NUCLEAR ENERGY: THE ONLY SOLUTION TO THE ENERGY PROBLEM AND GLOBAL WARMING

By Bill Sacks and Greg Meyerson, March 2012

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When humanity looks back on the few centuries of capitalism, it will be immediately apparent that a particular economic and social system, into which history led first Europe and then the rest of the world, not only hijacked myriad resources of limited supply, without concern for their longevity, but also disposed of the waste products in a careless way, destined to greatly diminish the livability of the planet. This global human process that will have occupied no more than the blink of a geological eye may yet prove to have made living conditions immeasurably more difficult for humans, as well as for other animals and plant life, for a much longer duration than the destructive process itself -- perhaps many millennia. These conditions will, if they come to pass, faintly echo the hostile world environment tens of millions of years ago, long before the very appearance of humanity on the world stage. The thorough elimination of such a system, by the vast majority of humanity who suffer at its hands, cannot occur too soon for the sake of the human species.

Preface

There are numerous books and articles on nuclear and other sources of energy, many of which we have drawn on and cite. But none of the items that we have seen combine and agree on four major points that form the basis for this essay and that justify our effort in writing it. Those four points are that 1) global warming increasingly threatens the human habitat and is now due primarily to the burning of fossil fuels (coal, oil, and natural gas) for energy, 2) if fossil fuels are to be replaced with clean energy on a world scale, this can only happen through the predominant use of nuclear energy, the other clean sources being entirely inadequate for the job at that scale, 3) as a corollary to the latter point, radiation, far from being the ubiquitous danger that extreme exaggerations claim it to be, actually promotes health *at the levels likely to be encountered even from possible, though rare, nuclear plant accidents*, and 4) capitalism, a system that by its very nature places profits before human needs, is an inherent and absolute obstacle to achieving this goal.

There are many people who will agree with one, two, or even three of these premises, but few who will agree with all four. We hope through this essay to open a door to thinking about these four issues at the same time, even if there are many readers whom we fail to convince of all of them.

I. Introduction

A. Background

There are also overwhelming numbers of peer-reviewed papers in scientific journals, as well as numerous popular articles and books, demonstrating that global warming is happening on a scale unknown to humanity previously and that it is due to the industrial and transportation-caused rise in greenhouse gases (GHGs). After decades of cover-up, generally in the interests of the fossil fuel industries (coal, oil, and natural gas), this has finally been accepted now by the media in general, all over the world. Furthermore there are many articles and books demonstrating that unless fossil fuels are replaced in their entirety as sources of energy, tipping points will be reached, if they have not been reached already, that will make continued global warming impossible to reverse in the scale of time that is meaningful to human beings. The consequences of such warming will be devastating to vast sections of humanity, mostly concentrated among, but not confined to, the poorest and most exploited throughout the world. These consequences include melting glaciers, lessened snow pack, shifting habitats and accelerating extinctions, floods and droughts, greater extremes of weather, and rising sea levels

It is the purpose of this essay to demonstrate that nuclear energy is the only alternative form of clean energy that is in a position to challenge fossil fuels for supremacy. We also hope to show that this is true because of the *physical* nature of the various sources of energy, including nuclear and the leading non-nuclear alternative clean sources -- wind, solar, biomass, hydroelectric, and geothermal (all to be defined and described below). Each of these may have a role to play in local situations, but this is not where our focus lies. Rather it lies in national and world-scale replacement of fossil fuels.

It is important to note that the use of any alternative source, particularly nuclear, in order to complete the conversion from fossil fuels, would require that fossil-fuel-related companies preside over the destruction of vast amounts of capital in the form of oil-drilling, coal-mining, and gas-fracking (fracturing) equipment, along with pipelines, storage tanks, and ocean tankers, as well as manufacturing plants for each of those plus for the various modes of transportation from road vehicles to airplanes, and countless other items costing them billions of dollars, yen, yuan, euros, and so on. Such widespread capital destruction would put many of the companies out of business. And as far as the fossil fuel companies themselves are concerned, any significant increase in nuclear energy would presage the extinction of their very sources of profits. Thus the profit system offers an enormous obstacle to achieving clean sustainable energy.

Aside from the political and economic issues, it is our contention that profound technical obstacles exist to the necessary scaling up of solar, wind, and the other non-nuclear alternatives to completely replace fossil fuels. We further contend that this is why the fossil companies and the media spend little effort in opposing these -- either propagandistically or in lobbying against outsized government subsidies directed toward these non-nuclear sources. Indeed some fossil companies have actually invested money in wind and/or solar and proudly advertise this fact by way of pretense to environmental virtue. The only real threat to their immense profits and capital infrastructure is nuclear energy.

As it is, nuclear power plants provide around 20% of U.S. electricity, and a little less than 15% of world electricity, varying anywhere from none to about 80% in one country or another. Nuclear plays no role as yet in the other major energy-consuming arena of transportation, with the one exception of nuclear powered submarines and certain surface vessels for the U.S. Navy and those of a few other countries. However, nuclear energy can, in fact, completely replace the need for fossil fuels and provide all transportation energy. In order for fossil fuels to be completely replaced, many businesses would also require significant capital investments to enable them to be supplied strictly by electricity rather than, in many cases, directly by fossil fuels.

All these sections of the capitalist classes are aided immeasurably -- whether they make under-the-table payments or not -- by any number of anti-nuclear environmental groups and self-appointed anti-nuclear experts, who act either out of honest but misguided and completely ignorant beliefs, or out of careerism and a love of their own positions of authority. They are further aided by venture capitalists who hope to cash in on generalized fear of nuclear energy with solar and wind collection devices, and by huge state and federal subsidies provided to these start-up industries by pandering demagogic politicians. Subsidies to solar and wind start-up companies are currently between 10 and 20 times as great per unit of energy as subsidies to nuclear. The demagogs pretend that in this fashion they are doing their part to fight fossil-fuel-caused global warming.

> Note: When we use the term “anti-nuclear” in this essay, we are referring to opponents of nuclear power plants for the generation of electricity and not to opponents of nuclear weapons, which is a much broader category of people in all classes and includes the present authors. Where we intend to refer to the latter we will make it explicitly clear.

Let’s get one thing on the table: the third greatest disaster for the world’s working classes, aside from 1) wars, both direct and proxy, between rival imperialist powers and 2) the catastrophic effects of global warming, would be an interruption in the supply of electricity and transportation. More than 1.3 billion workers in various parts of the world (about 20% of the world’s population) already lack electricity, and billions more suffer from inadequate amounts (http://www.iea.org/weo/electricity.asp). But for those who now have electricity, interruption of supply would mean that, given the realities of modern life, hospitals would be shut down, homes and other buildings would be subject to extreme temperatures in many parts of the world, many workers would be unable to get to work or to obtain food, all sorts of daily necessities would become unavailable and/or unpreservable, and computers would routinely crash. In short, as a result of these failures, in addition to the millions who already die young, many more would die. Most people in the industrial countries have already seen isolated and limited examples of these interruptions when storms have shut down electrical supplies for days at a time. And indeed extreme weather events are, in many cases, a reflection of global warming, but the serious negative consequences would become commonplace in the absence of reliable sources of electricity.

Many of those who demand the immediate replacement of fossil fuels by solar and wind ignore this reality in favor of a fantasy world in which they imagine that these two most popular alternative energy sources could be scaled up to have an impact at a national or worldwide level (discussed in more detail below). In particular, the most obvious features of solar and wind that they ignore in their wishful thinking are the consequences of intermittency and geographical dilution. That is, the sun doesn't always shine during the day in every place in the world, and never shines at night (except near the poles), and wind doesn't always blow. These two features are so profound -- as predicted on theoretical grounds but also as shown in practice where either of these has grown to a small but significant penetration -- that the only way that electricity can be provided 24/7 is by having natural gas plants at the ready to quickly come on line whenever the frequent and erratic interruptions of wind or sunlight occur. That is, wind and solar are parasitic on natural gas or sometimes coal, though gas has become the most common choice to take the place of solar and wind on cloudy or calm days, or at night, when either one or the other, or both, is unavailable.

Natural gas is a fossil fuel that, during usage, has lower greenhouse gas (GHG) emissions than coal or oil -- about half that of coal for the same energy output -- but half of a huge amount is still a huge amount, and the greenhouse effect from burning natural gas is still extreme. This is particularly true, since the extraction process of fracking produces leaks of an estimated 4% of the gas, according to a recent article in the British science journal *Nature* (http://www.nature.com/news/air-sampling-reveals-high-emissions-from-gas-field-1.9982). Natural gas is primarily methane, CH_4, which is a far more powerful GHG than CO_2. It traps about 75 times as much heat for the same weight as CO_2 during the first two decades, though it clears from the atmosphere in around that time, while CO_2 sticks around for about 100 years, with a net effect about 25 times worse than CO_2 over that century. Thus the net GHG effect of natural gas, taking into account the extraction process in addition to the burning for energy, seems to be worse than that of coal or oil.

So, far from being able to replace fossil fuels completely, solar and wind *necessitate their retention* -- with one possible exception. That is if nuclear power plants were to replace the fossil plants. But if this were to happen, then the utility of solar and wind would be reduced to local uses such as on house tops or on farms, or perhaps for moments of unusual extra demands for electricity. Which brings us back to our contention that only nuclear energy can *completely* replace fossil fuels, and their replacement is an absolute necessity for humanity.

Nor do such partial measures as energy conservation and efficiency (both worth pursuing) or the *limited* expansion of nuclear energy solve the problem. They will at best only delay the inevitable climate disasters that lie in wait and at best temporarily lessen, but not eliminate, the death-dealing pollution -- much as if Thelma and Louise (in the movie of the same name, in which two women end by deliberately driving their convertible off the edge of a cliff) simply slowed their car.

This atmospheric pollution relates primarily to GHG *concentrations* in the atmosphere, rather than simply GHG *emissions*. GHG concentration is not the same as GHG emissions. The former is akin to the national debt, and the latter to the annual deficit: the one is the accumulation of the other. Decreasing GHG emissions -- the only thing that governments around the world are even talking about (but without doing much, if anything) -- will still increase the concentration, albeit at a slower pace. What is absolutely necessary to minimize the damaging climate change, and pollution, is to decrease the *concentration*, which in turn requires completely *eliminating* the emissions, or at the very least severely limiting the emissions and at the same time increasing carbon sinks (such as forests) to take up the remainder, and then finding ways to pull major amounts of GHGs out of the air to decrease their concentration. But forests take generations to grow to adequate size to have much impact on GHGs, and, rather than forests increasing in area, they are currently being *removed*, through at least three mechanisms: Local economic conditions are forcing poor farmers to clear forests in order to create more cropland, and the competitive profit imperative lead big planters to do the same, such as in Indonesia and the edges of the Amazon jungle; lumber and paper companies in the U.S. are clear cutting forests to enhance their profits; and global warming is causing migration of destructive pine bark beetles to more northern latitudes in places like British Columbia, destroying trees wherever they go. The solution is not to *delay* the inevitable but to prevent it, and this requires that clean energy sources replace fossil fuels, as soon as possible. Energy conservation and expansion of non-nuclear alternative energy sources ("renewables") are elements of greenwashing -- all talk and woefully inadequate action -- that merely delay, but eventually assure, the inevitable.

In the present essay we will, without getting overly technical, try to explain enough about nuclear energy and nuclear weapons, as well as about fossil fuels and "renewables," to convince the world's ordinary people that nuclear energy is in our interests. More than that, nuclear energy is, we hope to show, the only clean, sustainable, reliable, and abundant source of mass electrical and transportation energy in today's world, and, contrary to anti-nuclear claims, nuclear has been the safest -- *by far*. We also hope to show that, with the proper nuclear technology, already developed long ago in the U.S., there is enough fuel to last the remaining lifetime of the sun and earth (another 4.5 billion years, give or take). And that without its being put into place soon, the livability of the planet is in serious danger for billions of us, for centuries to come. This demonstration will require us to combat the fearmongering hysteria and nuclear-phobia or radiation-phobia that is decidedly the most potent weapon, among several, in the anti-nuclear arsenal. It will also require us to offer some suggestions as to how everyone can distinguish the real and honest experts from the pretend and/or dishonest ones.

Are "renewables" really renewable? The more popular non-nuclear alternatives to fossil fuels -- most often including wind, solar, hydroelectric, and geothermal -- are usually referred to by their supporters as "renewables," but in fact they are no more renewable in terms of supply than fossil fuels or nuclear. Rather they are replaceable *with virtually unlimited supply*, which fossil fuels are not. But, as we will show below, so is nuclear energy replaceable with virtually unlimited supply for the remaining life of the planet. If wind, solar, hydro, and geothermal deserve a special term to distinguish them from fossil fuels, such as "renewable," so does nuclear. Any of these energy sources, other than fossil fuels, will last as long as the sun and earth exist in their present forms -- another 4-5 billion years -- though in no case are the materials necessary for their conversion to useful forms of energy unlimited in supply.

A true example of renewability would be something like clean water, which can be used and then cleaned and reused. But whether something is renewable or simply comes in unlimited supply for the life of the planet, and is therefore infinitely replaceable for all practical human purposes, makes little difference. The inaccurate term "renewables," however, is commonly used specifically, and falsely, to exclude the one feasible solution to the problem of global warming -- nuclear -- for a variety of reasons that we will also discuss below.

Here, for example, is a quote from a website of the U.S. Department of Energy addressed to children: "Renewable energy comes from things that won't run out -- wind, water, sunlight, plants, and more. These are things we can reuse over and over again. … Non-renewable energy comes from things that will run out one day -- oil, coal, natural gas, and uranium (http://www.energystar.gov/ia/kids_site/swf/ny_te.swf)." Note the inclusion of uranium in the list of non-renewable energy sources, which is the main fuel used in today's nuclear reactors. There are other fuels for reactors, such as thorium, but the main point is that there is enough uranium in the oceans alone to satisfy energy needs for the life of the planet. However, long before it comes to that, breeder reactors (described below) can expand the energy obtained from uranium by a factor on the order of 100 thereby extending the life of already spent fuel by that same factor, and there is plentiful uranium in the ground in more than a dozen types of geological formations (Till and Chang).

Furthermore since wind and solar are extremely variable (the better word is "erratic") over the course of a day or a year, as we discuss below, they might more accurately, and more revealingly, be called "unreliables." Nevertheless because "renewables" is the one term that is understood to include the four leading non-nuclear alternatives to fossil fuels, we will continue to use it in this essay, but always with quotation marks in order to remind us that it is only a concession to common usage.

A related and misleading misnomer is the term "backup," used by advocates of wind or solar to describe natural gas plants that are called upon to take the place of these unreliables when the wind isn't blowing or the sun isn't shining. But to call a natural gas plant "backup" to wind or solar, given that significantly more than half the time neither wind nor solar is available and natural gas has to be called upon, is like calling the Mona Lisa "backup" for the frame.

Biomass (also referred to as "renewable") as fuel for social energy, other than as food for our individual biological energy, we will not discuss in any depth, mainly for two reasons: 1) it is not clear that the energy it takes to grow, harvest, and deliver biomass doesn't exceed the energy that it provides, in which case rather than being a source of energy it is a sink, though this depends to some degree on the specific crop or vegetation, and 2) because the growth of plants absorbs CO_2 from the atmosphere but gives it right back when it is burned for fuel, biomass simply recycles GHGs, rather than decreases them. Its advocates, however, point out that at least it doesn't increase them. But reversal of global warming requires not just a steady state but rather a drastic decrease in GHG *concentration* in the atmosphere. This, in turn, requires a complete end to all GHG *emissions* and some way of removing GHGs from the air.

Plant life constitutes about half of the biomass in the world, the vast majority of it on land, with the other half consisting mainly of bacteria, and with animals constituting much less than 1%. But much of plant life, both on land and in the ocean, is part of the food chain, and already the use of corn cropland for ethanol fuel is limiting the supply of food for humans and driving the prices of food sky high. Already hungry people in various countries have staged mass rebellions against this misuse of corn. Chemists are also working on ways of breaking down the tough molecules of inedible biomass residue from crops and forests that would otherwise be reabsorbed into the earth's surface, thereby helping to maintain soil health, but they are not yet able to use these residues as a fuel source. Furthermore this residue only represents the equivalent of one third of the current annual supply of transportation energy in oil fuels (See, for example, *Scientific American*, "Ten Unsolved Mysteries," October 2011).

One thing we will *not* do, though much propaganda from all sorts of directions often does, is *rely* on exposure of behind-the-scenes profit interests to argue for or against any particular energy source, since it is in the very nature of capitalist competition that there are always profit interests both for and against each energy source. Once the practicalities of various energy sources are compared, it may be of interest to expose such distorting profit interests, but such exposés should always remain as adjuncts rather than central to the evidence for or against any energy source. That one or another type of business finds something profitable in any particular energy source, says nothing about whether that source is beneficial or harmful to the public.

Often anti-nuclear propaganda attacks strawpersons, namely the nuclear industry and their greatly exaggerated supposed government backers in at least the U.S. The propagandists claim that because there are businesses that would profit from nuclear energy (a given under capitalism for any business) it should be rejected out of hand. Such a misguided and/or deceptive approach was used, for example, by the leaders of the 200,000 anti-nuclear demonstrators in Germany right after the Japanese quake/tsunami that damaged three of the reactors at the Fukushima Dai-ichi nuclear power plant in March 2011. They completely ignored the fact that the fossil fuel industry profits tremendously from their rejection of nuclear energy. It would be just as deceptive of us to accuse the leaders of these demonstrations of being fronts for the fossil fuel industry. Neither charge sheds any light on the issue.

B. Energy -- the political and economic context

While many readers may agree with what we have to say about energy, or at least will be willing to consider it, they may balk at what we have to say and conclude about the associated economic and political issues. But as far as we are concerned, dealing with one without dealing with the others will lead us down a garden path to a dead end -- in more ways than one -- as we hope at least to suggest if not demonstrate to everyone's satisfaction. Therefore we encourage equal consideration on the part of the reader of those aspects of our essay.

Today's world is dominated by a political and economic system that came into being only a mere 500 years, or so, ago. Humanity, on the other hand, came into existence in its modern form close to 250,000 years ago, with human-like ancestral species arising almost a million years earlier. The modern political and economic system, involving the vast majority of humanity, is capitalism, and the schools and media around the world would like us to believe that capitalism has been around forever and will continue to be around forever -- because competition and profit-making, they say, constitute the only way of life consistent with an imaginary fixed human nature. But this contention serves only the interests of the current ruling classes around the world -- those rich lords of banks, industry, commerce, farms, and mines. The slightest study of anthropology will show that the forms of human society are many and varied, and only in the last couple of thousand years have the social forms of class societies encouraged a tolerance of, and in some a love for, individualism, competition, and the need to make profit from the labor of others. Given the profit system's brief life to date, it is not clear how much longer humanity will tolerate such a system.

However, one thing that will persist at least as long as humanity survives is the universal need of all plants and animals, including humans, for energy. Yet there are many sources of energy in today's world, and among those sources we have choices. The main current sources of energy on the social level are fossil fuels (coal, oil, and natural gas), hydroelectric (dams), geothermal (tapping natural heat from below the ground), wind (wind turbines), solar (photovoltaic panels or mirrors that concentrate sunlight to heat a fluid in a pipe), waves, tides, wood, manure, and a few others in addition to nuclear processes.

In this essay we will explore the more important of these various sources of energy -- their political and economic aspects, as well as the way they work to provide for our needs for heating and cooling, transportation, food and clean water, and industrial power. We will discuss the strengths and weaknesses of each, and particularly expose the lies that are produced in the course of the capitalists' competition to control these various sources of energy and to profit from their use. Such competition compels those corporations that profit from one or another source of energy to try to convince us that their particular domain is the best way to power our homes, transportation, and industries. Furthermore the ExxonMobils and Chevrons benefit greatly if we believe that wars to secure sources of oil and natural gas in the Middle East (Iraq, Afghanistan, and Pakistan) are in our interest. This is true even as the government claims that the motivation for those wars is not oil, but rather to put an end to terrorism -- a self-defeating and anti-working-class method of resistance, led by smaller rival capitalist forces.

We will temporarily put aside these competing interests as we explore the history and nature of each of these sources of energy.

C. Energy – the science

An aside: We ask the reader's indulgence for the sometimes seemingly trivial and, for many, overly elementary explanation of the history and science of energy below, but what can seem trivial to some may contain some revealing aspects even to them. After all, in this essay we may be offering a new way of looking at things, for almost everyone. Indeed much of the way we present things here reflects the new way of seeing relationships that we have acquired during our own few years of investigation. Such new ways of seeing things often reveal previously unrecognized relationships, even to those who may be the most familiar with the subject. Furthermore to the extent that we ourselves consider something to be vital, should we not also be interested in how much understanding others have of such issues?

As it turns out we are both professional teachers – one current and one former – and we both teach largely in order to learn. We learn from our efforts to communicate our understanding, which often reveals unrecognized misunderstanding, and we learn even more from the responses of our audiences. We encourage discussion and disagreements, since learning from each other often involves struggle to reconcile our respective ideas with reality and with each other. But it is far less useful for ideas to come from the tops of our heads without our own investigation and contemplation. Unfortunately most of the debate around nuclear energy comes from that arena, from people who really have not thought about or investigated the subject – particularly some of those who make a living or career out of providing leadership to environmental organizations.

And finally, by delving into the more elementary explanations, and continuing on to the more complex aspects, we hope to end up with everyone as much on the same page as possible -- at least as much as is allowed by the different avenues along which we each approach the subject.

The public, under present circumstances, may be unable to have much bearing on the outcome of the struggle over energy sources that is now occurring in the world -- not only among rival imperialist powers who go to war and kill literally millions in order to control oil fields and gas pipelines, as well as minerals and other profit-related resources, but even within individual national capitalist classes with differing energy investments. But if the working classes can commandeer the power to govern, replacing the capitalists in that role all over the world, it will become vital that we all understand the essential realities of energy, imbued with reasonable caution but free of fear. The realities involve questions of safety, energy concentration (or intensity), cleanliness, sustainability, abundance, impact on the environment, and relative ease of attainment. We believe that it is not too soon to start filling the critical need for this understanding.

All plants and animals require energy and certain chemicals to do the things necessary for continued life. Plants derive the energy from sunlight and carbon dioxide (CO_2) in the air, as well as from nutrients soaked up through their contact with the earth or oceans. With this energy they undergo internal chemical reactions (called metabolism) that keep them alive, growing, and producing oxygen partly for internal use but also emitting it as a waste product. Individual animals, including humans, derive energy partly from food, which consists primarily of plants and other animals. They (we) also derive energy from oxygen, a plant "waste" product, while one of the primary "waste" products of animals (and bacteria) is CO_2, which is a necessity of life for plants. Thus plants and animals, along with bacteria, have evolved together, needing each other -- a so-called symbiotic relationship. Humans collectively also create a higher level of organization than individuals, namely societies. At this level there are other energy needs, and it is mainly the control over both individual and societal energy, as well as material, requirements that gives capitalists their all but complete power over us in today's world -- a situation that will continue only so long as the world's working classes leave them in control.

Early in the evolution of humanity, according to overwhelming evidence from implements and tools that are unearthed by archeologists, people survived mainly by spending their days getting food. Two major activities were involved, one in the quest for animal protein (hunting) and the other for plant nutrients (gathering). A major step forward occurred much later when animals were domesticated and herded, saving the danger and effort of hunting, and when plants were domesticated and grown, i.e., agriculture. It was only then that sufficient time became available for pursuits other than food acquisition, which in turn offered the opportunity for a small portion of the population to control the food supplies and eventually, through this process, to force the majority to yield to their will, either in the form of outright slavery or other arrangements such as serfdom, or, in the modern world, labor exploitation in its many forms – from ongoing bonded labor to "free" wage slavery (referred to by the exploiters as "employment").

But what exactly is energy? Energy can be thought of roughly as a property of matter related to its motion, and matter can be thought of roughly as stuff that you can touch and feel, and often see, smell, taste, and/or hear. Energy can also be thought of as the medium of exchange with which different portions of matter communicate, either through collisions (think one billiard ball hitting another) or through radiation of light or other parts of the type of radiation called the electromagnetic spectrum. The latter includes everyday things such as microwave, radio and TV waves, and infrared (all with energies lower than that of light), and ultraviolet, x-rays, and gamma rays (all with energies generally greater than that of light). Light, after all, is just that very narrow part of the spectrum for which our eyes happen to be sensitive. Other animals have ranges that may overlap that of humans but may extend beyond the human range at one or the other end. The entire electromagnetic spectrum, however, is far wider than that which vision permits us to detect, extending in principle from zero to infinity. All these parts of the spectrum differ only in the amount of energy they embody (quantitatively) but are the same otherwise (qualitatively).

Note: The terms "energy" and "power" are often incorrectly used somewhat interchangeably. Particularly in describing utility company plants that provide both power and energy. The explanation of the difference between them will be found in a footnote at the end, where all footnotes will be found.[1]

Energy draws its significance mainly from the process of exchange, whether between separate chunks of matter or between different forms of storage that are capable of later undergoing exchange between separate chunks. For example, water on top of a cliff that is held there by a dam is a way of storing energy, but it means little to us unless and until it is allowed to fall and turn a fan blade (called a turbine) that forces electrons to flow in a wire in the vicinity of a magnet, thus creating electricity, similar to a generator (alternator) under the hood of a car. The term "potential" energy is used for the water above the dam and other means of storage. All matter stores energy that can potentially be turned into useful exchanges of one type or another, whether it is electricity, heat, large-scale motion, sound, light, or some other form of energy. These forms all have in common that they can be transformed one into another, and sometimes back again, with appropriate equipment or natural structures. Because of this exchangeability they are all regarded not as separate entities, but rather as separate forms of the same thing, called energy.

In order for energy to be exchanged it has to have a certain type and degree of organization or order -- organization which is diminished in the course of the exchange. Therefore what animals and plants really take in is not merely energy itself, but a more organized form of energy that becomes less organized once it is used. The concept of organization of energy is known as entropy, though the concept of organization is ambiguous. However, this is a technicality that may be critical in some contexts, and that we mention for those with more detailed experience with physics, but it does not add to understanding at the level we aim for.

Energy can be stored in large- or small-scale matter, the latter consisting mainly of atoms and/or molecules. In large-scale matter, energy can be stored, as we have mentioned for example, at a higher altitude (e.g., behind a dam or on a shelf) in such a way that gravity can pull the matter down and make it go faster and faster, until it is stopped by some obstacle, such as the ground or a hand, thus transferring that energy from the falling matter to the matter that stops it. In small-scale matter, energy can be stored in such a way that reactions involving electron clouds surrounding atomic nuclei (about which, more in the next section) can transfer it from one atom or group of atoms to another, or rearrange atoms in molecules -- an exchange called *chemical* energy. A battery in a flashlight or car, or fuels like gasoline or coal, are examples of stored chemical energy. The release, or transformation, of stored chemical energy can be seen, for example, in an internal combustion engine, in which gasoline, mixed with oxygen in just the right amounts, undergoes repeated explosions against a piston in a cylinder, driving a crank shaft that, through a series of gears and linkages, moves the vehicle. Another example of release of chemical energy is the burning of wood or coal to transform the energy into the form of heat. That heat can either be used for comfort and protection in cold weather, or it can further be used to boil water, letting the steam expand and blow against a turbine to turn it to create electricity. There are many more examples, of which this is but a small selection.

In even smaller-scale matter, energy can be stored in such a way that powerful reactions that break up nuclei can release that energy to be exchanged with other matter and do many things, including heating water to drive a turbine for electricity or producing a deliberately destructive explosion, as with the so-called “atomic” bombs that the U.S. dropped on Hiroshima and Nagasaki in World War II, killing more than 200,000 people, some immediately and some a short time after. An “atomic” bomb is more accurately called a nuclear fission bomb, to differentiate it from chemical energy, which, after all, is also atomic, and from a nuclear fusion bomb, called a thermonuclear or hydrogen bomb. Below we explain the three forms of nuclear processes -- fusion, fission, and decay (radioactivity).

So to summarize, chemical energy involves the electron cloud surrounding an atomic nucleus, while nuclear energy, as the name implies, involves the central nucleus. The previous examples of food, batteries, coal, and gasoline all involve chemical energy. Atom for atom, there is tens of millions of times more energy stored in a nucleus than in an electron cloud. This extreme concentration of energy is one thing that makes nuclear energy that much more practical once the accompanying design problems have been solved. It also makes it that much more dangerous than other forms of energy in some contexts (bombs), though *far safer than other forms of energy* in other contexts (reactors). The failure to acknowledge this enormous distinction -- between far more dangerous and far safer -- is one feature of the anti-nuclear position, a position that unjustifiably conflates nuclear energy with nuclear weapons, about which more below.

We will further point out below that the accompanying design problems have, for the most part, long since been technically solved for electricity-producing reactors, even as testing and research around the world continues the search for even more advanced designs. That is to say, the problems have mainly been solved as far as the science is concerned, though, given the nature of capitalism and its inherent creation of inter-imperialist rivalries, the politics produces additional problems, particularly in its fostering of those very situations in which nuclear, in the form of deliberately made bombs, is more dangerous.

D. Energy -- a brief history of its social uses

Today, on a higher level of organization, such as a society, energy is transferred from various sources, such as fuels, in order to accomplish desired tasks. These include manufacturing, lighting, heating or cooling buildings, and running cars, trains, planes, and ships. A little less than half of this energy in the world is used in the form of electricity. Electricity is most useful in buildings and houses, because it can be sent along wires over great distances. In a stored form, such as in a battery or in the form of hydrogen, electricity could also be used to power modes of transportation, and already is in the case of some trains, ships, and a few models of cars. The other slightly more than half of social energy use is in forms other than electricity -- e.g., the direct use of fuels such as gasoline for cars, gas for stoves, and oil or coal for heating.

According to the World Bank, about one quarter of the total population in today’s world have no access to electricity -- mainly located in Asia and Africa and divided roughly equally between these two continents. This absence of electricity is a monumental demonstration of worldwide racism, endemic to capitalism, that would be visible even from a distant planet, perhaps even more obvious from that vantage point. The absence of electricity is a major feature of capitalist-produced impoverishment, along with lack of access to clean fresh water and food. The maldistribution of these vital needs -- and the general features of impoverishment, including starvation, lack of health care, and lack of education -- is a result of capitalism's structurally inherent exploitation and thievery. The International Energy Agency (IEA) estimates that it would cost about $50 billion per year to provide electricity to those areas, which is to be compared with about $400 billion spent each year on the world drug trade and more than twice that much spent on the world's military. In the absence of electricity, the only method available for warmth and cooking is through fire, i.e., the burning of wood and other biomass, which generally involves the progressive destruction of carbon-absorbing forests, thus worsening the global warming problem and lowering life expectancy due to pollution.

Fire was discovered many tens of thousands of years ago, most likely from natural sources such as lightning. The technological triumph, however, lay in methods first of maintaining fire in controlled ways so that it was permanently available, or in restarting fires when they went out or in starting new ones where there was none before. To this day fires sometimes get out of control, as exemplified by wildfires every summer in the southwestern U.S. and in Australia, and in 2010 near Moscow. The struggle to control them can consume tremendous resources and time, and they often kill people and destroy homes. Fire therefore can be either a boon or, when not adequately controlled, a hazard -- no different in this regard from nuclear energy.

The source of energy for fire lies in the chemical reaction that various fuels undergo in the presence of enough oxygen. Since oxygen constitutes one fifth of the atmosphere (most of the rest being nitrogen plus a number of trace gases), it is readily available to participate in this chemical reaction, if it is not deliberately excluded by such methods of dousing a particular fire as water, foam, or a blanket. But the other primary participant in this reaction with oxygen has changed over tens of millennia, from wood to coal to oil to gas. All of these contain large amounts of carbon, the primary constituent of all life from bacteria to fungi to plants to animals. Those carbon-containing substances, consisting of complicated or large molecules, are called organic matter. A molecule is simply a collection of two or more atoms that are held together by electrical forces.

Fire was used to keep warm during winters and particularly during the last ice age -- from about 120,000 to about 10,000 years ago -- by which time modern humans, as well as the better known Neanderthals, had arisen from ancestral hominin species that had split off from the ancestors of what became today's two chimpanzee species. Later, fire was used to transform food that was otherwise difficult to eat into food that was chewable and digestible, through the invention of cooking. Fire is a chemical reaction that requires energy to get it started but once started provides its own further energy to keep itself going -- called, for obvious reasons, a chain reaction. Because of its self-perpetuation, it can get out of control, unless carefully managed. We will have more to say below about chain reactions and their control when we explain nuclear reactors.

Until the middle of the 1700s and before humans invented modern appliances and devices, the chief fuel for heating and cooking was wood. But because in certain areas of the world wood was being overused and forests were becoming cleared and lost, sometimes deliberately to create farmland, around the middle of the 1700s coal came to overtake wood as the chief fuel. Coal was first used in Europe several hundred years earlier but took a back seat to wood as an energy source until much later.

While wood smoke has its problems, with difficulty seeing and breathing, coal was, and remains, far worse. Indeed there were cities particularly in Europe where the coal smoke blackened buildings and caused so much respiratory damage that ways had to be found to contain this waste product. However, the lack of success over the last two and a half centuries is illustrated by a little remembered London smog that lasted 5 days in December 1952 and that killed what is now estimated at 12,000 people and sickened 100,000 more. To this day coal and oil fumes kill an estimated 50,000 people in the U.S. alone every year, and an estimated 2 million around the world, from heart and lung diseases, including heart attacks, strokes, emphysema, asthma, chronic bronchitis, and cancer. That's 2 million every year, or 100 million deaths in half a century -- the approximate interval over which nuclear energy has been used to produce electricity and, in the form of commercial reactors, *has killed no one*.

Coal, as well as oil, have killed, and continue to kill, more people than all the wars in the 20th century combined, including World Wars I and II. In today's local paper the main front page headline reads, "UA study: Diesel exhaust here linked to childhood wheezing." One is tempted to yell sarcastically, "No kidding!" Such headlines are emblematic of a society that provides far more resources to study a problem to death than to fix it to prevent death.

Worse yet, the locations of the greatest amount of emissions are near coal plants and highways, and the people generally forced to live in these locations are the poorest and more often than not either black or Latino, but many white workers are also forced to live in these neighborhoods. Racism is a major component of this assault on the health of the working classes, in every country in the world.

Because little is done to purify mined coal, the fly ash (the part that is spewed out of the smokestacks in a coal power plant) contains many toxic metals, such as lead, mercury, cadmium, cobalt, and arsenic, as well as several radioactive metals, such as uranium, thorium, and radium. The most harmful component to personal health are the particles of coal dust, and next comes the toxic heavy metals which stay around forever both where they land and in the bottom ash that is retained at the bottom of the coal burner and is either used in such things as road building or is buried in landfill. Because bottom ash has not been named "toxic waste" by the EPA, the landfill need not be insulated from neighboring underground water supplies. This unconscionable assault on public health is a reflection of both the enormous political clout of the coal lobby and the necessary slavishness of self-serving political careerists (i.e., politicians) and their appointees.

Believe it or not, in addition to the toxic metals, a coal stack emits into the surrounding atmosphere more than 100 times more radioactive substances than does a nuclear plant. It turns out that the radioactivity is not the harmful part of coal emissions. Indeed the radioactive component not only does no harm, but, as we will see below, and contrary to conventional wisdom and governmental fiat, it actually helps mitigate the bad health effects of the other ingredients -- including the *chemical* toxicity of even the radioactive components (mainly uranium, thorium, and radium). **But if the anti-nuclear environmentalists -- who are terrified of radioactivity and try to terrify everyone else -- were to be consistent, or honest, they would expend their efforts in demonstrations to shut down all the coal plants, rather than attempting to prevent the construction of nuclear plants, as they have in fact done many times, unfortunately often successfully.**

Wood, coal, oil, and natural gas are all carbon-based substances, known as organic materials, along with other living or recently-dead plant and animal life. But coal, oil, and natural gas are the result of long-dead organic material that has accumulated underground as it decomposes. For that reason these three are referred to as fossil fuels. Because fossil fuels come from this long-dead organic matter they are neither renewable nor replaceable for very long. That is, once they are all used up, that will be the end of their supply. The first of these to approach exhaustion is oil, which is at or near its peak, while coal and natural gas supplies will last somewhat longer, as will nonconventional oil sources such as tar sands and shale oil. But their exhaustion will come as well -- that is if they continue to be used as fuels until that time.

But today, the most cataclysmic effect of coal and oil fumes, as well as natural gas fumes, is the currently accelerating global warming due to the greenhouse gases (GHGs) that fossil fuels emit continually. If it were not that these fossil fuels produce fantastic profits for very powerful capitalist interests, and if it were not that these interests currently rule the world, we would have stopped using fossils for fuel long ago. Instead of burning them away, we would be using the materials only to manufacture many useful things, including plastics, road materials, and lubricating oils, although the extraction and production processes would have to be made free of pollution and GHG production.

As already mentioned, the world is on the verge of reaching, and in many places has already reached, peak oil with respect to underground oil lakes. New technologies are being developed to extract less easily gotten forms of oil from the ground, namely tar sands and oil shales, in which the oil is trapped in the pores of solid and pulverized rocks. The exhaustion of easily extractable oil, under the operation of the capitalist market, causes it to increase in price, due to falling supply in the face of increasing demand. This price increase, in turn, makes less easily extractable forms increasingly profitable. Indeed these sources are being exploited in such places as northeast Alberta in western Canada, which is giving the oil industry a new lease on life, at least for an estimated few decades. A proposed underground 2000-mile pipeline to carry the oil all the way from Alberta to Texas Gulf refineries is being fought by environmentalists and the state of Nebraska. They are rightfully fearful that pipeline oil leaks can contaminate the largest underground fresh water supply in the U.S., the Ogallala Aquifer that underlies much of the central continental U.S. This vital aquifer -- as with virtually all lakes, rivers, and other underground fresh water supplies -- is drying up and/or receding even as we write, all due to global warming (Pearce). As it turns out, the newly proposed pipeline, the Keystone XL, will be the third such pipeline from Alberta to Texas, the other two of which have been in operation since 2010, one of which is already located over the Ogallala, known as the Keystone Phase 1.

Contributing to the recent profitability of tar sands and oil shales is the fact that the world's transportation is currently trapped in a cycle of dependency on oil due to the manipulations of both the oil companies and particularly the auto companies, thus guaranteeing continual high demand for oil. In the late 1800s horseless carriages were introduced to replace the horse-drawn carriage. At first they were mainly run on electricity, but since oil was discovered in Pennsylvania in 1859, which led to exploration in many other places in the world, the then falling price of oil made internal combustion engines (ICEs) much more profitable.

It should be pointed out that the source of electricity for the charging of vehicles was mainly, if not exclusively, coal, so that at that time the main "advantage" of electric vehicles was that, instead of spreading oil fumes wherever they went, particularly in the residential areas of those who could afford automobiles, coal fumes arose only in the vicinity of the electric power plants near where workers were forced to live.

Since a certain amount of coal energy was wasted, particularly during night hours when there was little demand for electricity, and since coal plants could be turned down to some degree but not turned off without the difficulty of restoring their output in the morning, charging electric vehicles at such times added little if any to net coal fumes. Of course, since electricity can now technically be created everywhere from non-fossil fuels, electric vehicles could completely eliminate such fumes, which would grant the greatest benefit to workers of all ethnicities. The overshadowing structural barrier to this conversion from fossil fuels is the profit system.

As ICEs became more profitable, electric vehicles were abandoned by Edison, Ford, and others in favor of these gasoline-burning cars. And to guarantee that people would become dependent on ICE vehicles for transportation, U.S. auto (GM and Mack Truck), oil (Standard Oil), and tire (Firestone) companies literally conspired, in the late 1930s and later, to buy up many of the urban/suburban electric rail systems in the U.S. through phony front companies, and actually dismantle them in favor first of GM ICE busses and later in favor of individually owned cars. This is not just a "conspiracy theory," which we always reject in the absence of confirming evidence. Rather in the late 1940s, under pressure from many urban politicians who suffered at the hands of voters because of the disappearance of clean trolley public transportation, the U.S. government actually brought the above named companies to court to break up their collusion, using the 1890 Sherman Antitrust Act. The upshot of this long and hard fought litigation was a decision against the companies and a series of fines leveled by a judge against both the companies and their main executives -- $5,000 per company, and $1 (!) per executive. The judge justified the small amounts on the grounds that the damage had already been done, so he didn't see the point of any higher fines, completely ignoring any possible deterrent effect on future swindles -- a favor that rarely if ever is applied to much less significant individual crimes (Black 2006, Doyle). What Bush and others have called our "addiction to oil," thereby spreading the blame to everyone, contains a grain of truth, but they neglect, of course, to mention that Big Auto and Big Oil have been, and continue to be, the pushers -- as surely as the drug cartels.

But what other forms of energy can replace fossil fuels? There are a number of energy sources that do not emit death-dealing fumes or pollute the atmosphere with GHGs that trap the heat and warm the planet. Or more precisely, they do not emit such fumes during operation, though the manufacturing, assembly, and transportation of the equipment needed to capture these energy sources may initially involve such emissions, and the ultimate disposal of the materials at the end of the equipment's life may involve chemically toxic or radioactive waste. **The latter problem, radioactive waste, as we will show, has been technically solved in a way that the disposal of permanently chemically toxic materials has not.**

Below we will examine the leading candidates for replacement of fossil fuels, recognizing that, regardless of their technical features, they will never significantly replace fossil fuels during the remainder of the reign of capitalism on earth because of the required destruction of massive amounts of fixed capital that would be required. And, as we have said, nothing short of the *complete* replacement of fossil fuels will permit solution of the problems of air pollution and global warming. Additionally, pollution of water and other necessary inputs of life are also critical assaults on our health and wellbeing, but we leave comment on these till farther below.

Again, there are two major uses of energy in today's world -- electricity and transportation -- with other uses in heating, cooking, and certain direct industrial and commercial processes. Electricity uses about 40% and transportation about 25% of total global energy -- with road transportation using almost 2/3 of that. Transportation could also be made to run on electricity (or direct nuclear power), but the technology at this stage is poorly developed to do so, with the notable exceptions of nuclear submarines and surface vessels and a few models of electric cars. So we will confine our analysis to the production of electricity.

II. Nuclear processes and nuclear reactors

A. General background

As we mentioned in the introduction above, the main alternative (to fossil fuels) sources of energy for human social use are wind, solar, biomass, hydroelectric, geothermal, and nuclear. First let's mainly discuss their similarities, and afterward their differences. Interestingly wind, solar, biomass, and hydroelectric, as well as fossil fuels, all trace their origins to the sun, while geothermal and nuclear trace their origins to the earth, below the surface. When the earth and solar system formed some 4-5 billion years ago, the majority of the material found itself plummeting toward the center under gravitational forces and formed the sun, with minor clumps of material collecting around separate centers and forming the planets, their moons, comets, and asteroids (small irregular chunks of material that probably represent the break-up of larger bodies). Since the dust out of which each of these bodies formed came from explosions of older stars in the form of supernovae, the content included mostly very light elements (atoms) but also many heavy elements, the heaviest of which are unstable, for reasons that we need not go into here. Unstable, in the case of atomic nuclei, is just another way of saying radioactive. We explain radioactivity below.

How is it that the first five energy sources above trace their origins to the sun? It is obvious that solar energy comes from the sun, but it requires some reflection to realize that localized wind energy also comes from the sun, when there is differential heating of portions of ground and ocean, causing updrafts of heated air and surrounding downdrafts that produce horizontal circulation of air, i.e., wind. Large scale winds that girdle the earth are partly a product of the earth's rotation, but small localized winds come from the sun's heating. Hydroelectric energy comes from dammed rivers that form lakes behind the dams. Rivers, in turn, come from rain or snow, which result from solar heating of the atmosphere and water sources, including oceans, lakes, snow pack, and glaciers, with consequent evaporation and later precipitation. The growth of biomass, the source of energy from the burning of vegetable matter, comes from the absorption of sunlight by plant life. And finally, fossil fuels are the leftovers of decayed animal and vegetable matter over many millennia and longer.

The other two sources mentioned above, geothermal and nuclear, come from the ground, both shallow and deep. Geothermal energy comes from tapping hot liquid magma, the stuff of volcanic eruptions. But from where does magma get its heat? When the earth formed 4.5 billion years ago, partly out of heavy radioactive elements, these remained within the substance of the earth, undergoing nuclear decay (radioactivity -- see next section). Natural radioactivity is the main thing that keeps the earth's mantle hot and partly liquid (magma). Magma, in turn, accounts for the floating of the tectonic plates within the earth's crust that allows continents and ocean floors to move very slowly over the surface of the earth, producing such common phenomena as earthquakes, mountains, and volcanoes. By transferring its heat to natural water, the magma also produces geysers and hot springs, as well as hot underground rocks. Each of these can also be tapped for heat energy. Virtually all this heat comes from nuclear reactions (radioactivity) below ground -- the rest, a minor component, comes from friction within the liquid magma due to the earth's rotation.

B. A physical explanation of nuclear processes

In the previous section we distinguished between the various energy sources that originate in the sun and those that originate within the earth. But, in fact, all energy on earth, whether it originates in the sun and other stars or in the ground, *ultimately* comes from nuclear processes, though some may take intermediate forms before becoming useful, such as chemical processes. Once again: ***All* energy on earth ultimately comes from *nuclear* processes**.

What are nuclear processes? There are basically three types of nuclear reactions -- called **fusion**, **fission**, and **decay** -- but all of them involve the small central core (the nucleus) of atoms, as opposed to the cloud of electrons that surrounds these cores, the latter being involved in, and defining, chemical processes. Nuclei are made up primarily of protons and neutrons, with a scattering of many other particles that are much smaller, and that show up briefly only under particular circumstances -- e.g., when nuclei are broken up by very fast collisions in experimental equipment like the Large Hadron Collider in Geneva, Switzerland, of *Angels and Demons* fame (novel and movie by Dan Brown). Neutrons and protons are both relatively heavy particles that differ little in their masses (roughly, mass can be thought of as weight for our purposes[2]), while electrons are very light particles having approximately

1/2000 the mass of either a proton or neutron. We will speak loosely of "heavy" and "light" to refer to either mass or weight.

All elements have more than one form that either occur in nature or can be produced in the laboratory, or both. These multiple forms of an element are called "isotopes" of each other, much as sisters and brothers are called siblings of each other. The various isotopes of any one element differ from each other only in the number of neutrons in the nucleus, though they have the same number of protons. Indeed it is the number of protons in the nucleus that identifies each element in the first place, and, by attracting to the nucleus the same number of electrons in the cloud around it, confers on the element its chemical properties. So, because they have different numbers of neutrons, different isotopes of the same element have different weights, called atomic weights, and they are designated by the element's name or symbol and the atomic weight -- for example, uranium-238 (or U-238, for short) and U-235 are the two isotopes of uranium that occur in nature, though others, such as U-233 can be created in the lab (in a reactor), as can Pu-239 for one isotope of plutonium. The thing that makes an element uranium is the presence of 92 protons in the nucleus, so U-238 must then have 146 neutrons, since 92 + 146 = 238, the atomic weight, and U-235 must have 143 neutrons (92 + 143 = 235).

Uranium, as it turns out, is the heaviest *naturally* occurring element on earth, because, while its existing natural isotopes are mildly unstable, they decay very slowly and have not yet disappeared from the 4.5 billion-year-old earth. Meanwhile all elements heavier than uranium, the so-called transuranics, are more unstable and decay more quickly, thus having disappeared in nature, though they can be recreated in the lab. [*It is worth mentioning here that a major scare tactic of such anti-nuclear crusaders as, e.g., Helen Caldicott -- a former pediatrician in Australia -- is to claim or imply that radioactive elements (discussed a few paragraphs below) are all human-made and therefore unnatural. For example, the one element that is most often recruited for such fearmongering, is plutonium, a byproduct of nuclear reactors. But plutonium has existed in nature in the past, and has simply decayed away faster than uranium, leaving only trace amounts in the ground. The plutonium produced in nuclear reactors still decays slowly enough that it is not very radioactive.*]

The first type of nuclear reaction is **fusion**, in which two nuclei become "glued" together to form a heavier nucleus, which may be followed by further fusing together of still more nuclei. Fusion requires a significant input of energy to overcome the mutual repulsion of nuclei, energy in the form of extremely high speed collisions, which means it cannot happen spontaneously under ordinary circumstances on earth and requires large human-made accelerators. The resulting combined nucleus is heavier than either constituent, but is slightly lighter than the sum of the two constituents. The "missing" mass of the combined nucleus is released in the form of energy, with a quantitative relationship according to what is arguably the most famous formula in physics: $E = mc^2$, where E is the amount of energy, m the amount of missing mass, and c the speed of light. [Don't ask; it just turns out that way both theoretically and experimentally and is beyond the scope of this essay, but suffice it to say that it is intimately related to the conclusion from special relativity theory that no chunk of matter can be accelerated to attain the speed of light without applying infinite force, because the faster something goes -- i.e., the greater its energy of motion (kinetic) -- the greater its mass becomes.]

All that we need to know is that when fusion takes place, energy is released, and a lot of it, though it requires lots of energy input to make it happen in the first place. However, for fusion of lighter elements the required input energy is less than the output. The hydrogen bomb is a fusion bomb, which has never yet been used in warfare, though it has been tested in the past by several countries, primarily the U.S. and Russia, by exploding it either mainly in the air or underground. Many of them are stored in underground silos all over the world, the vast majority of which are in the U.S. and Russia. Furthermore to make a hydrogen bomb explode requires such a tremendous amount of energy input, that it has to come from an attached fission bomb (next paragraph). Work in many laboratories continues on the development of fusion nuclear reactors to produce electricity, but as is often said only half facetiously, fusion for electricity is 20-40 years in the future, and always will be. Efforts over time will tell.

The second type of nuclear reaction is **fission**, in which a heavy nucleus splits in two -- the opposite of fusion. The two product nuclei generally have approximately equal masses, but usually not quite equal. Fission also requires an input of energy, such as bombardment with neutrons. This is usually done deliberately, but on rare occasions fission can occur spontaneously, i.e., without deliberate input. When fission occurs the two product nuclei have less mass together than the parent nucleus had before the split, and this is the source of energy from fission, similar to the missing mass in fusion. But when a heavy nucleus fissions it also releases a few neutrons. Under the right conditions the neutrons produced by one fission event can hit other heavy nuclei and cause a second fission event, and so on and on in a chain reaction.

This is a second type of chain reaction, similar to the chemical reaction of fire that we mentioned above, in which once you get the process started and conditions are just right, it will keep going on its own. The chain reaction in fire requires kindling and enough wood or other flammable material, while a fission chain reaction requires an initial source of neutrons and a sufficient amount of fissionable material (usually called fissile in the trade). Fissile material includes certain isotopes of uranium and plutonium, but there are many other fissile nuclei. They are all heavy elements, however.

Just as fire either can be controlled or can get out of hand, such as with wildfires in forests or buildings, so can fission be controlled or get out of hand, either accidentally in a reactor or deliberately in a fission ("atomic") bomb. The difference between conditions that govern controlled fission (reactors) from deliberately uncontrolled fission (bombs) is far greater than the difference between conditions that govern controlled and uncontrolled fires. We will say more about this below when we explain why nuclear power plants are almost completely unrelated to bombs, and can be made completely so by international inspections in today's world of inter-imperialist rivalries in which no capitalist ruling class can afford to completely trust any other.

To summarize so far, the lighter elements can undergo fusion to form heavier, and the much heavier can undergo fission to form lighter. Each type of reaction requires an initial energy input from some external source, but in each case the energy released is greater than the input energy -- generally much greater.

The third type of nuclear reaction is **decay**, in which an unstable nucleus releases one or more very small matter particles or an electromagnetic unit like light (called a photon), or both. Decay shares with fission the feature of separation, and it is contrasted with fusion's opposite feature of joining together. But decay is distinguished from both fusion and fission by being a completely spontaneous and individually unpredictable process, whereas the conditions necessary for fusion or fission to occur usually require human intervention on earth to provide a source of external energy -- though in the center of stars, like the sun, the temperature and pressure are sufficiently high that the frequency and force of collisions is enough to produce fusion without human intervention. On occasion fission can also occur spontaneously, but much more rarely than decay. Furthermore decay involves only the spitting out of a small particle that leaves the nucleus almost the same size, while fission splits it into two almost equal halves.

For decay to occur, no external energy input is required, which is why it can easily occur spontaneously. By the same token, the amount of energy released by decay is far less than in fusion or fission. Because of its spontaneous nature, decay was the first type of nuclear reaction to be recognized, in the late 1800s, and was called radioactivity -- "radio-" referring to the radiation of particles of matter or of photons. The radiation, depending in part on which element is involved, was thought, early in the 20th century, to consist of one of three types of particles, based on their pathways through magnetic fields -- i.e., whether the path bent to the right, to the left, or not at all. One type was found to have positive charge, one negative charge, and the third was found to be electrically neutral. Before they could be otherwise identified, they were first called alpha, beta, and gamma particles, respectively, after the first three letters of the Greek alphabet. It later turned out, under further experimentation and observation, that an alpha particle is a helium nucleus (2 protons plus 2 neutrons), a beta particle is an electron, and a gamma is a photon, the last consisting not of matter at all but rather pure electromagnetic energy. A collision by any one of these will activate an instrument called a Geiger counter and cause it to click -- the rate of clicks being a measure of the amount of radioactivity.

The rate at which any particular isotope tends to undergo decay is a fixed characteristic of that isotope and varies from one isotope to another -- from extremely fast to extremely slow. A simple, though not the only, way to characterize this rate is according to the time it takes for half of a collection of the particular isotope to decay, and is, logically enough, called the **half-life** of that isotope. For example, the half-life of U-238 is 4.5 billion years (very slow decay -- and coincidentally the age of the earth and solar system) and of U-235 is 700 million years (still very slow), while the half-life of N-16 (nitrogen) is only about 7 seconds (fast), with many isotopes having half-lives only very tiny fractions of a second (very fast) and others having many values in between. A completely stable isotope, such as He-4 (helium), can be viewed as having an infinite half-life, and there are many, many such stable isotopes. Just to complete the point, the concept of half-life, which is a particular characteristic of each type of isotope, applies only to the spontaneous (independent of external circumstances) process of radioactive decay but does not apply to either fusion or fission, since their occurrence depends on circumstances external to the particular nucleus and therefore cannot be characteristic of the nucleus alone.

C. A brief explanation of how nuclear reactors work

All nuclear reactors, at least today, are fission devices, in which a controlled fission chain reaction takes place, involving the splitting, by collisions with neutrons, of fuel atoms into two smaller atoms of approximately equal weight, accompanied by the release of a small number of additional neutrons at high speeds. Without going into the large number of different reactor designs, the 104 U.S. commercial reactors work as follows: There is 1) a core made of multiple parallel, usually vertical, rods containing fuel (in the U.S. today the fuel is uranium), 2) a cooling substance (water) that circulates around the fuel rods and that both carries away from the fuel the heat produced during the fission reactions and, through collisions, slows the neutrons down, 3) in some a second heat exchanger where the now hot water gives up its heat to another closed circuit of water turning it to steam to turn 4) a turbine that generates electricity, and 5) another cooling substance to re-condense the steam into water to go back and pick up more heat again, over and over. This last cooling substance is generally water from a river, ocean, lake, or pond, which can be put back into its source, or the steam can be cooled by air which is ejected up a cooling tower gathering moisture in the form of clouds of water vapor. This final cooling stage is the same in a coal plant. In each case the heat in the last stage represents more than half the energy generated by the internal process, leaving roughly 30-40% for electricity. But regardless of the energy source, this heat could be captured and used for intentional heating rather than being wasted, a process known as combined heat and power (CHP).

The essential function of a nuclear reactor, like a coal or natural gas plant, is the production of heat. In a nuclear power plant the heat is generated by the fissioning, and is transmitted in steps to end up by forming steam, whose pressure drives an electric turbine that produces the electricity -- thus nuclear energy into heat into steam into electricity. The core fuel in the U.S. and most other countries is primarily uranium, and it comes in two forms in nature -- the first is U-238, which constitutes about 99.3% of all uranium found on earth, and the second U-235, which makes up the other 0.7%, i.e., only about 1/150 of the total uranium. As explained above, the numbers after the symbol U for uranium (i.e., 238 and 235) indicate the atomic weights of the two isotopes.

The key difference between a nuclear reactor and a nuclear bomb is that in a reactor the chain reaction is controlled and takes place over decades or longer, while in a bomb the chain reaction is out of control once started and takes place in split seconds with tremendous amounts of energy released all at once -- i.e., an explosion, which is the whole deadly point of the weapon. In order for the chain reaction to start, two things are required: First, some neutrons must be made available to collide with some of the U-235 atoms and cause them to fission (U-238 does not fission easily), with further neutrons released during the fissioning to keep the reaction going. Second, there must be a sufficient amount and concentration of U-235, without too many other atoms getting in the way, so that the released neutrons can find other U-235 atoms to keep the chain reaction going. This sufficient mass and concentration is called a “critical mass,” though it might more correctly be called a “critical mass/concentration.” The most important point here is that if there is less than a critical mass or concentration, the reaction will fizzle. It cannot possibly be kept going. It’s as though a fire were started with one piece of kindling, but there were no other wood around to keep it going.

Since there is a critical mass and concentration in a reactor in order to start and maintain a chain reaction, there must be a method of keeping it controlled. This involves, among other things, so-called control rods that are made of a neutron-absorbing material and that can be inserted to varying depths into the fuel-containing core, to keep a certain portion of the neutrons from colliding with more U-235 atoms and causing further fission. There is a balance between the need to allow some fissioning and the need to prevent it from getting out of hand. But all modern reactors are so designed that if it begins to get out of hand and the fuel begins to overheat, the reaction will automatically shut down, even without any human intervention. This automatic shutdown is what happened even in the 40-year-old reactors in Fukushima, Japan, in March 2011, and at Three Mile Island near Harrisburg, PA, in 1979, but did not happen at Chernobyl, Ukraine, in 1986, because of its particular design -- one that is no longer being built anywhere in the world. Chernobyl had a combination of materials and design that permitted an acceleration, rather than a deceleration, of any initial tendency to overheat. In addition, rather than being solely a commercial reactor for generating electricity, it was intended mainly to produce plutonium for weapons.

Since U-238, for reasons that we don’t need to go into, is not fissile (will not fission easily), and since it constitutes over 99% of natural uranium, randomly mixed in with the fissile U-235, natural uranium in U.S. reactors requires some so-called enrichment in the concentration of U-235 before it can be used as fuel in the reactors. The enrichment process is simply the removal of enough of the U-238 so that the concentration of U-235 will be great enough to sustain the chain reaction. In other words, enrichment means getting much of the non-fissile U-238 out of the way of the fissile U-235, so that U-235 nuclei can communicate with each other. This can be accomplished in a few ways, one common way being through the use of a centrifuge in which the spinning causes more of the slightly heavier U-238 to move to the outside, leaving more of the slightly lighter U-235 toward the center, permitting their partial separation. The removed U-238, which will inevitably take a certain small amount of U-235 with it, is called “depleted uranium,” or DU as its known in military and technical circles -- depleted, that is, in the naturally occurring relative amount of U-235.

DU then is mainly U-238 with only a little U-235 impurity, less than the 0.7% concentration found in nature. DU is used to make bullets because, being the heaviest naturally occurring element, uranium bullets are capable of penetrating armor. Holding one in your hand will startle you at how heavy it is for its size, heavier even than lead. DU bullets are very weakly radioactive, but their death-dealing characteristics come from the impact rather than from the radioactivity. Only breathing in dust spiked with DU can cause health problems if enough is inhaled over a long enough time, but holding a bullet in your hand does you no damage at all. The reason that DU held in the hand does no damage is that the radiation from the decay is mainly in the form of alpha particles, and they are so heavy that they cannot penetrate your skin and only travel a few inches in air. Neither can U-235 held in the hand do you any damage.

But DU is also very useful in a type of specially designed reactor, called a breeder reactor, since it can be made to produce plutonium, in particular Pu-239, when the U-238 is bombarded with neutrons. Pu-239 is fissile like U-235, and it can therefore also be used as fuel. Furthermore when both U-235 and Pu-239 fission they release more neutrons that go on to breed (out of the U-238) more Pu-239 than is consumed. Clearly if all the non-fissile DU (mainly U-238) could be converted to Pu-239 fissile fuel, all the energy in uranium, both in U-235 and in U-238, could be captured and turned into electricity. Because of its convertibility to a fissile material, U-238 is called fertile rather than fissile. But in the type of reactors used in the U.S. and in most countries in the world (called “thermal” reactors for reasons explained presently), the energy in the U-235 provides the major portion of the total energy produced, with the energy in the U-238 tapped to a slightly lesser degree, through the formation of some fissile Pu-239. In fact, U-238 constitutes the main component of nuclear “waste,” but it only becomes waste if it is wasted, rather than recycled into a breeder reactor and consumed in the chain reaction to produce further electrical energy. It is as though a 15-inch-long wood log were to be removed from the fireplace after only 1/10 of an inch had been burned, with the rest buried. Furthermore the U-238 component (the vast majority) of the nuclear “waste” from U.S. reactors is harmless, even if buried. After all, it is a naturally occurring isotope that comes from the ground in the first place, and we will say more about natural background radiation below.

There are two minor components of spent fuel from a thermal reactor, the first called the “actinides,” named after the element actinium, which is slightly lighter than uranium, meaning all those elements heavier than, but including, actinium (as well as uranium). These are also consumed in a breeder reactor, through recycling of the fuel, and their fission produces further electricity. The rest of the minor component of spent fuel from a thermal reactor is comprised of the much lighter fission products -- each element of which is about half the weight of uranium -- and these do indeed have to be buried, though there may be experimental or medical uses for at least some of the fission products. The actinides, if not consumed in a breeder reactor, have long half-lives for the most part, on the order of centuries to billions of years, while the fission products generally have much shorter half-lives, on the order of seconds to decades. The longer the half-life the lower the radioactivity, and the shorter the half-life the greater the radioactivity. Therefore it is the relatively light fission products that constitute the main source of radiation in spent fuel, but precisely because of the shorter half-lives, their radioactivity decays away in much shorter times -- a century or two rather than the hundreds of thousands or millions of years claimed (ignorantly or dishonestly) by the anti-nuclear forces. The issues surrounding burial of spent fuel, or nuclear waste, are covered below.

Coolants can be made of various liquid or gas materials, so long as they can circulate within the core among the fuel rods and absorb the heat generated by the fission reactions. Normal water is the most common coolant today, but helium gas, argon gas, and liquid metals, such as sodium, are also used in different reactors -- the latter in breeder reactors. In most cases, though not at Chernobyl for one example, the coolant also acts as what is called a “moderator,” to moderate or control the average speeds of the neutrons that are released and that cause the next round of fissioning. Neutrons are emitted in all directions, bouncing off atomic nuclei in the surrounding materials (including the fuel itself), though when they are first emitted they travel at much higher speeds than the average speeds of atoms in the surrounding materials. When a neutron collides with something about the same weight, such as a hydrogen nucleus (a proton) in water -- which consists of H_2O molecules (meaning two atoms of hydrogen and one of oxygen) -- it generally slows down considerably, just as a pool ball can even come to a complete stop when it hits another ball of the same weight. These are then called “thermal” neutrons, since their speeds are slowed down until their kinetic energy is about that of the average kinetic energy of all the materials in the core, i.e., until they are in thermal equilibrium, and their motions are then part of the heat (thermal refers to heat). The reactors with such moderators are called, logically, “thermal” reactors.

On the other hand, when a neutron collides with a nucleus in a moderator that is made of much heavier atoms, such as liquid sodium that is 23 times heavier than a neutron, the sodium hardly feels it and the neutron goes bouncing off with approximately the same fast speed it had when it hit. These are called, again logically, “fast” neutrons, which gives rise to the often used term, “fast breeder” reactors.

As it happens, while both thermal and fast neutrons will convert U-238 to Pu-239 and other actinides, fast neutrons cause a greater proportion of actinides to fission than do thermal neutrons. Furthermore when Pu-239 (or for that matter, U-235) fissions due to fast neutrons, it produces more secondary neutrons than when that fission is produced by thermal neutrons, enough indeed to produce still more Pu-239 than is consumed in the fission process. Therefore reactors that use fast neutrons will continue to produce Pu-239 out of the U-238 as long as the fuel is reprocessed periodically to remove the fission products and fed back into the reactor, and as long as the U-238 lasts.

All of the U.S.’s 104 commercial reactors are thermal reactors. They are also called “light water” reactors (LWRs), because the water used as both the coolant and the moderator is normal water with regular hydrogen, consisting of just one proton. It is the lightest form of hydrogen. There are also two other forms (isotopes) of hydrogen that can occur in combination with oxygen to form water, and these are deuterium, with one proton and one neutron, and tritium, with one proton and two neutrons. They are all forms of hydrogen, since they all have one proton, but have atomic weights of 1, 2, and 3, respectively. Tritium is radioactive, with a half-life of about 12 years, but it is also by far the rarest isotope of hydrogen and is generally so dilute in water as to cause no harm at all -- even when produced in minor amounts in a reactor. [3]

Sometimes water made of deuterium, rather than of regular hydrogen, is used as the coolant and moderator. This is called “heavy” water, as opposed to the “light” water (made of regular hydrogen) that is used in U.S. reactors and most other reactors in the world today. Heavy water is used in a few countries, particularly in Canadian reactors, which are cleverly called CANDU reactors, for CANadian Deuterium Uranium. They provide about 15% of Canada’s electricity. The advantage of using heavy water as the coolant and moderator is that it slows neutrons down to thermal speeds *without absorbing as many of them as light water absorbs*, and therefore it can be used with *natural* uranium as fuel without requiring the time-consuming and expensive fuel enrichment that U.S. reactors need. That is, the greater number of neutrons returned to the fuel after collisions with heavy water permit use of a smaller concentration of the fissile U-235 that is found in natural uranium -- 0.7% found in nature versus the enriched 3-5% in light water reactors.

III. Comparison of the various sources of energy

A. General background

The source of energy that we receive from the sun, in the form of light and other portions of the electromagnetic spectrum, is nuclear **fusion** -- in which four hydrogen nuclei, through a series of steps, end up fused into a helium nucleus, with two of the four protons turned into neutrons. It takes place in the center of the sun, where the pressure and temperature are sufficiently high to produce frequent and extremely high-speed collisions between what mainly consists of hydrogen nuclei. The dust between stars and galaxies is also predominantly hydrogen, the lightest possible element. In other words, the center of the sun, at temperatures of about 25 million degrees Fahrenheit, is a place where there is sufficient energy input to permit fusion to take place. The hydrogen nucleus consists of one proton, and helium of two protons and two neutrons. When protons and neutrons become glued together to form helium, the tremendous amount of energy it releases flows out of the sun through its many layers and in all directions into outer space in the form of electromagnetic radiation (including light), a small portion of which hits the earth -- in the form of sunlight and other parts of the electromagnetic spectrum. And above we have mentioned the various energy forms that derive from sunlight -- solar, wind, and hydroelectric.

It will be useful, in comparing the various energy sources, to do so according to the following criteria, some of which will take far less discussion than others:

i) cost,
ii) safety,

iii) susceptibility to terrorist attack,
iv) continual round-the-clock reliability,
v) abundance,
vi) locations,
vii) concentration, and
viii) cleanliness

However, in trying to separate these out entirely and take them one at a time, we discovered that the cross referencing needed to clarify each point is sufficiently entangled as to make this a confusing approach, and confusion is the enemy of clarity. So we will be weaving them together as needed. We list them here so that you can refer back to them.

A note about the difficulties in doing this research

In researching all these aspects of energy, we find that there are many studies and authors who are supported on one or another point by many other independent studies and authors, as well as by the mathematics. We judge them to be correct by virtue of their having included all apparent necessary aspects without cherry picking, i.e., without omitting important issues, and being willing and able to multiply and divide. On the other hand, it doesn't take long to find that those who may be correct on one aspect are completely wrong on other aspects, again using the criteria of independent support, valid mathematics, and the absence of cherry picking. For example, there are those whom we judge to be correct on the relative feasibility of the different energy sources but who are denialists when it comes to global warming and/or the role that human activity plays in causing it.

Similarly there are those whom we judge to be correct on global warming but dead wrong when it comes to nuclear energy. These include some environmentalists who are correct about the need for clean, non-GHG-producing energy, but so fearful of nuclear energy as to be worse than useless, and who end up touting one or another unreliable, instead of nuclear energy. Each study has to be evaluated on its own merits, and no author's word can be accepted uncritically on anything without independent checking -- which we have tried to do on every aspect. This, of course, doesn't necessarily mean that we are correct on every point, but we are certainly open to being shown where we have erred. Indeed in working together collectively on this research each of us often found ourselves filling in a gap in the other's knowledge or understanding, and while two heads are certainly better than one, more than two are even better. We vigorously encourage further study and informed discussion about these vital issues.

The first aspect, cost, is not only relevant with respect to the relative likelihoods of each of these alternative energy sources being called upon during the last portions of capitalism's reign on earth, but it is one of the revealing arenas in which competing business interests weave their distortions. Such distortions usually stem from self-interested bias, including downright dishonesty, but are even still more often transmitted by people and organizations -- journalists, scientists, engineers, lay persons, environmental organizations, politicians, and business organizations -- who often have not investigated them in enough depth to be aware of the untruths they may be spreading. **Various organizations, both governmental and nongovernmental and in various countries, provide very complex cost calculations that depend on so many hidden assumptions that they shed more darkness than light on the comparisons, but nuclear energy can be one of the cheapest to produce if done in the most efficient way.**

The building of a nuclear power plant can cost about $2,000 to $10,000 per kilowatt (thousand watts, abbreviated as kW) of electricity, often expressed as $2 to $10 per watt, but that depends on who is building them and where. Quantitative comparisons should always begin by relating costs to some common quantity of electrical power. The kW is such a quantity and one that most people are familiar with, since the monthly electric bill is usually based on the price of a kW of power used for an hour, or a kW-hour (kWh). Everyone is familiar with watts, if only through their connection with the ratings of light bulbs, such as 60W or 100W bulbs. (You might want to refer to footnote 1 again, at the end.) Sometimes it will make for more manageable numbers to use megawatts (MW) or gigawatts (GW) -- millions or billions of watts, respectively.

The next major cost-related quantity over the lifetime of the equipment is precisely the span of that lifetime. The longer a plant can be operable without wearing out and having to be decommissioned or replaced, at least in part, the less the cost of initial construction contributes to the cost of energy (as opposed to power – see footnote 1). This is because the initial cost is fixed, while the energy continues to be produced over the lifetime of the equipment, and the longer that production, the less the contribution from the initial cost to each unit of energy. Wind and solar gathering equipment has a projected lifetime of approximately 25 years, while a nuclear power plant has a projected lifetime of anywhere from 60 to 100 years. Both may, of course, be increased as experience leads to improvements, but at least at this point in time, nuclear becomes very much cheaper by that longevity difference alone.

A typical coal or nuclear plant produces on the order of one GW of electrical power, more or less. Solar or wind farms produce a couple of orders of magnitude less, i.e., 10 to 100 times less. Wind and solar farms cost on the order of $2,000 to $4,000 per kW to build -- calculated assuming the wind is blowing and the sun is shining. This means that they cost even more per kW when their erratic output is taken into account -- by a factor of anywhere from 4 to 7 times as much. Figures vary depending on the source, but the main point is that nuclear is not initially more expensive than solar or wind. It is initially more expensive than a new coal plant, according to most estimates, but it is much cheaper to run, primarily because the amount of fuel required is so much less (about which more below). It would also be much less expensive if breeder reactors were to be employed, now that we have several decades worth of stored nuclear "waste" that they could use as fuel. Therefore over time nuclear naturally becomes progressively cheaper than coal, which is currently one of the cheapest but also the most harmful, to public health and the planet.

The usual aspect that favors solar and wind -- the two favorite "renewables" of environmentalists -- is that these "fuels" are completely free, whereas nuclear *initially* requires the mining of uranium or thorium. What solar and wind advocates often overlook is that it is not the fuel that matters so much as the equipment necessary to capture the energy and convert it into electricity and in some cases to store it for future use, as well as the equipment needed to send it to homes and buildings all over the countryside. Thus solar and wind energy are anything but free in the sense of monetary cost, though they, like nuclear and hydro -- and possibly geothermal (though with the latter, tapping the underground source of heat may also release GHGs) -- have the definite virtue of being free of GHGs, at least during operation. All these cleaner fuels require initial plant construction and transportation of equipment, and those processes do generate GHGs as long as cement remains as it is currently constituted and as long as transportation depends on oil. Cement manufacture, as it is done now, produces about 5% of the total CO_2 emissions in the world, and CO_2 is the main GHG. However, there is already research underway to discover cleaner replacements for standard cement.

Because of the way nuclear reactors are presently designed in the U.S. and for the most part in every country, about 99% of the uranium fuel's energy is completely wasted and held in storage, though it is not too late to recover and use it in breeder reactors for reasons that we will see. As pointed out above, in breeder reactors over 99% of the energy in uranium can be used, which means that, given over 40 years worth of buildup of spent nuclear fuel, the fuel for nuclear reactors is also free for a couple of centuries, at least in the U.S., requiring only transportation to where it is needed. Another virtually free source of nuclear fuel comes from decommissioned nuclear weapons, thousands of which, purchased from Russia and gathered from the U.S. stockpile, are already fueling many nuclear power plants in at least the U.S. In fact, decommissioned nuclear bombs now provide about half of U.S. nuclear energy fuel. **Those who argue against nuclear energy, often because of a false link between it and nuclear weapons, are also unwittingly, and ironically, arguing against the currently best way to destroy weapon-grade uranium and plutonium.**

We will have nothing more to say about monetary cost, since it is the least important of the various criteria, other than to mention that the main thing that makes nuclear energy appear to be more expensive is that environmental groups have held countless local demonstrations against projected nuclear power plants and forced power companies into long drawn-out court proceedings that have delayed, and in some cases prevented, their construction. This drives up costs of borrowing capital -- since interest payments on the borrowed capital continue, possibly for years, during long drawn-out litigation even before the cornerstone is laid -- and drives up the risks to power companies of even beginning such projects. **Thus the very same people who often point to the excessive expense of nuclear energy are the ones who make it more expensive, through their ignorant and self-defeating actions.**

However, while cost is not a good argument when comparing nuclear to wind and solar, it is very relevant in terms of the obstacles of moving from still cheaper natural gas power plants. This is because capitalism focuses on price and cost, rather than on the needs of the public. The cost argument only adds to the reasons cited above that make it all but impossible to eliminate fossil fuels so long as we allow capitalism to persist on the historical stage.

In comparing solar, wind, hydro, geothermal, and nuclear with respect to safety or any other criterion, it is important, as we implied above, to include everything that is necessary to their production. This means taking into account the production and construction of the equipment needed to turn the energy into electricity, the equipment needed to distribute it, as well as the fuel itself -- and of equal importance in the calculation, the disposal of the equipment once it has reached the end of its useful lifetime and requires decommissioning, as well as the length of that lifetime. It also means taking into account the disposal of used fuel residues where relevant. Omissions of one or another of these, as well as exaggerations, are often a prominent part of the pronouncements by authors wedded to one or another "renewable" energy source. That we have our own preferred source in nuclear energy we make no attempt to hide, as our title indicates. But we have attempted to be as objective as possible in omitting no relevant details and by avoiding exaggeration or the manufacture of purely imaginary problems.

B. Comparative safety of the various sources of energy

We will show that far from being extremely dangerous to both plant workers and the "public" (i.e., anyone who does not work in the nuclear power plants), nuclear energy has by far the most impressive safety record, for the last 60 years, of all energy sources (see table below). In fact, not one single death or injury to the public has resulted from a *commercial* nuclear reactor anywhere in the world in over half a century of operation. The fatalities listed in the table for the non-OECD states include those from Chernobyl (OECD = Organisation for Economic Cooperation and Development, consists of 34 nations, but excludes China, India, Russia and the rest of the former Soviet Union, among most others). We will discuss Chernobyl more fully below, but, as mentioned above, it was not purely a commercial reactor. Rather it was used to generate plutonium for nuclear weapons, and the number of deaths that resulted from the accident has been outrageously exaggerated by anti-nuclear forces for a variety of reasons -- exaggerated by anywhere from a hundred to ten thousand times.

Summary of severe (i.e., more than 5 fatalities) accidents in energy chains for electricity 1969-2000

	OECD		**Non-OECD**	
Energy chain	**Fatalities**	**Fatalities/TWy**	**Fatalities**	**Fatalities/TWy**
Coal	2259	157	18,000	597
Oil	3713	132	16,500	897
Natural gas	1043	85	1000	111
Hydro	14	3	30,000	10,285
Nuclear	0	0	31	48

The third and fifth columns express the numbers of deaths in terms of the energy generated by the various sources, in terms of terawatt-years, where a terawatt is a trillion watts.
(Data from Paul Scherrer Institut, in OECD 2010.)

Note that in the table the three fossil fuel sources account for the overwhelming majority of fatalities, at least in the OECD nations, and that nuclear accounts for none, over the 32-year interval for which the data are available. And these figures only deal with accidents rather than the daily operation of the power plants, from which fossil fuels kill millions every year and, again, nuclear none. And in the non-OECD countries, without Chernobyl there would be no fatalities from nuclear, but even with that accident, the number of nuclear fatalities is far less than for fossil fuels. Furthermore in the non-OECD countries hydro has killed tens of thousands from bursting dams in that 32-year interval alone. Yet the fearmongering by the anti-nuclear forces is all concentrated on nuclear, the energy source that is the safest by far.

There have been a few injuries and deaths among reactor workers from military or experimental reactors, but not from a commercial reactor, and none among the public. In part that is because there is more experience with nuclear than with most other energy sources, with the notable exceptions of hydro, but even with all the hydro experience bursting dams have drowned tens to hundreds of thousands of people over the decades. The nuclear experience has been gained mostly over the last 40 years or so around the world, where there are about 430 nuclear power reactors in operation at any one time, with 104 of these in the U.S., gathered into 65 nuclear power plants -- each with one, two, or three reactors -- located in 31 states, providing anywhere from none to almost 90% of the state's electricity, and largely located in the states east of the Mississippi. While, partly because of its size, the U.S. produces more nuclear power than any other country in the world, it only uses nuclear for about 20% of its electricity. Whereas the country with the highest percentage of nuclear in its electricity production is France, at around 80%. We round these figures off slightly for ease in remembering. Other countries use nuclear for up to 30% of their electricity, though the approximate overall percentage for the world as a whole is about 15%.

Mining

There have also been a number of deaths among uranium miners, due primarily to smoking. There has never been any proof that this results from the radon gas alone that seeps into the air not only in uranium mines but everywhere on the surface of the earth. In fact, radon accounts for more than half of the natural background radiation to which everyone in the world is exposed, and studies have shown no higher rates of cancer among inhabitants of land surrounding uranium mines or in families of the miners (Boice). Thus it would appear that the increased deaths among the miners are due to their smoking rather than to the radon, though the combination may worsen the chances of cancer, since the particles of smoke remain in the lungs a long time and can adhere to radioactive atoms, trapping them there. It would not be radon atoms, however, since radon is an inert gas that is exhaled as quickly as it is inhaled and will not adhere to particles. Its main decay product, polonium, on the other hand, may adhere to smoke particles and is indeed a well-known component of all tobacco smoke even when not associated with mining. It comes from the natural deposits in the ground where tobacco crops are grown. That there may be an interaction between smoking and radon/polonium is suggested by the fact that ever since the mines have been better ventilated, beginning in the 1980s, the rate of death among uranium miners has decreased. On the other hand, this could also possibly be related to venting secondhand smoke (a known carcinogen) rather than radon and/or its decay product. So, as far as we know, the question of an interaction between smoking and radon's decay product is perhaps still unsettled.

A comparison of deaths due to mining *accidents* among uranium miners with those among coal miners was described in a book by physicist Petr Beckmann in 1976, called *The Health Hazards of Not Going Nuclear.*[4] In it he showed that there were almost 100 times as many deaths from mine accidents among coal miners as among uranium miners, *for the same amount of recoverable energy contained in the ore*. In the last third of a century since the book was written there have been some improvements in safety, at least in the U.S., in both coal and uranium mining. But these improvements have not been enough to prevent a certain amount of ongoing murder, especially by coal mine owners, who refuse to correct hazardous conditions in favor of protecting their profits. Nevertheless the comparison is revealing, particularly insofar as the ratio is not a mere 2 or 3 times, but rather two orders of magnitude, i.e., almost 100 times. Furthermore at that time there were about 40 times as many coal miners with black lung disease as uranium miners with lung cancer, and black lung also kills. These are the dangers to workers who mine the fuels.

Beckmann also calculated the ratio of deaths due to transporting each fuel from mine to power plant, and found the ratio to be even higher than 100 to 1, but all of these ratios are mainly due to the far greater concentration of energy in a pound of uranium than in a pound of coal -- almost 3 million times as much in uranium. Besides the relatively safer work in mining uranium than in coal due to this tremendously different energy concentration, there are other advantages in the far higher concentration of nuclear energy in uranium versus chemical energy in coal. Expense of fuel is definitely one of these, but others include amount of land needed for mining, amount of land needed for plants, frequency of feeding fuel to the plants, and amount of transportation needed to get from mine to plant, which has its own hazards that are roughly proportional to the miles traveled for each mode of transportation.

France's peculiar position as the country with the highest percentage of electricity from nuclear dates back to the 1973 oil embargo by OPEC (Oil Producing and Exporting Countries), an alliance of countries in the Middle East, Africa, Latin America, and Asia that sit on huge quantities of oil. The French government realized that they had "no coal, no oil," and, as they put it, "no choice" but to rely on nuclear. They have 59 reactors in operation at the present time, about half the number in the U.S. In order to clear the way for this massive construction project, the French government had to educate the public away from its fear of nuclear energy and from the counter-propagandizing anti-nuclear environmental organizations, just as exist in other countries. But because of the extreme felt need for energy independence, they accomplished this goal. Necessity is the parent of many a problem conquered and could also be accomplished in any other country in the world whose ruling class decided on such a course. As a result the French public has accepted the existence of its nuclear electricity, though interestingly there are still objections to storing spent fuel in or near certain French towns by the town's inhabitants – a phenomenon well known in the U.S. as NIMBY, which stands for not in my back yard. Furthermore, according to surveys taken since the March 2011 tsunami that damaged the Fukushima Dai-ichi nuclear reactors in Japan, a majority of the French public has come to oppose the building of *new* nuclear plants. As in France prior to the Fukushima events, surveys in the U.S. over the last few decades have yielded a majority public acceptance of expanding nuclear energy, of around 70%, which becomes the greatest in those geographical areas that already have had long-standing nuclear reactors in operation, of around 90% (Herbst and Hopley).

There are four aspects of nuclear energy that typically are the focus for fear: 1) that a reactor could overheat and suffer a meltdown that could, it is feared, scatter radioactive material into the air and into water supplies, 2) closely related, that a reactor could undergo a nuclear explosion, 3) also closely related, that there is a link between nuclear energy and nuclear weapons, and 4) that nuclear waste is dangerous and impossible to dispose of safely. Taking them one at a time, some reactors under certain circumstances have indeed seen a meltdown, in which the fuel becomes so hot, due to leakage of coolant, that it turns into liquid metal and flows to the bottom of the reactor. Such events have happened at Three Mile Island (TMI) near Harrisburg, PA, in 1979, and at Fukushima, Japan, in March 2011, but in no case has the melted fuel, despite megatons of anti-nuclear propaganda to the contrary, hurt anyone, including at Fukushima. At TMI there was no detectable escape of radioactive material other than some inert substances like xenon gas that do not interact significantly with plants or animals, though there was, and continues to be as of this writing, escape of radioactive material at Fukushima, including cesium and iodine.

But remember that we exist in a sea of radiation from natural sources in outer space and the ground. The doses of radiation at Fukushima are rapidly decreasing and within a couple of months already approximated the average natural background doses in Japan, with the possible exception of a few small relative hot spots that can easily be cordoned off. The radiation has not been found in sufficient quantities to be hazardous to the public outside the plant (see the report from the Canadian Nuclear Safety Commission, an agency of the Canadian Government, describing the radiation levels around Fukushima, though the report takes no position on the danger or safety of these levels -- http://www.nuclearsafety.gc.ca/pubs_catalogue/uploads/October-2011-CNSC-Fukushima-Task-Force-Report_e.pdf).

Indeed there are places in the world where the natural background radiation exceeds that in any of the areas surrounding Fukushima, and people have lived there for generations without elevated rates of cancer, and, as we show below, even significantly lowered rates. Interestingly this includes Misasa, across from Fukushima on the west coast of Japan's main island, Honshu, where natural radioactivity produces hot springs that people use for their health (see http://onlinelibrary.wiley.com/doi/10.1111/j.1349-7006.1992.tb02342.x/pdf -- more on this phenomenon below). Inside the plant itself, as at TMI, the levels of radiation have often been higher than are safe, but the hazard depends entirely on the length of time spent in its vicinity and the distance from the source, and the Fukushima workers have been rotated so as to avoid prolonged exposures. Yet outside the plant the amount of radiation is of little consequence, just as we have evolved to defend ourselves against natural background radiation wherever it occurs in adequate amounts. The section below on hormesis goes into this perhaps surprising statement in much more detail.

Explosions

As to the possibility of a nuclear explosion, we have explained above, and explain more below, why this is not possible in any modern nuclear reactor. While there was a runaway chain reaction at Chernobyl in a portion of the reactor core that caused uncontrolled overheating, the reactor was designed for the purpose of generating plutonium for nuclear weapons. That design was used nowhere else in the world even then. It guaranteed that when the circulation of the cooling water decreased (as it did in a poorly thought out experiment that day, performed in the absence of nuclear engineers who understood the workings of the reactor), rather than the reactor's shutting down (as all other designs will do, and have done) the chain reaction sped up, created still more heat, and set the graphite moderator on fire, which then burned like coal, and caused a *chemical* explosion. This reactor design permitted an amplifying feedback event, rather than the countering feedback inherent in all reactor designs in current use everywhere in the world outside of Russia. The chain reaction finally ceased when enough of the fuel melted. But by this time the fire was out of control, and it burned for 10 days before the firemen could bring it under control.

Everywhere that there have been accidents at nuclear power plants, including Chernobyl as well as Fukushima, the precipitating event has involved the coolant and *any explosions have been chemical rather than nuclear*. Chernobyl, as we have said, was designed not primarily as a commercial electricity-producing plant, but as a manufacturing center of plutonium for nuclear weapons for the Soviet Union. There is no newer reactor in today's world designed like Chernobyl, which, in addition to the graphite moderator, had no containment building. Such a design, as opposed to every reactor in the world today outside of Russia, permitted an overheated core to *increase* its activity rather than to *decrease* it and *automatically shut down*. While there are some eleven remaining similar reactors in Russia today, now all with at least partial containment structures, there has been political pressure to shut these down. The newer Russian reactors are now failsafe against such runaway chain reactions. But even at that, the moderately slow runaway chain reaction at Chernobyl was nothing like a split-second nuclear bomb explosion, as in Hiroshima and Nagasaki.

Chernobyl has been the whipping boy of the anti-nuclear forces. But when the event is examined openly and honestly, rather than being used in irresponsible ways to push an anti-nuclear program, the lessons of Chernobyl prove to be extremely valuable, and have been taken to heart by every nuclear reactor manufacturer and ruling class around the world ever since. No new reactor in Russia or the Ukraine is any longer designed so that the reaction accelerates when coolant is lost, nor were any commercial reactors ever so designed outside the former Soviet Union. Furthermore this is likely due, in part, to the fact that Russia and the U.S. are in the process of dismantling nuclear bombs and using the uranium and plutonium in them for reactor fuel to generate electricity. The fission reactions in every one of the world's current 430 or so commercial reactors -- save for the remaining eleven older Russian graphite-moderated reactors -- will decelerate and shut down under those conditions. The secondary problem, well known to nuclear engineers and physicists but clearly revealed to the entire world by the events at Fukushima, is to keep the cooling process going in the event of a reactor shutdown so that the ongoing heat-producing radioactive decays of the fission products will not overheat and melt the fuel. The most recent reactor designs have inherent failsafe mechanisms with regard to this problem as well, in which gravity is the mechanism of circulation rather than an electric pump, the very things that failed at Fukushima due to flooding by the tsunami. (See http://ap1000.westinghousenuclear.com/station_blackout_home/animations1.html for an animated demonstration of how at least one model LWR, Westinghouse's AP1000, works today.)

Aside from the Chernobyl plant workers and firemen who died immediately or within a few weeks, there is plentiful evidence from the investigations of Chernobyl by disinterested international organizations that among those in the vicinity of the plant there have been *lower* than background rates of cancer. Even some 600,000 workers who were sent to clean up the site and were exposed to the *relatively* high levels of radiation have suffered 15-30% *fewer* solid cancers than elsewhere in the former Soviet Union. Hundreds of thousands of nearby former inhabitants, on the other hand, suffered diseases and injuries traceable to the massive relocations and the phobias, and *not* to radiation.

Chernobyl, a historical exception, was and remains the worst possible nuclear reactor accident, and yet fewer people died there (fewer than 60) than from many accidents involving other types of energy sources. On the contrary, due to the hormetic effect of the radiation (as we will demonstrate in section IV) there were large numbers of cancers that were *prevented*, cancers that would have occurred in the areas surrounding Chernobyl in the absence of the radiation. Of course, discovering which particular persons were thus saved, other than statistically, is impossible even in principle. Nevertheless when considering the anti-nuclear propaganda, seemingly concerned with harm to public health, why was there no similar call from these forces for a *complete* end to the use of coal when 29 coal miners were killed in April 2010 in the explosion at the Upper Big Branch Mine in West Virginia? Why was there no outcry from these forces for a *complete* end to the use of oil two weeks later when the 11 British Petroleum workers were killed in the Gulf of Mexico explosion on the Deepwater Horizon oil platform? Yet they call for a *complete* end to the use of nuclear energy.

Indeed the six worst deep sea oil disasters of all time, involving either oil platforms or drilling ships, occurred in the 11 years from 1979 to 1989 -- a decade that included both the TMI (1979) and Chernobyl (1986) nuclear accidents. Each one of these oil accidents killed more workers than did Chernobyl, yet it is likely that virtually no one either knows or remembers any of them. Certainly the present authors did not, until we looked them up. These were, in chronological order, the 1979 sinking of China's Bohai 2 platform in a storm off China that killed **72** workers out of 74 aboard, the 1980 capsizing of Phillips's Alexander L. Kielland platform off Norway that killed **123** workers out of 212 aboard, the 1982 capsizing of Mobil's Ocean Ranger platform in a North Atlantic storm that killed all **84** workers, and the 1983 sinking of Arco's Glomar Java Sea Drillship in a South China Sea typhoon that killed all **81** workers -- all prior to Chernobyl. Then in 1988, two years after the worst nuclear plant accident in history, the worst oil platform disaster of all time took place. It was a fire and explosion on Occidental's Piper Alpha platform in the North Atlantic, that killed **167** (including 2 rescue workers) out of 227 on board, followed the next year, in 1989, by the sinking of Unocal's Seacrest Drillship in a typhoon off Thailand that killed **91** out of 97 workers on board (http://home.versatel.nl/the_sims/rig/i-fatal.htm). In all, 618 workers died in these six worst deep sea oil disasters, and each of them *individually* killed more workers than Chernobyl.

The recitation of such lists of disasters doesn't begin to do justice to the lost workers or their friends and families, and may even seem a callous misuse of such tragedies. But the comparison is vital to give perspective to the *actual* misuse of *inflated* figures when nuclear accidents are involved. In particular, Chernobyl has become the central event for the anti-nuclear organizations, who scream for a complete end to the use of nuclear energy. Meanwhile the deaths among both coal and oil workers and the public from the burning of fossil fuels go marching on year after year, yet no member of the public has died from radiation due to commercial nuclear energy in the over half century of its use, and hundreds of times fewer workers in the nuclear industry have died than in any other energy industry.

The Fukushima reactors (of which 3 of the 6 were in operation at the time of the March 2011 quake/tsunami), unlike Chernobyl, shut down immediately when the quake and tsunami hit, as they were designed to do. The lack of a backup source of electricity for the cooling pumps to keep going after shutdown, in a 40-year-old reactor, was the cause of the problem, as the fission products, being highly radioactive, continued to generate heat. Prevention of this type of occurrence is an easy fix. For example, the auxiliary coolant pumps could have been placed on the roof instead of in the basement where they were drowned by the tsunami. The meltdown only occurred because of TEPCO's refusal to design sufficient ways of avoiding it, despite warnings by Japanese seismologists that such a strong quake was possible at any time, based on the geological history of the Pacific coastal regions. In particular, a quake and tsunami of roughly comparable magnitude had occurred in the same area in Japan in 869 AD. For example, the auxiliary circulation pumps for the coolant were in the basement rather than on the roof and were drowned by the tsunami. As with mines and oil platforms, such criminal neglect of worker safety on the part of profit-maximizing capitalist firms, with government connivance, is the cause of significant, and justified, unease about a repeat of such an event. But over-regulation of radiation levels in Japan and in all other countries is not the solution. Rather the solution lies in adequate inspection and modern designs of nuclear power plants. Improved designs are already available, even if adequate plant inspection may be more than can be reasonably expected under the rule of the profit system.

Many modern designs, as mentioned above, are failsafe against such losses of cooling power, with gravity-governed passive coolant circulation providing a minimum of 72 to 96 hours of cooling without human intervention -- or in one design (IFR, see below), for an indefinite period. Even in Fukushima this would have afforded ample time to remedy the loss of electrical power from the tsunami. Early airplanes and cars and every technical invention under the sun has had early engineering problems that get worked out over time. For example, in the 1880s, as electricity was beginning to flood cities, buildings, and homes under Edison and Westinghouse in the U.S., there were countless electrocutions, causing the media and a popular upsurge to question whether electrical generation was worth the risk. Yet today electricity dominates world energy, with long-distance transmission lines carrying well over a million volts, even though there are still occasional injuries and deaths from it. In the late 1800s when self-moving (literally, auto-mobile) vehicles were beginning to replace horse-drawn wagons -- initially electric-driven before the internal combustion engine took over -- there were strong popular forces opposing such vehicles on the grounds that speed (15 miles per hour) kills and cars were scaring the horses, among other objections. Nuclear reactors are no exception to this development, and we have now reached the stage where such passive design protections are becoming mandatory, at least in many countries. Just as electricity and vehicular traffic are now accepted without question, so, some day, will nuclear energy be accepted, but because of probable irreversible climate changes due to global warming the people of the earth cannot afford to wait any longer.

As pointed out above, the anti-nuclear forces emphasize and exaggerate accidents at nuclear plants and de-emphasize, or completely ignore, accidents involving chemicals or fossil fuels. While in recent times the mine and oil platform explosions in April 2010 killed a total of 40 workers (29 mine and 11 oil workers), here is a small selection of recent events that killed or injured members of the public. A toxic cloud of bromine gas was released by a railroad accident on 9/2/11 at Chelyabinsk, Russia, which resulted in over 100 hospitalizations and evacuation of the town. On 9/6/10 a natural gas explosion from an underground leak in San Bruno, California, destroyed a neighborhood that, more than a year later, is still rebuilding. On 9/13/11 in Nairobi, Kenya, a poor working-class neighborhood was destroyed by a gasoline pipeline leak and explosion, with more than 70 people killed and many houses destroyed. This alone is a greater death toll than at Chernobyl, at fewer than 60, but where are the demonstrations against gasoline pipelines? Actually there have been recent demonstrations against the proposed Keystone XL pipeline to carry crude tar sands oil from northeast Alberta to the Texas Gulf coast refineries, but mainly because of the potential harm to the atmosphere and underground aquifer from possible leakage -- which is valid enough of course -- but not because of possible death-dealing explosions.

And, of course, the biggest chemical explosion of modern times was at Bhopal, India, on 12/2/84 at a Union Carbide (U.S.-owned) plant, resulting in an estimated 3,000 deaths in the first few weeks and 8,000 chemical-related deaths since, for a total of 11,000 -- though other reports place it as high as 20,000, more likely closer to the truth, given the power of Union Carbide's (now taken over by Dow Chemical) influence to minimize the official death toll and thus its legal liability. There were also over half a million injuries. None of the higher executives in charge at Union Carbide has ever been made to pay for these events, nor has this tip of the iceberg dissuaded environmentalists from concentrating all their attacks on imagined *potential* deaths from a possible nuclear accident rather than on *actual* deaths from fossil fuels and other chemicals. Thus a double standard has arisen, one for nuclear and quite a different one for all other energy sources.

Yet the record is clear – absolutely no deaths among the public from any accident at any of the 430 or so purely commercial nuclear reactors in the world. As we said, Chernobyl was not merely a commercial reactor, but rather was involved in producing material for nuclear weapons. But even at that, with the highest predicted eventual death toll by some international agencies, including the UN's World Health Organization (WHO), lying at 4,000 for Chernobyl -- based on a completely fallacious method of (over-) estimation, linear-no-threshold or LNT, that we discuss below -- this worst nuclear plant accident of all time was far exceeded by the Union Carbide chemical explosion at Bhopal. Yet nowhere in the world are there major demonstrations to prevent the construction of chemical plants, and nowhere do the media continue to pound away year after year at the extreme dangers of chemical plants, fanning the flames of fear in the populace.

But let's catalog a few other energy-related deaths in the 20th century to give Chernobyl some further perspective: Coal smog killed about 12,000 people in London in the 3 months following the December 1952 temperature inversion that trapped the cold polluted air near the ground. Chinese coal miners suffered an average of 7,000 deaths per year in the 1950s, down to 1,000 deaths per year in the 1990s. And a series of hydroelectric dams in China collapsed in 1975 from the rainfall of a major typhoon, killing close to 100,000 (estimates run even higher) people. Compared to these horrendous death tolls associated with other various energy sources, Chernobyl was a minor incident, but has much greater psychological impact because of the continued falsehoods about radiation damage that we discuss in section IV below. These represent a combination of events ranging from typical to unusual, but even if we compare average death rates over time *per unit of electrical energy* produced, we find that Chernobyl's death rate was 9 times lower than that from liquefied natural gas and 47 times lower than that from hydroelectric power. And this is based on the *worst* single nuclear accident compared with only the average production of electricity from gas and hydro, meaning that if *average* nuclear deaths were to be compared to the other two averages the figures would be many orders of magnitude lower (Jaworowski).

Environmental disasters

And just 3 ½ years after Chernobyl came the largest oil tanker spill up to that time -- greatly exceeded since then by the 2010 British Petroleum drilling disaster in the Gulf of Mexico at almost 300 million gallons -- when the Exxon Valdez tanker ran aground in 1989 in Prince William Sound in Alaska, spilling what Exxon claimed was only 11 million gallons, but that court records show was three times that amount -- around 33 million gallons. The media, naturally, continue to repeat Exxon's lying minimization without question. This entire episode is well described in Dr. Riki Ott's 2005 book *Sound Truth and Corporate Myth: The Legacy of the Exxon Valdez Oil Spill*. She further documents almost 7,000 illnesses and injuries mainly among workers hired to clean up Exxon's catastrophic mess. These were caused by toxic chemicals that polluted the ocean and shore and included injuries to lungs, eyes, nervous system, and joints, causing great pain and suffering. Yet the media let this go, just as they have let go the BP oil spill, both of which ruined fishing, beaches, and entire livelihoods for many thousands of people.

Nor is this the only large spill in the Gulf of Mexico. How many people know about, or remember, the blow-out of the Ixtoc-I well, owned by Mexico's Pemex oil company, that dumped over 140 million gallons of oil into the Gulf and took more than 9 months to contain? Even worse than the spills from drilling platforms are the multiple spills from oil tankers, making the Exxon Valdez look like an ad for paper towels. How many people know that in the 1970s alone and involving only U.S. tankers, the first half of the decade saw an average oil spill of about 50 million gallons a year and the second half an average twice that, about 100 million gallons a year, which for the decade totaled about 750 million gallons, dwarfing the more highly publicized platform and Valdez disasters (Cohen)? Many of these spills fouled beaches around the world and killed immense amounts of wildlife and destroyed livelihoods. The website http://en.wikipedia.org/wiki/List_of_oil_spills lists 126 oil spills, both large and small, as of this writing, the majority of them taking place in the last decade. This publicity-driven control over collective memory is just the tip of the iceberg of the power that the fossil fuel industries and their financial backers have over the "free" press -- all over the world.

Nuclear waste

As far as nuclear waste disposal is concerned, this is perhaps the main arena in which the anti-nuclear forces shine their darkness. They claim that it is an insoluble problem. The truth is that even if spent fuel were to be buried in salt mines or turned into glass (vitrified) and buried in deep ocean abysses, it would be perfectly safe. Aside from modern research into this topic, there is an interesting demonstration of this fact by a peculiar natural reactor in Oklo, Gabon, in West Africa, where there is a uranium mine. About 40 years ago it was discovered that almost 2 billion years ago the uranium in several pockets in the mine area had begun a spontaneous fission chain reaction due both to the presence of groundwater that acted as a moderator, similar to the moderator in modern LWRs, and to the greater proportion of U-235 at that time. None of the fission products, still present in the neighborhood of the mine, has ever reached any nearby external water supply, and no one has ever been hurt by this natural reactor. Also glass from millennia past has been found in the ocean having suffered no erosion, demonstrating the safety of enclosing nuclear waste in glass and burying it underground or in deep sea abysses without fear of its leaking out, even if it were still dangerous when massively diluted. Indeed the oceans are full of *natural* uranium, a possible future inexhaustible source of nuclear fuel, incidentally.

But the good news is that there is no need to bury the long-term spent fuel at all. Since the vast majority of current reactors in the world, and all in the U.S., are designed to use less than 1% of the energy in the uranium (with the rest unnecessarily considered to be nuclear waste), it need not be buried at all. Indeed one breeder reactor, the IFR (discussed below), can use this spent fuel and is capable of utilizing over 99% of the energy in the uranium, because as it uses up the fissile components (U-235 and other actinides produced ultimately from U-238, including Pu-239), it breeds even more fissile Pu-239 than it uses, until the very end of its life when both the non-fissile and fissile portions of uranium and other actinides are used up and gone.

The breeder reactor was first developed near Idaho Falls, Idaho, by nuclear physicists and engineers at the U.S. Dept. of Energy's Argonne National Labs. The first was called the Experimental Breeder Reactor I (EBR-I), followed by the larger EBR-II. EBR-II ran without incident, providing electricity for the entire site of multiple buildings, from the early 1960s to the 1990s. It could have provided the electricity for the city of Idaho Falls, were it not for the competition it would have represented to the local power company. To utilize 99% of the energy in uranium requires only that the spent fuel from one round be reprocessed, to remove the fission products, and reinserted into the reactor for the next round along with enough uranium (mainly U-238) to replace that which was used up in the previous round. This can take place over and over, for the life of the reactor, and taking all breeder reactors together, indefinitely for the life of the planet. Then the only waste products are the fission products, each atom of which weighs about half that of uranium, more or less (Till and Chang).

There is both bad and good news about fission products. They happen to be very much more radioactive than the initial fuel (uranium and/or plutonium), but for that very reason they decay away in far less time, and would only need to be buried for a couple of hundred years, rather than the fabled couple of hundred thousand years. [*The box immediately following this paragraph explains the reason for this greater degree of radioactivity in the fission products*.] Fission products, along with the vast bulk of the uranium and the other actinides, are today safely stored for decades on-site in 40-foot pools of water with perfectly safe shielding by the water itself, such that workers at the plant have been known to safely swim in those pools. This was intended to be temporary storage until some place like Yucca Mountain northwest of Las Vegas was opened up, but that project was halted by Obama in the face of political wrangling based on unconscionable lies and political demagoguery. This opportunism in the furtherance of political careers is yet another obstacle, produced by capitalism, to the achievement of clean sustainable energy to replace fossil fuels.

For those more interested in why fission products are more radioactive (i.e., more unstable) than the approximately twice-as-heavy parent elements: It has to do with the ratio of neutrons to protons in the nuclei. The heavier an element is, the greater the number of protons, and since protons are electrically charged they tend to repel each other, making it more difficult to hold them together in a single nucleus. The glue that keeps heavier and heavier nuclei at least semi-stable is provided by the presence of electrically neutral neutrons. The greater the number of protons, the relatively more neutrons are required to hold the nucleus together. Therefore the ratio of the number of neutrons to the number of protons is greater in the heavier elements than in the lighter ones -- up to approximately one and a half times as many neutrons in uranium as protons. Meanwhile for the stability of lighter elements that ratio is much less -- down to about a ratio of one. So when a heavy parent nucleus splits into two so-called daughter nuclei, the ratio of neutrons to protons is at first characteristic of the heavier parent, i.e., about one and a half to one, or more simply about 3 to 2. But this is greater than the number of neutrons required to hold the lesser number of protons in the lighter elements together, which produces its own instabilities. So the lighter nuclei find that some adjustment must be made in order to re-establish a relative stability -- either by ejecting neutrons, or by converting neutrons to protons through the ejection of electrons, or some other combination of ejections (decay) to arrive at a more stable ratio. This adjustment takes place relatively quickly, which gives rise to the greater radioactivity of the lighter daughter nuclei. And this explains the higher level of radioactivity of the fission products than of the heavier parent nuclei.

The next advance on the pioneering EBR-II, located on the same site, is now called the Integral Fast Reactor (IFR) -- "integral" because, as with EBR-II, the reprocessing is entirely contained within a separate wing of the same building as the reactor, and no plutonium or uranium can be carried away without exposures to radiation that would deal fatal doses in split seconds, and "fast" because the neutrons are not slowed down by a water moderator and therefore after turning all the non-fissile form of uranium (U-238) into Pu-239 and other actinides, over many cycles, efficiently cause these to fission and produce electrical energy. Indeed the fission products in the spent fuel, that must be separated out in the reprocessing and stored, is so highly radioactive that the reprocessing has to be handled remotely through master-slave manipulators, robotics, and thick shielding. Funding for further development of the IFR was cut off in 1994 through the efforts of President Clinton in a cowardly self-promoting act of pandering to anti-nuclear forces. He claimed that ending the IFR project would prevent proliferation of nuclear weapons, though the IFR was, in fact, and remains, the reactor design that most clearly prevents removal of the plutonium for the purpose of making bombs. Furthermore this action by Clinton has not, in fact, prevented proliferation of nuclear weapons since 1994.

Several other countries already, or are beginning to, manufacture IFRs or some similar form of breeder reactor, but to this day the U.S. government does not allow their construction in the U.S. As of this writing, the UK is considering whether to purchase a couple of breeder reactors, primarily in order to use up their plutonium stock in their LWR spent fuel pools. IFRs could solve the nuclear "waste" problem and prevent theft of plutonium due to the huge radiation exposures in the recycling part of the plant, and they are passively failsafe against loss of coolant and meltdowns -- indefinitely. There are numerous other designs today that share some of these features, but the IFR has all of them (Blees, Till and Chang).

The forerunner of the IFR, the EBR-II, was itself a further development of the still earlier EBR-I. The latter was built in 1951 to prove the principle that nuclear power could produce electricity, and indeed it initially powered four 200-watt light bulbs. Both EBR-I and II (later called the IFR) are located west of Idaho Falls, Idaho, at the Idaho National Labs (originally part of Argonne National Labs) on Naval Ordnance grounds. Even though the reactor was shut down by Clinton in 1994, with further development of various engineering aspects and fuel constituents prevented thereby, its fuel reprocessing portion is still in use to a limited degree, mostly experimentally. Reprocessing for use as fuel in a fast reactor would be a win-win situation for the public and would be to an even greater extent if the U.S. government's regulatory agency (NRC -- Nuclear Regulatory Commission) would permit their rapid construction to produce the vast majority of U.S. electricity.

C. Comparative susceptibility to terrorism

Closely related to the relative safety of fuel acquisition and plant operation is the often cited potential catastrophic effects of a terrorist attack on a nuclear plant. Such tactics are raised generally in the absence of an evaluation of the potentially equal, if not greater, catastrophic effects of a terrorist attack on a fossil fuel installation or any type of building. We have already seen what damage such attacks can do to life and property when a building is attacked by terrorists, both in Oklahoma City in 1995 where 168 people were killed and on 9/11 in New York and Washington in 2001 where close to 3,000 people were killed, with many other workers dying slower deaths as a result of their participation in clean-up efforts of the toxic waste.

Many writers have pointed out that a nuclear plant is one of the least vulnerable types of power plant to terrorism, either by a plane crash or by theft of uranium and/or plutonium. This is due both to the presence of a several-inch-thick stainless steel containment vessel and to a several-feet-thick concrete containment wall with inch-thick rebar imbedded in the concrete. An airplane is a hollow metal tube, and regardless of the speed with which it might hit, the tube would crumple before it could penetrate the concrete. This is not just a theoretical point but has been tested by engineers. As to the possible theft of uranium or plutonium to make bombs, not only are the plants at least in some countries heavily guarded but the fuel, both fresh and spent, is so hot radioactively that contact with it would result in death soon after with only split second exposures, as has been described above.

A recent event in which members of the anti-nuclear Greenpeace invaded a nuclear plant in France to show it could be done, clearly demonstrates the need for more consistent guarding of the plants, but they still would not have been able to steal the highly radioactive spent fuel or cause a nuclear explosion. The owners of such a plant would have endured the greatest damage -- to their profits -- though the public would have suffered a loss of electricity. As it is, however, such losses of power occur frequently today as a result of natural extreme weather events, which are becoming more and more common as the earth warms due to fossil fuel-caused global warming and which a complete conversion to nuclear energy would bring to an end.

But power plants in general, not just nuclear plants, are less accessible than dirty bombs, which are explosions powered by TNT or dynamite and used to spread radioactive material locally. Clearly 9/11 represented the second most spectacular recent example of terrorism's ability to kill and destroy. But the wars in Iraq and Afghanistan represent the most spectacular example, causing well over a million deaths among Middle East workers and others -- much of this due to deliberate U.S. bombing of infrastructure, involving electricity, fresh water, and sewage (http://www.counterpunch.org/2002/09/02/us-war-crimes-during-the-gulf-war/). These are not called terrorism in the U.S. (or other) mass media, and many may miss their significance in that regard. In addition, the media focus only on deaths among U.S. soldiers, reporting the cumulative total daily but never reporting on the cumulative deaths of those men, women, and children who inhabit the invaded lands. So not only are nuclear plants nearly impossible targets of terrorism, but there are many other far more accessible and effective methods for terrorists to use within U.S. territory or for the U.S. military to use abroad -- as we have already seen on numerous occasions.

Meanwhile failures of maintenance in the absence of deliberate terrorism have caused tens of thousands of deaths and injuries in coal mines, at oil refineries, and from natural gas lines -- over the course of the 20th century about 100,000 among U.S. coal miners alone. The focus on nuclear plants as targets of terrorism is manipulated by anti-nuclear forces simply to fan the phobias they seek to associate with nuclear energy. This effort is greatly aided by the limited nature, or absence, of accurate and all-sided information given to the general public in the schools and media.

D. Relationship of nuclear energy to nuclear weapons

Before we leave the subject of relative safety, a major criticism of nuclear energy on the part of some promoters of wind or solar, among others, is that nuclear energy inevitably leads to nuclear weapons. Political scientist John Mueller, for one, in his book *Nuclear Obsession*, points out that this has simply not been true historically (Mueller), and Stephen Younger, an experienced nuclear arms expert, confirms this assessment (Younger). The reasons that various nations opt to expend tremendous resources on the development of nuclear weapons lies in shifting political relationships and not in the availability of nuclear power plants. It has been stated falsely that all nations that have nuclear weapons started with nuclear power plants, but even if that were true, this would not say anything about whether nations with nuclear power plants always develop nuclear weapons. A list of nations with nuclear weapons includes the U.S., Russia, UK, France, China, North Korea, and Israel, as well as India and Pakistan. North Korea and Israel have no nuclear power plants to this day. The rest all had nuclear weapons before they turned to nuclear energy plants, except for India and Pakistan, the only two countries that developed nuclear energy before nuclear weapons. So clearly this can go in either one direction or the other, or neither. There is no more a necessary advance, nor has history shown one, from nuclear energy plants to nuclear weapons than there is an advance from marijuana, or for that matter from cigarettes, to heroin.

Okay, one might object, but the availability of nuclear power plants makes it easier for a nation to obtain nuclear weapons. This is where an understanding of the difference between nuclear fuel and nuclear bomb material is necessary. We explained enrichment of uranium above. For a light water reactor, the most common type in the world and the only type in the U.S., the uranium has to be enriched from 0.7% U-235 (the fissile component) mixed with 99.3% U-238 (the nonfissile component) to 3-5% U-235 with 95-97% U-238, and in a fast reactor it *initially* has to be enriched to about 20% U-235 with 80% U-238 (or, more practically now that LWRs have been running for several decades, a fast reactor could be fueled with the plutonium and other actinides derived by reprocessing the spent fuel from LWR reactors). A uranium bomb, such as was dropped on Hiroshima, requires over 90% U-235, though it could be designed with a somewhat lower concentration if the overall mass were greater.

A plutonium bomb, such as was dropped on Nagasaki, requires Pu-239, but commercial reactors also produce Pu-240 along with Pu-239, and the mixture of these two isotopes of plutonium will cause a bomb to fizzle if there is less than 93% Pu-239 (i.e., more than 7% Pu-240). While there does exist a practical way to *chemically* separate the combination of isotopes of plutonium (derived from any type of reactor) from the other elements, e.g., the so-called PUREX process, there is currently no practical way to then go on to separate these two isotopes of plutonium from each other for a nuclear weapon. The enrichment process that is used to separate U-235 from U-238 would be much more difficult to use to separate Pu-239 from Pu-240 and the higher isotopes of plutonium. In fact, no nation has used such a process for plutonium. The reason for this greater difficulty is that the difference in atomic weights of the two isotopes of plutonium is only unit (0.4% of 240) while the difference in atomic weights of the two isotopes of uranium is three units (1.3% of 238), which makes enrichment of uranium difficult enough but enrichment of plutonium even more difficult. Therefore plutonium that has sufficiently little contamination by Pu-240 for use in a nuclear weapon has to be produced directly in a reactor and removed from the reactor after a short time of build-up. To leave it in the reactor too long would permit too much of the Pu-239 to capture a neutron and transform to Pu-240 and higher. Then the Pu-239 has to be submitted to a chemical separation of plutonium from the uranium and other elements (through e.g., PUREX).

Enrichment in general is a very expensive and time-consuming process, and the excessive enrichment of uranium required for a bomb is regarded by rival imperialist governments as easily detectable with international inspection -- even in the face of this rivalry. It is more than possible that the Iranian rulers aim to develop nuclear weapons, but they were willing to have their enrichment done abroad, until the U.S. provocatively refused to agree, and this would have all but guaranteed that it was only for nuclear energy generation. In summary, the degrees of enrichment required for each of these two very different purposes are miles apart in both time and detectable effort.

An IFR uses a reprocessing method, called pyroprocessing, that does not separate any of the actinides from each other, but does separate these useful fuel elements (useful, that is, as fuel in an IFR) from the fission products. Since the plutonium from an IFR is mixed with several other elements, including many isotopes of each, and since much of this material is made up of fission products that are highly radioactive and must therefore be handled remotely through robotics and master-slave manipulators, and since the pyroprocessing takes place completely within the IFR facility without ever leaving the building, plutonium cannot possibly be stolen from an IFR for use in a nuclear weapon. Commercial use of IFRs would completely prevent removal from them of plutonium for use in nuclear weapons.

E. Comparative availability of fuels over the long term

One subtle anti-nuclear position holds that, like fossil fuels, the supply of uranium is limited. This is a complete misapprehension. First it should be noted that fossil fuels derive from decayed life forms that arose when the earth was already a couple of billions of years old, while fissile materials are minerals present at the very formation of the earth in large quantities. Thorium is also a possible fuel for nuclear reactors and is about 6 times more abundant in the ground than is uranium. But the more general point, that overrides all suggestions of limitations, is that there are two abundant sources of uranium or uranium-based fuels that are far less limited: spent fuel from light water reactors (LWRs) and, far more importantly, the oceans. With respect to the LWR spent fuel, IFRs can extract about 100 times as much energy out of it as LWRs have extracted, since, through reprocessing over and over and replacing used U-238, IFRs convert virtually all the U-238 to fissile material (Pu-239 and other actinides), and U-238 constitutes the vast majority (99.3%) of uranium on earth. This fuel has already been mined and is sitting in pools adjacent to thermal reactors in many parts of the world waiting to either be buried (a wasteful effort) or recycled and used in breeder reactors like the IFR. In addition, also available is the much greater supply of DU (predominantly U-238), removed during enrichment from the thermal reactor fuel stock, even before the fuel is fed into the reactors.

Since the world has been running 430 or so reactors for several decades, say a conservative average of 35 years, and since these reactors have only used up less than 1% of the energy available in the uranium, and since IFRs can use over 99% for a ratio of roughly 100 to 1, this means that, all other things being equal, 430 IFRs of similar power, for example, would have enough fuel for 100 times as long as the 35 years -- a very long time (about 3,500 years) -- during which no further uranium mining would be required. Of course, to the extent that the capacity of these reactors were to be increased or the number of them were to exceed 430, the time until we needed to obtain more uranium would be concomitantly shortened, but the number of years would still be very great.

But even at the end of that time, since the ocean contains virtually unlimited amounts of uranium that could be extracted with the help of nuclear power, there would be unlimited supplies of fuel for nuclear power plants. Indeed estimates from ocean samples predict that there is enough uranium for the remaining life of the planet, about 4-5 billion years. This is when the sun is expected to run out of hydrogen at its core, expand mightily, engulfing and destroying the earth and several other planets, and turn into a “red giant” star. This, of course, will at the same time also bring an end to the “renewables” of solar and wind energy. Therefore the supply of uranium is not, for all practical purposes, limited at all. In particular, it is no more limited than is sunlight for solar or wind energy, the usual favorite of those who cry “limited” supply over competing energy sources. But long before then the advance of technology would likely make energy generation even more available, clean, safe, and reliable.

F. Comparative reliability of fuels for energy generation around the clock, around the year

Electricity is needed 24/7 to run computers, refrigerators, lights, communication equipment, and hundreds of other appliances, as well as to recharge electric vehicles and other electronic items and to desalinate water. Therefore it must be steadily available around the clock and in all seasons, and it must be possible to keep supply and demand in synchrony over the course of the day and the year. But there are also both predictable and unpredictable fluctuations in electricity demand, due to time of day, seasonal temperatures, and so on. There are three levels of electrical demand, called baseload, which is the constant portion that is called for all the time, midload, which is the slower variability in demand over a day or a year, and peakload, which is the shorter term and often unpredictable component. In order to meet these three levels of demand, electrical power plants must be able to be turned up and down quickly, but most of all must be able to provide the constant baseload.

Electricity generated by burning coal or natural gas or through the use of nuclear fission all satisfy the baseload requirement and indeed make it available 24/7. But, of course, the entire point is to replace pollution- and CO_2-generating coal and natural gas altogether. Do any of the other clean fuels produce electricity with a comparable degree of constancy?

Hydroelectricity from dams is relatively reliable for a portion of baseload, at least over the course of the day. But over longer times it may lose its reliability as global warming keeps the winter mountain snow pack from gathering and large dammed sources of electricity like Lake Powell at Glen Canyon Dam in Utah-Arizona or Lake Mead at Hoover Dam in Arizona-Nevada begin to dry up, as they have been doing for many years now. The same drying has been seen in the Himalayas that feed many of Asia’s rivers and hydroelectric dams, and in the Andes and other of the world’s great mountain ranges. Of course, this drying not only affects the supply of electricity, but even more importantly the supply of fresh water for drinking, washing, and growing food. As it is, some of the more than 50,000 dams in at least the U.S. are being dismantled for ecological reasons, ending an era over the course of the late 19^{th} and most of the 20^{th} century, during which they were being built one after another (Reisner). And even now hydro provides only about 6% of U.S. electricity, while coal provides 55% and nuclear 20%, with the rest coming mainly from natural gas. Wind, solar, and geothermal together provide only on the order of 1-2%, which means, among other things, that there is a long way to go to scale up these sources to even begin to match the well-developed nuclear portion. While geothermal could in certain locales provide baseload, it is limited geographically to those areas where magma is closest to the surface. We have dealt with biofuels above on other grounds, though they could also provide baseload.

But the main problem with considering wind and solar for baseload is that they are very erratic and fickle, with solar severely limited in the presence of cloud cover and completely disappearing at night, and with wind depending on many highly variable things, including geographical features and degree of differential solar heating of the surrounding countryside, something that varies through the seasons and over the course of minutes to hours. Until the problem of very significant amounts of storage of wind and solar energy can be solved, these unreliables will produce a problem for an energy distribution grid, which cannot tolerate abrupt changes in either supply or demand if they cannot be synchronized. We will discuss the geographic features of these two in the next section when we discuss suitable locations for equipment to capture energy, in solar and wind farms, and we will see that they involve amounts of land that exceed that needed for nuclear by many orders of magnitude.

So in order to provide baseload electricity, the necessary bedrock of electrical energy, the only way that solar and wind could conceivably fill the requirement, either together or alone, is if there were a way to store sufficient excess energy when the sun is shining and/or the wind is blowing. Furthermore there would have to be built significant collection capacity above the average requirement, so that the energy in excess of immediate demand could be spared for storage. There are several possible methods of storing such energy, including batteries, pumping water above dams to be used as hydro later, or compressed air underground to be released to run turbines like hydro. These are ecologically unsound in many ways and extremely expensive, and, except for portable batteries, not necessarily available in those locations where the sun shines the most and the wind blows the most consistently.

In fact, none of these methods for storage has been found to be practical or profitable, at least not yet, so that wind and solar have been confined everywhere they are used -- more in Europe than in the U.S. -- to peakload and perhaps to midload. The primary problem then with wind and solar is that they cannot be used at all for baseload, which lets them out of consideration for completely replacing fossil fuels for electricity. They cannot even be relied upon for midload or peakload, since these represent largely unpredictable fluctuations in *demand* that could only by sheer chance be matched by unpredictable fluctuations in wind/solar *supply*, and which would therefore match only a very small percentage of the time.

As to the lack of profitability in wind and solar, it has been partially overridden by subsidies from governments in Europe and the U.S., with these subsidies provided by compliant politicians who receive their kickbacks (campaign contributions, trips to exotic places, and many more hidden forms of under-the-table payment) from the involved corporations, while the public bears the cost in the form of taxes and higher energy bills.

Those entrepreneurs whose eyes glaze over when they contemplate following in Bill Gates's pecuniary footsteps, and who propagandize that their favorite sun-driven technology will be able by half a century from now to provide all electricity, are either mathematically incompetent or truth challenged, or both. And they and their environmental supporters are not rare. They are also promoted by the media, so that their voices far outweigh their numbers.

An excellent source that exposes the limitations of both wind and solar, and explains the benefits of nuclear, is the website run by Australian physicist Barry Brook, at bravenewclimate.com. For some other sources see Etherington on wind, Hayden on solar, and MacKay on just about every aspect of energy (and arithmetic). MacKay, incidentally, a professor of physics at Cambridge University, has recently been appointed chief scientific advisor to the UK's Department of Energy and Climate Change (DECC). He also put his entire book *Sustainable Energy Without the Hot Air* on the web, free of charge, before it was published in paper, demonstrating in the most clear terms that he has no self-interest in his contentions, other than as a member of the human species.

On the self-interested advocacy side, consider two articles in the popular monthly magazine *Scientific American*, one on solar in the January 2008 issue and one on wind in the November 2009 issue. The solar article was written by three solar entrepreneurs, one of whom is Ken Zweibel, who began as the President of Prime Star Solar in Colorado and more recently has become the director of a solar research think tank, the George Washington University Solar Institute, which gives him an academic cover for his profit-making goals. Their article projected that solar energy would be able to satisfy over 2/3 of the U.S. electricity needs by 2050, a little more than 40 years from the date of the article. They describe the two ways of capturing solar energy -- photovoltaics (PV), which turn sunlight directly into electrical current through use of the photoelectric effect, and concentrated solar, often called solar thermal, which captures sunlight and with curved trough-like mirrors concentrates it on a tube containing a fluid that is thereby heated, which heat is ultimately used to create steam that drives a turbine to generate electricity. They project, by the year 2050, the construction of 30,000 square miles of PV panels, the kind you see on rooftops, and 16,000 square miles of solar thermal mirrors -- all to be located in the ever sunny (except when it isn't) southwestern U.S. Bear in mind that the state of Arizona is about 120,000 square miles in area, so they plan to use more than a third of that amount of land, even if it is distributed more widely throughout that general area of the country.

Now here comes the mathematically challenged part. Tom Blees, in his highly recommended book on IFRs, *Prescription for the Planet,* first calculated that in order to build just the 30,000 square miles of PV panels by 2050, they would have to build about 2 square miles per day every day for over 40 years. Now if that doesn't sound implausible enough, let's see what that amounts to per hour, per minute, and per second. That's equivalent, assuming an 8-hour work day, to a square 2,600 feet on a side every hour (about half a mile on a side), a square 350 feet on a side every minute (somewhat more than the area of two football fields), and a square 45 feet on a side every second (the footprint of a modest house). And that's using every working hour for a 7-day week for over 40 years, an entire working career. If we confine the work week to 5 days, it would require the building of squares 3,640 feet, 490 feet, and 63 feet, on a side, every hour, minute, and second, respectively.

Worse yet, this doesn't even take into account the volume of industrial production needed to manufacture the panels and mirrors at that rate, nor does it account for the necessity to clear the ground of weeds that would otherwise overgrow the panels and block the sunlight, nor does it account for the frequent cleaning that is needed (discussed two paragraphs below). We have no idea whether they have simply failed to do the math, have done it and hope that no one else will, or don't care how many people figure it out. Either way, that's the type of conflict that solar and wind advocates get into in their ongoing idealist determination to ignore the real material world.

Moreover Solyndra, a start-up firm that invented and manufactured cylinders of rolled up PV material, just declared bankruptcy, and that was after Obama granted a $535 million federal loan guarantee, and after Solyndra cashed in on almost the entire amount. But Solyndra was only one of three solar start-up companies who declared bankruptcy within a 3-week period. Even Zweibel admits that the solar industry is in crisis all over the world, according to the magazine "Electric Light and Power" in October 2011. This doesn't, of course, prevent solar entrepreneurs from soaking up, along with sunlight, handsome government subsidies, no doubt with kickbacks to the politicians who award these prizes, either under the table or through open campaign contributions.

One further consideration is that both PV panels and solar thermal mirrors require relatively frequent cleaning in order to rid them of the dust that blocks the full force of the sunlight from reaching their intended destination. The very locations that are optimal for collecting sunlight, namely deserts, are precisely the locations where water for cleaning is the most scarce and dust the most abundant, both destined to worsen with global warming-caused droughts. And 46,000 square miles of frequent cleaning is a daunting project, at best, and one that is ignored by Zweibel et al. Research, as it turns out, is still ongoing for methods other than PV panels to collect sunlight, such as through simulated leaves that mimic the way plants capture and convert sunlight to other forms of energy, but none of these is yet able to detect even a whiff of prime time.

The article on wind in the November 2009 issue of *Scientific American* made a claim that the fluctuations in wind and solar could be taken care of by allowing the fluctuations in both to cover for each other, with the rest of worldwide baseload taken up by geothermal and hydro, both for electricity and otherwise, by 2030. That is, the authors claim that when the wind stops blowing in one location there will undoubtedly be other locations that will still be able to take up the slack. Now in this case we happen to be able to judge that lead author Mark Jacobson is deliberate in his falsehoods, though he may also be mathematically challenged. Jacobson, a professor of civil and environmental engineering at Stanford University, is featured in a YouTube debate over nuclear versus wind with Stewart Brand, an ecologist. Brand, incidentally, after putting in his time as an opponent of nuclear energy, has finally looked into the topic and has realized, and admitted, that he was wrong all along, chastising his former colleagues for their continued failure to do the same investigation and asking rhetorically how people who are so smart can be so stupid (Brand). Whether or not Jacobson exhibits stupidity or cupidity, however, we leave to the reader to judge.

In the course of the debate Jacobson presents a graph to the audience, which is also in his *Scientific American* article, that purports to show how the combination of solar, wind, geothermal, and hydro will compensate for each other over the course of what he calls a typical day in a particular part of California. He stresses that this is not a model, but shows "actual data," a phrase he uses several times to convince the audience that he is an engineer who measures actual things rather than just a theoretician, like a physicist or some such dealer in unreality. And here's the deliberate falsehood: this graph represents actual data, but it is averaged over many days, and represents only a typical day *in July*. But that's precisely the way to cover over the minute-to-minute, hour-to-hour, day-to-day, and season-to-season fluctuations that render wind and solar unusable as baseload. Brand did his best to counter Jacobson's other nonsense, though he was somewhat taken by surprise and weakened in his exposure of the falsehood embodied in Jacobson's description of the graph. When the moderator took a vote of the audience both before and after the debate, it turned out that Jacobson had swayed a part of the audience away from nuclear with his mendacity. No good lie goes unrewarded.

In fact, Etherington (*The Wind Farm Scam)* shows that over very large areas of Europe the blowing of the wind is correlated in time, such that when it stops blowing in one country it essentially stops over very wide areas covering several countries. Furthermore such cessations of wind can last for many days, overwhelming any storage capabilities. The problem with solar is similar. (See also, for an example of high nominal capacity providing virtually nothing for the past week as of this writing, http://transmission.bpa.gov/business/operations/wind/baltwg.aspx.)

The problem then with wind and solar is that they are completely dependent on fossil fuels to take up the considerable slack when their practically infinitely replaceable sources are unavailable for capture. That is, the sources are infinitely replaceable for all practical purposes *from time to time*, but nowhere on earth are they available 24/7. The fossil fuels could be replaced by nuclear for social needs, and wind and solar could serve small local needs, either on rooftops or on farms. They just cannot replace fossil fuels on a social level without depending on nuclear energy for a reliable 24/7 source of clean energy -- at least not in the foreseeable future.

However, to show how low the Jacobsons of the world will stoop to win the debate over time, their article claimed that nuclear energy, unlike wind or solar, would foul the air, but didn't say how they arrived at that conclusion. In a technical journal article that was subject to peer review before being published (unlike with a popular magazine), on which their popular *Scientific American* article was based, he and his co-author, Mark Delucchi, based their claim on the assumption that nuclear energy necessitates the breeding of frequent nuclear wars, and the explosion of so many nuclear weapons every so many years would produce this negative effect on the atmosphere (they "estimate" somewhere between zero and one nuclear bomb exchange every 30 years, http://bravenewclimate.com/2009/11/03/wws-2030-critique/). Now that's hiding quite an outrageous claim just to justify developing wind over nuclear energy, particularly since no nuclear weapon has been used in any of countless wars over the last 2/3 of a century since Hiroshima and Nagasaki, not even by the only ruling class that has ever used them, the U.S. Among other things, this shows one of the limitations of peer review of new scientific conclusions, which is often exaggeratedly touted as the gold standard for valid science. It turns out to be more like a tin standard -- perhaps *necessary* (though perhaps not) to ensure scientific validity, but far from *sufficient*. Furthermore the revelation by Jacobson and Delucchi of their reasoning in a technical journal, in the face of their concealment of it in a popular magazine, suggests their awareness that the former would reach a much smaller and largely different audience than the latter -- not the sort of behavior one would like to see in scientists and engineers.

But perhaps the most revealing feature of the mental projections for solar and wind over the next 20 to 40 years is that they are based on extrapolations from relatively small current examples, rather than through actually building and testing on a scale that even approximates those that are claimed to be possible. People less dazzled by these technologies can readily see a number of obstacles that will probably turn these daydreams into dashed hopes, but the starry-eyed entrepreneurial advocates don't even try to take such potential obstacles into account (Etherington, Hayden).

For example, Etherington shows, using official government figures from both UK and Germany, that as wind has grown to greater percentages of total electrical power, from a little over 1% up to 7% in Germany, the integrated electrical grid throughout Europe has become more unstable and prone to brownouts or blackouts. Instability occurs because of the need for synchronization of all sources into a single distribution grid of electrical power lines, and the erratic and unpredictable intermittency of wind (and solar) requires the construction of additional fossil or nuclear power plants -- currently natural gas plants -- which have to remain on standby (i.e., operating at low output, but not silent) to prevent such losses of power when demand suddenly either rises or falls relative to supply or when supply suddenly falls or rises relative to demand. This instability is analogous to the fluid mechanical phenomenon in which there is organized flow of either a gas or a liquid at low enough speeds, but which turns into chaotic turbulence at a certain speed -- a transition found, for example, in the interaction of wind with wind turbines. This is an example of a more general law of nature, prominently recognized by a dialectical approach as the transition, at some point, from quantitative changes into a qualitative change.

The need for constant standby gas power increases with greater penetration of the intermittent sources (wind and solar), and is costly in capital, and further increases CO_2 emissions -- the latter being the very aspect that the intermittent sources are touted to obviate. The more wind and/or solar, the more standby gas power required and therefore the more wasted capital and the more CO_2 emissions. In fact, this puts an upper limit to the amount of CO_2 emissions that intermittent sources can actually save, as their requirement for replacement by natural gas reaches a point of diminishing returns, beyond which any additional required added fossil power produces emissions equal to those "saved." The British government estimates this upper limit for wind to be about 10 million tons of CO_2 emissions per year saved if the UK were to replace fossil fuels with wind. This is to be compared with the UK's total 2010 CO_2 emissions of 542 million tons, or 1.8% "saved," and would contribute a "savings" to the *world's* annual CO_2 output (36,900 million tons in 2010) by less than 1/3000 (that's one three-thousandths). Furthermore 10 million tons "saved" by the UK is exceeded by their own annual *growth* of emissions of 19 million tons between 2009 and 2010 (though neither year was as high as 2008, presumably due to the recession), and even more so by the world's annual growth of 2,100 million tons in that same interval, a figure that itself increased from the growth the previous year of 1,900 million tons (see http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions.)

While this estimated 10 million tons "saved" by the UK is only one country's contribution, it nevertheless gives some idea of how small a saving in GHGs would be produced if many countries increased their wind capabilities to the point of diminishing returns, and it does not even keep up with the annual growth in GHGs. Even if the "saving" from wind were equal to the growth for one year, the "saving" would remain constant while the growth would continue, thereby increasing annually the amount of GHGs in the atmosphere despite maximizing the energy contribution of wind. Etherington takes the UK government to task for dishonestly purveying untruths and imposing on the public the growing tax and electricity-bill burden for this wind "scam," as he calls it.[5]

As has been pointed out many times, whether in the U.S., the UK, or the rest of Europe and many other countries, whenever lobbyists bribe their way to subsidies from Congress or Parliament there will be capitalists who grab at the chance for a free handout. This, in turn, enhances their ability to lobby and thus their ability to guarantee both the continuance and the increase of such subsidies -- a case of amplifying feedback. Meanwhile the public is taxed for these false hopes with the rationale that at least these "renewables" use natural "fuel" that seemingly avoids the emission of GHGs -- though not necessarily, when the entire process is considered.

Contrast this limited appreciation for the necessity of empirical testing at the levels required with the approach of the nuclear pioneers who built the first experimental breeder reactors, EBR-I and II, from the 1950s to the 1990s. They took tentative theoretical conclusions and applied them to designing, building, and testing first a small reactor that was able to light four 200-watt bulbs. The bulbs lit up, proving for the first time in history the validity of the theoretical conclusion that nuclear energy could provide electricity. After a quiet celebration of their success they began to design, build, and test the next larger reactor. At each step of the way, they tried to anticipate everything that could possibly go wrong, knowing full well that there would likely be surprises that they could never have anticipated. One example of such a surprise was the behavior of the alloyed stainless steel cladding that surrounded the fuel rods in the core. The heat and neutron flux caused the stainless steel to exhibit a weakening with which the project metallurgists had no prior experience. They then had to go back to the drawing board to modify the materials, build again, and test again, over and over, in order to go on to the next unexpected discovery.

It took them more than 20 years of running the reactor, finding failures, and redesigning the components based on those failures before they were finally ready to give a demonstration, to an international gathering of some 70 scientists and engineers, of the way the reactor would automatically shut itself down without human intervention when they deliberately turned off the coolant circulation pumps. Ironically and by sheer coincidence, this demonstration took place a scant 3 weeks before the accident at Chernobyl. The demonstration at EBR-II was successful, not because of wishful thinking, but because of testing, failing, redesigning, testing again, failing again, redesigning again, and on and on. This testing-failing cycle was aided by a number of other experimental breeder reactors in the U.S., both smaller and larger, that suffered a variety of accidents from leaks to fires to meltdowns, but from which much was learned. This testing-failing cycle and learning from the failures is the only way that any technology can finally be brought to the level at which it is ready for practical use. All these failures were contained, and, aside from a few early injuries and deaths among workers in military experimental reactors, no one was hurt.

An engineer named Henry Petroski, who writes popular books about this type of process, proclaims that the mother of invention is not so much necessity as it is failure (Petroski). Further projected tests by the IFR (renamed from EBR-II) of such things as the handling and employment of materials were stopped cold by the loss of funding in 1994 -- in the U.S. But such building and testing still goes on today in several other countries, including, among others, Russia, Japan, France, India, UK, and China.

The difference and relationship between physics and engineering is loosely akin to the difference and relationship between theory and practice -- they are inseparable aspects of all labor, though in any particular situation one may be emphasized more than the other. While physicists, of necessity, have to base their theorizing on some measure of practice -- in this case, experiment and systematic observation -- in general, as individual scientists, they are more oriented toward theory. And when they are experimentalists, as not all physicists are, they are designing experiments to deal with a particular set of conditions that are abstracted, only a part at a time, from more complex combinations of these conditions -- combinations like those found in nature or in complex constructed applications like bridges, buildings, automobiles, airplanes, or nuclear reactors, among many others.

Engineers, on the other hand, of necessity, have to base their practice on theory, even if at times this is implicit rather than explicit, i.e., unrecognized fundamental ideas versus deliberate and conscious use of theory. But, in general, engineers are more oriented toward practice -- generally in the designing and building of complex structures like the aforementioned bridges, buildings, automobiles, airplanes, or nuclear reactors. In such construction, which puts together separate aspects of theory, new properties emerge on the higher level that often cannot be anticipated from the lower levels, and the discovery of which leads to further theorizing. The emergence of such new properties will assuredly be found as the attempts are made to combine wind and/or solar farms into larger and larger combinations, particularly through the grids that centralize and distribute their electrical energy, but their advocates act as though all the problems have been solved at the smaller levels. Whether this is wishful thinking, dishonesty, or just plain ignorance may vary, but only construction at the higher levels will reveal the realities of these forms of energy, and many are already emerging that are not favorable to the wind and solar advocates.

It is no accident that the person chosen to head Argonne's EBR-II project was a mechanical engineer, Len Koch, who, according to those who worked with him, was always a reliable source of new ideas when some aspect of the project would dash expectations or some new arrangement of parts or clever mechanism was required [source: multiple personal communications, since the spouse of one of us (Sacks) has been writing Len's biography]. Moreover, Len was chosen by a physicist, Walter Zinn, who headed the Argonne Lab at the time, and many of those who worked with Len on EBR-II were also physicists. Both engineers and physicists worked collectively as colleagues, with minimal appeal to hierarchical structure. Because of his leadership in this project, in 2004 Len was awarded the Global Energy Prize, Russia's equivalent of Sweden's Nobel Prize.

Wind and solar advocates rely far more heavily on theory, of a sort, than on practice when they (incompletely and inadequately) theorize about how the world's energy needs can be served mainly, if not solely, by wind and solar energy. Those who have actually built solar panels, solar thermal devices, and wind turbines have definitely combined theory and practice, but there is a vast difference between building these structures one at a time and knowing what would be needed to provide the major portion of a nation's or continent's electricity. It is in the latter arena that the wind and solar advocates lack, and even disdain, practice, but it is on the level of nation- or continent-wide grids that unanticipated problems are sure to arise, and already have arisen. The nuclear pioneers, however, have wedded theory and practice through the combined efforts of thousands of physicists and engineers over a number of decades. It is all the more ironic that wind advocate Mark Jacobson is an engineer but shuns the practice on a level necessary to make valid pronouncements about scaling wind farms up to meet the major portion of electrical needs. It may also explain why he finds it necessary to substitute outrageous lies for fact.

G. Locations of the various types of energy plants and the amount of land needed

While a coal, natural gas, or nuclear electricity-generating plant can be located just about anywhere, with the main considerations being where the land is uninhabited and where earthquakes are very unlikely to occur, wind and solar farms have to be located where the wind blows and the sun shines the most. Geothermal has to be located where the hot magma is closest to the earth's surface and most easily available, which will often be in the vicinity of volcanoes. And hydro has to be located at a river with a dammed lake. It is not an irrelevant point that fracking of shale for natural gas sources has already produced small earthquakes in places where none had occurred before. Thus, because of its tendency to produce small earthquakes, the longer the use of natural gas is allowed, and under capitalism this is almost completely out of the control of the public (without massive demonstrations at the very least), the greater might be the limitations on possible locations and construction requirements of power plants of any type. Furthermore earthquakes threaten all buildings, not just power plants.

Besides earthquakes, there are tornadoes, hurricanes, and floods to take into account, and for these, solar and wind farms are the most vulnerable. For example, a recent monsoon rain in India destroyed a significant number of PV panels, and winters commonly freeze and break wind turbines in northern Europe, where they are prevalent. Meanwhile each of these extreme weather events is becoming more and more frequent as the earth continues to warm during this frittering away of time over impossible dreams of profit opportunities, aided by manufactured fables about the unmanageability of the dangers of nuclear energy. Only the needs of the public are being left out. Perhaps the most relevant consideration is precisely the loss of time. While solar advocates project 40 years and wind advocates project 20 years, nuclear power has been fully developed, even though development for still better designs continues unabated. Adequate numbers of nuclear plants could easily be built in only a few years, except for the wrangling over profit, mixed with lies and distortions. Indeed, as of this writing, they are being built in many other countries at a rapid pace, with some 65 under construction, 155 already planned, and another 341 proposed, as of the beginning of 2011, in addition to the existing 430 worldwide (http://www.world-nuclear.org/info/reactors.html).

Any doubt that this could be accomplished in the U.S. in relatively short time, given the political decision to proceed, should evaporate with the knowledge that in the 1940s at the beginning of World War II, and even before the U.S. sent troops abroad, President Roosevelt enlisted the Detroit auto companies, particularly GM and Ford, to switch their manufacturing plants from civilian automobiles, busses, and trucks to military trucks, jeeps, tanks, and even airplanes, as well as ordnance. The conversion took only a few months before large numbers of these items were rolling off the assembly lines and sent overseas. As an aside, GM had for a few years already been manufacturing tanks and trucks for Hitler's blitzkrieg through its German subsidiary Opel (Black 2009). Even prior to this era, at one point in the 1880s, Westinghouse had overseen the construction of more than 100 electrical generating plants in less than 2 years, coal-powered at the time (Jonnes).

As to the amount of land needed, we have already seen that solar requires tens of thousands of square miles of land. Wind turbines stud hundreds of mountain tops, making the landscape almost as unattractive as blown away mountaintops, or, for that matter, big holes where uranium has been obtained in the past. At some level the concept of "unattractive" is a matter of taste, but surveys confirm that majorities generally object to wind turbines, not only because of their appearance but also because of their rhythmic noise. Hydro has required the creation of lakes by damming the rivers, which has destroyed huge tracts of land bordering these lakes, though the lakes themselves often come to be quite scenic. Fracking to get at natural gas, in addition to its potential to cause earthquakes, has become a tremendous hazard from its more than 200 toxic chemicals. It threatens to contaminate widespread water supplies near, for example, the huge Marcellus Shale underlying Ohio, West Virginia, Pennsylvania, and part of New York. Piping crude oil from the tar sands of northeast Alberta to the Texas Gulf refineries, as mentioned above, threatens the Ogallala Aquifer, the largest aquifer (underground water lake) in the U.S., underlying most of the central portion of the continental U.S. The power plants themselves, however, of any type, occupy small amounts of land and are generally confined to less than a square mile. Nuclear plants require no further mining, and therefore require only a few acres of land altogether.

H. Comparisons of the amount of fuel needed

This comparison involves only fossil fuels and nuclear energy, since the energy sources for wind, solar, hydro, and geothermal come from nature without human intervention, though, again, the equipment needed to turn those sources into electricity most assuredly requires human intervention.

Because the energy from fossil fuels is chemical energy (coming from the electron cloud arrangements around atoms), while that from uranium, thorium, and plutonium is nuclear energy (coming from the central nuclei of atoms), there is a vast difference in the amount of energy available from the two different types of fuel. In fact, the difference is about six orders of magnitude, or in plain language, over a million times greater from nuclear processes for the same weight of fuel. This means that nuclear is an extremely concentrated source of energy.

To give this difference a somewhat intuitive feel, the energy available from a golf-ball size piece of uranium is equivalent to that from 8700 barrels of crude oil, which would cover about half an acre if stacked one barrel high, and 2,250 tons of coal, which would fill about 25-30 railroad cars, depending on their size. Natural gas, unlike liquid oil and solid coal, is far more expandable, so comparisons with volumes are more difficult to make without specifying some temperature and pressure, but the idea is similar in terms of weight.

In fact, one day's operation of a 1 GW nuclear plant requires a little less than one and a half golf-balls worth of uranium, while a 1 GW coal plant requires some 37 to 45 railroad cars of coal, and for the more than 600 operating coal plants in the U.S. this would amount to something like 22,000 to 27,000 railroad cars of coal per day – a train that would stretch from about Maine to South Carolina, if it were all to be carried in one train. That's how much coal would be used every day to generate somewhat over half the electricity in the U.S. -- if all coal plants produced 1 GW of power. On the other hand, if there were 600 nuclear plants in operation rather than the current 104, and if they were all 1 GW plants, they would require about 840 golf balls worth of uranium, or a box measuring a little over a foot on each side, each day (a golf ball has a radius of 2.13 cm, which gives a volume of 40.5 cm^3; so 840 golf balls have a total volume of about 34,000 cm^3 or about 1.2 ft^3).

Mining that much coal would take a chunk out of a mountain, while mining that much uranium one could almost do with a hand shovel. Fracking for the energy-equivalent amount of natural gas would contaminate countless wells, aquifers, rivers, and reservoirs. While environmentalists may demonstrate against coal mining and fracking, they're mainly out demonstrating against safe, clean nuclear power plants that would obviate the need for coal mining and fracking in the first place. Thus they defeat their own goals.

This difference between environmental impacts of fossil fuels versus nuclear energy has implications for the waste products as well. As a round figure, the relative amounts of coal ash, both collected on the bottom of the plant (bottom ash) and emitted from the smoke stacks (fly ash), to that of a nuclear plant of the same energy, is a similar figure, namely a factor of over a million to one in terms of weight. But bottom ash is usually put into land fills or used to manufacture asphalt, and no one bats an eyelash about the toxins that are included and which remain forever toxic, and leach into water supplies. Meanwhile much anguish is spent on the potential burial of a box, measuring a foot on a side, worth of nuclear "waste," which decays away over time. And this is a "problem" that could be solved with breeder reactors that would reduce that spent fuel to only the fission products, which decay away much faster and can easily be shielded by salt, water, glass, or any number of other materials, for the few centuries necessary to return the level of radiation back to that of the natural background.

IV. <u>The beneficial response to low levels of radiation -- hormesis</u>

A. The science

Now we come to a part of the story that faces even greater ideological obstacles than the foregoing, but may be the most interesting, and is exceedingly well established scientifically. This concerns the biological effects of ionizing radiation, which is the only type of radiation we are talking about, since non-ionizing radiation, like sunlight, is not the great monster in the minds of the public and is not the type associated with nuclear reactors. Were it not for the tremendous fear of radiation and its alleged cancer-causing effects even from small amounts -- and if there were a clear understanding of the differences between nuclear energy and nuclear weapons -- there would be no question that nuclear energy is the only candidate to replace fossil fuels completely. But this fear of radiation has been the very reliable weapon of the anti-nuclear forces -- perhaps the most effective "nuclear weapon" in the world -- to shield from public discovery and rejection their distortions, whether some of them realize it or not, and often their deliberate lies. So for that reason we are bound to deal with this issue.

In sickness and in health -- the dialectics of disease

It is useful to begin with the broadest level of analysis. Illness (or injury) and health are ranges along a spectrum of states of being -- for all animals and plants, but we will confine our comments to humans. What determines whether we are ill or healthy is a sort of "class struggle" -- a battle within our bodies between influences that tend to push us in one direction versus those that tend to push us in the opposite direction. Under ordinary circumstances, there is a standoff between those opposite influences, and we remain relatively healthy. For example, we don't get an infectious illness simply because our bodies harbor some group of bacteria or another. After all, roughly 90% of our cells are bacteria, which, being among the smallest cells, constitute only about 1-2% of our average total body weight. The vast majority of bacteria are either good for us or neutral, while only a minority cause illness, and those are usually held in check by other bacteria and our fairly complex immune systems. We get sick not because we harbor bacteria, but rather because of an *imbalance* in that normally healthy state of affairs, i.e., when one side is strengthened or the other is weakened, or both. For example, when there is an influx of an unusually large number of bacteria from someone else who is sick, or when the other side in the battle, our immune system, is somehow weakened, either through stress or illness. But our bodies have evolved with responses that help us to fight off the invading bacteria, particularly responses from our immune system, which consists of special cells, antibodies, certain hormones, etc. In other words, sickness or health depends on the outcome of internal conflict. When our defenses are failing to win the battle, we can deliberately intervene with antibiotics to aid our overwhelmed immune systems.

Such outside interventions, however, often have their own unintended consequences, known as side effects. Often these side effects have to be dealt with by still another deliberate intervention, such as when antibiotics also kill beneficial bacteria and allow an overgrowth of fungal organisms that the beneficial bacteria ordinarily hold in check, resulting in oral thrush or other yeast infections. Then the thrush or yeast infection often requires another medicine. Thus the internal conflict can become fairly complicated, but regardless of complication the processes are still forms of internal struggle between opposing forces.

Another example is cancer. Because our normal metabolism produces *a million times as many free radicals* as radiation ever could, and because free radicals tend to damage our DNA, we have evolved biological responses that mend that damage and detoxify some of the free radicals. When a cell, because of its damaged DNA, becomes cancerous and threatens to spread and overwhelm our bodies, our immune systems have evolved to kill such cells, and do so continually every minute of every day -- another case of internal conflict. If our immune systems had not so evolved, we would not survive long, perhaps not long enough to have children, and the species would have long since become extinct. Of course, there are so many new toxins in our environment, particularly chemical toxins that are being developed in industry at a rate of scores every year, the cancer-causing toxicity has tended to overcome our natural defenses in many people, making cancer the second leading cause of death, at least in the U.S. -- second only to heart disease, which itself is largely due to human-made toxins, such as cigarettes. Assaults on our well-being from human made chemical and physical agents have developed so quickly that evolution has not been able to keep up with them. However, there is ample evidence (described below) that higher levels of radiation than those due to natural background would be able to protect us to a large degree against even the continual influx of new toxic chemicals.

Other types of illnesses, such as allergies, can be the "unintended" consequence of our immune system just doing its thing by attacking molecules that otherwise might not harm us -- for example plant pollens. Immune cells, after all, are not that smart and indeed are pretty ignorant of our needs, and they simply work automatically without reading any instruction booklet. Transplanted organs, being foreign to our bodies, are also normally attacked by our immune system, and we have to tame it by such things as the use of steroids, which have their own problems -- in particular, steroids cause osteoporosis (thinning and weakening of bones) and overweight, among other side effects.

This internal "class struggle" becomes more and more complex with intrinsic processes that fight illness but have side effects, similar to medicines, that themselves sometimes must be opposed through outside intervention. Degenerative diseases like osteoarthritis (wear and tear on cartilage and bones) elicit a bodily response of inflammation that can function to oppose and rebuild worn bone, but usually with inadequate effect -- sometimes requiring bone or joint replacements. On the other hand, there is a healthy level of wear and tear that exercise produces leaving a temporary destruction of muscle and other tissues that remains within the capability of our bodies to repair. Similarly traumatic fractures usually elicit an inflammatory response that initiates rebuilding of bone, but only if the fragments are not too numerous and are not too greatly separated from each other. Cuts heal with scar tissue, and so on.

The main point is that our bodies have evolved, through natural selection, to have biological responses that fight off damage of a wide variety of types. As we will see below, this is the rule and not the exception, and radiation is among those agents to which the body has evolved to respond, even to the point of overcompensation that yields further benefit.

Radiation in particular

The amount and impact of exposure to radiation is partly dependent on the route of entry -- i.e., whether the radioactive material is inhaled, swallowed, or remains outside the body. The exposure is also partly dependent on whether the radiation consists of alpha particles (helium nuclei with two protons and two neutrons, the heaviest of the radiation particles), beta particles (electrons, which are almost 2,000 times lighter than a proton or neutron), or gamma rays (a stream of electromagnetic photons, like light but of much higher energy). An alpha particle produced by radioactive decay of a source outside your body, even held in your hand, cannot penetrate your skin and travels only a few inches in air. A beta particle will barely penetrate your skin and travels only a couple of feet in air. Each of these travels even smaller distances in water. And finally, a gamma photon can penetrate deeply into the body or even pass through it completely, and this is the source of most radiation effects on health. On the other hand, if the source of alpha or beta particles is either inhaled or swallowed and stays within your body for any significant length of time, then radiation damage to cells and particularly DNA can indeed occur. Then dose makes all the difference, and it remains to be measured just how much of a dose determines the difference between harm and benefit. We repeat, lest there be any confusion or misunderstanding, that high enough doses of radiation can sicken and kill. It is low levels that cannot do harm and will produce a protective beneficial response, as we will show. This also assumes that the level is not *too* low, which also can cause harm in certain circumstances.

Which brings us to the next point -- benefit. The following paragraphs will naturally come as a surprise to almost every reader, just as it did to us when we first discovered a few years ago what turns out to be the extremely well-established reality, even if it is often ignored or denied. To make this even worse, one of us is a radiologist, but was assiduously trained, as are all radiologists, in the falsehood that no matter how low the population's exposure to radiation, it will cause a certain number of cancers – though, the story continues, the lower the exposure the fewer the cancers. But there are more than 3,000 studies from around the world, a few going back more than a century, that label this an out and out falsehood, with the finding that below certain relatively high thresholds, and within a particular range of dose, there is not only no *increased* risk of cancer, but rather there is actually a *decreased* risk of cancer and a prolongation of life expectancy, as well as a lessening of the likelihood of birth defects in the babies of exposed mothers.

These studies include many done in Japan, by a significant number of Japanese and other researchers, of survivors of the Hiroshima and Nagasaki nuclear bombs in 1945. Also they include studies of radiation workers, studies of apartment dwellers in radioactively contaminated buildings, studies of natural radon gas and lung cancer, studies of x-rays and breast cancer, studies of irradiated lab animals, and many other types of studies. Of course, in each of these fields the wheat must be separated from the chaff of bogus studies done to satisfy either misinformed and biased researchers or self-interested sponsors.

By way of introduction to these studies, low-level radiation, as you will see, can be thought of as though it acts like a vaccine, in which a small dose of the germ, or in this case radiation, stimulates your immune system to protect you against larger doses. But, in fact, exposure to low level radiation is better than a vaccine, since low exposures (within a certain range) stimulate protective mechanisms not only against higher exposures of radiation but also against many other chemical, physical, and particularly infectious threats to health and life. This defense mechanism stimulated by low levels of radiation -- whether it protects against many other insults or just to higher exposures to radiation -- is called the "hormetic" effect, and the defense phenomenon is referred to as "hormesis." The very word "hormesis," like the word "hormone," comes from a Greek word, meaning "to stimulate."

But note, just as with a vaccine, too little does nothing to protect and leaves the body vulnerable to either specific or general disease causing agents, while too much can either sicken or kill.

Scientific studies and other evidence from around the world

Just a small sampling of some of these studies includes the following: Among Japanese survivors of the Hiroshima and Nagasaki bombings 66 years ago, and who were about a mile and a half from the center of the blasts or farther, there have been fewer than average numbers of cancers or birth defects in their babies, when compared with the rest of Japan. There was a closer zone, perhaps from a mile to a mile and a half where the victims suffered from radiation sickness and either died shortly thereafter or recovered from the immediate sickness but suffered higher than average numbers of cancers in later years. Those within about a mile from the center of the blast died immediately, though not from the radiation but rather from the blast and resulting fires which didn't give them a chance to suffer the effects of radiation (Sanders). The pictures, repeated ad nauseum, of the infamous mushroom cloud that arose over both cities gives the misimpression that nothing survived for many miles around, but this is not at all true. We will have something more to say below about those in the middle zone who survived the blast and fires and recovered from the radiation sickness but later died from radiation-related cancers.

It need hardly be emphasized that these two events rank among the most horrible genocidal actions of all time, but, trying as best they can to turn a bad thing into a good thing, the many Japanese researchers and others who have studied the long- and short-term survivors have discovered many useful biological facts about the impact of radiation on humans. These lessons are applicable to nuclear energy in general.

Some 70,000 shipyard workers, who are all presumably healthy enough to do this heavy labor, have been followed for many years -- both those who work around the nuclear reactors that they install in submarines and in some aircraft carriers for the U.S. Navy, and those who do their construction work remote from reactors and their radioactive fuel. It was found that those who worked with the nuclear reactors had significantly lower cancer rates and lived significantly longer than those who worked elsewhere in the shipyards, implying that the former were also somewhat protected against other causes of death, though no one can be protected against death forever (http://www.ecolo.org/documents/documents_in_english/low-dose-NSWS-shipyard.pdf). This became part of an overall analysis of studies including a total of 250,000 nuclear workers in various types of jobs from the U.S., Britain, and Canada, who have been followed for decades and have been found to have an average death rate (at any given age) approximately half that of non-nuclear workers overall, but ranging as low as one quarter to no higher than three quarters the death rate of non-nuclear workers (http://www.radpro.com/641luckey.pdf). Internal communications between different departments of the U.S. government often suppress such studies and/or misrepresent the actual findings (see for example, http://www.radscihealth.org/rsh/Docs/Correspondence/DOE-GAO-WPost%20letters/GAO_Report-DOE_Misrepresents_NSWS.htm).

Ten thousand apartment dwellers, who had lived in a 180-building development in Taiwan for one or two decades, were studied by Taiwanese researchers. The reason for this attention is that the steel used in the building construction had been inadvertently contaminated with cobalt-60, a radioactive isotope of cobalt that is also used in radiation therapy for known cancer sufferers, with a half-life of about 5 years, making it fairly radioactive and explaining its utility in radiotherapy. These apartment dwellers were continually irradiated for years whenever they were at home, at doses well above the background natural radiation. It was found that they had only about 3.5% the rate of cancer of the rest of the Taiwanese and about 6.5% the rate of birth defects in their babies -- that is, stunning reductions in cancer rates of about 96.5% and of birth defects of about 93.5%. The conclusion was that the continual above-background irradiation conferred tremendous protective benefit, perhaps the most outstanding of any of the observations (http://www.jpands.org/vol9no1/chen.pdf).

Radon is a natural decay product of underground uranium and is a radioactive gas that seeps up out of the ground, the recognition of which gave rise to a widespread push in the 1980s to urge people to pay to have their homes inspected for radon levels and protected. The radon protection companies behind this push, who stood to profit mightily, were aided by the government's attempt to scare people with cries of danger. Indeed it is still not uncommon that, in order to sell a house, the owner has to provide a certificate of radon inspection to the buyer. A multiyear study of the relationship of lung cancer and home radon exposure in the early 1990s was performed all over the U.S. involving over 1700 counties and over 90% of the U.S. population. The researcher, a physicist from the University of Pittsburgh, Bernie Cohen, began by assuming that the higher the radon levels in any particular county, the higher would be the rates of lung cancer from the inhalation of this gas. He was merely trying to find just how steeply the relationship rose and to test whether the rise in cancer was proportional to the dose. But he found the exact opposite. There was a direct negative correlation, such that the counties with the highest radon levels had the lowest rates of lung cancer, and vice versa. Since the result startled him (he was not biased in the direction of this finding), he worked with a statistician to discover what factor "ruined" his results. After testing more than 500 possible factors, such as smoking rates, they were forced to conclude that the result had to be real, i.e., that breathing radon, at least at the levels found in homes, protected against lung cancer. (See Cohen, B.L., "Test of the linear-no threshold theory of radiation carcinogenesis for inhaled radon decay products," Health Physics 68: 157-174; 1995. Also http://www.phyast.pitt.edu/~blc/ for a list of more of Cohen's papers.)

Much has been made over the fact that uranium miners, who also breathe in a significant amount of radon in the mines, have relatively high rates of lung cancer, but, as we mentioned above, it has also been found that people who live in the vicinity of these mines, including the miners' families, have no higher rates of lung cancer than those who live distant from the mines (Boice). Since this discovery, the ventilation inside the mines has been markedly improved. But because many southwest uranium miners happen to be members of the Navajo nation, though not a majority, the mine owners were rightly accused of severe racism in their previous failure to ventilate the mines adequately -- again, and as usual, with the collaboration of the governmental regulatory agencies. And again, white miners were hurt by this racism along with the Navajo. Racism, as is always the case, hurts not just the targets of the racism but all workers.

But the problem still remains as to why the miners had higher rates of lung cancer if those who lived near the mines did not. It turns out that a very great proportion of them were also smokers, in addition to which they spend very long hours over many years in that atmosphere. It is conceivable -- though we are not aware of any studies of this one way or the other -- that an interaction of smoke particles in the lungs with radon's decay products can actually cause them to stick around longer than otherwise and contribute, along with the smoke itself, to the lung cancers. In other words, the biological half-life (how long it takes for half the material to leave the lungs) may be the more important variable than the radioactive half-life. But in the absence of smoking, or perhaps even in the presence of it, radon is protective, at least at levels found outside mines and most likely even within them.

There are actually mines and caves with high levels of radon, both in Europe and in Wyoming and Montana, where people go deliberately to alleviate such ailments as the pain of arthritis, with great success. Many hot springs are used as health spas, particularly in Canada and Europe, and the source of the heat is underground radioactivity. One of us visited the town this past summer (2011) in British Columbia called (imagine this being advertised in the U.S.) Radium Hot Springs, where a huge swimming pool was filled with radioactive water and with people seeking to improve their health. And there are a number of radiation therapists in Japan and China -- and we know of at least one in the U.S. plus a hospital in Ontario, Canada -- who use low level total-body radiation to try to cure cancer or prevent relapse, with relatively high levels of success. Survival rates far exceed those who do not receive this total-body radiation (Pollycove et al., Cuttler et al.). This is different from the far more commonly accepted high level radiation therapy that is targeted only to the tumor, avoiding the normal surrounding tissue as much as possible and spacing out the treatments to allow the normal tissue to heal itself. However, even with such high level targeted doses, there have been found no significant increases in other cancers in such patients.

A study in Canada of tens of thousands of women who were subjected to great numbers of chest x-rays in the 1930s and '40s, to follow cases of TB, which was previously endemic there, found that those whose breasts had been exposed to total radiation doses between certain limits (about 10,000-30,000 mrem; a mrem, pronounced millirem, is a common unit of absorbed radiation dose) experienced lower rates of breast cancer than those who had been exposed to either lower or higher radiation doses beyond that optimal range (http://www.jpands.org/vol8no2/kauffman.pdf). That is, rather than keeping patients to the *lowest* possible dose, we should be kept within the *optimal* dose range, meaning adequate levels.

Then there is the better known fate of those women in the 1920s U.S., who painted the glow-in-the-dark radium on clock and watch faces. They were in the habit of licking the tips of their paintbrushes to bring them to a sharp point after they had been dipped in the radium. Many of these women died from bone cancers from the radioactive radium, which is chemically similar to calcium and therefore deposits in bones. What is much less well known is that the only women who contracted those cancers were those who received a dose above a certain threshold, and those who received below that threshold developed no cancers. And only about half of those who received doses above the threshold developed cancers (http://www.rerowland.com/dial_painters.htm). But the main point for our purposes is that there was a threshold of exposure, below which no apparent harm was done.

Also fairly well known is the case of Marie Sklodowska Curie, the Polish-French researcher of radium in the early 20th century. She is better known as Madame Curie because of the sexist practice of identifying women only with respect to their relationship to their husbands, in this case fellow-researcher and Prize winner, Pierre Curie. She is also known as one of the handful of scientists who have received not one but two Nobel Prizes. What is perhaps even better known about her is that she died from aplastic anemia (a blood cancer), presumably contracted as a direct result of her long-term unprotected work with the radium during an era in which little was known about the biological effects of radiation. But lesser known is the fact that she did not die early. She lived to the age of 66, which exceeded the life expectancy of French women at the time by a few years. Her longer-than-average life may not have been *because* of her years-long exposure to the radium at very close range, but at the very least it was in spite of it. (Pierre, as it turns out, died tragically at age 46, though not from radiation but rather as a result of an accident when he slipped in the rain and was hit by a horse-drawn cart.) The main lesson from this experience, as well as many others, is that even a relatively *high* dose of ionizing radiation is a fairly weak carcinogen (cancer-causing agent), particularly when compared to the effects of thousands of chemical elements and compounds, including many associated with fossil fuels as well as with some of the materials used in solar PV cells and wind turbine blades.

The weakness of radiation as a cancer-producing agent is also manifest in the relatively low frequency with which it causes damage to our DNA, compared with the frequency of such damage caused by the free radicals produced *continually* by our normal metabolism -- final score: Normal Metabolism 1,000,000; Radiation 1 (a million to one). That is, the home team "wins" hands down. Yet if our bodies had not developed defenses against the side effects of our own normal metabolism, we would not be here. Not only is the damage due to radiation a million times less than that due to our normal metabolic processes, but radiation actually enhances those very defense mechanisms that are already present to protect us against our normal metabolism. The net result is that radiation helps us to even better withstand the assault by DNA-damaging free radicals. That effect of ever-present normal background radiation has, no doubt, been part of what has allowed humans and other animals to evolve to our present status (Sanders). Details on the differences between damage to both strands of (double-stranded) DNA and to only one of the two strands do not change the overall conclusion and are therefore omitted here as unnecessarily complex.

This is a very tiny sample of the studies and other demonstrations of the normal biological protective response to low-level radiation in humans. The only reason these results may seem incredible is that this information has remained hidden, almost since World War II, from the public and the media. But, again, more than 3,000 studies spanning more than a century provide evidence for what turns out to be the *net* beneficial effects of low levels of radiation, due to the natural biological responses of exposed plants and animals, including humans.

Laboratory studies on non-human animals include, just to give an idea, studies involving the irradiation of mice with low levels of radiation followed only a few hours later by high levels that are enough to kill, with the result that those who received the earlier low levels survive without harm, while those who were not given the low levels all die. And this is after only a few hours delay, indicating how quickly the protective biological response sets in. The human studies are more useful to demonstrate the *existence* of the protective responses in humans, while the animal studies help determine the *mechanisms* through which they work. These have been found to include stimulation of production of repair enzymes in the nucleus to fix damaged DNA (the hereditary material in each cell's nucleus), stimulation of cell suicide (called apoptosis) to eliminate DNA-damaged cells before they become cancerous, effects that damaged cells have on their neighboring cells thereby stimulating the neighbors to secrete proteins that help the damaged cell with repair or cell suicide (called the bystander effect), detoxification of free radicals that are created to a small extent by the radiation but to a far greater extent by normal metabolic processes in virtually all cells, and stimulation of certain functions of the complex immune system to rid the body of cells that are in danger of becoming cancerous. The latter effect, because it involves a systemic impact on the entire body, is perhaps the most important in conveying general resistance to other agents, including a wide variety of both bacterial and viral infections and a wide variety of chemical toxins. There may be still other mechanisms, but, regardless of the mechanisms, the *fact* of hormesis from low levels of radiation is undeniable if one examines the overwhelming evidence with an open mind and is honest.

In each of these cases there are papers and articles both by those who claim that all radiation is bad for the health and by those who understand and demonstrate the reality of hormesis. Steering one's way among them, and trying to see who is right and who is wrong, takes a significant amount of work, but generally the last word is from the hormesis advocates, who defend their own findings and expose the various tricks that are used by the opposition to distort reality -- some tricks are statistical, some use various averaging techniques that mask the differences within and departures from average, as well as a variety of other devious methods including suppression and misrepresentation of data. One relatively reliable way to tell which group is scientifically correct is to look for those who rebut all opposing arguments versus those who avoid them and bring up entirely new arguments from right field.

Current government regulations are the real source of harm

So the good news, as it turns out, is that, because of our normal biological protective responses, low levels of radiation, within certain dose ranges, are actually good for you, and insufficient levels are harmful to your health, as are levels that are too high. Don't, however, rely on the U.S. government regulators in the Environmental Protection Agency (EPA), the Nuclear Regulatory Commission (NRC), the Center for Disease Control and Prevention (CDC), or the Food and Drug Administration (FDA), or, for that matter, nuclear and radiation regulatory agencies of any government in the world, to tell you this. One way that we know about this veritable dark ages of misinformation is that one of us (Sacks) worked for the FDA's Center for Devices and Radiological Health for almost 8 years. While many friends and colleagues there know very well that low levels of radiation produce a protective response, they nevertheless say it would be too complicated to regulate radiation based on this truth (one colleague claimed that to do so would be "a regulatory nightmare") and much easier to base it on a particular lie (described more fully in the following paragraphs) because it is much simpler mathematically. The colleague quoted in the previous sentence, generally a very honest person, also expressed the rationalization that this lie errs on the safe side, saying it is "the more conservative" point of view. We will show below that this is too narrow a view and that the opposite is the case, if the resulting hysteria and phobia of radiation are taken into account. Of course, while regulators, despite their rationalizations, may be protecting their careers and egos, the fossil fuel companies are drooling all the way to the bank, whether or not they actually pay under the table for such outcomes.

Instead of being honest, the regulators base their regulation on what is called the linear-no-threshold (LNT) approach. LNT, as the name implies, is the pretense that even the smallest amount of radiation causes deaths from cancer. This falsehood, while correct about the damage to DNA done by low levels of ionizing radiation, deliberately denies the very existence of well-proven protective responses to this radiation damage. And the official purveyors of LNT routinely ignore, rather than try to refute, the huge numbers of studies that prove them wrong.

Nor is it because they are unaware of these studies, since a number of hormesis researchers have appealed directly -- repeatedly and strenuously but without success -- to the various regulatory agencies to pay attention to their research findings on hormesis. The reason the agencies ignore these studies of hormesis is that they are, in fact, unable to refute their findings. They can even sort of admit the probable existence of hormesis on occasion, yet then go on to admittedly pretend it isn't so for the sake of mathematical simplicity (see, for example, the U.S. NRC's website: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html).

And here is where lessons from the Japanese nuclear bomb survivors come into play. LNT is a mathematical extrapolation from the true cancer rates due to high-exposures -- suffered by those Japanese survivors in the middle zone of distance from the nuclear bomb blasts -- down to imaginary cancer rates due to low-exposures, all the way down to zero. This false extrapolation ignores completely the lessons to be drawn from the fact that even in Hiroshima and Nagasaki no such linear relationship was found in the long-term survivors who were more than about a mile and a half from the blast and therefore received lower and lower doses down to essentially zero above natural background. Rather, not only did they not develop cancers at successively lower rates *above* the average in Japan, but they actually developed cancers at rates *below* that average. Thus a threshold exposure clearly was found, below which the radiation was not only harmless but actually produced a protective response -- and certainly it was not (simply less) deadly, as LNT holds. This information has been effectively thrown away by the LNT advocates, who prefer the simple mathematical extrapolation from the high exposures down to zero -- one that would hold in the absence of a protective biological response -- rather than use the real information from those who actually received those doses. Such ostrich-like behavior is certainly much easier, even if it is also dishonest and far more harmful, as we will see.

But the regulatory adherence to LNT produces irrationalities such as if, for example, companies that produce aspirin -- known to kill in high doses and not infrequently used in suicides -- were forced by the FDA to place a warning label to the effect that those adults who take a couple of aspirin (whether they call their doctor in the morning or not) are vulnerable to a certain low risk of death from the pills. In particular, since 100 aspirin will kill 100% of the people who take them, it would be like assuming that 2 aspirin would kill 2% of the people who take them -- one out of every 50. The fact is, of course, that older men and women are well advised to take a baby aspirin once a day for its apparent protective properties against heart attack and stroke -- notably due to aspirin's anti-inflammatory effect. One baby aspirin a day, in other words, lowers rather than raises the risk of death according to numerous clinical studies. And so do low doses of radiation. It should be added that under certain circumstances children, as opposed to adults, may indeed suffer from low doses of aspirin.

One inherent implication of LNT that illustrates its nonsensical conclusion is the contention that a particular total dose of radiation energy will cause the same number of cancers, several decades in the future, regardless of the number of people who share that dose -- called the "collective dose" concept. In other words, it implies that if one person exposed to 2 million mrems will get cancer from it, then if 2 million persons are exposed to 1 mrem each, one will still get cancer from it. However, this could only be true in the complete absence of any defense mechanisms, and many of these mechanisms are well known even to those who deny hormesis. Consider the following facts.

Radiation is natural and all around us

In the U.S. *on average* we each experience about 360 mrems a year due to natural background radiation, with variation over a range of more than twenty to one, depending on geography. As we mentioned above, this background comes from the sky (cosmic radiation from stars) and from the ground (radioactive elements that have been part of the earth since its formation billions of years ago, including uranium, thorium, radium, radon, polonium, and others). Locations at higher altitude, such as in the Rocky Mountain states, receive more cosmic radiation because of less atmosphere to shield us from the stars, and more ground radiation because of the large amount of underground uranium, etc. in the mountains. So living in a place like Denver at one mile altitude gives far more radiation every year than living in a sea level city such as New Orleans.

Our food is already loaded with naturally occurring radioactive potassium (K-40) and carbon (C-14). Of the 360 mrems each year, about 20 mrems comes from inside of us from the potassium and carbon that we eat and absolutely need in order to live. You read that correctly -- every one of us already contains radioactive material, round the clock from birth to death.

Humans and other animals, as well as plants and bacteria, have evolved in a veritable sea of radiation. This radiation, over hundreds of millions of years of evolution, has selected for living entities that had hormetic responses, because in the absence of a hormetic response -- i.e., if radiation really killed at these levels, as LNT maintains -- we might not even be here. Furthermore the levels of background radiation vary not only within the U.S. but around the world, covering a range of about 250 to 1. The highest levels are found in Ramsar, Iran (26,000 mrem/year), Guarapari Beach in Brazil (7,500 mrem/year), and Kerala, India (7,500 mrem/year), among other places in the UK and China -- compared to 360 mrem/year average in the U.S. If LNT were true, populations in Iran, Brazil, India, UK, and China, as well as in the Rocky Mountain states in the U.S., would have higher than average cancer rates and lower than average life expectancy. Yet hundreds of studies of populations in all these high-radiation areas around the world show that the rates of cancer are lower, or at the very least not elevated, in these regions. Denver, for example, has lower cancer rates than in the southeast U.S., though both the levels of cosmic and ground radiation are higher in Denver. Of course, using the example from one place without looking into other chemicals or cancer-causing practices, such as smoking rates, doesn't prove anything. It is the widespread information from all over the U.S. and the world, in which smoking and scores of other possible influences were also investigated, that gives the more reliable conclusions.

In fact, to make this even worse, the U.S. Nuclear Regulatory Commission (NRC) even admits that low levels of radiation have never been shown to cause harm (see, for example, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/bio-effects-radiation.html). But still the NRC promotes fear, whether deliberately or not, by maintaining admittedly unfounded rules for exposure, which propose upper limits that are absurdly lower than the natural levels of radiation in many places around the world, as well as in the U.S. So while hormesis may be *artificially* controversial, there are no studies that confirm LNT -- or even could confirm it against the background of huge numbers of cancers due to the sea of human-made chemicals that submerge our lives -- and thousands of studies that prove it false.

In response to our speaking and writing about hormesis in a number of outlets, including our local newspapers and professional meetings, we have encountered the charge, from those who have done no investigation themselves, that hormesis is controversial, intended to imply that there is no hard evidence for it. What such skeptics fail to recognize is that controversial does not mean ambiguous. Controversy can be produced at will by even a single opponent, whereas ambiguity is a property, either present or absent, of scientific evidence. Remember, for many years the causal link between smoking and lung cancer was kept artificially controversial through the combined efforts of the tobacco companies and their buddies among government regulators of drugs, even though the scientific evidence of the causal link had long since been unambiguous (Oreskes and Conway). Indeed, in their book *Merchants of Doubt*, Oreskes and Conway describe the way a handful of scientists were hired by special interests to deliberately and dishonestly create artificial controversy on a number of issues over the years, including acid rain, the ozone hole, secondhand smoke, global warming, and the harms of DDT. The reality of radiation hormesis would be no more controversial than the causal link between smoking and lung cancer if the government regulatory agencies would finally admit that they have been operating on a demonstrably false basis. The reality of radiation hormesis is already scientifically unambiguous, and becomes more so with every study. LNT has rightly been called by Gunnar Walinder, former chair of the Swedish Radiobiology Society, "the greatest scientific scandal of the [20th] century."

As mentioned above, imagine if governmental regulators operated as though everything that is toxic in high doses were also toxic in low doses. They would outlaw, or force death-warning labels to be placed on, things like vitamins, aspirin, zinc, selenium, and so on, while warning people to shield themselves completely from sunlight, oxygen, and water. That, in fact, is what they are doing with ionizing radiation. Everything in the world is toxic in high enough doses and most, if not all, are also dangerous at inadequate doses, but many are life-saving in a middle range (the hormetic range). Radiation is no different in that respect from things like vitamins, sunlight, and oxygen.

Hormesis is not the exception -- it is the rule

Let's look briefly at how all these other agents work on us. It can be embodied in the phrase "All things in moderation." Too little oxygen, for example, will suffocate and kill, while too much oxygen will cause blindness and many other harmful nerve conditions, while there is a zone of amount that is just right for health and life. Or too little sunlight used to cause rickets and malformed underdeveloped bones in children until vitamin D was put into milk and other foods, while too much sunlight causes skin cancers and sunburn, and just the right amount in that midzone promotes health and life. The midzone is called the hormetic zone, and sometimes, somewhat wistfully, the Goldilocks zone, after the fairy tale. Another everyday example is water – too little and you die of dehydration, too much and you dilute your electrolytes and cause abnormal heart rhythms, but there is a hormetic zone in the middle.

Vitamins, in general, were each discovered in populations that lacked the particular vitamin in their diet and as a consequence suffered from such diseases -- in addition to rickets (vitamin D) -- as scurvy (vitamin C), beri beri (thiamine), pellagra (niacin), a particular type of blindness (vitamin A), and so on. Restoration of each of these vitamins to the diet, once discovered, cured and/or prevented the diseases. Yet an overdose of any one of these vitamins harms your health. Even well known poisons like cyanide and arsenic are present in fruits, for example apples, but in such small amounts that they do no harm, even if they may do no particular good -- a question perhaps not yet settled for some chemicals. What is considered a poison is strictly dependent on the dose, i.e., an overdose, as already noted long ago by the 15th century Swiss physician, Paracelsus.

It would be extremely strange if ionizing radiation were somehow different from everything else that impinges on, or in, our bodies, and exhibited no threshold. Rather evolution, through natural selection, has permitted survival in the face of *all* natural harmful agents by means of particular protective biological responses. The result of this very lengthy natural process has been the production of an organism in which higher levels of radiation than those normally encountered inhibit defense mechanisms in the body and sicken and kill, while low levels in a certain range stimulate those defenses, just as with many other harmful agents. Thus ionizing radiation is necessarily one among numerous hormetic agents. Furthermore levels that are too low, in fact, fail to stimulate protective mechanisms adequately and result in higher rates of cancer and death than do levels within the hormetic range. Mice raised from birth in radiation-shielded environments in the lab fail to develop immune systems and die young, from a variety of insults. Government regulations that push upper limits down below the hormetic range increase our cancer and death rates above what they otherwise might be -- i.e., inadequate doses kill as surely as overdoses. Fittingly a now out-of-print book by Gunnar Walinder (who was mentioned four paragraphs above) is titled rhetorically *Has Radiation Protection Become a Health Hazard?*

The existence of a hormetic zone even applies to things such as psychological states. Consider, for example, a phenomenon that we have had much to say about in this essay, namely fear. Too little fear and a baby can crawl off a changing table, too much fear and one is afraid to leave the house, but a certain amount of fear of such things as oncoming trains stimulates an appropriate care response. Or consider skepticism. Too little skepticism and one might put one's life savings into Enron stock, too much skepticism and parents might refuse to have their child vaccinated, but a certain amount of skepticism over such things as our claims that nuclear is the best source of energy for the public, or that global warming is caused by human activity, is healthy -- but only if it stimulates you to engage in a certain amount of investigation on your own. That is how the authors arrived at our present position on these subjects.

If the regulators would instead identify the thresholds for radiation harm versus benefit, as they at least claim to do for most other agents, we would be far better off. The LNT fiction, with its denial of the existence of well-proven, and evolutionarily assured, protective biological responses, contributes to tremendously harmful and destructive fear. This fear, as we mentioned above, prevents many women from seeking life-saving mammograms to detect breast cancer early enough to cure it or prevents many people from getting CT scans that they need for diagnosis of a possibly fatal but potentially curable condition. Here one of us (Sacks) speaks from personal experience as a radiologist. In addition, the fear has been the basis of mass relocations in the vicinities of Chernobyl and Fukushima that are wholly unnecessary as far as the possibility of physical harm is concerned but that cause untold amounts of psychological harm, with consequent alcoholism, voluntary abortion, depression, stress-related heart attacks and strokes, and suicide from loss of jobs, of community and family ties, of homes, and of familiar surroundings. But most important for the long-run wellbeing of the world's people, fear fuels the anti-nuclear environmental organizations that have often blocked the construction of needed nuclear reactors to replace coal and natural gas power plants and oil-requiring vehicles. These reactors would save millions of lives over short periods of time and would preserve the planet's livability for future generations. Thus does the LNT falsehood kill. It most assuredly does not err on the safe side, as many of the more knowledgeable and honest regulators rationalize.

Chernobyl and Fukushima

The only relevant question with regard to Fukushima is whether the amount of leaked radiation is within the hormetic zone. If so, then the only harm that will be done, other than to TEPCO's profits, will be from the government-forced relocations of thousands of people living in the vicinity of Fukushima away from their communities, homes, and jobs. Such a mass relocation was done to over 300,000 people around Chernobyl, resulting in immense numbers of suicides, epidemic alcoholism, and many other signs of stress such as heart attacks and strokes. And that was just in the vicinity of the plant. Because of the widespread and uninformed fear, in the wake of Chernobyl there were an estimated 100,000 to 200,000 voluntary abortions among Western European women and over a thousand suicides in Northern Europe. It was not the radiation that took this terrible toll . It was the falsehood of LNT and the fear it engenders. The U.N.'s World Health Organization (WHO) still predicts up to 4,000 deaths eventually from Chernobyl, basing their calculation on the LNT falsehood, but even WHO admits it is possible that no more cancers due to the radiation will appear. However, even this admission understates the truth by a tremendous margin, since it has been found that the second most severely exposed group to Chernobyl's radiation (the more than half a million workers who were part of the clean-up crew) have developed, in the ensuing quarter century, significantly *fewer* cancers than people elsewhere in Russia.

In over half a century, aside from a handful of workers killed at experimental and/or military reactors, this has been the only nuclear power plant accident that has killed anyone, and the number of deaths from radiation has been wildly exaggerated beyond the fewer than 60 among plant workers and firemen. The exaggeration has come not only from anti-nuclear forces but also from neighboring Belarus for purposes of their court suit against Russia for compensation. The latter falsely and outrageously manufacture a claim of a million deaths -- an exaggeration by more than four orders of magnitude, i.e., by a factor of more than 10,000. They accomplish this sleight of hand by pretending, in essence, that every death within the area over a couple of decades, regardless of cause, was due to Chernobyl, as though all deaths from natural causes, illness, injury, and so on, had suddenly ceased for over 20 years to make way for deaths due strictly to radiation. (The opposite has, in fact, been shown to be true -- that is, the radiation has actually decreased the numbers of cancers and deaths among the involved populations.)

Unfortunately a book with this claim of a million deaths, commissioned by Belarus, was published by the New York Academy of Sciences (NYAS) in 2009, apparently without having been evaluated for its lack of scientific basis (Yablokov). Since then the NYAS has been the object of vehement criticism from many of its members and others for its implied endorsement of this travesty of subjective cherry picking, even though in the wake of this criticism NYAS has tried to deny any support for the claim. The best exposé of its made-up "facts," written by M. I. Balonov, can be found at http://www.nyas.org/publications/annals/Detail.aspx?cid=f3f3bd16-51ba-4d7b-a086-753f44b3bfc1. Yet the big lie technique rides again. It pushes people to ask, "Why would someone claim a million deaths if it weren't true?"

One Polish doctor, the late Zbigniew Jaworowski, who aided in the treatment and relocation of people around Chernobyl, looks back and regrets having participated in the relocation. He has written a number of papers about the basis of his conclusion that no one needed to have been moved at all, and that it was the biggest mistake of his career to have been part of that effort. His eventual conclusion is based, as you might expect, on his having come to understand hormesis in the interim. Furthermore he was a member of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) for almost 40 years and was its president for 3 years. His insider's viewpoint is valuable, since he points out that while the organization discussed the hormetic effect in 1994 with his participation, the report that it issued that year does not mention the discussion, apparently reflecting some outside influence on the report to hide the discussion from public view.

Continuing their ongoing campaign to fan the flames of fear, Greenpeace has released a photo album of the contaminated zone around Fukushima to mark the one-year anniversary of the Dai-ichi meltdown, relegating the more than 20,000 deaths from the tsunami to secondary status. One picture shows an abandoned building in the hot zone, taken of course on a forbidding looking cloudy day, but all of them imply falsely that the zone is uninhabitable (http://www.greenpeace.org/international/en/campaigns/nuclear/safety/accidents/Fukushima-nuclear-disaster/Shadowlands/.) Both in this Greenpeace release and in many other sources the radiation level is often reported in a less easily understood hourly dose, though their reported 5.7 microseiverts per hour comes to about 5,000 mrem/year, and is declining every day due to radioactive decay and to the natural dispersal of the cesium. Such sources fail to mention that there are many places in the world where the natural background radiation level is much higher -- up to 26,000 mrem/year in Ramsar, Iran -- and where the rates of cancer are not elevated, and instead are usually lowered. That is, Greenpeace and other anti-nuclear organizations thrive on half truths and complete falsehoods designed to aid their campaign to create anti-nuclear hysteria.

B. Over-regulation is even more harmful than under-regulation

This may come as a startling statement, or at first even appear completely ridiculous. But to follow the logic, what then should regulatory agencies be doing with respect to nuclear power plants? As with all capitalist concerns -- both industry and governmental regulators -- they cannot be trusted based on any imagined concern for the wellbeing of the public, since the profits of industry are the first and main concern of both capitalists and their governments world over (though we hasten to say that there are many honest concerned scientists and other workers in government agencies whose advocacy for public health is swept aside by their supervisors and administrators -- again, a point confirmed by Sacks's personal experience at the FDA). But there is a basis for some degree of trust other than concern for public welfare.

First of all, when the public eye is kept as firmly, through the media, on an industry as it is on the nuclear power industry, their movements are somewhat restricted, though this should not be exaggerated. Second, the capital investment in a nuclear plant is substantial, and the owners therefore have an interest in preventing, as best they can, any major accident that would destroy that capital, such as happened at TMI, Chernobyl, and Fukushima. Of course, this always competes with the profit-driven tendency to cut corners and save costs in the short run, but the above points support the desire to protect the safety of the plant more than the cutting of corners. There have been a number of relatively minor problems in commercial nuclear power plants in the U.S., France, UK, Japan, and no doubt everywhere in the world that they exist. These include fires, leakages, failure to inspect integrity of reactor materials and surroundings, among others. But **not a single one of these in any *commercial* reactor has resulted in harm either to the workers or to the public outside the plants**, with the qualified exception of Chernobyl (not really a commercial plant). And third, the scientists and engineers who design and build nuclear power plants have generally been employees of the government, for example in the U.S. Department of Energy laboratories, such as Argonne, Oak Ridge, and so on, and not employees of private industry. The government scientists and engineers have been granted relatively high job security with prolonged status in their positions, that they accept for lower salaries, so that their interests lie primarily not in enlarging the profits of some private energy company, but rather in contributing something useful to humanity, which includes maximizing safety (Till and Chang -- this also accords with Sacks's experience at the FDA).

There have been occasional similar small problems with reactors on submarines and aircraft carriers, but by and large these have been among the safest means of vessel propulsion. Ted Rockwell, one of the nuclear pioneers in developing the reactors for U.S. naval vessels, has recently declared, "Naval Reactors have run 6300 reactor-years, driving 528 reactor cores on 220 ships over 145,000,000 miles without a single radiological incident or injurious radiation exposure to crew or public" (Rockwell -- www.learningaboutenergy.com). Absolutely no fossil fuel energy source can come close to that record, to put it mildly.

But regulatory agencies around the world, in reaction to Fukushima, have declared that they intend to tighten up still further on radiation regulations. Focusing on *radiation* regulation, however, is not the way to enhance still further the safety of commercial nuclear plants. It only throws up more obstacles, based on a falsehood, that make it much harder to obtain licensing to build a nuclear power plant, encourages fearful and/or dishonest people to demonstrate against their construction, and discourages the only feasible transition away from fossil fuels, so long as capitalism rules the roost. But even today, the focus needs to be on the plants, not the radiation limits, which are so far below natural background radiation levels as to be farcical, and an incredibly deadly farce at that, as we showed above. This absurd reaction on the part of regulatory agencies only offers further evidence that they cannot be trusted with the public's health. Just as with the increasing reports of near catastrophic errors by overworked air controllers, the inspections at the point of energy production or air control are the very thing that is needed and is largely being avoided. It's so much easier to put out rules from an office than to hire and train enough inspectors to cover multiple power plants.

Nevertheless nuclear power plant owners have huge investments and face a bright spotlight on their doings. For these reasons they cannot afford to let things deteriorate to the point of any real danger, and there is a tremendous safety factor already in the designs by nuclear engineers, who have no other motivation in general than the health of the industry. Their jobs, after all, depend on its remaining alive, just as the jobs of regulators depend on their over-regulation. This offers some balance, but, if not the science, the long unmatched record of safety is the most compelling reason to let go of the fear and hysteria that prohibit the further development of nuclear energy, particularly in the U.S. and Germany, which are the two countries that seem to be the most under the spell of anti-nuclear movements and their backers in the fossil fuel industries, whether through cash or just favorable publicity.

(It should be noted that as of this writing, the U.S. NRC has just approved the construction of two large nuclear reactors in Georgia, the first to be licensed in over a third of a century, and seems to be about to approve two more in South Carolina in the near future. The vote among the commissioners, interestingly, was 4 to 1, with the sole dissenting vote coming from the chairman, Jaczko, who is a known nuclear fearmonger. The other 4 have recently tried to have him removed from at least the chairmanship if not the commission.)

But a far more serious issue is that over-regulation targeted at radiation levels obscures the very real possibility that most humans suffer from *radiation deficiency*. From the fact that about half of the studied 250,000 nuclear workers mentioned above have been protected from early cancer deaths by their years-long exposure to above-average radiation, Don Luckey -- a pioneer in studying and summarizing several thousand studies of hormesis, as well as in producing some early studies of his own -- has concluded that a deficiency of radiation is similarly responsible for about half the early cancer deaths in the general U.S. population (Luckey). This means that, of the 600,000 persons who die from cancer each year in the U.S. alone, approximately half (300,000 every year, or over 800 persons per day) could have had their lives prolonged if everyone had access to hormetic levels of radiation above the background.

Even more striking is a corresponding conclusion based on the Taiwan apartment complex experience described above. If those who were exposed to continual radiation (when home) from the cobalt-60 in the structural steel, for one to two decades, suffered cancer rates only 3.5% that of the surrounding Taiwanese population, then the radiation-deficient surrounding population was condemned to a cancer rate 30 times that of the fortunate apartment dwellers, and if the rate of birth defects in the apartment-dwellers' offspring was only 6.5% that of the surrounding population, then the latter was condemned to 15 times the rate of birth defects in their offspring. And the exposure of the apartment dwellers may not even the be optimum exposure, so that both groups might benefit even more from research on the hormetic zone maximum for continual low-dose radiation. (One proviso must be stated about this study, which is that the authors admittedly only partially controlled for age. They did so by performing the calculations both with and without school children. They found even lower rates of cancer when the children were excluded, though of course the rates of birth defects to babies born to the apartment dwellers were unchanged by excluding the children, as they were below childbearing age. So while the *magnitude* of the protection might be held in abeyance until further refinement of the data is forthcoming, the general conclusion accords with thousands of other studies.)

The regulatory agencies that demand that radiation exposures be as low as possible are then responsible for, among other harmful effects, withholding this life-saving radiation from hundreds of millions of people. We conclude that, while governmental regulators who are aware of the hormetic effect rationalize that they are erring on the conservative side to enhance the public's protection from radiation, LNT's denial of hormesis is not a benign fiction. This lie-by-omission has horrendous consequences, not least among them being the aid it lends to the cause of the anti-nuclear forces in their crusade against life- and planet-saving nuclear energy.

Public understanding of all the aspects covered in this essay would go a long way toward relieving the phobia that haunts and utterly distorts our energy landscape. It would also alleviate fear and stress that by themselves are harmful to our health.

V. <u>On anti-nuclear organizations and spokespersons</u>

> The most difficult subjects can be explained to the most slow witted man if he has not formed any idea of them already; but the simplest thing cannot be made clear to the most intelligent man if he is firmly persuaded that he knows already, without a shadow of doubt, what is laid before him. (Lev Tolstoy, *The Kingdom of God Is Within You*)

> I know that most men -- not only those considered clever, but even those who are very clever and capable of understanding most difficult scientific, mathematical, or philosophic, problems -- can seldom discern even the simplest and most obvious truth if it be such as obliges them to admit the falsity of conclusions they have formed, perhaps with much difficulty -- conclusions of which they are proud, which they have taught to others, and on which they have built their lives. (Lev Tolstoy, *What is Art?*)

> It is difficult to get a man to understand something when his salary depends on his not understanding it. (Upton Sinclair, *I, Candidate for Governor: And How I Got Licked*) [6]

Motivations behind falsehoods

As we stated above, only after the comparisons of nuclear energy with the other sources have been explained is one really justified in exploring the nature of those who make the counter claims. What motivates people to stubbornly resist evaluating the foundations of their expressed beliefs, particularly when those foundations are completely false? Aside from the motives described by Tolstoy and Sinclair in the above quotes, there may very well be those spokespersons, particularly, who are directly paid to lie, though they undoubtedly represent at most a very small proportion of such misguided persons. As usual, the main problem is not conspiracy but rather false and unscientific ideology.

To which of these categories Ralph Nader belongs, we don't know for sure, but in the early 1990's, he told an audience at a U.S. conference called to discuss a "nuclear-free 90's," that the way to kill nuclear energy is to require a solution to the "Nuclear Waste Problem" and then use the NRC (Nuclear Regulatory Commission) to prevent any solution from being implemented. Neither Nader, nor any other anti-nuclear spokesperson, has ever to our knowledge referred to the "Fossil Fuel Waste Problem," though it is many orders of magnitude worse for public health and planetary livability. In particular, fossil fuel waste contains scores of chemical toxins that never decay, while nuclear fission products decay away in a couple of centuries at most and, as even the billions of dollars of government studies for Yucca Mountain show, can be safely buried for far longer. Also the sheer volume of fossil fuel waste is on the order of a million times that of the fission products, or even, for that matter, tens of thousands times that of the spent fuel from the wasteful once-through reactors, for the same amount of generated electrical energy.

Misleaders of the anti-nuclear movement, who use fear as their controlling weapon, are no better than clergy who maintain control of congregations through threats of hellfire and brimstone, or eternal damnation, or any of a large number of guilt-inducing formulas, thus forcing reliance on that very clergy, who claim to be the only ones who can act as our protectors. It creates a dependency cult around the misleaders, which, given the overwhelming moral corruption of capitalism, can be quite attractive to many would-be gurus.

While current misleaders may be motivated by individual self-building, aided by the self-deceptive rationalization that, after all, they are helping humanity by protecting it from some scourge, it is instructive to seek the origins of the falsehood that no amount of radiation is harmless, i.e., the LNT (linear-no-threshold) lie. As it turns out, the longstanding denial of the hormetic (defense-stimulating) effect of low levels of ionizing radiation has recently been traced by a U. Mass Amherst toxicologist, Ed Calabrese, to a geneticist named Hermann Muller. Muller was the recipient of the 1946 Nobel Prize in Physiology or Medicine for his discovery that *high* levels of radiation could induce mutations in fruit-fly DNA. During his acceptance speech for the Prize in Stockholm, Sweden in December 1946 (little more than a year after Hiroshima/Nagasaki), Muller claimed that the evidence was inescapable that even low levels of radiation could produce harm by causing birth defects and cancer. Muller was a political activist who embraced socialism and abhorred the new era of nuclear weapons. As part of his campaign against nuclear weapons testing and its resultant radioactive fallout he deliberately lied about the effects of low levels of radiation, denying the existence of a threshold between high and low levels. He apparently felt that claiming that even the lowest levels of radiation would cause cancers and shorten lives would strengthen his demand that there be no more testing of nuclear weapons. That this was a deliberate lie is clear from the fact that just one month prior to his acceptance speech he had reviewed some work by a respected colleague providing evidence for a threshold, and he had stated in a note at that time that his lab would have to do more testing of this when he returned from Stockholm.

Not only was Muller now a Nobel laureate, but he was also a member of the prestigious National Academy of Sciences, on which he wielded tremendous influence. He could hardly suspect that what he apparently thought was an innocent lie in support of saving lives would turn out almost half a century later to be one that has since fed uninformed hysteria over radiation and that, as a result, has caused great loss of lives. In the months and years following Muller's public, and knowingly false, declaration that the evidence demonstrated the absence of a threshold, he and his colleagues protected this deliberate falsehood from exposure by suppressing and discrediting all evidence to the contrary, with results that are still causing tremendous harm (Calabrese). Scientific evidence cannot be overridden in the name of benefit to humanity without sooner or later producing the opposite effect.

Even more important than motivation is the self-defeating character of the anti-nuclear position, particularly on the part of environmentalists who are genuinely concerned with the destruction of the environment and human health and lives by the continued burning of fossil fuels. We have already explained how the use of solar and wind is parasitic on either natural gas or nuclear energy, and since the anti-nuclear forces are dead set against nuclear this necessarily means that their solar/wind advocacy entails the continued use of natural gas, one of the fossil fuels, which can be turned on and off rapidly to compensate for the sudden loss of sunlight or wind.

When is one culpable for an unintended consequence?

While their conscious and deliberate opposition to fossil fuels is praiseworthy, how do we regard their possibly unconscious and unintended advocacy of a course that necessitates the use of one of those very fossil fuels? When is one responsible for an *unintended* harmful consequence of one's actions? Our answer is -- when that consequence is predictable and that predictability either is understood or should be understood. One might consider the crime to be somewhat less severe when the predictability is not understood than when it is, but when there are many sources of such understanding from which to draw, and therefore the predictability should be understood, it still remains a crime.

Another situation for which the question is relevant, and which may help to evaluate culpability for unintended consequences, is exemplified by the concept of "collateral damage." When the U.S. military uses that term, they are attempting to exonerate themselves for the deaths of large number of civilians in war zones from bullets, bombs, and rockets. In essence, they are saying that this "damage" was unintended, but by that phrase they also imply that the deaths were unpredictable, that they had no way of knowing they would occur. And that's in addition to reducing killings to the more benign sounding "damage." This is an attempt to separate such attacks from deliberately intended efforts to kill masses of civilians, such as the fire bombings during World War II of Dresden, Hamburg, Tokyo, and some 65 other Japanese cities, as well as the nuclear bombings of Hiroshima and Nagasaki -- which is a very small selection of such acts that were committed by the British and U.S. air forces and which were equally as horrendous as those committed by the Nazi and Japanese militaries. Even for unintended killings, the concepts of "unintended" and "unpredictable" are miles apart. Such "collateral" deaths in Korea, Vietnam, Iraq, Afghanistan, and Pakistan are definitely predictable, and military statisticians are well able to give good estimates ahead of time of the expected degree of such "damage," just as doctors are able to predict side effects of certain drugs -- though they generally help the patient to overcome these side effects. But with the predictable and devastating military "side effects," to repeat an execrable quote from President Clinton's Secretary of State, Madeleine Albright, "We think the price is worth it."

The legal system in the U.S., no doubt among other countries, regards premeditated murder as a more serious crime than a murder committed in the passion of the moment, which, in turn, is regarded as more serious than causing an unintentional death in the course of a grossly negligent act. But involuntary manslaughter, as the latter is termed, is still a crime. And so, in our opinion, is the anti-nuclear position of environmentalist organizations and spokespersons, for the same reasons of gross negligence. To borrow still another quote from a political careerist, this one from Senator Moynihan, "Everyone is entitled to his [*sic*] own opinion, but not to his own facts."

There are many other examples of subjects for which there is an ocean of misinformation available in the media, on the web, and in books and articles. Among these are two that have passed their prime, namely the argument over whether smoking causes lung cancer and denials that human activity causes the current global warming. But one that is still very much alive, in addition to the anti-nuclear misinformation campaign, is an extremely dangerous movement to convince parents not to have their children immunized against various debilitating and often deadly diseases, such as polio, measles, and diphtheria. This all started with an article in a British medical journal in 1998, subsequently proven to have been a complete fraud, by a researcher/surgeon named Andrew Wakefield who claimed that vaccines cause autism. Despite the exposure and his forced withdrawal of this lie, there are still those who make a career out of misleading parents and others, and who have had such a great impact that there are a growing number of regions where so many children are being denied vaccines by their confused and frightened parents that the diseases are beginning to reappear, even in those children who have been vaccinated. This occurs when the percentage of children with vaccinations drops below about 95%, called a loss of herd immunity (a particularly uningratiating terminology). Some U.S. schools have taken to prohibiting children from attending until they are vaccinated. Indeed, even as we write, the media announce a rise in measles, and consequent deaths, in Europe with a drop below 95% of children immunized (loss of herd immunity) -- the rise occurring mainly among the unvaccinated but not confined to them. But for our purposes this only shows that such misinformation can seize hold under capitalism around everyday things that are deadly, and not just around the parent-of-all-prevarications that capitalism is the best system for *everyone* and that, even if it isn't, there's nothing the public can do about it.

The differences between anti-nuclear environmentalists, on the one hand, and those equally concerned and possibly active about preservation of the environment but who have investigated the issues concerning nuclear energy, on the other hand, is not simply one of degree. That is, they do not differ simply in the degree of investigation in which they have engaged, which would be a *quantitative* difference. No, there is a *qualitative* difference, and this lies mainly in the presence or absence of curiosity, skepticism, open-mindedness, and often honesty -- at least on the topic of nuclear energy. Surely some of the most anti-nuclear people may not lack curiosity, skepticism, open-mindedness, and honesty about many other aspects of life, but in this one arena they do. In particular, they are often the very same people who have applied the most curiosity, skepticism, open-mindedness, and honesty in their investigations of the causes of global warming. It is stunning to find so many people who are open about one of these major issues but closed about the other -- in both directions. They bear a certain resemblance to Mary Mallon, also known as Typhoid Mary, a cook in early 20th century New York, who was healthy herself but was unwittingly a carrier of the typhoid bacterium, and who, without realizing it, infected more than 50 people, of whom several died.

How to find out who's naughty and nice

For those seeking to learn more about it, the more important point is how does one tell the difference between writers or website contributors who have truth on their side and those who scorn the truth in favor of some predetermined conclusion? Once you have done your own investigation and come to your own conclusions with sufficient effort, you have a direct basis for judging. But how do you tell when you are either just beginning to look into a topic, or have only a casual interest, at least until the critical nature of getting it right becomes clear? The enthusiasm with which a writer attacks the subject does not convey any help along these lines.

First, more often than not, distinguishing who has science and reality on her/his side and who is making statements that are false, whether knowingly or not, requires following some sort of a dialog between the two opposing points of view. This dialog can either be a live realtime debate between representatives of each side or a drawn-out written alternating series of comments, or any other form of confrontation between the two points of view. On rare occasions it may be possible to tell right away from exposure to just a single set of comments by one side or the other, but usually not. However, it need not be an overly complicated and difficult process to get a good idea of whom to trust and whom not.

One common distinction is the amount of evidence provided and the consideration of alternative viewpoints, as well as the willingness to admit that there are some aspects with which the writer is not yet familiar. **Cherry picking**, in which the information provided is overly limited in geography or duration (space or time), is a favorite gimmick of deliberate distortionists. But what about the honestly misled? They, too, frequently end up cherry picking without necessarily realizing it, but the limitations are there nevertheless. For example, climate-change denialists have often pointed to a particular choice of places on earth that have been colder than normal for the last few years. Their choice of places is selected for just that purpose (limited in geography) and the last few years have likewise been chosen for that purpose (limited in time). One of us (Meyerson), upon reading a claim on the web that global warming was not happening because the writer could name a thousand places on earth where it has gotten colder this year, had to grit his teeth to resist pointing out facetiously that one could name *a thousand and one* places where it had gotten warmer – as though either one of those would prove anything. This was a classic case of cherry picking.

An important distinction to realize is that between a skeptic and a denialist. A skeptic is someone who has not yet seen enough evidence to make up her/his mind on some issue and is not ready to simply take one side of the issue as scientific truth and the other as falsehood. Skepticism is a necessary and vital characteristic in all scientific investigation in the early stages, and even to some degree after any particular theory of nature has, for the time being and for all practical purposes, been settled. There is nothing dishonest about skepticism at an early stage of investigation. Denialism, on the other hand, is a deliberate refusal to even consider the evidence for and against any particular conclusion, and a stubborn insistence on clinging to one point of view regardless of how much evidence there is in favor of the opposite conclusion. Denialism is plain dishonesty. Denialists generally have a monetary or other personal interest in a demonstrably false point of view. They usually call themselves "skeptics," often with the media going along with this charade, a misnomer designed to mask their dishonesty. Scientists in one or another specialty, even in the one in question, are often found in the ranks of the denialists, along with non-scientists, which makes it even more difficult for those outside the field to perceive their dishonesty, particularly when the subject is in the scientist's field of expertise. Being a scientist in no way guarantees honesty. Furthermore having training and experience in one field of science does not necessarily make one an expert in another field -- thinking that it does constitutes a common misperception -- though there are certainly those who can be experts in more than one field.

Other signs to look for, to tell whether someone is a denialist, include their **making up** things out of whole cloth that parade as facts or evidence (in other words deliberately lying), **controlling** the wording of reports by panels of experts (when in a position to do so), and being given favored access to the **mass media** for their falsehoods (while the scientists are often forced by the media to confine their responses to journals that are not read by the public). These plus **cherry picking** are associated with the falsehoods told by the denialists.

Additionally there are a number of ways that denialists oppose the facts offered by those who have the science on their side. These include taking what the scientists have said **out of context** (which is another form of cherry picking -- i.e., quoting partial statements out of context, while ignoring other portions that show that the opposite is intended, is analogous to citing partial data while ignoring other portions that disprove their contentions), completely **ignoring** evidence provided by the scientists, **exaggerating** one aspect (such as admitted uncertainties) and **minimizing** another (such as a critical point). Other methods include **suppression** of the scientific conclusions when in a position to do so (e.g., the editor of a scientific journal), **ridicule** (particularly when the science demonstrates the fallacies of the conventional wisdom that is spread by the media and hence accepted by the general public), and creation of **strawpersons** (e.g., attributing a false statement to the scientists that they never said and then attacking them on that basis, e.g., Senator Inhofe's "Climategate").

And finally and perhaps the easiest criterion to detect, the scientists with the preponderance of evidence on their side usually take the time to **rebut** every point raised by the denialists, whereas the denialists usually change the subject and fail to rebut real evidence. Of course, repeated and ignored rebuttals don't prevent denialists from raising the same falsehoods over and over, which, at some point, makes it necessary for scientists to stop offering such rebuttals, so they can get on with their work. This denialist tactic is similar to that of politicians who, when asked a tough question, learn very quickly to answer a different question instead of the one that was asked. Searching for actual rebuttals, as opposed to the raising of new "facts," generally requires the least work for interested readers who haven't the time to delve more deeply. These are a few shortcut hints for easy ways to tell who's naughty and nice.

VI. Summary – a revealing example of the irrationality of the profit system

Let's look side by side at the three groupings of energy sources: **fossil fuels**, **non-nuclear alternatives (solar/wind/hydro/geothermal)**, and **nuclear**. Advocates for the second group, as we have pointed out above, call their sources "renewables," but none of them is really renewable. Rather they are virtually infinite in supply, for all practical purposes, and therefore replaceable, over the long term. Furthermore these advocates point out that they are all clean in that they create no GHGs. But practically speaking, nuclear is just as infinite in supply and is just as clean as the second grouping, though advocates for "renewables" either never agree to that fact or they ignore it. Whenever we think of "renewable" clean energy, nuclear should be included.

Fossil fuels, having been created out of living matter on earth quite some time ago in a process that took millions of years, with no significant ongoing creation, are about to peak and will eventually run out -- for good (in both senses of the word). In its final stages, the more easily extracted forms are being replaced by the forms that are more difficult to extract, for which the extraction processes are even dirtier. Their waste is dirty and creates pollution that kills on an ongoing basis in the short term. Their waste also creates GHGs that are destroying the livability of the planet, for generations at the very least. They are also used to create many very useful products, including plastics, road materials, and lubricants, but they are being burned up at a much greater rate than they are being used in manufacturing these products. That is also a waste. They lay waste to immense sections of scenic mountainsides or tar sands or necessitate the breaking up of underground rock with toxic chemicals and contamination of extensive supplies of otherwise clean underground water. The extraction industries are very dangerous to the workers in those industries, and distribution pipelines rupture all the time with leakage into the environment, causing explosions and fires deadly to the public, as well as contamination of water supplies in lakes, rivers, and oceans. Yet fossil fuels make, for the owners and managers of the extraction and refining industries, the largest profits of any materials in the world, which confers on their owners and financial backers the greatest degree of control over the state as well as a dominant command over the media. In addition, the subsidies that are directed mainly toward solar and wind, among the non-nuclear alternatives, are overshadowed by many orders of magnitude by the often hidden government subsidies to the most profitable energy source of all, namely oil, and to only a slightly lesser extent, natural gas. These subsidies to oil and natural gas, in addition to tax loopholes and direct grants, come mainly in the form of trillions of dollars spent, and working-class lives destroyed, in wars to control oil supplies in the Middle East -- wars in Afghanistan and Iraq, and spreading into Pakistan, in the current period. But ever since World War I, all wars in the 20th century were essentially to secure imperialist control over resources, much of which has been oil, and more recently, natural gas.

Non-nuclear alternatives (solar/wind/hydro/geothermal) involve energy sources of practically unlimited supply but that are very difficult to capture and render useful, and have significant side effects. They are not all available all the time, varying erratically over the hour, the day, the week, the season, and the location. Either they cannot supply electricity round the clock and round the year or they require enough overbuild to enable huge amounts of very expensive and possibly dangerous storage, for release during less sunny/windy moments, or in practice they require nearly continual reliance on fossil fuels to maintain steady supply. Given the geographical variation in their availability, they can be captured in only special locations and must therefore, once captured, be distributed widely over great distances, with the possibility of decentralization to some extent for small scale use but with immense physical barriers to decentralization on a social scale. Such decentralization would require the disturbance of vast amounts of land, with visual and/or noise pollution, in the form of solar or wind turbine farms. Since everything has a life time, perhaps measured in decades, they must be continually maintained and sooner or later they must be decommissioned, with a waste disposal problem of toxic materials that do not decay away but remain toxic forever, threatening aquifers and other water and food sources, as well as the air, if not sealed properly. There are a growing number of would-be energy entrepreneurs investing money in these sources, but relying heavily on long-term government subsidies (paid for by all of us through taxes and higher utility rates), without which these energy sources would be a net loss rather than a source of profits. Even despite these subsidies, many solar and wind companies are going out of business. And finally, these energy sources start from a very small basis today, supplying less than a few percent of electricity in the world. *In short, as a potential escape from fossil fuels, the non-nuclear alternatives constitute a massive bottleneck that guarantees, both directly and indirectly, the continued growth of fossils for the near future -- at least until fossils become increasingly unavailable and energy production suffers a rapid and devastating decline*. Either of these eventualities would be catastrophic for humanity, for much of nature, and for our planet's livability.

Nuclear involves virtually unlimited supply, particularly in the U.S., that is today very easily captured for the next few centuries in the spent fuel pools around current nuclear power plants with no further mining of uranium required for the time being. Decommissioning of nuclear weapons from both Russia and the U.S. has been a further source of nuclear fuel. Continued mining may, however, be necessary for the time being in developing countries that are forced to turn increasingly to nuclear for their fast growing needs. Ironically this includes some dozen or so of the Middle Eastern countries that sit on most of the remaining lake oil reserves but who are nevertheless planning to build, or already engaged in building, nuclear power plants in the face of dwindling fossil fuel supplies. The operation of a nuclear plant emits no GHGs at all, and the GHGs that are currently emitted in the construction or transportation of supplies is no worse than that in the other two categories, and is only an initial short-term problem that is partially resolvable with electric vehicles. Over the long term the use of nuclear fuel produces no further GHG emissions. The so-called heat pollution of the neighboring rivers, lakes, or oceans that are used to accept the waste heat of operation (though this heat could be captured and made useful and is often vented into the air rather than into the water) is no worse than that from a fossil fuel power plant. And finally, the relative safety of nuclear plants, and even uranium mining, leaves fossil fuel plants and coal mining in the shade.

And to put these three paragraphs together in one narrative, the attempts by both fossil fuel interests and anti-nuclear environmental groups/individuals to choke off nuclear energy, in part by preventing the safe disposal of nuclear "waste," consigns humanity to one of two extremely harmful alternatives: 1) growing use of deadly fossil fuels until their supply can no longer keep up with demand, and a rapid decline in energy ensues, since the non-nuclear alternatives involve prohibitive obstacles to being scaled up to replace fossils, or 2) with the consequently necessitated acceleration of nuclear energy, "waste" at existing and future nuclear power plants will build up with no way of safely using it, let alone disposing of it. The only way to prevent one or both of these outcomes is to employ fast breeder reactors -- primarily the most advanced of these, the IFR -- to act as both a replacement for fossils and as a pathway to relieve the nuclear "waste" build-up, and to further the development of the cleanest, safest, most abundant, and most reliable source of energy for the remaining life of the planet. The anti-nuclear forces cannot see beyond their stubborn refusal to investigate this reality, and pandering and paid-for politicians cannot see beyond the next election. They should not be permitted to stand in the way of humanity's need for energy.

One life-providing resource that is fast being destroyed by the profit-makers' prolific pollution is clean fresh water. Rivers around the world are running dry and aquifers are fast disappearing, even as glaciers melt and run down the slopes into the salty oceans (Pearce). This is all due to capitalism's global warming. This disappearance can be reversed by the use of abundant nuclear energy to desalinate ocean water. Such a use is not merely on the drawing board, but was one of the uses for the large nuclear plant in the former Soviet Republic of Kazakhstan on the shores of the inland and very salty Caspian Sea, from 1972 to 1999.

It should be clear by now that profitability in the fossil fuel industry trumps both public health and the unmatched advantages that are available from nuclear energy. The propaganda use of non-nuclear alternatives (solar/wind/hydro/geothermal), as well as the directed orientation of government subsidies toward them, to foil the development of nuclear in the U.S. and some European countries, notably Germany, plays right into the hands of the fossil companies, who are well aware that nuclear, and only nuclear, offers a challenge to their supremacy and grants humanity the abundant source of electrical energy that is needed today and will be needed in the foreseeable future.

However, even more important than nuclear energy is the achievement of a social and economic system in which the common people will be able to make that decision. Without such a system, all energy is, in part, a potential weapon in the hands of the capitalist classes against the public interest all over the world, whether nuclear or not. Nevertheless the struggle for nuclear energy, even under present day capitalism, is still a reform that we strongly advocate fighting for -- now.

And back to the opening paragraph: When humanity looks back on the few centuries of capitalism, it will be immediately apparent that a particular economic and social system, into which history led first Europe and then the rest of the world, not only hijacked myriad resources of limited supply, without concern for their longevity, but also disposed of the waste products in a careless way, destined to greatly diminish the livability of the planet. This global human process that will have occupied no more than the blink of a geological eye may yet prove to have made living conditions immeasurably more difficult for humans, as well as for other animals and plant life, for a much longer duration than the destructive process itself -- perhaps many millennia. These conditions will, if they come to pass, faintly echo the hostile world environment tens of millions of years ago, long before the very appearance of humanity on the world stage. The thorough elimination of such a system, by the vast majority of humanity who suffer at its hands, cannot occur too soon for the sake of the human species.

Footnotes

[1.] Technically power and energy differ in that power is the rate at which energy is transferred or used. Thus a 1 GW power plant provides energy at the rate of 1 GW, but after a certain amount of time 1 GW of power will have provided so many GW-hours (GWh) of energy. For example, since there are 8,760 hours in a year, 1GW of power provides 8,760 GWh of energy in a year. A power plant is rated by its power, since that's its permanent status and does not involve an arbitrary time interval. Most nuclear plants are rated at 1 or more GW. The largest in the U.S. is the Palo Verde Nuclear Power Plant just west of Phoenix, Arizona, with three reactors, rated at 3.6 GW for the entire plant, though there are only a scattering of nuclear plants in the western half of the continental U.S., with the vast majority of them in the Midwest and the Atlantic states.

[2.] The qualitative difference between mass and weight is that mass may be viewed as a property of a chunk of matter alone, while weight is a relationship between that chunk of matter and the earth, or whatever planet the chunk may be occupying. Weight depends on the masses of both parties to the relationship, namely both the chunk and the earth, and not just the chunk alone, as well as on the distance between the centers of both bodies. Mass is a measure of the amount of material in either the chunk or the earth, while weight is the force of attraction between them -- amount of matter versus force of attraction. Because weight is a relationship between two chunks of matter, whatever you may weigh here on earth you would weigh differently -- about 6 times less -- on the moon. This is not because *you* would be much different on the moon but because the moon has less mass than the earth and you would be a different distance from its center. Your weight would change but your mass would stay roughly the same -- apart from any slight loss due to the stress of space travel, or possibly gain due to the boredom.

[3.] But what do you say to a person who claims that they lost all their hair from the tritium leak at the Vermont Yankee nuclear power plant in the southeast corner of Vermont that supplies 85% of Vermont's electricity? Do we point out that the luminous dial watch they are wearing and the exit sign over their head both contain tritium, that their smoke alarms contain radioactive americium, that their granite counters or brick walls contain uranium, thorium, and radium? Such claims are fully believed but are a result of the radio-phobia successfully promoted by the anti-nuclear forces and by the regulatory agencies of the many governments. The person may very well have lost her hair from something (there is no particular reason to think she made up the claim), and one is in a weak position to argue whether or not they really did lose it, but one thing we can be sure of is that it was not from the tritium. The strength of a false belief can often trump reality in that person's mind, at least temporarily.

[4.] Warning: Beckmann is a strong apologist for free-market capitalism, the very aspect that interferes with our ability to influence continued use of fossil fuels. It is very difficult to find authors with whom we agree on every aspect.

[5.] Warning: Etherington is a global warming denialist. See comment in the previous footnote.

[6.] Aside from the sexist form of these quotes, they prove to be particularly relevant for our topic. The sexism was rarely questioned a century ago and is still prevalent to this day, but it is easily fixed by substituting “person” for “man,” “people” for “men,” “she/he” for “he,” “her/him” for “him,” and “her/his” for “his.” We have left them in the original form for historical accuracy.

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A note about the authors

To introduce ourselves to our readers, we have, in the last few years, made a study of nuclear energy and other alternatives to fossil fuels, the political and physical relationships between nuclear energy and nuclear weapons, and the biological effects of radiation. We are true amateurs, which means that we have an intense interest in our subject and derive no monetary reward from our efforts. But we have also transformed ourselves from being previously ignorant and/or fearful of things nuclear into moderately knowledgeable investigators in the field. We don't claim to be anywhere near as expert as nuclear engineers and physicists or oil geologists or pulmonary specialists or molecular biologists, but we have engaged in sufficient study, writing, speaking, and mutual discussion, as well as in sufficient direct communication with nuclear engineers and physicists, as well as with biologists and others who study the effects of radiation on plants and animals, to regard ourselves as fairly informed about these various aspects -- at least at such a level as required to write this essay. In fact, we have directly met with a dozen nuclear engineers and physicists -- several of them having been involved decades ago in the pioneering efforts in building nuclear reactors, particularly the EBR-II and its successor, the IFR. Over the last couple of years we have also frequently communicated with them by phone and email and with a dozen or so other nuclear engineers and physicists, as well as having been in regular email communication, over the same time frame, with several researchers in the biological effects of radiation.

There are many notable authors of books and articles that render scientific findings available in lay language to a wider public. Most of these are not themselves science specialists but rather have also educated themselves in one or another field of science well enough to explain it to other lay persons.

As to formal credentials, one of us (Sacks) happens to be both a physicist and a radiologist, and the other (Meyerson) is an English professor with specialization in critical theory, but formal credentials in our view, are completely irrelevant with respect to whether someone knows what she/he is talking about or, even more importantly, is telling the truth. The only relevance perhaps is that prior training in related subjects makes the job of learning a subject somewhat quicker, though the creative writing professor has impressed the physicist/radiologist with his quickness to grasp complex topics and to recognize their significance in the present context. But honesty and open-mindedness are not a matter of technical training. They are a matter of attitude, which no amount of technical training can bring about.

As to whether we are among those experts who deserve to be listened to, we leave that to our readers to decide, but there is no contradiction between being amateurs and experts at the same time. Formal training is often not only insufficient to make a true expert, but in the case of radiologists (doctors who interpret x-rays and other imaging modalities) the formal training is so misguided with regard to the biological effects of radiation as to be a major obstacle to expertise. However, this obstacle is not insurmountable, with an adequately open mind and a strong desire to learn.

Finally, we consider ourselves fortunate to be in the company of many of the aforementioned nuclear engineers and scientists and biological hormesis researchers who have also been accelerating their attempts to reach the public with the truth about nuclear energy and radiation, in order to educate and mitigate the public’s phobic response, and to combat the anti-nuclear disinformation campaign. And finally, neither of us has any investments in any form of energy, let alone nuclear.