal, electrostatic filters and a panoply of purification systems, that greatly reduce the amount of chemicals that escape into the open air.)

Gabbard also documents that the *radiation dose from smoking tobacco far exceeds the dose from coal combustion, which far exceeds the dose from nuclear power*.

³⁷ A. Gabbard, “Coal Combustion: Nuclear Resource or Danger?”
<http://www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html>

³⁸ JP McBride, et al. “Radiological Impact of Airborne Effluents of Coal and Nuclear Plants,” *Science*, (Dec. 8, 1978)

Economics

Some of the bids now being submitted for construction of new nuclear power plants are priced shockingly high. Similar plants being built abroad are much cheaper. This is an issue that must be resolved. Some obvious first steps: loan guarantees (creating the government an incentive to resolve endless regulatory hassles), credit for pollution-free operation, and amortizing construction costs over 60 or 80 years, rather than the current 40 years. A few significant cost reductions have been negotiated, but not enough.

Is there reason to believe that nuclear power can be made cost-competitive with gas and coal? Yes, indeed. *Many plants* that have been running long enough to write off much of the original construction cost are *now operating profitably year after year*. In fact, the governments of Finland, Sweden, and Belgium, and even the Attorney General of Connecticut have complained that nuclear plants are so profitable, and so free of the uncertainties facing non-nuclear competitors, that they are *making “unearned profits” and should be fined a large windfall profits tax*. Italy’s Energy Minister recently announced that its anti-nuclear policy was a 50 billion euro (\$70B) mistake.

The World Nuclear Association Information Paper,³⁹ “The Economics of Nuclear Power,” cites a large numbers of European, American, Japanese and other reports, showing how the economics vary with location, date, and assumptions as to ecological penalties imposed. *Nuclear plants are expensive to build but cheap to operate*, compared with coal- or gas-fired plants. Thus, the cost of money is more critical for nuclear than for a fossil-fueled plant. If a gas-fired plant were selected when the price of gas was low, it might double during the plant’s lifetime. This “would typically *add 70% to the cost of electricity* from that source” whereas doubling the market price for *uranium would add only 7%* to the electricity cost of a nuclear plant.

In spite of the handicap of being charged up-front for decommissioning and handling of used fuel), *nuclear power is usually cost competitive with its competitors:*

Daily operating costs, excluding payoff of the initial construction cost, are as follows:⁴⁰

Oil	8.1 cents per kilowatt-hour (4.8 times nuclear)
Natural Gas	7.5 cents per kWh (4.4 times nuclear)
Coal (cheapest)	2.2 cents per kWh (1.3 times nuclear)
Nuclear	1.7 cents per kWh

With this in mind, let us *look at some of the myths that have been grown up, to claim that nuclear technology is uniquely hazardous.*

Myth: *What about the waste? Nuclear waste stays toxic for thousands of years. Humanity has never faced such a long-term hazard. Anthropologists have talked about setting up a “nuclear priesthood” to pass on word of where radioactivity is buried, so as civilizations rise and die out, people a million years from now will be warned to stay away from this dreadful poison.*

³⁹ <http://www.world-nuclear.org/uploadedFiles/org/info/pdf/EconomicsNP.pdf>

⁴⁰ Nuclear Energy Institute, for 2005. Later NEI reports show nuclear cost steady, the others rising.

Facts: The material nuclear critics call “waste” is actually used fuel waiting to be recycled. Like all radioactive materials, used fuel continually decreases in toxicity, whereas non-radioactive pollutants like mercury, lead, arsenic, selenium, cadmium, chromium, etc. maintain their toxicity undiminished forever. After a few hundred years, used fuel is no more toxic than the original ore, yet we plan to bury it 1,000 feet underground. The top 1,000 feet of U.S. soil contains more lethal doses of natural poisons than all the used nuclear fuel together. We make *10,000 times more lethal doses of chlorine each year than “nuclear waste,”* and *put it in our drinking water to kill germs.*

Even anti-nuclear activist, Sheldon Novick, author of *The Careless Atom*, wrote: “Once radioactive materials have decayed past the point at which their internal generation of heat is dangerous ... well within a single human lifetime – it is difficult to see in what way they are more or less hazardous than other poisons produced by industry.” (*The Electric War: The Fight over Nuclear Power*, Sierra Club Books, 1977) *And that’s if we turned it loose, which we don’t.*

During the first decades of nuclear power, there was no demand from the public to move the used fuel, until full-page ads by the industry in major papers telling people that used nuclear fuel containers were terrorist targets. This created the “Mobile Chernobyl” problem. Nuclear industry spokespersons also kept telling people that our most important problem was getting the nuclear storage site at Yucca Mountain (YM) approved, because they were convinced that, once the material was there, everyone would agree the “waste problem” was solved, and not before.

The nuclear community created this problem themselves. In an escalating effort to answer unreasonable demands for “more safety,” they offered Yucca Mountain, convinced that they could swallow the cost, and that this extreme solution would surely satisfy the most unreasonable skeptic. But the public reaction was just the opposite. People quite reasonably concluded that the problem must be extraordinarily dangerous to require such extraordinary measures.

So that’s the “high-level waste problem.” In addition, there is “low-level waste,” consisting of a larger volume of contaminated rags, tools, work clothes, etc. The radiation level from this material is too low to be hazardous, but any amount of radioactivity produced on the job is controlled and disposed of in special facilities, designed to handle low-radiation level material.

Radioactive fission products are not a public hazard. Our power plants and their fuel have never released a dangerous amount of radioactivity into the environment. High-level radioactivity is bound within the refractory ceramic fuel pellets where it was formed. These pellets are clad in stainless zirconium alloy tubes, and kept in water pools for several years, until less than 1% of the initial radioactivity remains. Then the fuel elements are removed from the water and are sealed into high integrity used-fuel containers, which are nearly indestructible. These containers are stood on a concrete or asphalt platform until the contents are recycled to recover most of the fissionable material still in them. Right now, it’s cheaper to keep using new uranium, but eventually the used nuclear fuel will all be recycled. The containers have been sitting there up to half a century, hurting no one, having no impact on the environment. They could stay there another century. Some plant owners invite the public—school children, church groups, scout troops—to visit and see these used fuel containers up close, touch them, measure their radiation level, to understand firsthand that they are neither mysterious nor dangerous.

In every real sense, *this problem was solved before it began.* Nuclear plants produce *less than one-millionth the volume of radioactive material from an equivalent coal-fired plant,* so it can be put into sealed, steel containers and controlled, rather than dumped into the environment.

Fifty thousand tons of used fuel was produced by all U.S. nuclear plants over the past 40 years. This is less than *2 pounds per person served*. You could put each American's lifetime share of used fuel into a 12-ounce soda pop can. So, it's no problem to keep it in these containers and never dump it into the biosphere.

Each person's corresponding waste from a *coal-fired plant is 140,000 pounds of solids, including toxic metals such as arsenic, lead, molybdenum, cadmium and chromium*. The mercury may have already gone out the stack. The ash is also richer in uranium and thorium than some uranium ores now being profitably processed by the uranium industry. The stack also releases the acids that cause acid rain, and carbon dioxide gas equal to the output of a million and a half automobiles, for each person's lifetime production of electricity. As previously noted, modern coal plants are now putting in facilities to capture and remove these pollutants.

U.S. Naval reactors can now operate for the life of the ship—**a million miles traveled, without refueling**. *All of the radioactivity from that operation stays locked up within the fuel elements, without causing any undue swelling or distortion*. That illustrates how small a quantity we're dealing with. Compare that to wastes produced by other industries. Even the volume of waste from construction and operation of *solar, wind and other renewables is greater* on a per-kilowatt-hour basis than used nuclear fuel, and some of the *solar power poisons are highly toxic forever*.

The "problem" provides income, reputation and jobs for many people. But so does building new nuclear power plants and operating them. We need to stop working on problems that aren't real, start building more of the plants we know how to build, and keep looking for ways to make better and better plants.

It is difficult to solve vaguely defined problems. For example, the oft-stated objective, "we have to find a safe solution to the nuclear waste problem" has to be clarified. Since "nuclear waste" has never created any measurable problem in the real world, we should define what problem we are trying to solve, and how we would measure the effectiveness of any proposed solution. As President Obama said, the current measures for handling used fuel and "nuclear waste" can be continued for decades without undue risk, so there is no short-term "waste crisis."

Myth: *What about those huge waste tanks that have been leaking radioactivity into the ground for years?*

Fact: Those tanks, at the Hanford site in the state of Washington, were built during World War II, to handle liquids used in the Army's Manhattan Project to build the atomic bomb. They have *nothing to do with the commercial nuclear power plants*. If no nuclear power plants had ever been built, the situation at Hanford would still exist. We've learned a lot since then, and there are no such tanks associated with the commercial nuclear plants. Incidentally, Hanford is now being cleaned up, and *there is no evidence of danger* to people or to any of the surrounding environment. The phrase "exposed to radioactivity" may make exciting headlines, but it is not evidence of bodily harm. We are all exposed to radioactivity, every day and night, and it does us no harm.

Myth: The government gives nuclear power lots of subsidy money, but the poor greens get only crumbs.

Facts: The greens get somewhat fewer total dollars, but produce very little in return for it. On a per kilowatt-hour basis, the subsidy is totally weighted in their direction. Here are the figures for 2007.⁴¹ The subsidies for wind and solar exceed the current cost of nuclear-powered electricity.

<u>Energy Source</u>	<u>Subsidy & Support Total</u>	<u>\$ per megawatt-hour</u>
Refined Coal	\$2,156 million	29.81
Solar	\$14 million	24.34
Wind	\$724 million	23.37
Nuclear	\$1267 million	1.59
Coal	\$854 million	0.44

Myth: *Nuclear power is not renewable or sustainable.*

Facts: That's simply untrue. Only one in 140 uranium atoms is fissile—i.e., fuel. The other atoms are “fertile,” that is, they are capable of changing into fuel by absorbing a neutron if the fuel is recycled. We are currently not generally recycling fuel because it is *cheaper to operate “once through,” and we can do so for several hundred years.* But we have demonstrated the recycling process in theory and in several experimental reactors that actually “breed” more fuel than they burn. As we go into recycling and then breeder reactors, we can eventually “tap” the seawater. As James Muckerheide has pointed out, in addition to hundreds of years of mineable uranium, the oceans contain an estimated 4 or 5 billions tons of uranium, which is continually replenished as uranium is leached from ocean life-forms and from the land, by the rivers emptying into the seas. In addition, there is *nuclear energy available from thorium*, which is several times more abundant than uranium. (Some of India's new reactors will probably be based on a thorium fuel cycle.) Like uranium-238, a thorium nucleus can capture a neutron and change into nuclear fuel. *That process can create a reliable energy source for millions of years.*

Myth: *Nuclear reactors are potential nuclear bombs. Shipments of spent fuel are “mobile Chernobyls.”*

Facts: This is simply untrue. No shading or ambiguity about it. We should have no hesitancy in asserting that the *Laws of Nature prevent accidental criticality* occurring in such cases. Period.

Myth: *Nuclear power is an especially unforgiving technology. A momentary slip-up, and it's a catastrophe.*

Facts: The opposite is true: *nuclear plants are robust and stable.* Hundreds of commercial nuclear power plants worldwide, and hundreds of naval reactors operating reliably for decades, confirm this. They can resist earthquakes, hurricanes, power loss, sabotage and operator errors. Ironically, although nuclear plants are designed to operate safely and reliably under conditions that destroy, or shut down, other facilities, a distorted sense of *caution* requires that they be shut down just when they are needed most (e.g., after an earthquake)! This may be another case where purported safety rules actually lead to a less desirable situation. The proven stability of nuclear plants spawns the next myth.

⁴¹ Energy Information Administration, Forms EIA-906, "Power Plant Report;" Form EIA-920, "Combined Heat and Power Plant Report;" October 2006-September 2007.

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Myth: *Nuclear plants are so touchy, they use them only for providing the steady base load. You wouldn't want to try load-following with a nuclear plant.*

Facts: This is a good example of portraying a nuclear asset as a problem. Nuclear fuel is cheap; building a nuclear power plant is expensive. So, once a plant is built, it makes economic sense to use the cheapest fuel as much as possible, and bring in the cheap gas-fired plants that burn expensive fuel only when you have to. It's the steam plant, not the nuclear plant, which limits how fast you can maneuver a naval plant. Commercial plants are bigger and thus more sluggish.

*The flexibility and responsiveness of a nuclear power plant is dramatically demonstrated in a working nuclear attack submarine. Admiral Rickover used to challenge the crews to see how fast they could change power level. They would select the biggest, strongest sailor aboard, and pass the order, "Crash back!," which is a maneuver that takes the ship from "All Ahead Flank!" to "All Back Emergency!" The sailor spins the ahead throttle closed, bringing the reactor from 100% power to zero. He then immediately opens the astern throttle as fast as possible, restoring the reactor to 100% power. The ship shakes violently, shrieks of various equipment protesting mixed with the clatter of coffee cups, operating manuals and other miscellany sliding off normally horizontal surfaces, as the ship shudders to an emergency stop. The reactor plant operator watches placidly as the reactor temperature drops a few degrees, which automatically raises the power smoothly to the required level. He could pull the reactor control rods a notch to restore the temperature, but he doesn't have to. The electrical plant operator and the steam plant operator are equally relaxed, as the ship's propeller reverses, and the plant accommodates itself to the new conditions. It's hard to imagine the need for any greater flexibility than that. Unlike a combustion-fired power plant that has to warm up and cool down very carefully, to avoid thermally shocking the system, the *temperature swings in a water-cooled plant are quite moderate, and impose no restraints on the operators.**

For various reasons, utility power plants cannot fully utilize this inherent flexibility. They don't need to, and by being less rambunctious, they avoid situations in which (fission product) neutron absorbers like xenon and samarium can build up, which are not a problem in the physically smaller naval reactors.

Myth: *We should stop creating all this radiation and radioactivity. It's unnatural, little-understood, an unprecedented, ever-growing threat to the natural earth. We're fouling our nest and degrading the human gene pool by continually adding to the earth's radioactivity.*

Facts: Radiation has been with us since the dawn of time. *Life evolved in a sea of radiation, several times more intense than it is now.* Our soil, water, air and our bodies are naturally radioactive. Radioactive processes light the sun and the stars and keep the earth's core molten and our environment livably warm. Radiation is better understood than most environmental challenges. Tests show it's probably essential to life. The report NCRP-136, by the U.S. National Council on Radiation Protection and Measurement, states right up front (page 6) that *most people exposed to low-dose radiation are benefited, not harmed by it.*⁴²

⁴² J. Cuttler and M. Pollycove, "Nuclear Energy and Health, and the Benefits of Low-Dose Radiation Hormesis" *Dose Response*. 2009; 7(1): 52–89, available at: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2664640/>

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Fission changes long-lived uranium into shorter-lived fission products, ultimately decreasing earth's radioactivity. All the radioactivity we generate is not enough to offset the earth's natural radiation decay. *The earth becomes less radioactive each year.*

Myth: *But radiation is spooky. You can't see it or smell it. You can't tell it's there until it's too late!*

Facts: Radiation is detectable at the single atom level by a simple, hand-held detector. *No other hazard is so easily detected.* As the respected physicist/physician, Zbigniew Jaworowski, wrote, humans and other animals have no organs for sensing ionizing radiation, because they have no need for them. Natural radiation levels up to hundreds of times the levels now being regulated have proved to be harmless, or even beneficial, as noted above.

Myth: *Shipping used nuclear fuel containers past schools and homes is a terrible risk.*

Facts: These shipments pose *no realistic risk whatsoever.* The shipping containers are nearly indestructible. They have been tested by high-speed collisions, and fire. The radioactive materials are *solid and there is no liquid to leak.* It can't "go critical" like a reactor. In tests, a special armor-piercing missile was mounted to ensure that it would hit exactly on the centerline of a used fuel container and not be deflected harmlessly aside. It blew a small hole in one side of the container, but the small amount of radiation released would not be harmful. The diesel fuel in the truck's gas tank would be a greater risk than the used fuel container, though no more dangerous than the diesel fuel in any other truck.

Myth: *The Chernobyl accident in 1986 killed thousands of people and disabled millions.*

Facts: *Not true. Thirty-one workers and firefighters at the plant were killed.* A 20-year investigation by the U.N. and World Health Organization concluded that *no members of the public were harmed.* However, careful screening identified about 2,000 cases of childhood thyroid nodules, with about 10 deaths following medical treatments for this condition. But the occurrence of these nodules doesn't correlate with radiation level, and are within the natural occurrence frequency for such nodules in locations like Chernobyl. Unfortunately, we don't have much pre-Chernobyl health data for that area to make a valid comparison. The World Health Organization (*WHO*) *said that fear of radiation caused much more harm than radiation itself.* It led to unnecessary, long-term evacuation of large population groups, 100,000 unwarranted "elective" abortions, unemployment, depression, alcoholism and suicides. Deformed "*Chernobyl victims,*" *displayed to raise money for relief efforts turned out to be a scam.* The "victims" suffered from conditions that were later shown to be unrelated to the accident. Some were from far away; others were deformed before the accident. Chernobyl was not a factor in their condition.

In any event, no one is suggesting that more Chernobyl reactors be built. It was a flawed design, built and operated without adequate safety considerations. The water-cooled reactors previously built and those planned *could not under undergo the type of casualty that occurred at Chernobyl.*

Let us look at the fundamental question about the safety of nuclear power plants: How bad could a worst-case nuclear power casualty be?

Many theoretical studies have claimed that a hypothetical mishap could cost thousands—even hundreds of thousands—of lives. Nuclear advocates reply that the particular casualty described is "a highly improbable scenario" and therefore an acceptable risk. Such a response—

that this sort of thing will not happen very often—does not answer the question. *Highly improbable events do happen. How bad could it be?* And what about scenarios not yet envisioned? We deserve substantive answers to those questions. *Putting extraordinary emphasis on safety without defining the hazard is misleading and irresponsible.*

It is easy to calculate what would happen if we assume that three unrealistically pessimistic conditions occur: 1) All of the radioactivity in a nuclear reactor is released into the air, and at once; 2) The radioactivity stays suspended in respirable form over large areas and populations; and 3) Any radiation exposure, no matter how small, can kill. Such calculations say that thousands could die. But *such a situation cannot be created in the real world.* “Worst case” calculations are not meaningful if they are based on conditions that defy the laws of nature and the known properties of materials and processes. What is relevant are *credible engineering evaluations of the consequences of the worst conditions that could realistically be created, based on known science*, both at the laboratory level and from large-scale tests and analyses. This has been done for pressurized water or boiling water reactors, of the type now operating in nearly all the world’s commercial nuclear power plants. Similar analyses of the Canadian CANDU reactors show that they have an even larger margin of safety for this situation.

The worst consequence of any postulated scenario would begin with a loss of the water that cools the fuel, leading to some molten fuel. So we can *presume* (for the worst case) that *a large part of the fuel melts*. Then we need not argue about what scenario could get us there. We’ve accepted the worst case: fission products from the fuel escaping into the coolant. We assume further that *the coolant system boundaries are compromised* by the casualty, and *fission products are escaping into the containment atmosphere.*

We know the **composition of fission products and the rate they are released** by molten fuel. Starting in the 1950s, extensive theoretical and laboratory work was done worldwide to explore these questions, and we know that in all of the real reactor accidents, measured releases were very much lower than the unrealistic assumptions used for safety studies. And *we know what happens to fission products as they enter the air, steam and water* surrounding the reactor coolant system. We have substantial field data showing that highly charged and reactive fission product particles rapidly clump together and accumulate in the water flows and settle in the sumps, are absorbed in steam and water, condense and plate out on cooler surfaces, and interact with other materials they contact. The water lost from the reactor cooling systems does not disappear; it does not all evaporate inside the building. It reduces the airborne radioactivity within the building many thousand-fold below the extreme assumptions used for some safety analyses.

So we assume that the worst realistic casualty also compromises the containment’s pressure-retaining ability and leak-tightness, so that it is no more effective a containment structure than other industrial buildings. Which, it turns out, is good enough.

We have large-scale experience, as well as lab data and theory, with just such casualties:

- The EBR-I accident resulted in almost complete core meltdown, in a regular warehouse building.
- The SL-1 accident resulted in about a 30% core meltdown, in a Quonset-type building.
- The Lucerne reactor incident resulted in about 10% core melting, in an unsealed cave.

Radioactivity released from these, and from the other 9 or 10 core-melt accidents or planned meltdown demonstrations, was many orders of magnitude less than predicted. No catastrophe!

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Measured radioactivity within the TMI containment during and after the casualty, was so low that, until the reactor fuel was inspected, it was widely assumed there had been no meltdown.

Outside the building, we have three more unrealistic premises to revise: 1) *Radioactivity does not disperse as predicted by the meteorological models used*; 2) *The radiation doses calculated in the models from the airborne and ground dispersion are unrealistically pessimistic*; and 3) *The near-term and long-term adverse biological effects attributed to small radiation doses do not agree with medical data. With these discrepancies resolved, we can more realistically evaluate the consequences, constrained only by known and measured characteristics of real-world materials and processes.*

The American Nuclear Society White Paper on Realism, a follow-on document to the September 20, 2002 and January 10, 2003 summaries in the Policy Forum⁴³ presented by 19 nuclear-expert members of the National Academy of Engineering in the mainstream, peer-reviewed journal *Science*, discusses and documents this question, answering that *the worst that can be expected is few if any deaths off-site.*

A detailed description of the whole casualty process, and the scientific evidence supporting it, needs to be collected, documented and promulgated to the scientific community at large, to receive the wide peer review and acceptance it deserves. But the magnitude of overstatement in current safety models is more than enough to cover the various uncertainties, and to support the conclusion just stated: that a catastrophic consequence of any realistic nuclear plant casualty is simply not possible in the real world.

Two Kinds of Impossible

The June 22, 2009 fatal collision of subway trains on Washington's Metro system was a type that the system design was said to make "impossible." Yet it happened.⁴⁴ *What does it mean when a scientist or an engineer tells us that something is impossible? Does it merely mean unlikely? And does unlikely mean once a century, or can it mean once a once a year? And if we can't tell, then is such a statement worth anything at all?*

In this context, there are two different kinds of *impossible*. A system can be designed so that, *if everything works as intended*, certain kinds of unwanted events will not occur. As I understand it, the subway had instruments to detect if two trains get too close to each other. It then calls for brakes to be applied. *If everything works as designed*, it would be impossible for the trains to collide. But it is not impossible for one or more parts of the system to malfunction. Human action, such as setting track switches, or responding to an alarm, may be part of the system that must work for the system to function properly.

This is a limited type of *impossible*, but a well-designed system and well-trained and competent operators can make the unwanted event highly improbable. The system owners and the involved public must then decide in each case if that's good enough.

The second type of *impossible* is very different. Suppose someone decides to worry that a shipment of used fuel for a nuclear power plant may "go critical," melt down, and release dangerous levels of radioactivity. He is told this is impossible. But he replies, "That's your

⁴³ www.radscihealth.org/rsh/realism/WP-TableOfContents.htm

⁴⁴ <http://www.cbsnews.com/stories/2009/06/22/politics/washingtonpost/main5102957.shtml>

opinion. You guys always say things are impossible, and then they happen anyway. I don't believe you." Is this any different from the subway crash? Yes, entirely different.

First, *in neither the subway case nor the nuclear fuel case is opinion involved*. We are dealing only with facts in both cases. *It's important to be clear as to what the facts cover and what they don't*. But there is no room for a difference of opinion once it's clear what the facts say. In the nuclear case, it can be shown beyond dispute that there is not enough fissile uranium in the fuel to support a nuclear reaction.

Am I saying there cannot be a collision? No; out of the several thousand shipments of nuclear fuel, there have been several traffic accidents. But in no case has there been any release of significant quantities of radioactivity.

Here's another case. In the September 20, 2002 and January 10, 2003 issues of *Science*, the mainstream, peer-reviewed journal-of-record of science, papers by 19 leading experts on nuclear technology, all members of the National Academy of Engineering, declared (and documented) that no realistic casualty to a typical nuclear power plant, or its fuel, could cause more than few if any deaths to the public, a statement concurred in by the then-Chairman of the Nuclear Regulatory Commission. What kind of *impossible* is that example?

Most nuclear safety studies focus on particular scenarios: a pipe bursts; an operator opens (or fails to open) a particular valve, and the consequences of that scenario are followed to their conclusion. If it leads to unacceptable consequences, then we have to make sure that scenario is acceptably improbable--once in 10,000 years or more. But we can make no statements about the scenarios we have not yet studied. So, in that case, we cannot say *impossible*, only *improbable*.

How then could the *Science* papers just cited claim *impossibility*? Because they ran an entirely different kind of analysis. First, we limited ourselves to the known and measured properties of materials and processes. We knew that the first step to trouble was melting of the fuel; so we assumed molten fuel. We didn't ask how we got there; it didn't matter. But nuclear plants have containment vessels around them, so we assumed that a large hole had been blasted through the containment wall. By starting with worst-case assumptions, we eliminated all need for probabilities. If the worst case is tolerable, that handles all cases. Over the past decades, we've spent a billion dollars on analyses, experiments and large-scale field tests, and we've actually driven several experimental reactors to destruction, in order to determine the limits to which Nature restrains the release and dispersion of the various kinds of radioactivity involved. It would be nice to fill in some thin spots in the data. But we already have enough information to declare with confidence that a nuclear reactor accident simply cannot lead to a catastrophe. Planning otherwise is not extra safe, it's just wrong.

And that's not like saying a collision of subway cars is impossible. That's a different kind of impossible, one that holds only if everything works as intended. The nuclear case is guaranteed by the laws of Nature—about the best guarantee there is.

Unwarranted fear of nuclear technology is based on two false premises:

- 1) the belief that a nuclear casualty could have catastrophic public health consequences, and
- 2) the belief that no amount of radiation can be small enough to be harmless.

These and other false beliefs are often accepted uncritically because nuclear power is demonized, and earthly solutions are considered inadequate by definition.

Appendix A. The nuclear curse – some history

From its beginning, nuclear technology has been cursed with a fear-mongering policy of demonization. It started with a need to convince the Japanese immediately after Hiroshima that atomic weaponry was destructive beyond precedent or imagination. That theme was maintained through the Cold War's policy of Mutually Assured Destruction. When John McPhee wrote *The Curve of Binding Energy* in 1973, he quoted nuclear bomb-makers saying casually, "I think we have to live with the expectation that once every four or five years a nuclear explosion will take place ... I can imagine a rash of these things happening. I can imagine—in the worst situation—hundreds of [nuclear] explosions a year."

Nuclear bomb-maker Robert Oppenheimer said that nuclear scientists have known sin, and, as he watched the first bomb test, said, "Now I am become Shiva, the Destroyer of Worlds." With the opera *Dr. Atomic*, this became, for many people, the public Voice of the Atom.

The sources of this fear-mongering are many. The military incentive to describe their weapons in fearful tones is clear and valid. The atomic scientists' motivations are less obvious, but are long-standing and widespread. Unlike engineers and project managers, whose money generally comes in when a job is completed, scientists are paid by the hour, like doctors and lawyers, to work on problems, not to solve them. When the problem is solved, the money stops. So scientists have a strong incentive to discover problems, and to characterize the problems as difficult, dangerous and mysterious.

Nuclear pioneer Alvin Weinberg, long-time director of Oak Ridge National Lab, had an additional incentive. Starting in 1973, he repeatedly characterized nuclear technology as a "Faustian Bargain," meaning that it was a gift of great value to humanity, but with the Devil to pay if we slip up. Weinberg called me to his death-bed to urge me to continue using the term, in order to spur nuclear workers to maintain the extraordinary level of technical excellence that has been so important to the field.

I told him I believe the term has done great harm; that excellence should be sold on its own merits; that the Satanic myth implies that several hundred years of engineering experience with "ordinary machinery" is never quite good enough for nuclear work. This leads to improvising untested solutions, without drawing on the very type of experience most needed. Adding unnecessary "safety features," to protect against events that can be shown to be physically unachievable, does not make a plant safer, just more complicated, more expensive, and prone to avoidable accidents.

He said, "You know that if the Davis-Besse situation had not been detected in time, the public would have demanded the shutdown of all nuclear plants." I replied, "Not at all. You're talking about a small hole in the reactor head. That situation has been thoroughly analyzed. The plant would shut down automatically with no significant release of radioactivity. If we treated the situation as we did Three Mile Island, we certainly could panic the public. But if it was handled sensibly, there should be no undue public response."

In practice, the policy of restraining nuclear power has taken many forms. Financial incentives were offered, favoring so-called "green" or "renewables" over nuclear, which were

characterized as quite the opposite. The financial subsidies grew, in some cases, larger than the incremental cost of nuclear. That is, the money could have been used to buy existing nuclear electricity, rather than subsidizing a non-competitive “green.” When this was not enough, state and local laws were enacted, forcing utilities to buy a certain amount of “renewable” energy that they would otherwise not purchase. The financial incentives reached the point that investors created “renewable energy companies,” which utilities could patronize, that could offer its customers 25% return on investment without actually generating any electricity, just reaping the bribes!

And we’re not even fair with the definitions. We are reluctant to define nuclear as “renewable” until we have a full-scale breeder reactor and reprocessing program in operation. Yet, the EBR (Experimental Breeder Reactor), the IFR (Integral Fast Reactor) and others here and abroad, demonstrated breeding and reprocessing for decades. In 1977, we put a breeder reactor into the Shippingport plant, and for five years sold electricity to the commercial grid while creating more fuel than we burned. Even in existing commercial nuclear reactors, about half of the electricity is produced by the fission of plutonium created from the fertile, non-fuel uranium during normal operation—a routine renewal program already in effect. In contrast, we unquestioningly grant the title “renewable” to the burning of 500 million tons a year of undefined “biofuels.” Agronomists, who are the experts in this field, generally react with shock and awe at the idea of such a program, and point out numerous serious concerns and unknowns it raises that have not yet even been explored.

There are more direct forms of nuclear discouragement. For example, in the early days of nuclear power, the U.S. made many agreements to help other countries strengthen their energy programs, but those agreements explicitly forbade any mention of nuclear. In 1982, the U.S. Nuclear Regulatory Commission hired the Sandia atomic bomb laboratory to prepare a table, listing each of the 130 nuclear plants, then built or planned, and calculate deaths, cancer cases and dollars damage for the “maximum accident” (defined for this study as a situation physically impossible to achieve). Each of these cases computed a hypothetical tens to hundreds of thousands of deaths. This study and the associated publicity were gratuitous, not in response to any public demand, and timed to hit the Sunday news editions. A steady string of such actions has had the effect of portraying nuclear technology as unprecedentedly hazardous, but it certainly created a generous flow of research money.

Another unique nuclear burden is the Price-Anderson Act, based on the demonstrably false premise that a nuclear power casualty (not a bomb) could overwhelm the financial resources of the world’s insurance companies. Under the Act, the nuclear industry pays for damages, relocation, etc., and Congress has the option of requiring additional compensation from the industry if the first two tiers of Price-Anderson are not sufficient to cover the costs of an accident. This unique law is cited in other insurance policies—automobile, house, business, etc.—noting that those policies do not cover a nuclear reactor disaster. Ironically, the insurance industry knows from its own statistics that the nuclear industry is one of the safest.

On January 11, 2001, Energy Secretary Bill Richardson announced proposed changes to legislation to enable “compensating thousands of current and former workers in nuclear weapons-related activities...whose service to the country left them sick or dying.” He said a recent study, based on previously discredited reports, showed that that death toll was large, and that previous government officials were aware of this situation but had covered it up. A preliminary list of locations where workers might have been affected named 317 sites in 37

states, DC, Puerto Rico and the Marshall Islands. The Energy Department sent out personnel to these sites, visiting retirement homes to ask residents if they were suffering any illnesses that might have been caused by radiation exposure decades earlier. I was familiar in detail with the radiation data, having published the *Reactor Shielding Design Manual* in 1956, and I knew there was no scientific basis for any charge that nuclear workers were being harmed by their occupational exposure. I wrote the Secretary's office and asked for a copy of this "new report." There was no such report. I received copies of the various "discredited reports." I was familiar with them. They are scientifically indefensible. The Assistant Secretary assured me this was only the beginning of the study, and "robust public discussion" would follow. It did not. With the change of administration, Richardson was replaced and immediately made a trustee of the anti-nuclear Natural Resources Defense Council.

In response to the repeated news stories, the U.S. Congress held hearings and issued a statement:

"It is the Sense of Congress that—

(1) Since World War II Federal nuclear activities have been explicitly recognized by the U.S. Government as an ultra-hazardous activity ... involved unique dangers, including potential catastrophic nuclear accidents that private insurance carriers would not cover ...

(2) ... large numbers of nuclear weapons workers ... were put at risk without their knowledge or consent ...

(5) Over the past 20 years more than two dozen scientific findings have emerged that certain Department of Energy workers are experiencing increased risk of dying from cancer and non-malignant diseases at numerous facilities ...

(6) ... Furthermore, studies indicate that 98% of radiation induced cancers within the Department of Energy complex occur at dose levels below existing maximum safe thresholds.

Each of these alleged facts is demonstrably false.

I had worked with a reporter, showing him data that demonstrated that low-dose radiation is actually beneficial, acting like a vaccination to reduce cancer rates and extend lifespan of nuclear workers and atomic bomb survivors. His first article received considerable favorable attention worldwide. We planned some follow-up stories, but they never appeared, and he stopped returning my phone calls. Thereafter, he published a series of stories based on discredited studies claiming increased cancer for nuclear workers and the surrounding population. These studies show that some counties near nuclear facilities were above average in cancer deaths. (Some were below average, but that is not newsworthy.)

During one week, he had four such stories above the fold on page one, and went on to win several awards, including a Pulitzer. These stories became the impetus behind the atomic workers compensation act that gave several billion dollars of the taxpayers' money to nuclear workers, despite the data cited in his first story that such workers are healthier than average.

Radiation protection policy and procedures declare that "human made" radiation is one or two orders of magnitude more harmful than "natural," though the body cannot detect any

difference.⁴⁵ This curious policy creates situations like lawsuits against oil companies for contaminating the ground with dirt by bringing up more naturally-radioactive dirt in drilling for oil. Yucca Mountain carries this curse to the extreme, ending up with radiation requirements that can't possibly be demonstrated (or justified), leading to a estimated cost of \$100 billion for a hole in the ground that must be guaranteed flawless for a million years—for material that will reach background radiation level in a few centuries.

Many important American public policies are arrived at via an amateur version of the Precautionary Principle. This principle says that if there is a particular national danger that overwhelms all others, then any indication that the danger may be imminent, dictates that action must be taken without waiting to prove whether the danger is real. "Better safe than sorry." I picture this as the opposite of the Hippocratic Oath. The Precautionary Principle says: "*begin immediately ... an all-out effort to use every policy and program, every law and institution, every treaty and alliance, every tactic and strategy, every plan and course of action—in short, every means to halt the destruction of the environment*" (Al Gore, *Earth in the Balance*, p. 27) vs. the Hippocratic Oath: "First, do no harm."

During the Cold War, the prevention of America's possible destruction by Communism was given overwhelming priority. I'm not concerned here with whether that was a wise position. I want to look at the consequences of arriving at it via the Precautionary Principle. Some people bragged that the Defense National Highway Act and the Defense National Education Act, passed under the Precautionary Principle, could never have passed on their own merits. Is that good? Shouldn't such important legislation be openly debated and passed on its own merits? Now we have climate-control advocates urging that we apply the same priority process to their particular concern.

A basic problem with the Precautionary Principle is that it examines only the scenario it is determined to prevent. By fiat, we mustn't wait to examine the potential consequences of the actions we actually take. "He who hesitates is lost." So we arm and train that brave commie-fighter, Ossama bin Laden, topple popularly elected leaders like Allende, spend 50 years trying to crush the Cuban economy, and sell arms to one side and then the other of the Iraq/Iran wars. And this strategy is now held up as a shining example of how to deal with climate control. In both cases, key scientific journals and public media announce they will publish no more articles questioning the scientific basis of the government policy, and those who raise questions are berated as Enemies of the People. This is not a good way to resolve scientific issues. As Voltaire said, when the Government is wrong, it is dangerous to be right.

Another policy-making process is a variation of the philosophical tool, *Reductio ad absurdum*. In the early days of nuclear power, the industry gave in to a number of unreasonable demands for "more safety," because it could. In fact, when the requirements were applied evenly to all competitors, it actually became profitable to accept them. As these requirements were put into effect, it became clear in some cases that the consequences were absurd (e.g., the requirements associated with Yucca Mountain, or the idea that a single gamma ray can kill you.) The Chair of the Nuclear Regulatory Commission complained that "The Public has to understand

⁴⁵ The complexity of carrying out such a distinction was discussed in a four-day Health Physics Society Professional Development School, whose content is published in a 550-page book, *Naturally Occurring Radioactive Materials (NORM) and Technologically Enhanced NORM (TENORM)* by PA Karam and BJ Vetter (Eds.). This book is available through Medical Physics Publishing Co. (2009) at: www.medicalphysics.org

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that there is such a thing as an acceptable radiation dose—such as the standard banana.” But the Government keeps telling us just the opposite. The nuclear community fears that acknowledging the absurdity would look like an embarrassing reversal of policy, so the absurdities are simply overlooked.

So nuclear technology suffers from many arbitrary shackles, which need to be acknowledged and shaken off, so that it can work with other technologies on an even basis. The mystery and romance has been exciting, but we need to start treating nuclear technology as a work-horse and not a show-horse. We’ve shown that unprecedented attention to engineering excellence pays off, and we must continue that course; not in fear of the Devil, but in the best tradition of American engineering.